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ORIGINAL PAPER

Ultrasound Imaging and Characterization of Cardiac Muscle Phantom

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ABSTRACT

Cardiac muscle phantom is a synthetic physical model to mimic the characteristics of actual cardiac muscle for simulation and training purposes. Tissue Mimicking Materials have been widely used in fabricating the phantom. Ultrasound imaging, as one of imaging modalities for cardiac monitoring, can be used to capture the structures. In this study, we aimed to define the best composition and texture feature for cardiac muscle phantom by performing ultrasound imaging characterization using texture analysis. The phantom samples were made by mixing Silicone Rubber with Calcium Carbonate in different percentages. Ultrasound imaging with different Dynamic Range settings (30, 60, and 90 dB) was used to scan the phantom samples. First-, Second-, and Higher order Statistical Texture Analyses were used to quantify structural features of the phantom samples. The results show that the addition of Calcium Carbonate affected the imaging structure of the phantom samples.

INTRODUCTION

Cardiac imaging phantom has been widely used to model the heart organ in medical imaging procedures in both in-vitro and in-vivo settings (Anon 2009). Although the generic models have been available, customization and optimization are still needed to obtain the best imaging technique to be implemented in the clinical settings. For this reason, customized design and fabrication of phantom are needed for precision with a known structure. As cardiac tissue structure may indicate the pathological condition of the heart, quantitative analysis of the structure is needed to identify its characteristics. The statistical analysis represents the texture indirectly by the way that the gray levels are distributed over the pixels in the region (Haralick 1979).

Tissue Mimicking Materials (TMMs) are an important method in characterization and calibration of medical imaging system that can be modelled in anatomical, mechanical and internal structures (Culjat et al. 2010; Lamouche et al. 2012). Ultrasound (US) imaging has become popular for medial diagnosis because of its non-invasive, real-time and cost effective (Anon 2010). Texture analysis has been used to characterize image in cardiac muscle tissues (Molinari et al. 2015; Gao et al. 2014; Kerut et al. 2000; Ferdeghini et al. 1991).

Silicon Rubber (SR), with its longevity, stability, and mechanical properties, can be used as TMMs for cardiac muscle physical model (Culjat et al. 2010; Zell et al. 2007). However, one of the main imaging issues of SR is attenuation weakness of the material that may affect image quality and interpretation of the cardiac muscle tissue (Culjat et al. 2010). In this research, a new improved cardiac muscle phantom study for US imaging using SR material has been developed. The additive material of Calcium Carbonate ($CaCO_3$) has been investigated to obtain improved attenuation in the US image. The objective of this study is to define the best composition and texture feature for cardiac muscle phantom by performing US imaging and characterization using Texture Analysis on phantom samples.

