A study of 3-way image fusion for characterizing acoustic properties of breast tissue

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ABSTRACT

A novel clinical prototype, CURE (Computed Ultrasound Risk Evaluation), is used to collect breast tissue image data of patients with either benign or malignant masses. Three types of images, reflection, sound speed and attenuation, are generated from the raw data using tomographic reconstruction algorithms. Each type of image, usually presented as a gray scale image, maps different characteristics of the breast tissue. This study is focused on fusing all three types of images to create true color (RGB) images by assigning a different primary color to each type of image. The resulting fused images display multiple tissue characteristics that can be viewed simultaneously. Preliminary results indicate that it may be possible to characterize breast masses on the basis of viewing the superimposed information. Such a methodology has the potential to dramatically reduce the time required to view all the acquired data and to make a clinical assessment. Since the color scale can be quantified, it may also be possible to segment such images in order to isolate the regions of interest and to ultimately allow automated methods for mass detection and characterization.

Keywords: Breast imaging, tissue characterization, ultrasound tomography, image fusion

1. INTRODUCTION

Although mammography screening of breast cancer has now been routinely used in clinical practice and proven to reduce the mortality rate in various screening trials[1], the lack of specificity, due to the nature of such x-ray based diagnostic imaging techniques, leads to false positive rates of ~ 80%. Consequently, a large number of unnecessary biopsies are performed based on these results without other supplemental tests[2]. Research has shown that ultrasound (US) imaging can be used to help differentiate cysts from solid masses and even characterize breast cancer[3, 4]. Conventional US imaging systems usually utilize a probe, with a set of transducers in a two dimensional array, to send US pulses into patient tissue. The reflection of those US pulses are collected by the same set of transducers in the probe. An US image can then be created based on analyzing the intensity of reflection signals, which depend on the incident density of tissue boundary[5-7]. Because the probe can only collect signals from opposite direction of the US pulses that it sends in, any scattered or transmitted US signals are lost in such an ultrasound imaging system. In addition, a conventional US system is operator dependent, which make it prone to inconsistence of image quality. The CURE system, however, employs a detector ring, in which equally spaced 256 individual transducers are embedded. A patient lies on the scanning couch in a prone position with the breast suspended inside the detector ring within a water tank. Each of the 256 transducers sends US pulses and collects signals in a predefined sequence when the detector ring moves step by step from the chest wall to the nipple of the patient. Therefore a series of two dimensional raw data are obtained. Since each of the transducers is able to send and receive US signals, not only the reflected signal, but also the scattered and transmitted signals are well preserved.

From the raw data, the following three types of image (Figure 1) could be reconstructed using different tomographic algorithms: reflection images (Figure 1a), based on signals that are reflected by tissue boundaries, shows

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more reflectivity at brighter scale pixels; sound speed image (Figure 1b), where increasing sound speed is represented as whiter area, is reconstructed from the arrival times of acoustic signals, and attenuation image (Figure 1c), which is essentially a map of attenuation intensity within breast tissue. The brighter scale, the more attenuation occurs. Since each type of image renders different characteristics of breast tissue, by appointing different colors to each image and fusing them together, the new image would display all these tissue characteristics in a single image. Studies have shown that the characteristics of reflection morphology, sound speed and attenuation have the potential to differentiate malignant from benign masses. By developing image fusion, our goal is to represent characteristics in a single image in order to minimize any extra time required by physicians to evaluate multiple parameters.

