**MI108:** Ultrasonic Imaging, Tomography, and Therapy

# Breast Imaging with SoftVue: Initial clinical evaluation

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*Abstract:* We describe the clinical performance of SoftVue, a breast imaging device based on the principles of ultrasound tomography. Participants were enrolled in an IRB-approved study at Wayne State University, Detroit, MI. The main research findings indicate that SoftVue is able to image the whole uncompressed breast up to cup size H. Masses can be imaged in even the densest breasts with the ability to discern margins and mass shapes. Additionally, it is demonstrated that multi-focal disease can also be imaged. The system was also tested in its research mode for additional imaging capabilities. These tests demonstrated the potential for generating tissue stiffness information for the entire breast using through-transmission data. This research capability differentiates SoftVue from the other whole breast systems on the market. It is also shown that MRI-like images can be generated using alternative processing of the echo data. Ongoing research is focused on validating and quantifying these findings in a larger sample of study participants and quantifying SoftVue's ability to differentiate benign masses from cancer.

## INTRODUCTION

Recently, Delphinus Medical Technologies (DMT) obtained FDA 510(k) clearance for diagnostic use of its flagship product, SoftVue. SoftVue is a whole breast ultrasound imaging device, joining the ranks of Automated Breast Ultrasound (ABUS) devices such as the Siemens Acuson S2000, GE Invenia (formerly U-systems) and the iVu Sofia Automated Tomographic Ultrasound (ATUS) system. However, unlike these other devices, SoftVue captures through transmission data and does not compress or deform the breast. The patient lies in a prone position with the breast fully suspended in a warm water bath. SoftVue utilizes a ring transducer immersed in warm water to scan the whole breast at a central frequency of 3 MHz. The ring geometry lends itself to software-based aperture synthesis techniques that allow reconstruction of cross-sectional B-mode images at a spatial resolution approaching that of higher frequency systems. Furthermore, the closed geometry of the ring allows the capture of through-transmission signals that can be used to improve the accuracy of the images by correcting for attenuation gradients and optimizing the grey scale level for added mass conspicuity. SoftVue's research mode also allows the reconstruction of sound speed and attenuation images, a capability that does not exist in current whole breast systems on the market. SoftVue is currently undergoing clinical testing with the goals of (i) assessing diagnostic performance utilizing its current (FDA cleared) imaging capabilities (clinical mode) and (ii) exploring future imaging enhancements utilizing the system's research mode.

The SoftVue system was designed to address current clinical challenges in breast imaging such as imaging dense breasts. For women with dense breast tissue, who are at much higher risk for developing breast cancer[1-8], the performance of mammography is at its worst[7]. Consequently, many early cancers go undetected when they are the most treatable. Improved cancer detection for women with dense breasts would decrease the proportion of breast cancers diagnosed at later stages, which would significantly lower the mortality rate. To that end, we present results from cases that illustrate SoftVue's imaging performance across a wide range of breast densities.

SoftVue's design is based on the principles of ultrasound tomography (UST)[9-16]. The original concept and early prototype were developed by our research team at the Karmanos Cancer Institute (KCI) [16-22]. The SoftVue imaging system was designed to provide enhanced performance relative to the prototype and to be ready for the clinical marketplace. The purpose of this paper is to describe the initial technical and clinical performance of SoftVue and to present a qualitative assessment of its performance.


**Figure 1**. The SoftVue system.

## METHODS

The SoftVue imaging system was first tested in DMT laboratories during August and September of 2012. The testing was carried out on anthropomorphic phantoms. Following laboratory testing, SoftVue was installed at KCI's Alexander J. Walt Comprehensive Breast Center to test the performance of SoftVue with human subjects. Participants were consented and data acquired with a verified and validated system under Wayne State University's IRB (approval number #040912M1F), beginning in May, 2013. Over Seventy healthy patient volunteers have been scanned to date. SoftVue's image reconstruction algorithm was used to generate cross-sectional images. A set of tomograms (image slices) were generated for each patient.

