Comparison of sound speed measurements on two different ultrasound tomography devices

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ABSTRACT

Ultrasound tomography (UST) employs sound waves to produce three-dimensional images of breast tissue and precisely measures the attenuation of sound speed secondary to breast tissue composition. High breast density is a strong breast cancer risk factor and sound speed is directly proportional to breast density. UST provides a quantitative measure of breast density based on three-dimensional imaging without compression, thereby overcoming the shortcomings of many other imaging modalities. The quantitative nature of the UST breast density measures are tied to an external standard, so sound speed measurement in breast tissue should be independent of specific hardware. The work presented here compares breast sound speed measurement obtained with two different UST devices. The Computerized Ultrasound Risk Evaluation (CURE) system located at the Karmanos Cancer Institute in Detroit, Michigan was recently replaced with the SoftVue ultrasound tomographic device. Ongoing clinical trials have used images generated from both sets of hardware, so maintaining consistency in sound speed measurements is important. During an overlap period when both systems were in the same exam room, a total of 12 patients had one or both of their breasts imaged on both systems on the same day. There were 22 sound speed scans analyzed from each system and the average breast sound speeds were compared. Images were either reconstructed using saved raw data (for both CURE and SoftVue) or were created during the image acquisition (saved in DICOM format for SoftVue scans only). The sound speed measurements from each system were strongly and positively correlated with each other. The average difference in sound speed between the two sets of data was on the order of 1-2 m/s and this result was not statistically significant. The only sets of images that showed a statistical difference were the DICOM images created during the SoftVue scan compared to the SoftVue images reconstructed from the raw data. However, the discrepancy between the sound speed values could be easily handled by uniformly increasing the DICOM sound speed by approximately 0.5 m/s. These results suggest that there is no fundamental difference in sound speed measurement for the two systems and support combining data generated with these instruments in future studies.

Keywords: Ultrasound tomography. Breast density. Sound speed. Hardware correlation.

1. INTRODUCTION

Ultrasound tomography (UST) is an emerging imaging modality that is currently used to produce three-dimensional images of breast tissue[1-3]. UST uses sound waves to measure the transmission and reflection properties of the breast anatomy[4]. One of these transmission properties is tissue sound speed. High breast density is a strong breast cancer risk factor[5-7] and sound speed is directly proportional to breast density. The longitudinal sound speed of any material is given by:

$$v = \sqrt{\frac{C}{\rho}}$$

where C is the bulk modulus and ρ is the density of the material in question. Studies have shown that the bulk modulus of breast tissue scales with the cube of its density[8-10]. This suggests that for breast tissue, the velocity has a direct relationship with density.

The quantitative nature of UST breast density measures are tied to an external standard, so sound speed measurements made in breast tissue should be independent of the specific hardware that was used to create the images. Updated UST hardware was recently installed at the Karmanos Cancer Institute (KCI) in Detroit, Michigan[11]. The new generation of the device, known as SoftVue, offers improvements in image quality, reconstruction time and patient convenience over the prototype CURE (Computerized Ultrasound Risk Evaluation) system. UST creates its sound speed images using time-of-flight measurements of ultrasound within a ring transducer. Different sets of hardware can have small changes in the ring's geometry. These differences need to be accounted for in the reconstruction algorithm in order to ensure the correct sound speed values are calculated. Breast density measurements should correlate strongly between SoftVue and CURE. The main goal of this work is to formally validate this correlation.

It is critical that sound speed measurements are independent of the hardware used to create the images. Several clinical studies are currently ongoing that use images created with both sets of hardware[11, 12]. Establishing the robustness of the sound speed measurements is important to ensure the validity of these ongoing studies. The ability to combine sound speed data is critically dependent on the correlation of sound speed between instruments. High correlation supports the robustness of breast density assessment using this approach and would support comparison of results obtained with different well-calibrated UST devices.

2. METHODS AND MATERIALS

Testing of the two devices was conducted as SoftVue was being installed at KCI. A sample of 12 women volunteered to undergo scans using both SoftVue and CURE under a Wayne State University IRB approved protocol. These scans were taken in short succession of each other, on the order of an hour apart. Most patients had both their left and right breasts imaged, but some had only one breast scanned. In total, for the 12 patients enrolled, 22 scans on each machine were produced.