MATERIALS AND METHOD

US imaging of cardiac muscle phantom samples

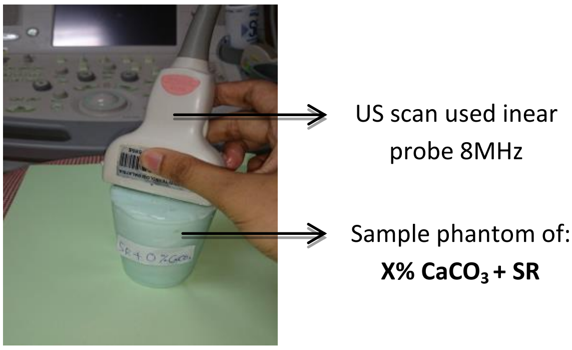

Fig. 1 Experimantal setup of cardiac muscle phantom scan using US imaging

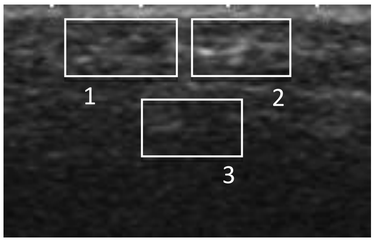

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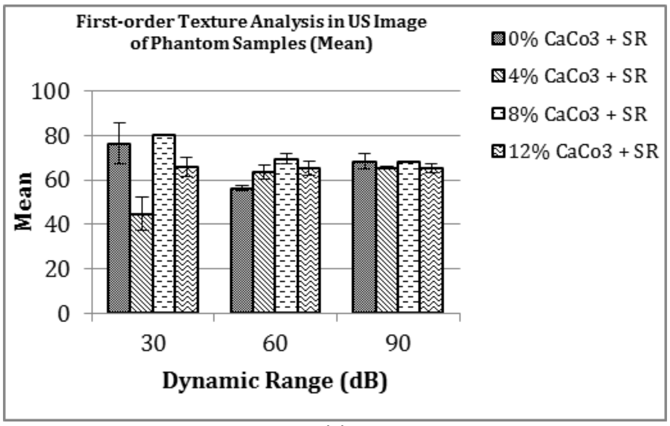
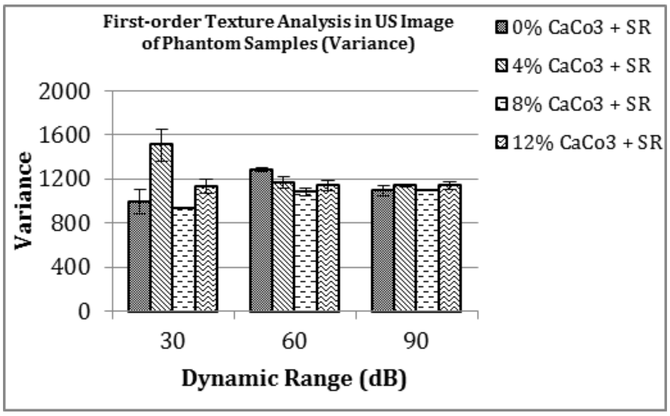
Fig. 2 Three random RoIs cropped of US images taken in randomized position

The cardiac muscle phantom samples were developed using SR (Multifilla™, Malaysia) with $CaCO_3$ (Qrec, New Zealand) in different percentages (0%, 4%,8%, and 12%) as additive. The dimension of each sample was made in a diameter of 5cm and height of 9cm. US imaging was performed to capture the muscular structures. The ultrasound of Toshiba Aplio MX setting used linear probe of 8MHz, adult heart, ON Tissue Harmonic (TH), and vary on Dynamic Range (DR) of 30, 60, and 90dB. The experimental setting is illustrated in Fig. 1.

The US image results were randomly trimmed into 3 Region of Interests (RoI) with 70×30 pixels size as shown in Fig. 2. The texture analyses (First-order, Second-order and Higher-order Statistics) were used to extract textural features. First-order texture analysis is histogram-based statistics calculated from the original image values. Four features of the first-order texture analysis; mean, variance, skewness, and kurtosis were used. Second-order texture analysis features; contrast, correlation, energy and entropy, were implemented. The Second-order texture analysis used gray level co-occurrence matrix (GLCM), computed using two important parameters: relative distance measured in pixel numbers and their angle. It considers among pixels or groups of pixels neighborhood relationships (Haralick 1979). The higher order is based on measurement for the horizontal and vertical directions of the pixels. The parameters comprise GLN, (Gray Level Nonuniformity), RLN, (Run Length Nonuniformity), LGRE, (Low Gray Level Run Emphasis), and HGRE, (High Gray Level Run emphasis) (Chappard et al. 2005).



(a)



(b)

Fig. 4 Comparison of First-order texture features in US images of phantom sam
(a) mean, (b) variance, (c) skewness and (d) kurtosis

RESULTS AND DISCUSSION

RoI images of SR + x % $CaCO_3$, where x is 0%, 4%, 8% and 12%, in US imaging are shown in Fig. 3. It can be visually seen from Fig. 4 that the texture image varies with settings of DR. In these images, the structures of image in DR 30dB were most visible, followed by those of in DR 60dB and DR 90dB. Fig. 4 shows the plots of first-order statistics results in mean, variance, skewness and kurtosis.

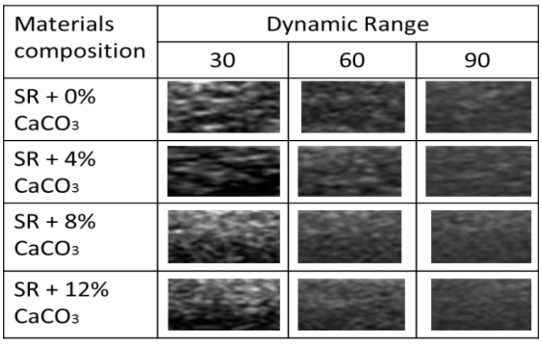
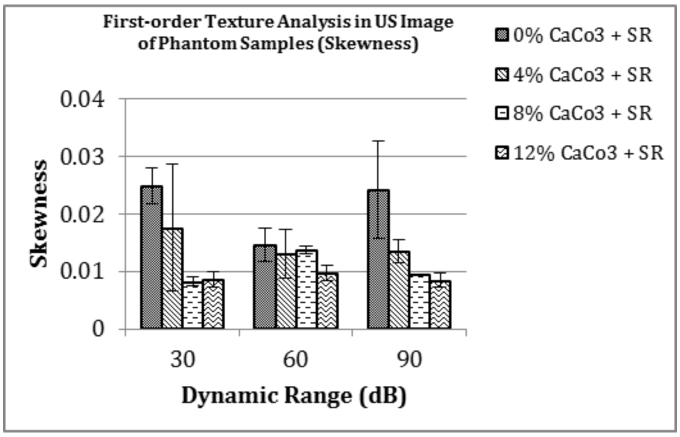