The first step in the analysis was to assess the ability of SoftVue's clinical mode to render a variety of breast masses under varying conditions of breast density, breast size and mass size. The second step was to utilize additional data from SoftVue's research mode to explore its ability to measure mass stiffness, in analogy to elastography. The third element of the study was to generate images that can be compared to MRI. In this mode, the echogenicity of the fat is suppressed to facilitate comparisons with MR images.

## RESULTS

**B-mode imaging**.

The following are representative examples of SoftVue images acquired in the ongoing study. Figure 2 demonstrates the ability to image masses in both a smaller dense and a larger fatty breast. The 2 cm fibroadenomata are clearly visible in 2 different patients, one categorized as dense (BIRADS 4 density) and the other as fatty (BIRADS 1). Furthermore, the circumscribed, slightly hyper-echoic capsular margins of the masses are clearly visible. Circumscribed margins are a key aspect of mass characterization and their presence indicates that SoftVue has the spatial resolution to accurately image the specular reflecting component of the capsular margin. The biopsy clip in the 5 o'clock mass can also be seen in the fatty breast. Breast size in Figure 2 (left) is 34B, while Figure 2(right) corresponds to a 36DD, demonstrating the ability to accommodate and image much larger breasts.

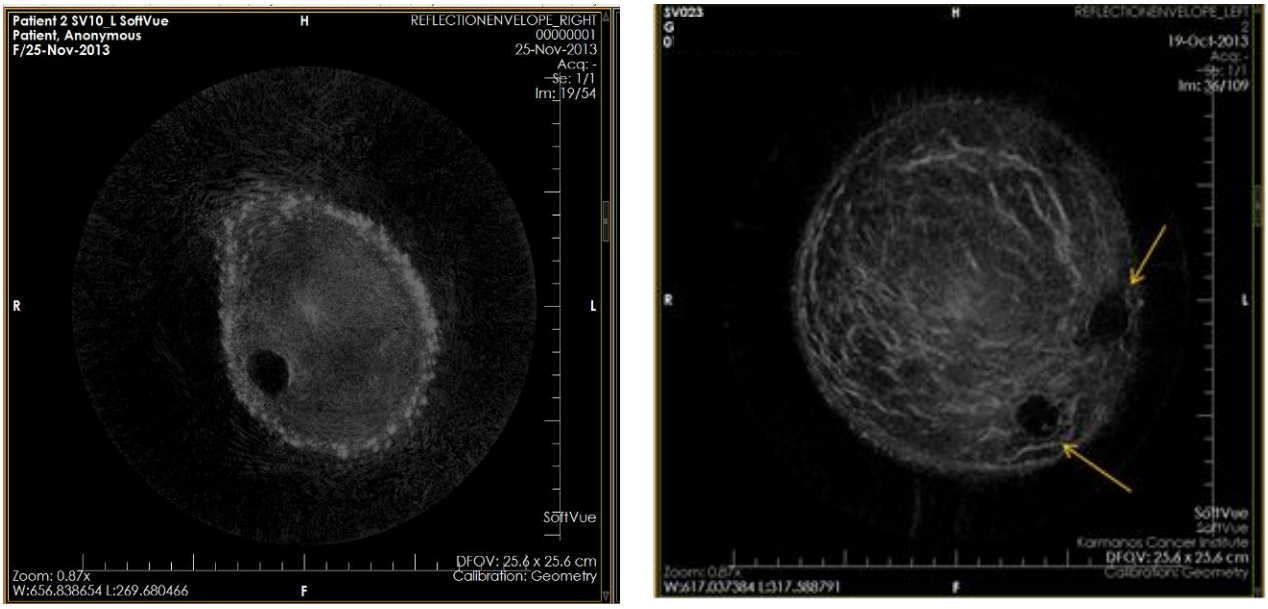


**Figure 2**. Single fibroadenoma in an extremely dense smaller breast is shown on the left. The right image shows two adjacent fibroadenomata in a larger fatty breast. The circumscribed margins of all three masses are clearly visible.

Figure 3 shows a cross-sectional image of large fibroadenoma with a small 9mm satellite mass. The lobulated aspect of the dominant mass is clearly visible and the smaller mass is clearly detected.

Similar to MRI, a key advantage of whole breast ultrasound imaging is the ability to image multi-focal disease. Figure 4 shows cross-sectional SoftVue images of multiple masses corresponding to a multi-focal papillary carcinoma, again in a dense breast which was mammographically negative but palpably detected.