For both CURE and SoftVue, the analyzed sound speed images are usually reconstructed using the saved raw data that was collected during the scan. The raw data for a SoftVue scan is much larger than the raw data for a CURE scan. Saving the SoftVue raw data to be used for image reconstruction takes much longer than for the CURE hardware and additional patients cannot be scanned on SoftVue until the data is completely written to disk. In clinical mode where SoftVue is used for imaging in a high patient throughput environment, the raw data is not stored for some scans. In these cases, sound speed images are created during data acquisition in the form of a DICOM image. This DICOM image is created using the same algorithm that would be used on the saved raw data, but is compressed into the DICOM format instead of the ascii format that the full reconstructions produce.

For each of the 22 scans, a total of three different sets of sound speed images were therefore produced. For the purposes of this report, they will be identified as follows:

1. CURE – Sound speed images created using the CURE hardware. They were reconstructed after the scan from the saved raw data into ascii form. Raw data was always saved when using CURE.
2. SoftVue – Sound speed images created using the SoftVue hardware. They were also reconstructed after the scan from the saved raw data into ascii form. In clinical studies, when SoftVue raw data is saved, this is the preferred image type.
3. DICOM – Sound speed images created using the SoftVue hardware. DICOM images were created during the scan from the raw data. In a research study, DICOM images would be created irrespective of whether or not the raw data is saved. When the SoftVue raw data is not saved, DICOM images would be the only image type available for analysis.

The average sound speed of each image was analyzed with the public domain software *ImageJ* by a single reader using a semi-automated method as previously described[13-15]. Briefly, for each image, the water bath surrounding the breast tissue in each slice was masked with an elliptical approximation of the breast. When each slice was masked, the remaining pixels corresponded only to breast tissue and the average sound speed value was calculated. Separate masks were created for CURE and SoftVue images individually due to the differences in patient positioning between the two devices. Because the SoftVue and DICOM images were created using the same raw data, the size and shape of the breast tissue in the SoftVue and DICOM images aligned 1-to-1. Therefore, masks were first created for the SoftVue image and then directly applied to the DICOM images.

3. RESULTS AND DISCUSSION

Table 1 shows the raw sound speed measurements made for all patients for all three image types. The average value and standard deviation of the measurements are also shown for each image type. The intraclass correlation coefficient (ICC) of the three measurements is 0.973 which indicates that the sound speed measurements appear to be reliable across the three image types.

Table 1 – Ultrasound Tomography Sound Speed Measures Collected from n=12 Volunteers for Three Image Types

Scan ID	CURE Sound Speed (km/s)	SoftVue Sound Speed (km/s)	DICOM Sound Speed (km/s)	CURE SoftVue Difference (m/s)	SoftVue DICOM Difference (m/s)	DICOM CURE Difference (m/s)
SoftVue001_L	1.43826	1.44979	1.44966	-11.5	0.13	11.4
SoftVue001_R	1.45505	1.45198	1.45162	3.1	0.36	-3.4
SoftVue002_L	1.44946	1.44479	1.44443	4.7	0.36	-5.0
SoftVue002_R	1.45101	1.44602	1.44532	5.0	0.69	-5.7
SoftVue003_L	1.43934	1.43925	1.43884	0.1	0.41	-0.5
SoftVue004_L	1.48584	1.49159	1.49158	-5.7	0.00	5.7
SoftVue004_R	1.48183	1.49173	1.49173	-9.9	0.00	9.9
SoftVue005_L	1.48461	1.47741	1.47664	7.2	0.77	-8.0
SoftVue006_L	1.48994	1.47619	1.47610	13.8	0.09	-13.8
SoftVue006_R	1.49419	1.49544	1.49524	-1.3	0.20	1.0
SoftVue007_L	1.45212	1.44606	1.44547	6.1	0.58	-6.6
SoftVue007_R	1.45429	1.44539	1.44414	8.9	1.25	-10.2
SoftVue008_L	1.44388	1.44250	1.44263	1.4	-0.14	-1.2
SoftVue008_R	1.44608	1.44276	1.44200	3.3	0.75	-4.1
SoftVue009_L	1.44344	1.44088	1.44006	2.6	0.81	-3.4
SoftVue009_R	1.44409	1.43967	1.43891	4.4	0.77	-5.2
SoftVue010_L	1.44895	1.44420	1.44310	4.7	1.10	-5.8
SoftVue010_R	1.45337	1.44539	1.44451	8.0	0.88	-8.9
SoftVue011_L	1.44356	1.44901	1.44901	-5.5	0.00	5.5
SoftVue011_R	1.44782	1.44799	1.44800	-0.2	-0.02	0.2
SoftVue012_L	1.43934	1.44399	1.44303	-4.6	0.96	3.7
SoftVue012_R	1.43912	1.44428	1.44347	-5.2	0.81	4.3
Average (km/s or m/s)	1.45571	1.45438	1.45389	1.3	0.5	-1.8
		Standard Deviation (m/s)		6.3	0.4	6.5