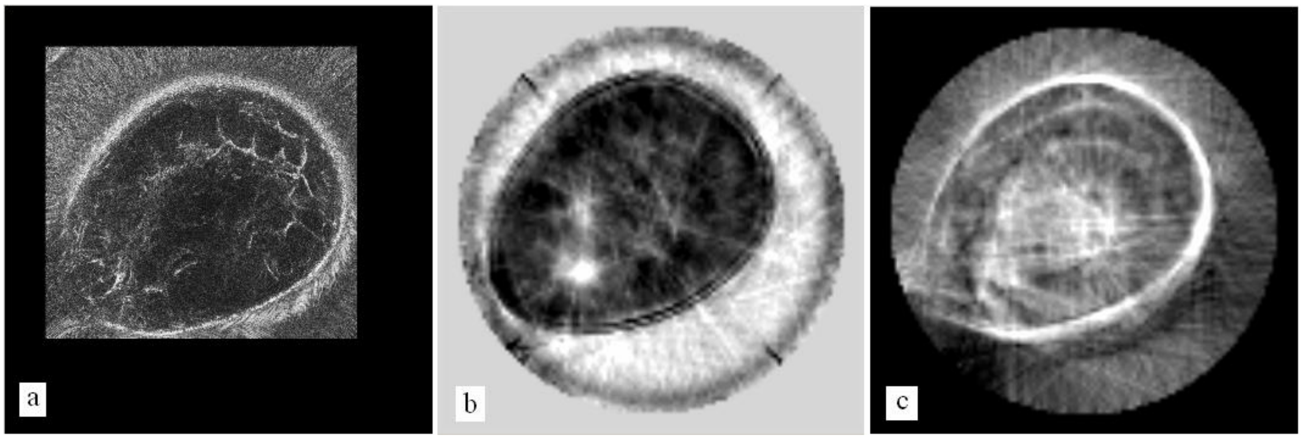

Figure 1. Sample of gray scale images of reflection (a), sound speed (b) and attenuation (c)

2. METHODOLOY

All the reconstructed data of the three image types of reflection, sound speed and attenuation, are stored as ASCII type files. MATLAB (version 7.0.4) programs were written to perform the image fusion. First, each type of image was read and converted from ASCII files to 256 gray scale images (Figure 1). Before converting to gray scale images, both sound speed data and attenuation data of all the patients are normalized to the ranges of 1.4-1.6 (mm/µs) and 0-1 dB/cm, respectively, in order to standardize quantitative information of these images. The boundary of water and patient's skin generally has much higher reflectivity than those inside breast. Therefore, contrast enhancement was always performed on reflection images to render better visibility for reflection boundaries inside breast tissue (Figure 2) before image fusion. Since the sound speed and attenuation images were reconstructed with the full field of view (FOV) and same orientation, they are ready to be aligned. However, due to the fact that the reflection images were reconstructed by customized software, in which the region of interest (ROI) is user defined, positions of the reflection images in the full FOV vary from patient to patient. So both the starting point and dimension of the reflection images had to be extracted from the header information of the ASCII files and be used to align with other two types of images for image fusion (Figure 1a).

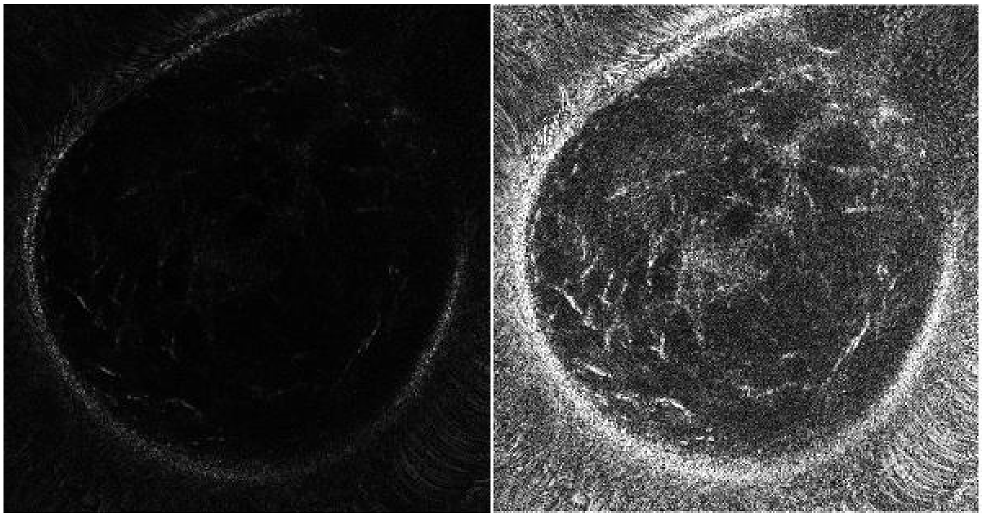

Figure 2. Original reflection image (left) vs. contrast enhanced reflection image (right)

Then, the normalized sound speed and attenuation data, as well as contrast enhanced reflection data, are mapped to a range of floating-point values that define the RGB format and are assigned colors of green, blue and red, respectively (Figure 3). Finally, to create the RGB image, a three dimensional matrix, all three sets of mapped data are saved in corresponding matrix elements thereby forming a composite image (Figure 4).