**Characterization of tissue stiffness**.

SoftVue's research mode was used to calculate the parameters of sound speed and attenuation and to use that information to characterize the stiffness of breast tissue using thresholding techniques described in earlier publications[21].

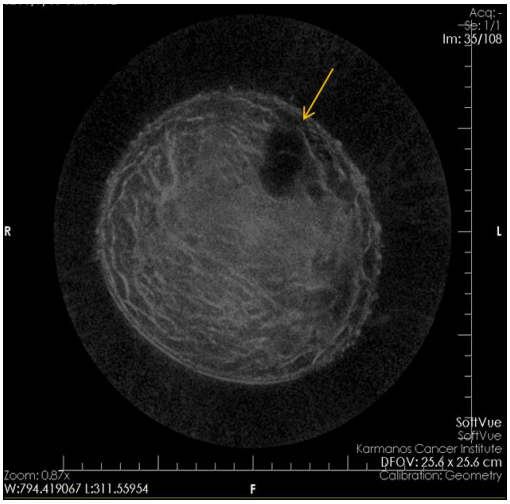


**Figure 3**. Large lobulated fibroadenoma and a small 9mm neighboring mass.

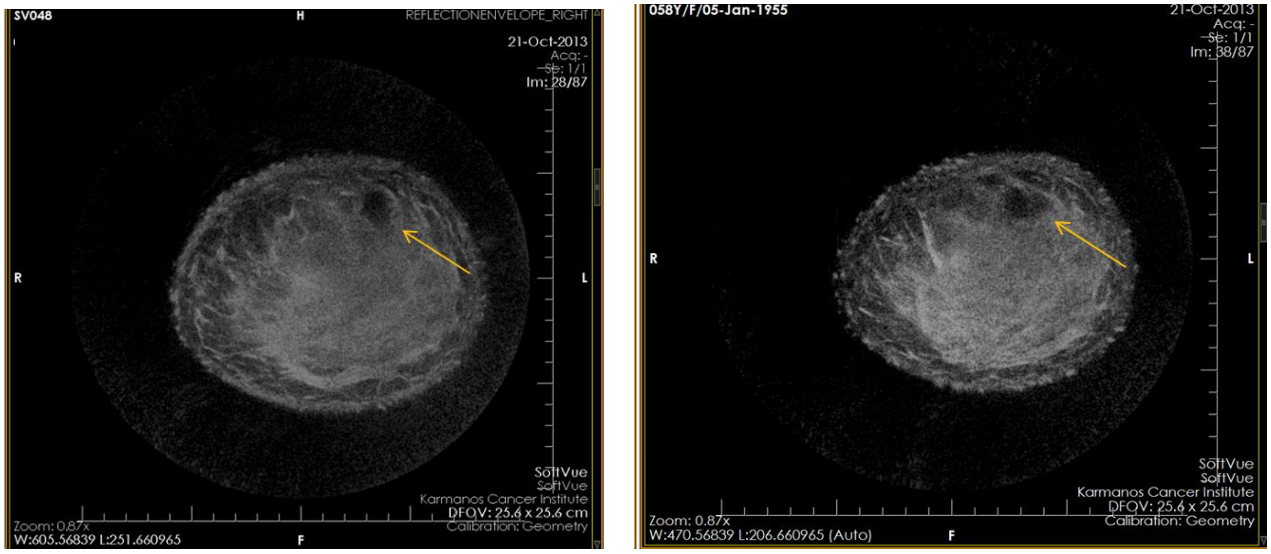


**Figure 4**. Two foci of a papillary carcinoma are shown.

Figure 5 shows three examples of images processed in this way, two cancers and one cyst. The top row displays the cross-sectional B-mode images which show the masses to be hypo-echoic with varying levels of echogenicity. These images were processed using a fusion technique so that the additional information about tissue stiffness could be overlaid on the B-mode images, corresponding to the images in the bottom row. The fusion process renders the two carcinomas as very stiff and attenuating while the cyst image is unaltered.