Because sound speed and breast density are highly correlated between breasts within the same woman, the 22 sound speed images obtained from each device could not be treated as independent observations. A weighted correlation between the measured sound speed values was therefore used. Patients with N scans had their N sound speed values averaged. The N unique scans were replaced with N versions of the average sound speed value and all analysis was done on this modified data set. Since the same patients were imaged on all devices, ideally the mean sound speed of the group should be equal across image types. Table 1 shows the mean sound speed value for all patients for each image type. Differences in mean values by image type were tested on the weighted data set using a Wilcoxon signed rank test and p-values are listed in Table 2.

Table 2 – Mean Difference in Sound Speed Values by Image Type

Image Pair Tested	Average Difference in Sound Speed (m/s)	Wilcoxon Signed Rank p-value
CURE to SoftVue	+ 1.3	0.291
SoftVue to DICOM	+ 0.5	< 0.001
DICOM to CURE	- 1.8	0.101

The mean CURE sound speed values were the greatest of all three imaging modalities followed by the mean SoftVue sound speed and then the DICOM sound speed. On average, CURE sound speed was approximately 1.3 m/s greater than the SoftVue sound speed measurements which in turn were about 0.5 m/s greater than the DICOM values. When comparing CURE to DICOM directly, the subset of aligned data showed that CURE sound speeds were, on average, 1.8 m/s greater than DICOM. The Wilcoxon signed rank test revealed that the average difference between the DICOM and SoftVue images was statistically significant (p-value < 0.001). The majority of the DICOM images systematically gave a lower average sound speed value than its corresponding SoftVue image. Average sound speed is therefore consistently underestimated when using DICOM images as compared to SoftVue images. This indicates that a bias exists when using DICOM images to calculate sound speed values. This bias may be attributed to a slight clipping of data values that was done to optimize the default brightness and contrast of the DICOM images. Because the raw SoftVue data may not always be saved in clinical studies due to time constraints between patient scans, a method to address this systematic difference between SoftVue and DICOM sound speed values must be developed.

We explored whether a correction factor could be applied to the DICOM sound speed values in order to more closely approximate the raw SoftVue sound speed data. As the correction required may be a function of the measured sound speed, we examined the difference between the SoftVue and DICOM sound speeds plotted as a function of DICOM sound speed (Figure 1). The figure shows that the difference does not appear to be related to the density (as estimated by DICOM sound speed) of the breast. It also shows that almost all sound speeds measured by SoftVue are larger than those measured using DICOM images, with a range from 0 to 1 m/s. We therefore conclude that the simplest correction may be to add a constant value of 0.5 m/s (i.e., the average difference shown in Table 2) to the calculated DICOM sound speed to align values with the SoftVue sound speed measures.

Our findings are limited in that they are restricted to a convenience sample of volunteers who tended to have lower sound speed values than those we have observed in the clinical setting. The majority of patients had average sound speed values between 1.44 km/s and 1.45 km/s. We have previously observed that the range of sound speed values can extend up past 1.52 km/s for the densest breasts[13], but no women with breasts as dense as this were imaged in this study. It therefore possible that in a larger more diverse patient population that the difference in sound speed values may proportional to breast density, in which case the application of the correction factor described above may not apply. We are currently comparing phantom measurements by image type in order to try to better understand potential differences in sound speed measures.

