PRE-CLINICAL EXPERIENCE WITH FULL-WAVE INVERSE-SCATTERING FOR BREAST IMAGING

Sound Speed Sensitivity

M.P. André, C.H. Barker, N. Sekhon, J. Wiskin, D. Borup, K. Callahan

Dept. of Radiology, San Diego VA Healthcare System, 3350 La Jolla Village Dr., San Diego, California 92161, USA, Dept. of Radiology (9114), University of California, San Diego, California 92093, USA, Techniscan Medical Systems, Inc., 1011 Murray Holladay Rd., Salt Lake City, Utah 84117, USA

Abstract: A new transmission ultrasound CT breast scanner (Techniscan Medical Systems, Inc.) was installed for pre-clinical testing at UCSD Medical Center. The scanner utilizes a 3D inverse scattering method to produce whole-breast tomographic images with resolution approximately 1.5 mm in plane, 3.5 mm slice profile and slice spacing of 1 mm. Sound speed accuracy and sensitivity were found to be highly linear (R^2=0.99) over the wide range of 1370–1620 m/sec. Attenuation provided a wide image contrast and is able to localize and identify breast lesions. We present representative cases of human subjects enrolled in the pre-clinical study and describe future plans for the system.

Key words: Breast ultrasound, Ultrasound CT, Speed of sound, Attenuation, Inverse scattering

1. INTRODUCTION

Conventional breast sonography is a notoriously challenging exam to perform. Quality of the results is highly dependent on the skill of the operator, the nature of the patient's breast tissue as well as technical features of the scanner. In order to obtain high resolution the field of view is very small, which complicates interpretation and localization of a mass. Laboratory and in vivo measurements have suggested that normal breast

I. Akiyama (ed.), *Acoustical Imaging*,

© Springer Science+Business Media B.V. 2008

tissue, benign lesions and cancerous lesions may be identified by their acoustic properties (particularly sound speed and attenuation).

Over the past 20 or more years transmission ultrasound computed tomographic (USCT) imaging of the breast has been applied to this problem by several researchers with varying degrees of success [1–4]. In general, these methods used two-dimensional linearization techniques to solve what is inherently a non-linear and three-dimensional problem. It is now clear that the range of tissue properties encountered in the breast is sufficiently large that linear approximations lead to severe artifacts and inadequate spatial resolution.

Figure 1. TMS USCT scanner.

Until recently the engineering technology and mathematical methods for full-wave inverse-scattering 3D tomography have been so complex that practical results in humans were not realized. Techniscan Medical Systems (TMS), Inc. (Salt Lake City, Utah), has developed a scanner (Fig. 1) for breast imaging that uses a multi-frequency non-linear 3D inverse-scattering algorithm [5,6].

The TMS system was installed at the University of California, San Diego (UCSD) to study clinical feasibility of using Ultrasound CT (USCT) to evaluate and detect breast masses. Performance of this pre-clinical prototype system especially with respect to sound speed measurements was examined for this report.

2. METHODS

The TMS scanner is an automated system that performs a standardized scan of the whole breast nearly independent of operator expertise. Furthermore, the images present a global view of both breasts in 3D. The patient lies prone with her breast pendant in a controlled 31°C water bath within the field of view of a transmitter and receiver array that rotate around 360° to collect 180 tomographic views of ultrasound wave data. The transmitter emits broad-band plane pulses (0.3–2 MHz) while the receiver array, comprised of 960 elements in 6 vertical rows, digitizes the time signal. A full data set consists of 50 or more overlapping levels of data, depending on breast size, are acquired 2 mm apart. An algorithm is utilized that simulates wave propagation in 3D and inverts for a fully 3D representation of sound speed and attenuation [6]. Unlike a 2D algorithm where one level of transmitted data is used, in the 3D inversion all levels of data are simultaneously inverted by the algorithm that propagates simulated 3D waves in a computational grid that extends above and below the data levels approximately 37 mm. The resulting image consists of voxels that are 0.8 mm by 0.8 mm in the horizontal, and 1 mm in the vertical direction.