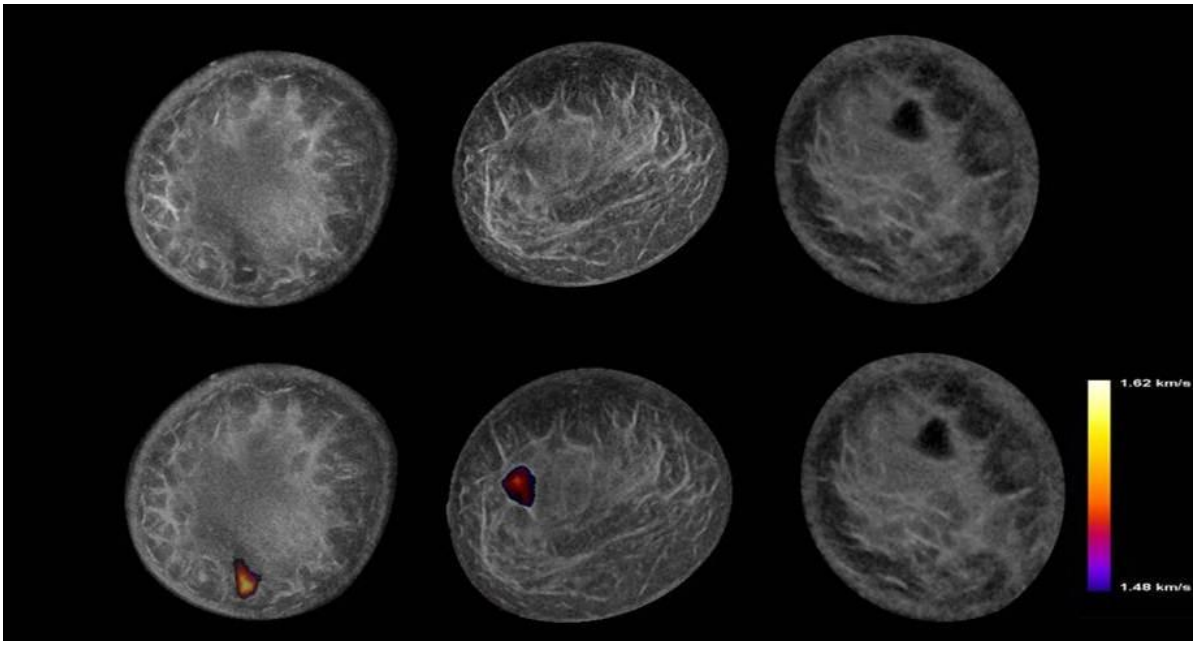


**Figure 5**. Three cases showing 2 cancers and a cyst (from left to right respectively). The top row shows the original B-mode images. The bottom row shows stiffness and attenuation information overlaid in color.

## Analogy to MRI.

In SoftVue's research mode, raw data can be collected so that subsequent signal processing can be used to suppress echoes from the fatty tissues and thereby provide an effect analogous to fat-subtracted MRI images. Figure 6

compares MRI (left) and SoftVue (right) coronal slices from roughly the same region of the breast. The reconstructed coronal MRI image is a fat-subtracted contrast-enhanced image showing the enhancing mass along with a wispy parenchymal pattern, which is slightly degraded by motion and reconstruction artifacts. The SoftVue image is shown after the application of the fusion technique[21]. The SoftVue image shows the mass as having the stiffest tissue in the slice with similar parenchymal pattern and a dark background corresponding to the fat.