In contrast, the CURE and SoftVue images did not show a statistically significant difference in sound speed. There were some patients where the CURE sound speed was higher than the SoftVue sound speed but there were other patients where the opposite was true. This result suggests that there is no inherent systematic bias between these two sets of images. The differences between these two systems are likely due to random variances in the reconstructed sound speed images. No further action is required to correct for this difference for these data sets. The average difference between the CURE and DICOM sound speeds was the greatest of all three comparisons, but once again, the p-value was not statistically significant. Had more data been collected for both devices, it may have been possible to detect a statistically significant difference in mean values. Thus, we cannot rule out the possibility that there may be a relevant systematic bias in all DICOM images compared to both CURE and SoftVue measures.

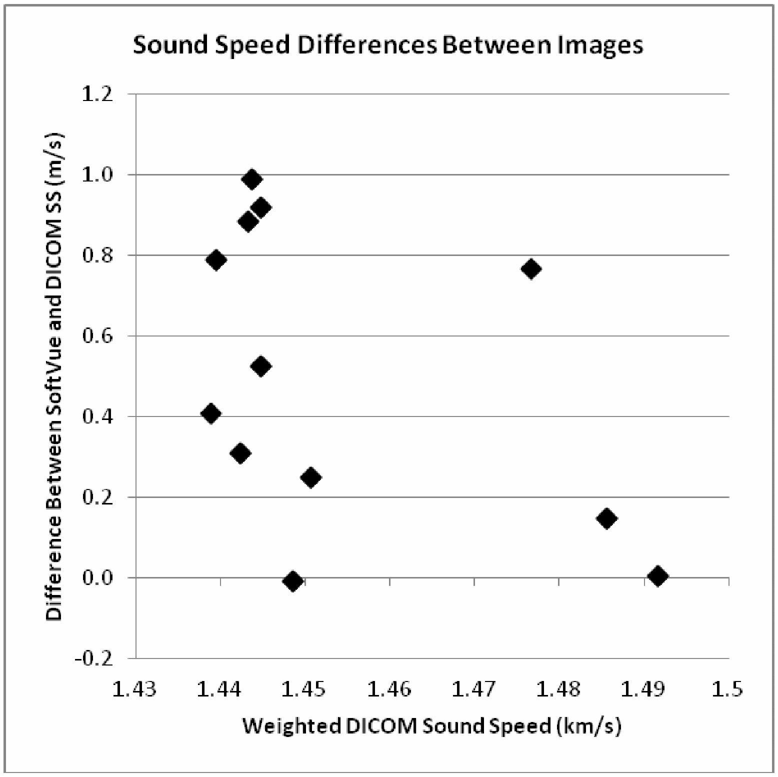

Figure 1 – Plot of the difference in sound speed between SoftVue and DICOM images as a function of the DICOM average sound speed.

We also measured correlations between the sound speed images using the weighted data. The results of this analysis are shown in Figure 2. The plots show the CURE-SoftVue, SoftVue-DICOM and DICOM-CURE relationships respectively. The Spearman correlation coefficients for each fit along with the slope and intercept of the lines of best fit are shown in Table 3.

Table 3 – Correlations between Sound Speed Measures from Different Image Types

Images Compared	Spearman Coefficient	Slope of Line of Best Fit	Intercept of Line of Best Fit
CURE-SoftVue	0.808	0.966	0.048
SoftVue-DICOM	0.991	0.989	0.016
DICOM-CURE	0.799	0.934	0.098