Fig. 3 RoI US images of SR with vary settings DR of 30, 60 and 90 dB



(c)

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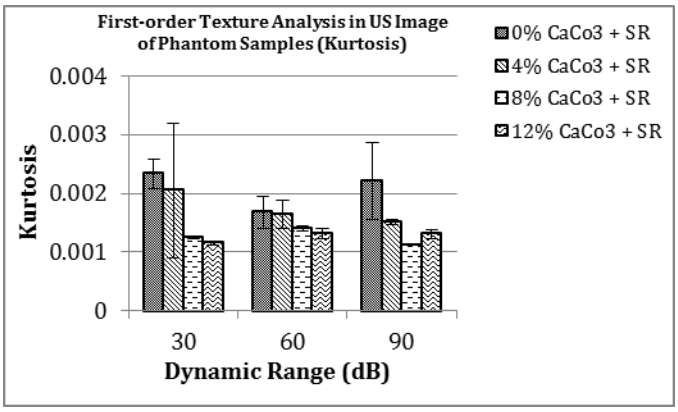
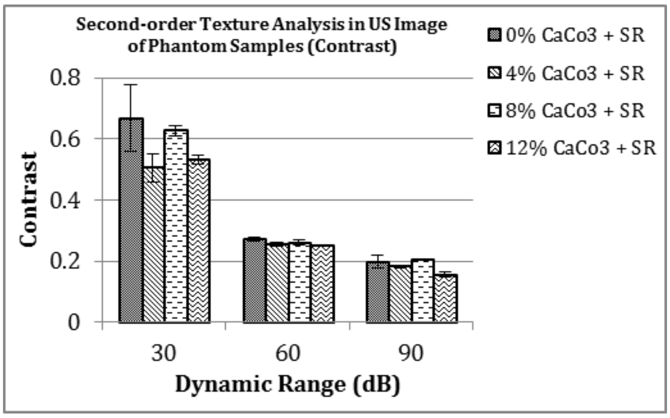
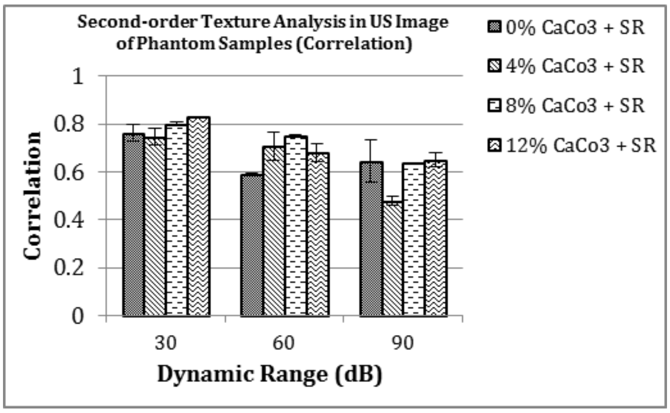


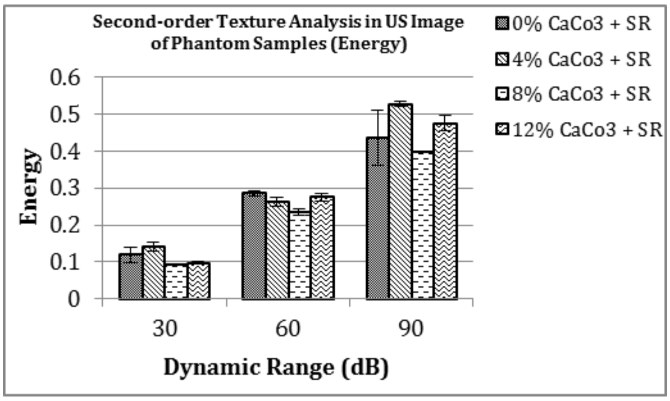
(d)