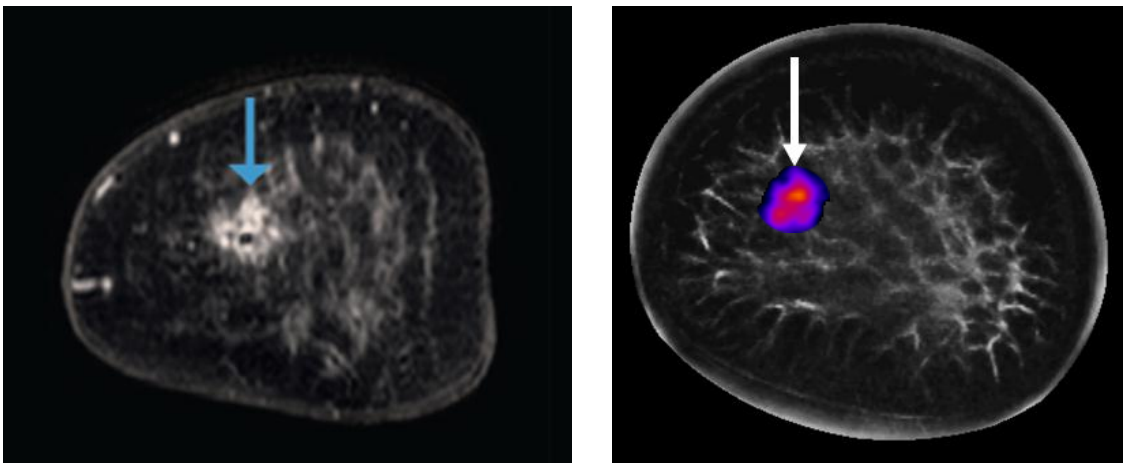

**Figure 6**. MRI fat-subtracted, contrast enhanced image on the left. SoftVue image with stiffness and attenuation overlay shown on the right.

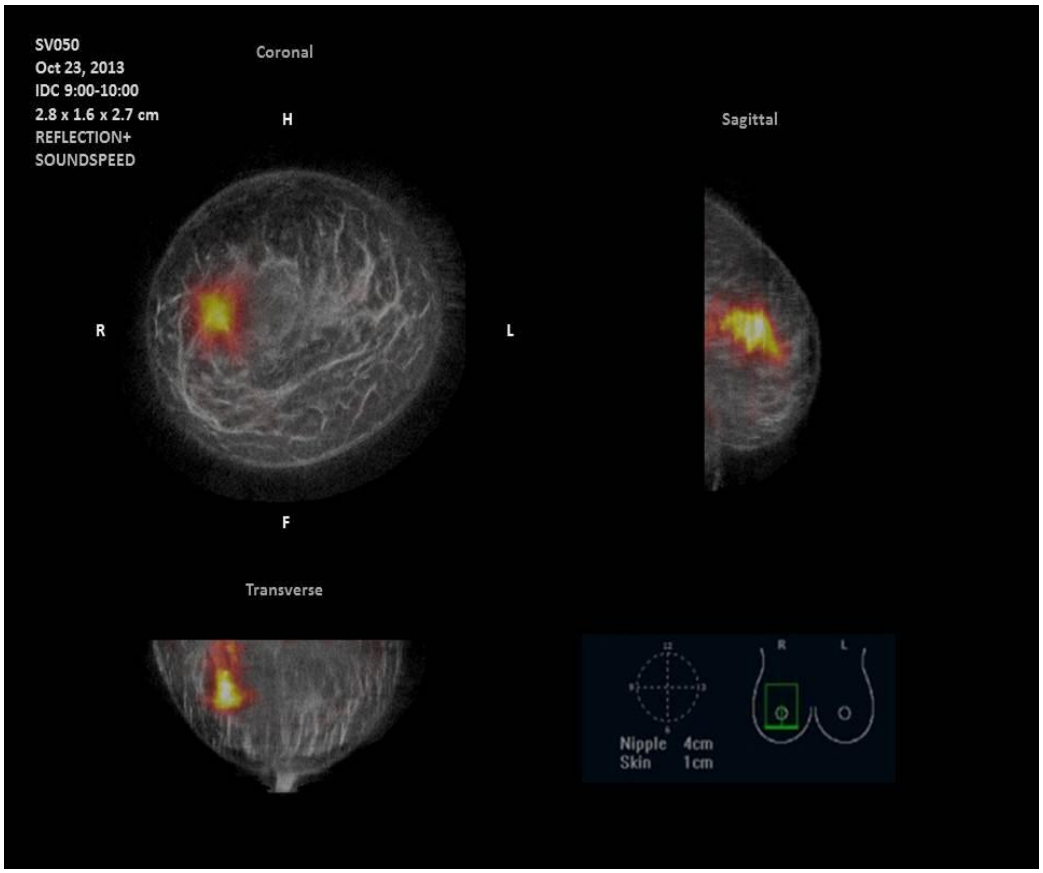


**Figure 7**. Multi-planar re-projections of SoftVue image stack with color overlay.

MRI and SoftVue both generate image stacks that can be volumetrically rendered and projected into different planes. Figure 7 shows a set of multi-planar re-projections from SoftVue data using a PET-CT-like color overlay. The native projection is coronal. The sagittal and transverse projections are also shown. These images demonstrate SoftVue's potential for 3-D multiplanar imaging.