The accuracy of sound speed measurements by USCT were tested with phantoms of known composition including solutions of CaCl, various oils and tissue-mimicking materials (CIRS, Waltham, MA). Solutions of CaCl ranging from 0.0 to 37.5% wt/vol, dilutions of isopropyl alcohol and various mineral oils were prepared in the laboratory to provide a range of sound speeds from 1370 ± 2.1 to 1620 ± 6.0 m/sec at 31°C. The materials were suspended in the USCT scanner water tank in thin-walled round 300 ml latex rubber containers and imaged at 31°C.

Under IRB approval, fifty-one patients with findings known on conventional breast sonography and mammography have been scanned to date in San Diego ranging in age from 20 to 78. Region-of-interest measurements were made in the sound speed and attentuation images for normal tissues and masses whose tissue types were known from other procedures (biopsy, aspiration, mammography, sonography, etc.).

3. RESULTS

3.1 Performance Measurements

Sound speed accuracy and linearity from the prepared solutions are shown in the plot in Fig. 2. Very high sound speed linearity was found (R^2=0.992) over the range of boundary values of the algorithm. Sound speed contrast sensitivity of the images was 3.5 m/sec. Speed of sound images were also computed at multiple temperatures ranging from 21 to 74°C. In the CaCl solutions, temperature changes were detectable under these conditions as speed of sound differences (SOS = 1.8·Temp + 1504) with a sensitivity of

2.1°C. In Fig. 2 the error bars (±SD) on the data points are smaller than the symbols.

In the current prototype, for the sound speed image the full-width half-maximum of the point spread function is approximately 1.5 mm in plane with ~3.5 mm slice sensitivity profile at 1.25 MHz. At present, the 3D algorithm is about 25% sharper than the 2D approach.

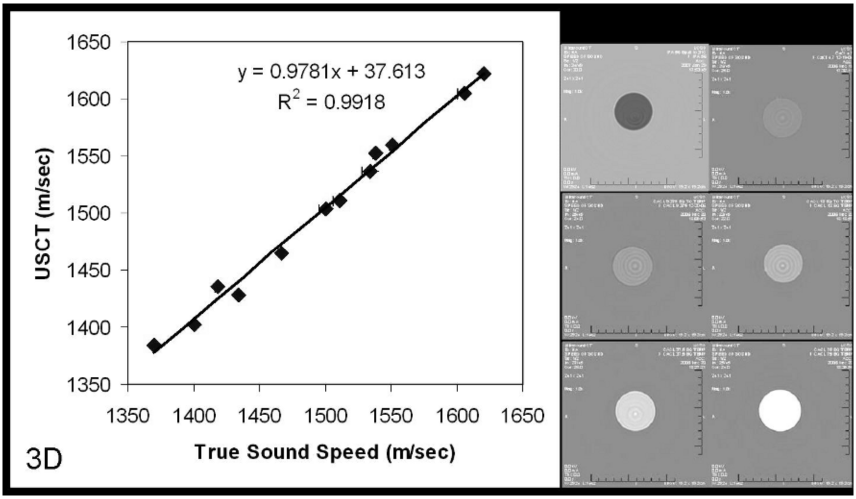

Figure 2. USCT sound speed sensitivity.