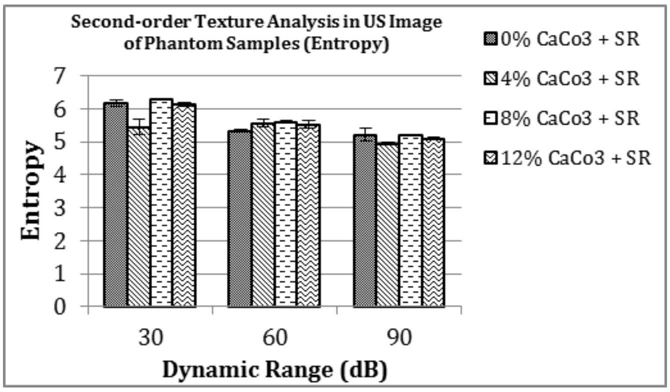
(a)



(b)

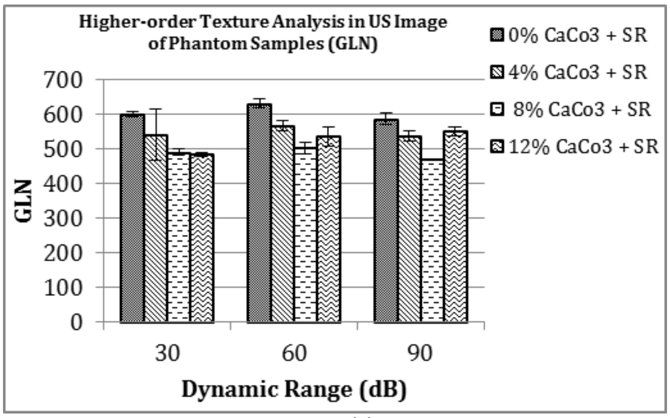


(c)



(d)

Fig. 5 Comparison of Second-order texture features US images of phantom samples with DR in 30, 60 and 90dB with SR and X% $CaCO_3$, (a) contrast, (b) correlation, (c) energy and (d) entropy.



(a)

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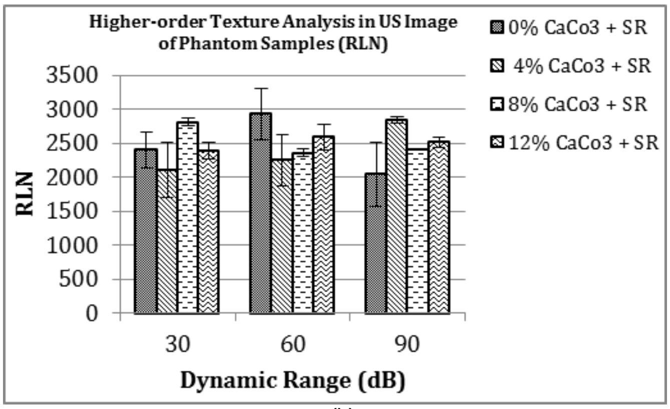
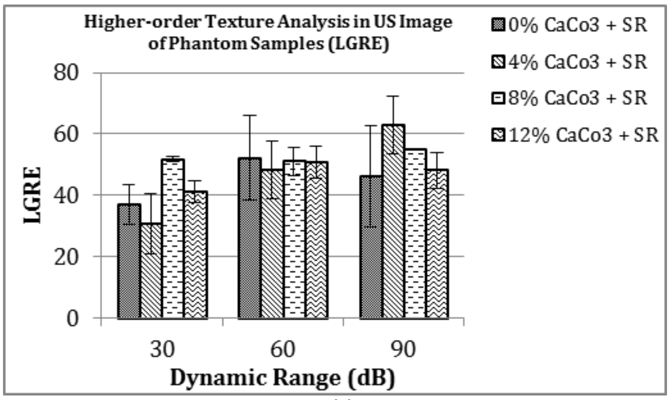
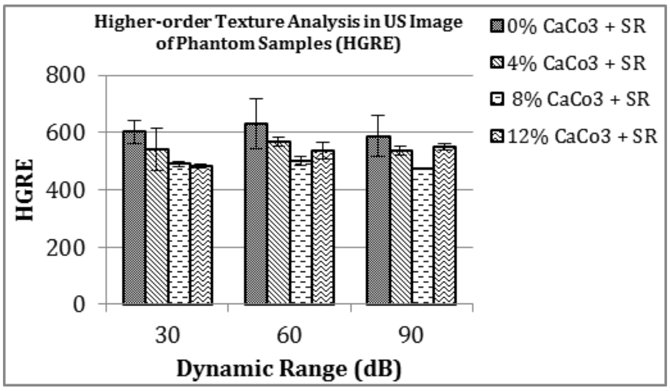