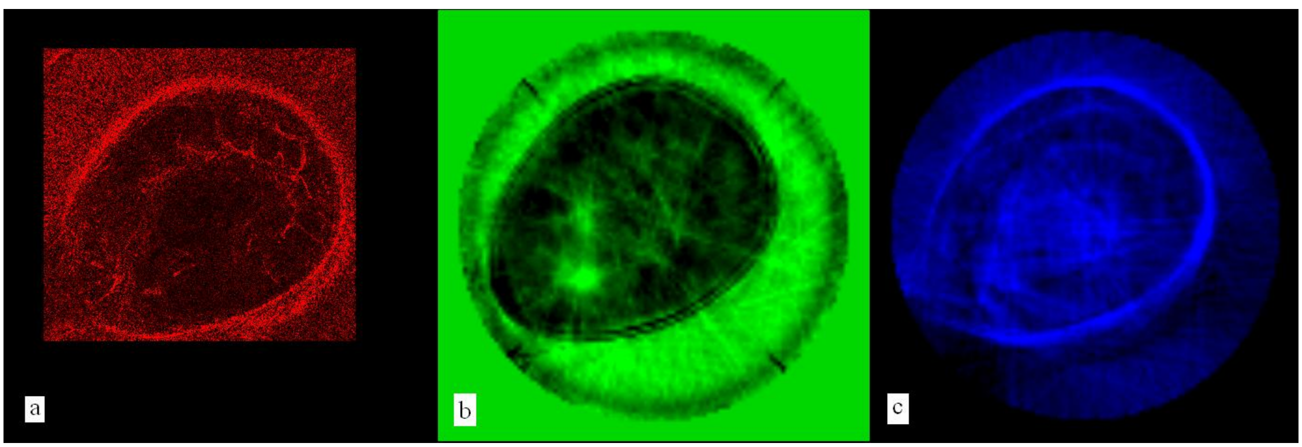

Figure 3. Sample of color scale images of reflection (a), sound speed (b) and attenuation (c)

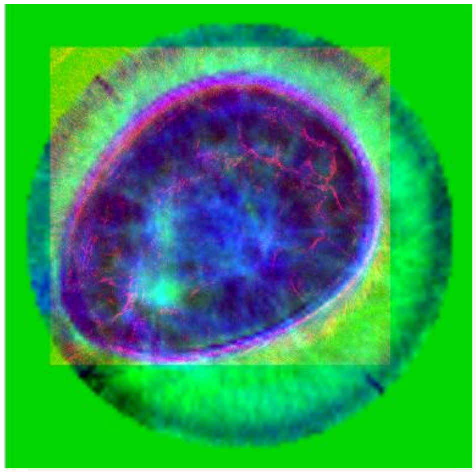

Figure 4. Sample of final fused GRB image

Further, a MATLAB graphic user interface (GUI) application was constructed to help assess the color variation of fused images in determining the tissue characteristics. As shown in figure 5, the GUI application presents both gray scale of sound speed, attenuation and reflection images and composite RGB image on the left hand side of window. On the right hand side, there are text boxes for entering patient ID number, slice number and fraction number (indicate how many times the patient had been scanned during the course of the treatment), as well as three scroll bars, which can be used to alter the saturation threshold of each type of image.