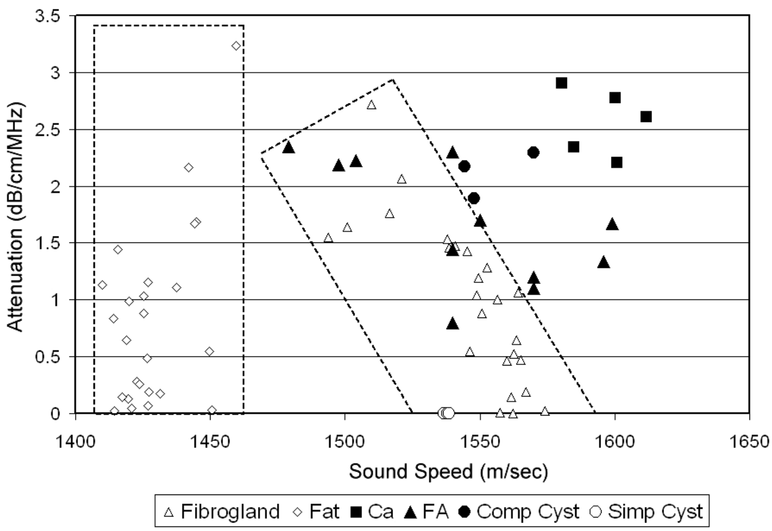

Figure 3. Sampling of acoustic properties of normal tissues and masses.

A sample of region of interest measurements from the sound speed and attenuation images for the research subjects is shown in Fig. 3 for normal structures and a variety of masses. These measurements are not yet complete but normal fatty and fibroglandular tissues (boxes) are well separated by speed and attenuation, while fibroadenomas (FA) and complex cysts show some overlap. Cancers (Ca) have both high speed and attenuation while simple cysts have very low attenuation comparable to water.

3.2 Case Presentations

For this study patients were recruited from women who were scheduled for a conventional diagnostic breast ultrasound exam. This generally included patients who had a screening mammogram requiring further diagnostic work-up or those with an abnormal physical examination that necessitated a diagnostic breast sonogram. Patients younger than 40 typically would not be screened with mammography, but several were enrolled in our study when clinical concern required an ultrasound evaluation. Patients received USCT scan prior to any biopsies.

Proprietary interactive 3D review software was developed by Techniscan to display volumetric USCT data in multi-planar format. Screen shots from the viewer are included below for the three sample cases (Figs. 4, 5, 6): a biopsy-proven malignant invasive tubular carcinoma, benign fibroadenoma and benign cyst. The upper row of images maps the speed of sound characteristics, while the lower row maps the attenuation of the breast tissue. The left-most images are coronal slices through the volume, the middle column are axial, and the right-hand images are saggital views. This image review software allows typical functions such as scrolling, window levelling, spatial and pixel value measurements. An extremely useful feature for the radiologists is a corellative feature that allows the operator to click on a point in any image and automatically register in 3D all three orthonormal views. For clarity in print, the three views are not displayed at identical scales.

3.2.1 Invasive Tubular Carcinoma

The patient is a 66 year old female with medical history significant only for hypertension and hypercholesterolemia. A suspicious mass was seen on her screening mammography and she was subsequently examined with conventional ultrasound, USCT, followed by needle biopsy. Pathology reported invasive tubular carcinoma. Note in Fig. 4 below that USCT images reveal a very bright area compared to any other structures including water in the speed of sound images (upper row), which corresponds to high speed throughout the lesion (approx 1610 m/s). The attenuation images (lower row) show a mass at the same location as the sound speed images with values of 300 dB/m. The mass appears to have irregular shape with a bright (high attenuation) “halo” with a less attenuating center.