(b)



(c)



(d)

Fig. 6 Comparison of Higher-order texture features US images of phantom samples with DR in 30, 60 and 90dB with SR and X% $CaCO_3$, (a) GLN, (b) RLN, (c) LGRE, (d) HGRE.

For first-order statistical analysis results in Fig. 4, it can be seen that phantom samples had generally similar trends along with the increment of DR. For mean feature, all phantom samples in DR 60dB and DR 90dB had almost similar values for around 60. However, for DR 30dB, 8% $CaCO_3$ + SR had the highest mean values. On the other hand, 4% $CaCO_3$ + SR had the lowest mean values. Conversely, for variance feature, DR 30 dB, 8% $CaCO_3$ + SR had the lowest variance values and 4% $CaCO_3$ + SR had the highest variance values. Furthermore, in skewness feature, all phantom samples had the decreasing trend with the increasing of percentage in $CaCO_3$. 0% $CaCO_3$ + SR had the highest skewness value along with the increment of DR while 12% $CaCO_3$ + SR had the lowest value along with the increment of DR. Besides, kurtosis feature had similar trend with skewness feature. Kurtosis feature had decreasing trend with the increasing of percentage in $CaCO_3$ for all phantom samples. Also, 0% $CaCO_3$ + SR had the highest kurtosis value along with the increment of DR while 8% $CaCO_3$ + SR and 12% $CaCO_3$ + SR had the most value for all DR settings.

The second-order statistics revealed that contrast, correlation, energy, and entropy as displayed in Fig. 5 generally had similar characteristics that they decreasing along with the increment of DR. Decreasing values from DR 30 to DR 90dB occurred in contrast, correlation, and entropy features, while energy and feature had increasing values. In contrast feature, 0% $CaCO_3$ + SR had highest contrast value along with the increment of DR. While, 4% $CaCO_3$ + SR and 12% $CaCO_3$ + SR had the lowest contrst features for all DR. In correlation feature, the values of DR 30 had the highest along with increment percentages of $CaCO_3$. While, in energy feature had the 4% $CaCO_3$ + SR in DR 90dB was the highest along with the increment percentages of $CaCO_3$. While in DR 30 had the lowest value of energy feature along with the increment percentages of $CaCO_3$. Entropy shows slightly similar features values within four to six values of entropy for all percentages of $CaCO_3$ and DR.

The higher-order statistics resulted that GLN, RLN, LGRE, and HGRE as shown in Fig. 6 generally had similar characteristics features along with the increment of DR. In the GLN feature, the values had similar the value within the 400 to 600 with all the DR. While, RLN feature had the value range of 2000 to 3000 with all the DR. Also, HGRE had the value range of 400 to 600. However, in LGRE feature, image in DR 60dB and DR 90dB had similar value range of 40 to 60 while in DR 30dB, had the lowest value range of 30 to 50.

In this study, the texture features of US image were analysed using statistical analysis from First-order, Second-order and Higher order techniques. It shows the possibilty of identifying the effects of $CaCO_3$ and variation of settings to the SR. The classification of the samples showed promising results. Certain experiments led to a good classification score that enables for correctly characterizing the features. However, because of the complexity and limition of silicone polymers-based tissue substitutes, it is necessary to test with many parameters. In this way, characterization of the composition and structure can be made more precisely to mimic the human cardiac muscle tissue. Besides, the results show texture characteristics depend on surface of the samples materials from the US scan. Thus, accurate result is highly dependent on the preparation and composition interaction that form the end results of the samples. Additionally, the design of the phantoms could be affected by other factors, such as different thickness, amounts of soft and fat tissues, and temperature. In the present study, these factors were eliminated by standardised cylindrical samples prepared with various composition of $CaCO_3$.

CONCLUSION

The study has verified that cardiac muscle US imaging phantom can be developed using SR. Variations in $CaCO_3$ percentage also provide various attenuation patterns. Ultrasound imaging settings also play role in defining specific textural features of phantom samples.

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