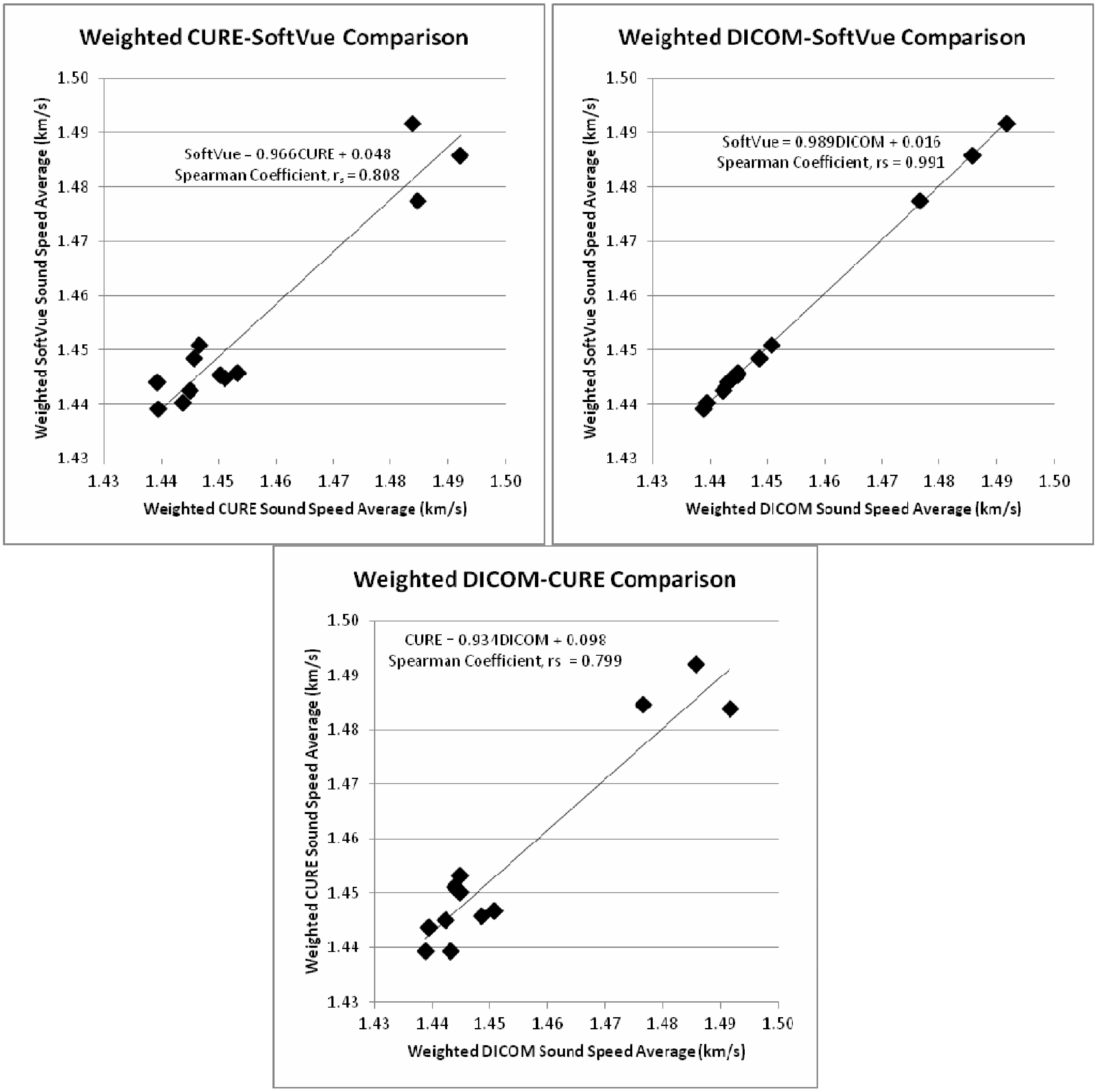

Figure 2 – The plot of the weighted average sound speed measurements as measured on the (Top Left) CURE versus SoftVue images (Top Right) DICOM versus SoftVue images and (Bottom) DICOM versus CURE images.

These results suggest that the sound speed measurements correlate strongly and positively with one another. No matter which image type was used, the measured average sound speed value was likely to correlate with the values measured using the other image types. The strongest correlation was between the DICOM and SoftVue images as they are created using the same raw data. The slopes of the lines of best fit are close to 1, although those involving CURE data are furthest from this value. There is more variability in the results when comparing across CURE and SoftVue sound speed values, but this does not indicate that there is necessarily a bias in the image reconstruction. The random variability is most likely due to the CURE system's intrinsically lower signal sensitivity (compared to SoftVue) which leads to a greater influence of noise on the sound speed reconstructions.

4. CONCLUSION

The comparison of sound speed measurements using an original UST CURE prototype and the next generation device SoftVue was performed on a sample of 12 patients. Between the CURE and SoftVue systems, the results were highly correlated without systematic bias toward lower or higher values. While the results on the two sets of images generated with SoftVue did show a systematic difference, such that the raw values tended to be higher than those from the DICOM images, this difference may be resolved through the application of a simple correction factor to the DICOM dataset. These results indicate that the UST approach is capable of yielding robust assessments of breast density with a three-dimensional non-compressive technique and support combining data generated with these instruments in future studies.

5. ACKNOWLEDGEMENTS

This work was supported (in part) by the Intramural Research Program of the National Institutes of Health, National Cancer Institute.

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