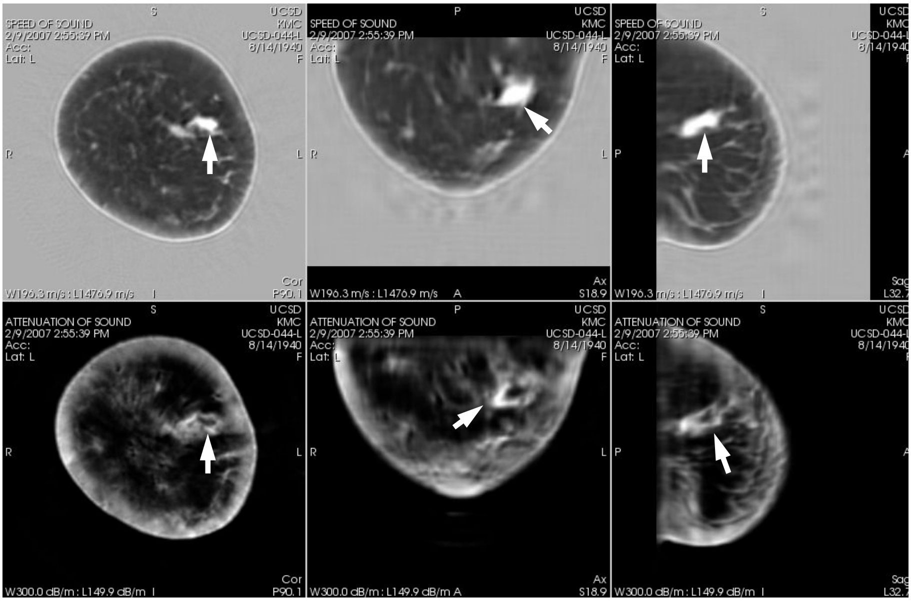

Figure 4. Invasive tubular carcinoma

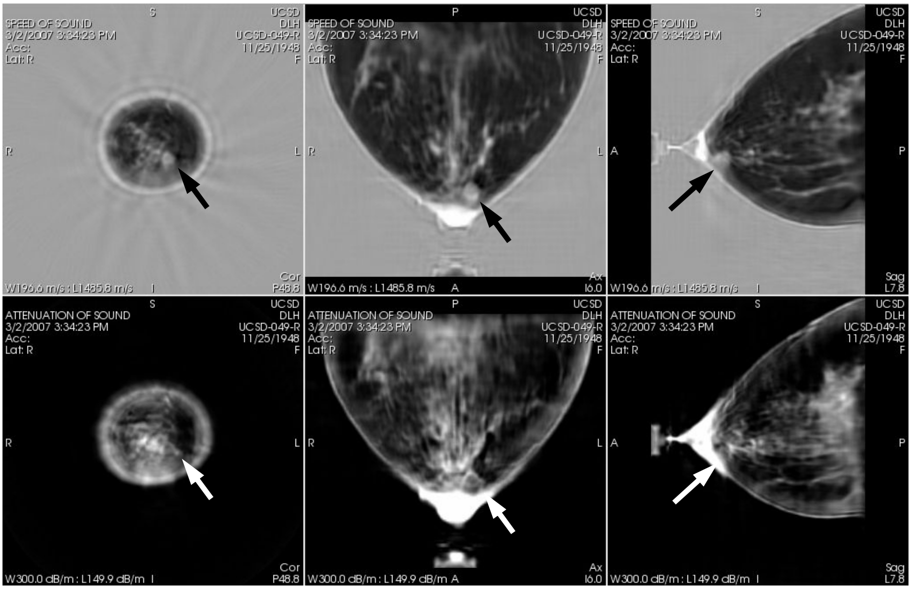

Figure 5. Fibroadenoma, 10 mm.

3.2.2 Fibroadenoma

The patient is a 58 year old female with no significant medical history concerning the breasts. The screening mammogram, follow-up diagnostic mammogram and sonogram all revealed a 10 mm, subareolar mass. USCT were performed prior to ultrasound-guided biopsy, which confirmed a fibroadenoma. The fibroadenoma is easily seen with USCT in the subareolar region (Fig. 5 above) as a well-circumscribed spherical 10 mm mass. The mass had both sound speed and attenuation values intermediate between fat and fibroglandular tissue (~1520 m/s and 130 dB/m, respectively).