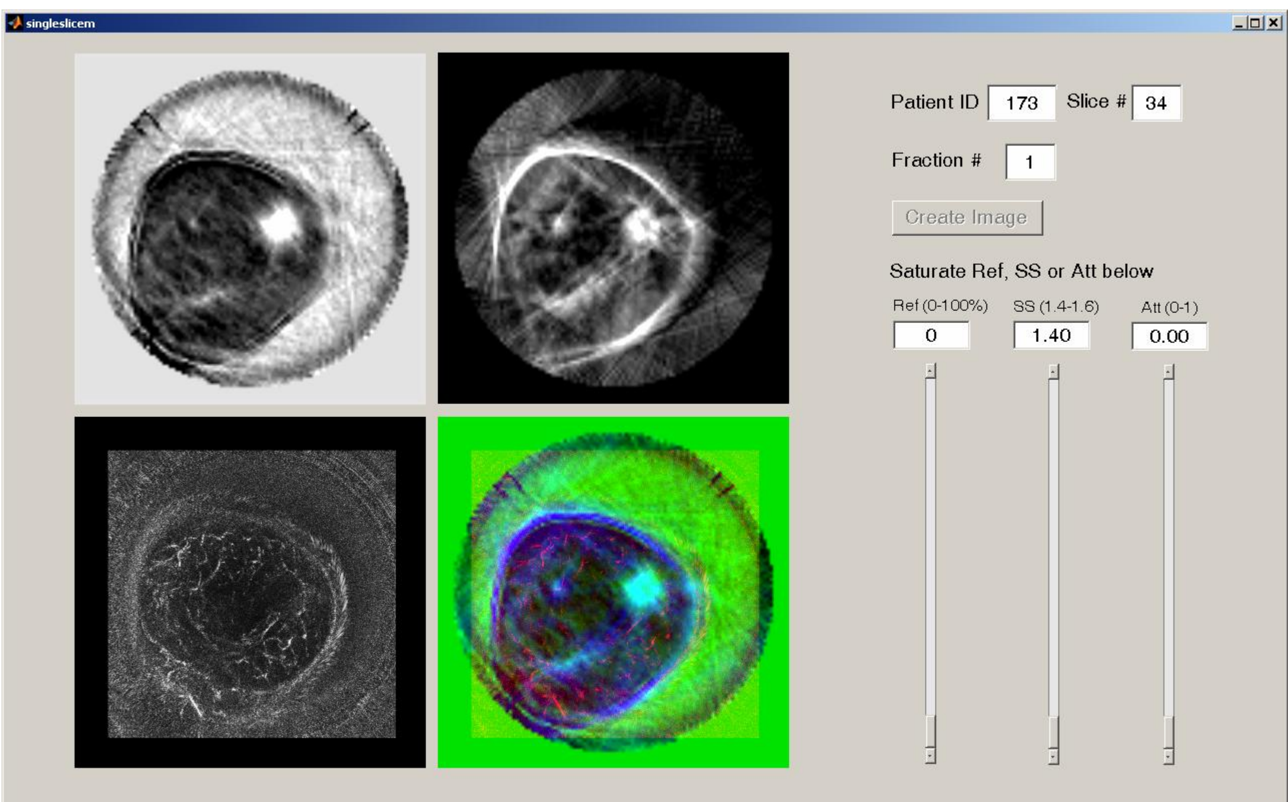

Figure 5. MATLAB GUI application for selecting specific slice and adjusting saturation of reflection, sound speed and attenuation

3. RESULTS AND DISCUSSION

A typical set of saturation thresholds of sound speed, attenuation and reflection and the modified images are shown in figure 6. Since the speed of ultrasound (1.5MHz, central frequency) in water and soft tissue (such as fat) are less than 1.5 mm/μs, by saturating the pixels representing sound speed below 1.5, only denser tissue (i.e. tumor) would be shown in the updated image. Similarly, by quenching the white scale in the attenuation image below certain values, 0.12 in this case (Figure 6), most of the background is invisible but only the most attenuating tissue (features) appears in the new image. Although it is not very clear that to what extent changing the reflection image would contribute to the final composite image, it is obvious that the saturation of lower value of reflection enhances the contrast even more, as shown in Figure 6. Combining the residual green and blue in the updated sound speed and attenuation images, the resulting cyan colored area (with the arrow pointed) in the fused image indicates the denser tissue with higher sound speed and more attenuation. In this case, this area represents a known mass (invasive ductal carcinoma).