## DISCUSSION

SoftVue has been cleared by the FDA for diagnostic whole breast B-mode imaging. In this mode, SoftVue identifies masses as hypoechoic regions against a more echogenic background of fat and parenchyma. As the images in Figures 1 to 3 show, mass shapes can be determined in both dense and fatty breasts. Furthermore, the whole breast imaging capability enables imaging of multi-focal disease as shown in Figure 4. Unlike other ABUS systems, the breast is imaged in a more natural pendant state without compression, a characteristic that SoftVue shares with MRI. To that end, Figure 7 demonstrates the ability to generate multi-planar reconstructions of an uncompressed breast.

In its research mode SoftVue can process the through-transmission data to generate parameters for assessing tissue stiffness and attenuation, then overlaying those thresholded regions in color[21], as shown in Figures 5, 6 and 7. This feature is analogous to color overlays of elastography on grey scale B-mode images in conventional sonography. However, SoftVue can compute and apply its color overlays over the entire volume of the breast in contrast to the localized measurements of elastography offered today. Ongoing research is aimed at correlating SoftVue's color overlays with that of standard elastography to optimize the display and provide a bridge to current techniques. If successful, such whole breast overlays will provide the analogue of whole breast elastography, a feature current ABUS systems lack.

In its default clinical mode, SoftVue processes the images to provide grey scale rendering similar to that of conventional B-mode imaging. Additional post-processing of the raw data, acquired in research mode, can suppress echoes from the fatty tissues and, thereby, provide an effect analogous to fat-subtracted MRI images. Unlike mammography and conventional ABUS systems, MRI is a natural comparative imaging mode for SoftVue because of prone patient positioning with the uncompressed pendulant breast. Thus, SoftVue and MRI yield similar whole volume geometries enabling slice by slice comparison of images, though noting gravity differences for the breast in water and air, respectively. Figure 6 shows such a comparison, indicating rendering of similar structures. SoftVue does not require the use of contrast but, as Figure 6 shows, the enhancing mass in MRI has a counterpart in the SoftVue image that is biomechanically distinct from the rest of the tissues in the slice. While MRI relies on tumor vasculature and SoftVue relies on biomechanical properties for mass conspicuity, the effect on conspicuity can be similar. Furthermore, future use of ultrasound contrast agents may allow SoftVue to also image tumor vasculature. .

## CONCLUSIONS

This paper presents results from an ongoing clinical study aimed at assessing the imaging performance of SoftVue, a novel breast imaging device based on the principles of ultrasound tomography and recently cleared by the FDA for diagnostic whole breast B-mode imaging. These results demonstrate the following characteristics of the SoftVue system operating in B-mode:

(i) Imaging of the whole, uncompressed breast is possible for even the largest breasts (size 36 DD shown in Figure 2) while size H (not shown) have also been successfully scanned).
(ii) Masses can be imaged in even the densest breasts with the ability to discern margins and mass shapes.
(iii) Multi-focal disease can be imaged by virtue of the whole breast imaging capability.

The system was also tested in its research mode for additional imaging capabilities. These tests demonstrated the following characteristics of SoftVue operating in its research mode.

(iv) SoftVue can generate tissue stiffness information using sound speed and attenuation maps reconstructed from through-transmission data. Such data can be fused with the B-mode images in a manner analogous to color elastography overlays.
(v) MRI-like images can be generated using alternative processing of the raw echo data.
(vi) Volumetric imaging with multi-planar reconstructions is possible in a manner similar to that of MRI.

Ongoing studies are aimed at assessing the clinical performance of SoftVue in its cleared mode to assess its effectiveness while additional research is being conducted to assess the feasibility of elastography-like overlays for characterizing lesions.

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