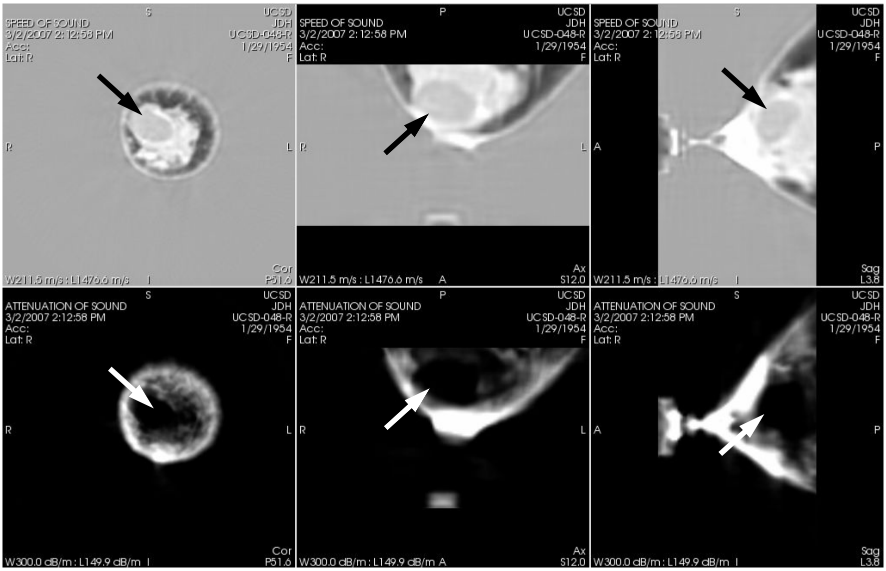

Figure 6. Fluid-filled simple cyst.

3.2.3 Simple Cyst

This patient is a 57 year-old female with history significant for profound nipple discharge of the left breast. The images in Fig. 6 above are of the right breast, which had a negative biopsy five years prior to our scan. The patient complained of a palpable abnormality on the right lasting for approximately one month. A mass was detected on mammography and was confirmed by sonogram to be cystic. USCT shows a large mass with sharp borders readily seen just posterior to the nipple. The sound speed values of the mass (upper row Fig. 6 above) are slightly higher (1540 m/s) than that of water (1510) while the attenuation images show a black void representing low attenuation values similar to that of water (0 dB/cm).

4. CONCLUSIONS

This pre-clinical study of a prototype inverse-scattering transmission ultrasound tomography system shows promise for breast imaging and characterization of tissue. We have shown examples where it was possible to readily distinguish breast masses on the basis of their intrinsic properties, attenuation and speed of sound. Image contrast and reproducibility are excellent and the current prototype scanner provides particularly clear images in patients with large fatty breasts.

Although it is incomplete, an overall assessment of the 51 patients scanned to date shows that the combined properties of sound speed and attenuation may provide a means to uniquely classify some tissues (Fig. 3). At this early stage of analysis there appears to be overlap between some types of solid masses and normal fibroglandular structures. This tissue characterization capability could be a worthy adjunct to the current methods of breast mass discrimination. Specifically, having the capability to better distinguish malignant from benign breast masses or to increase confidence in benign findings could give the radiologist a tool to decrease the dependence on breast biopsies.

Based on the experience gained with this study, a second generation scanner is currently under production that will implement a number of improvements. One modification will decrease the effective slice thickness while another will implement a high-resolution reflection tomography mode.

ACKNOWLEDGEMENTS

This work was supported in part by NIH/NCI 1 R44 CA 110203-01A2 and UCSD CTA #20060960. We are grateful for the generous support of Linda Olson, M.D., Laura Vinson, R.T. and Terry Lehmann, R.T.

REFERENCES

1. J.F. Greenleaf, S.A. Johnson, W.F. Samayoa, F.A. Duck: Acoustical Imaging (1975).
2. M.P. André, H.S. Janée, G.P. Otto, et al.: Intl J Imaging Systems Technol 8 (1997) p. 137.
3. N. Duric, P. Littrup, O. Rama, E. Holsapple: Acoustical Imaging 28 (1997) p. 173.
4. V.Z. Marmarelis, J. Jeong, D.C. Shin, S. Do: Acoustical Imaging 28 (1997) p. 195.
5. S.A. Johnson, T. Abbott, R. Bell, M. Berggren, et al.: Acoustical Imaging 28 (2007) p. 147.
6. J. Wiskin, D.T. Borup, S.A. Johnson, M. Berggren, et al.: Acoustical Imaging 28 (2007) p. 183