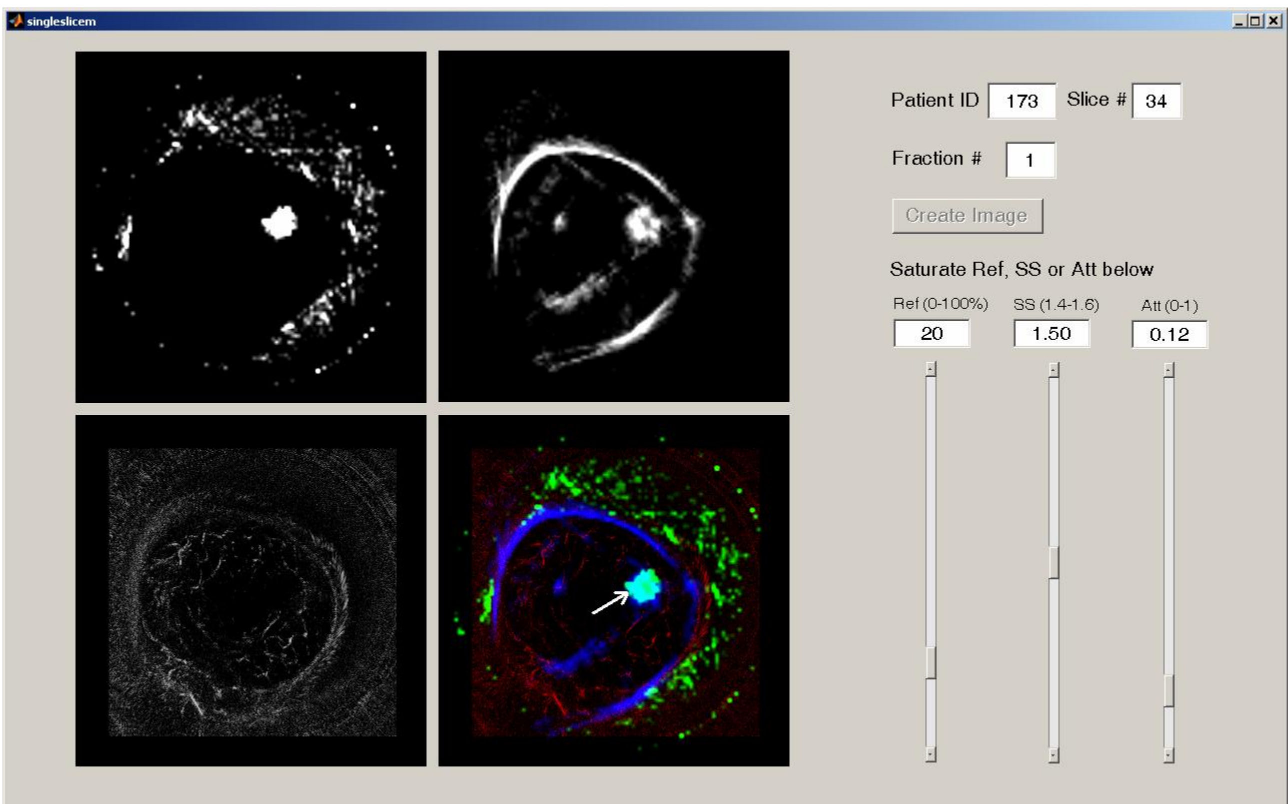

Figure 6. Result after quenching all three parameters at different levels to emphasize the (known) tumor area

Figure 7 presents three patients' fused images (from the GUI application), including the one shown in Figure 6, both before (marked by capital letters) and after (with little case letters) setting saturation thresholds of the sound speed and reflection to the same levels shown in Figure 6. As for attenuation thresholds, they are adjusted to values so that the background breast tissue is suppressed while the masses are still visible. Due to the variation of patients' breast tissue composition, the attenuation thresholds are also different from one patient to another. It is confirmed by biopsy that all of the three patients have invasive carcinoma, represented by the cyan colored areas in the updated images (with lower case letters). The cyan color is a manifestation of simultaneously high sound speed and strong attenuation.

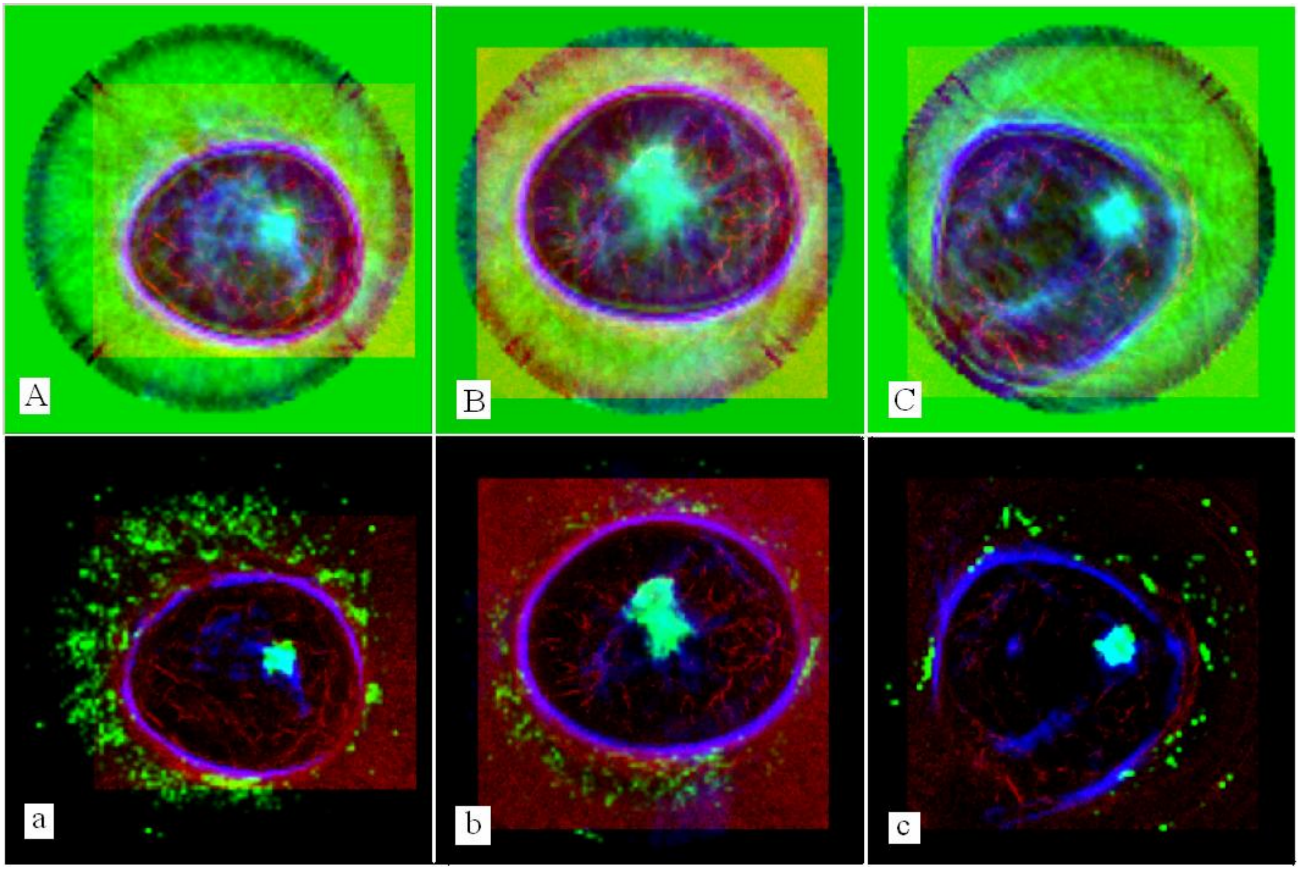

Figure 7. Three patients' fusion images with known malignant masses before (indicated by capital letters) and after (small cases letters) saturating all three parameters

Similarly, another three patients', all of them with benign masses, fused images are shown in Figure 8. Again, the modified images (with lower case letters) are obtained by adjusting the three parameters to the same criteria as those with malignant masses shown in Figure 7. It is interesting to notice that, by quenching the attenuation image background, the areas representing the masses are also quenched, which suggests that the attenuation of benign masses is not much different from that of surrounding tissues in contrast to that of the malignant masses, shown in Figure 6. As a result, the masses appear largely green in the fusion images.

Using the Volume Viewer plug-in (by Kai Uwe Barthel, Berlin, Germany) of ImageJ (by Wayne Rasband, National Institute of Mental Health, Bethesda, Maryland), three dimensional modified fusion image (stack of all the single slices) is shown in Figure 9. The whole mass (cyan) within the patient breast is clearly seen, demonstrating volume-based image fusion.

Overall our preliminary results suggest that it may be possible to use the RGB fused ultrasound images to better present and help evaluate the breast tissue characteristics. In addition, by tweaking the saturation thresholds of reflection, sound speed, and attenuation we are exploring the possibility of differentiating malignant masses from benign masses. Ultimately, it is our goal to detect, measure, and differentiate malignant breast tumor from benign masses automatically from the reconstructed images, so that the whole process is operator independent. Therefore, our future work includes, but is not limited to, optimizing the saturation thresholds, applying them to a larger patient database and finally integrating the algorithm into the CURE system.

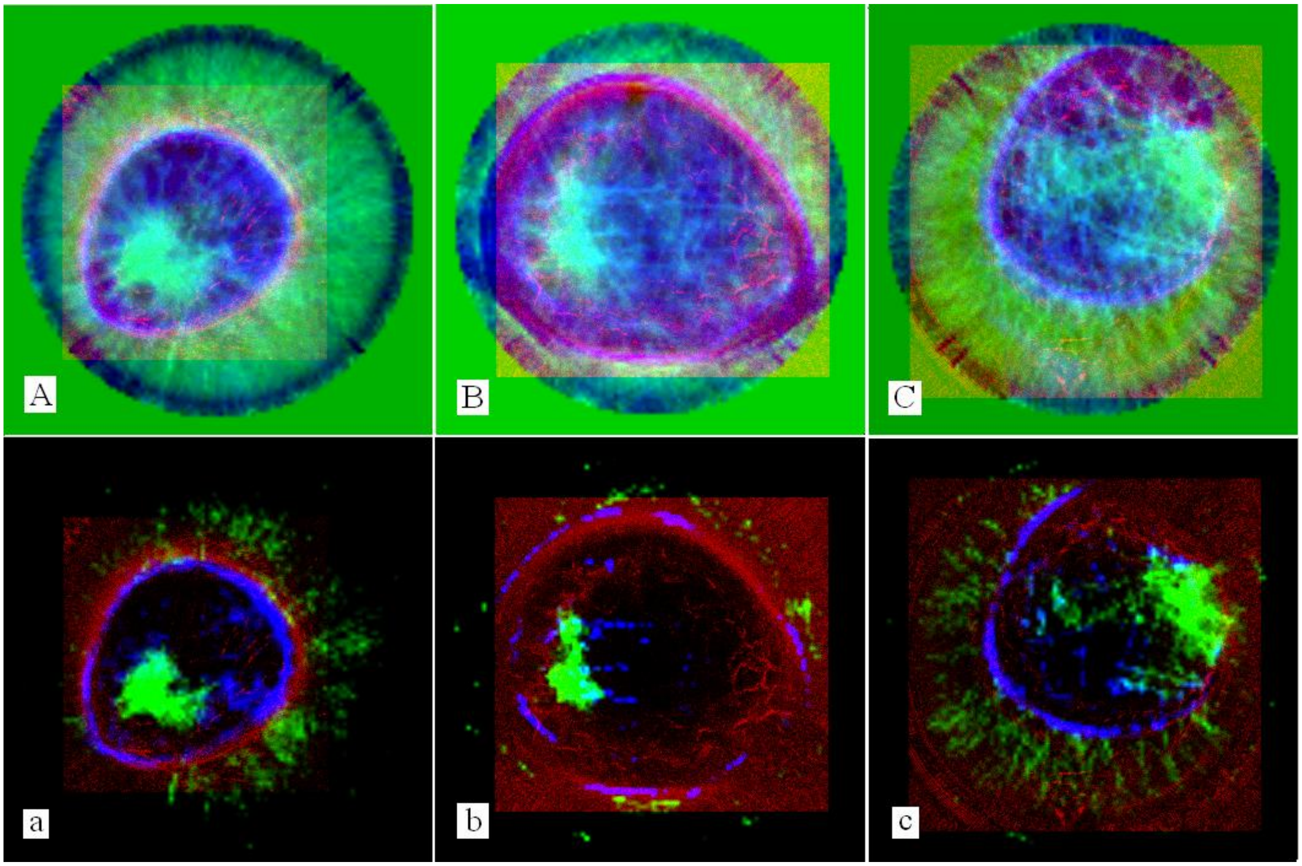

Figure 8. Three patients' fusion images with known benign masses before (indicated by capital letters) and after (small cases letters) saturating all three parameters

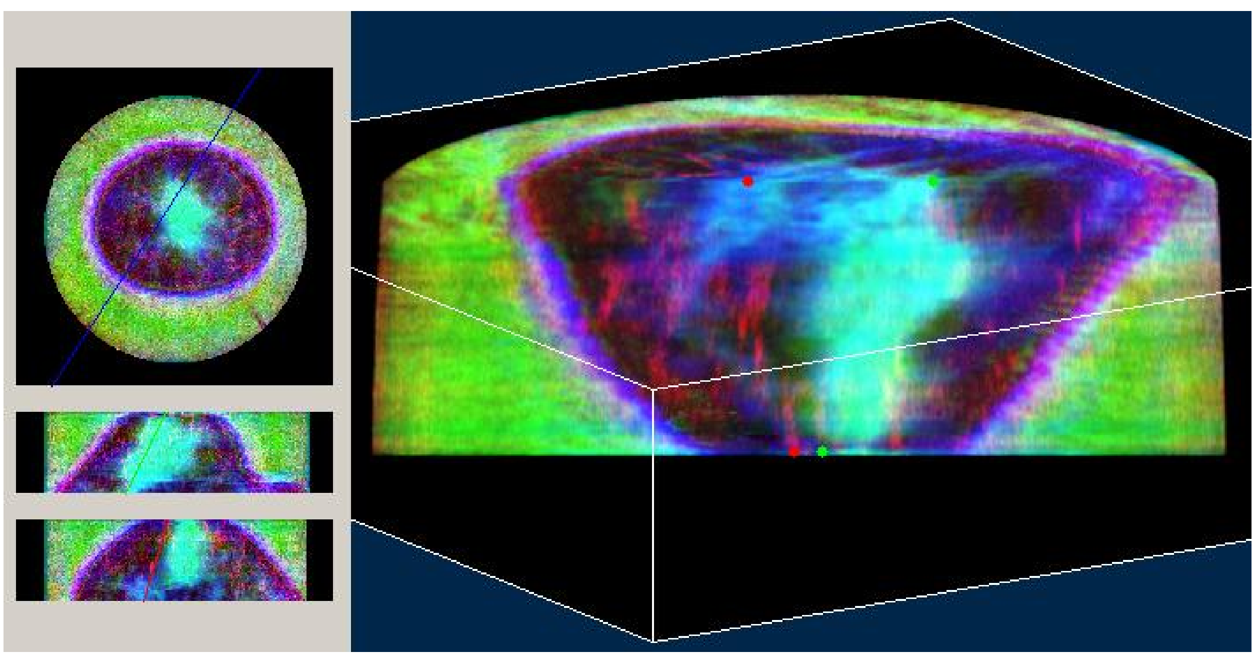

Figure 9. 3D fusion image generated by volume viewer plug-in of ImageJ

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