A NOVEL ACOUSTICAL METHOD FOR BREAST IMAGING

Azra Alizad, Dana H. Whaley, and James F. Greenleaf, Mostafa Fatemi
Mayo Clinic College of Medicine
Rochester, MN 55905

aza@mayo.edu

Abstract: Vibro-acoustography (VA) is an imaging modality that has emerged in recent years. This method is based on audio-frequency harmonic vibrations induced in the object by the radiation force of focused ultrasound. The resulting object vibration produces a hydrophone detectable acoustic emission that is a function of regional dynamic properties of the object at the vibration frequency. The amplitude of the hydrophone signal is mapped into an image that represents the object's "vibro-acoustic response" to the radiation force by scanning the focused ultrasound across the object.
This paper describes potential applications of vibro-acoustography for *in vivo* imaging. A Vibro-acoustography system has been combined with a stereo-tactic x-ray mammography system for *in vivo* breast imaging and has been tested on a number of volunteers. Resulting images show soft tissue structures and microcalcifications within breast with high contrast, high resolution, and no speckles. The results have been verified using x-ray mammograms of the breast. The encouraging results from *in vitro* and *in vivo* experiments suggest further development of vibro-acoustography may lead to a new clinical breast imaging modality.

Introduction

Ultrasonography and x-ray mammography are the common modalities used for breast imaging. Ultrasound is normally used to image soft tissue and detect possible lesions in breast.
X-ray mammography is the only imaging modality clinically used for detection of breast microcalcifications. The widespread use of screening mammography has resulted in the increased detection of microcalcifications [1].
A wide spectrum of breast lesions is associated with microcalcifications, ranging from benign (fibrocystic changes, vascular changes, fat necrosis) to malignant [2].
Ultrasonography and mammography both have limitations in breast imaging. For this reason, alternative methods are being sought. Especially, non-invasive imaging methods that can show both the soft tissue and microcalcifications are of particular interest.
Vibro-acoustography is a new imaging method based on the radiation force of ultrasound [3], [4]. This method can be particularly useful for detecting hard inclusions in soft material. For example, vibro-acoustography has been used to image calcifications in human arteries [5], [6], [7]. A comparative study of vibro-acoustography with other radiation force methods for tissue elasticity imaging is presented in [8]. The spatial resolution of vibro-acoustography is in the sub-millimeter range, making the technique suitable for high-resolution imaging [7], [9].
The purpose of this paper is to bring together the results of various studies on vibro-acoustography of breast tissues to demonstrate the potentials of this technology and the role that it may play in future as a breast-imaging tool [10], [11], [12].
Here, we review the literature and discuss applications of vibro-acoustography in breast imaging, including detection of microcalcifications, detection of arterial calcifications, and soft tissue imaging. We also present initial *in-vivo* images of breast vibro-acoustography.

Materials and Methods

Vibro-acoustography is based on vibro-acoustic response of the object to a vibrating force [3], [4], [6], [7], [9]. Radiation force is generated by a change in the spatial distribution of the energy density of an incident acoustic field. This can happen when an acoustic field interacts with an object. The energy density of the impinging sound may change due to energy absorption, scattering, and reflection. Thus, a radiation force is exerted on the object. The magnitude of this force depends on a number of parameters, including the scattering and absorption properties of the object. In a simple case of a plane wave reflected from a planar object, the force is proportional to the power reflection coefficient of the object. In vibro-acoustography, we use two intersecting continuous wave (CW) focused ultrasound beams of different frequencies. The two ultrasound beams are focused and they are aligned to intersect at their focal region. At this intersection region, which is normally a small volume, the combined ultrasound field energy density is sinusoidally modulated, and hence, the field generates a highly localized oscillatory radiation force when interacting with parts of the object in this region. Thus, the resulting radiation stress is confined to a small region, which acts as an oscillating point force placed remotely inside the object.

The general principle of vibro-acoustography is illustrated in Fig. 1. The two element concentric transducer produces two beams that are focused at a

ISSN: 1727-1983

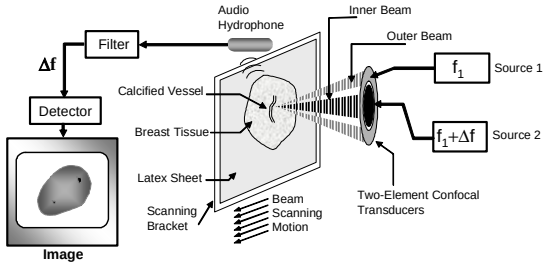

Figure 1.Vibro-acoustography system

joint focal point. The elements are driven by two continuous wave signals at slightly different frequencies of f_0 and $f_0+\Delta f$. One can show that the acoustic intensity in the intersection region is modulated by $\cos(\Delta ft/2)$. Thus, this beam can produce a radiation force at frequency Δf on the object being vibrated at the focal point. The radiation force vibrates the object at Δf. Amplitude and distribution of object motion is a function of its mechanical parameter such as the mass density, elasticity, and viscosity, as well as the boundary conditions, such as coupling to and the loading effects of the surrounding medium. The vibration motion results in a secondary acoustic field (acoustic emission) that propagates in the object. The acoustic emission which is at Δf frequency is detected by an audio hydrophone. As the ultrasound beam is scanned across the object, the hydrophone signal is recorded and its amplitude is mapped into an image.

A vibro-acoustography image depicts two types of information about the object: 1) ultrasonic properties of the object, such as the scattering and power absorption characteristics; 2) the dynamic characteristics of the object at frequency Δf, which also relates to the boundary conditions and coupling to the surrounding medium [4]. The former properties are those that are also present in conventional ultrasound imaging. The latter properties, which are related to object stiffness, can be described in terms of object mechanical impedance at Δf. Such information is not available from conventional ultrasound. Another characteristic of vibro-acoustography relates to image speckle. Speckle is the snowy pattern seen in conventional ultrasound images. Speckles result from random interference of the scattered ultrasound field. Speckles reduces the contrasts of ultrasound images and often limits one to see small structures, such as breast microcalcifications in tissue. Vibro-acoustography on the other hand uses the acoustic emission signal, which is at a low frequency. The image in this modality is practically speckle free, resulting in high contrast images that allow small structures to be visible. This feature makes vibro-acoustography suitable for detection of breast microcalcifications. (UIA).

Recently, we have developed a vibro-acoustography system for *in vivo* breast imaging and have tested it on a number of volunteers. This system is integrated in a clinical stereotactic mammography machine (Fischer Imaging Inc., Mammotest™ system). The combined system is designed in such a way that it enables us to produce matching (from the same view angle) vibro-acoustography and mammography images of human breast. System parameters are: transducer frequency = 3 MHz, resolution 0.7 mm, scanning increments = 0.2 mm, ultrasound intensity at the focal point = 700 mW/cm^2 in compliance with the FDA recommendation for *in vivo* ultrasound. The patient lies in prone position on the examination bed with a breast hanging down through the hole. The breast is slightly compressed and the audio hydrophone is placed in contact with the side of breast. Acoustic gel is applied to ensure proper acoustic coupling. Resulting images show soft tissue structures and calcifications within breast with high contrast, high resolution, and no speckles. Figure 2 demonstrates the diagram of the combined vibro-acoustography mammography system which is used for invivo breast imagng. Figure 3 is the diagram of the breast position with respect to the compression panel.

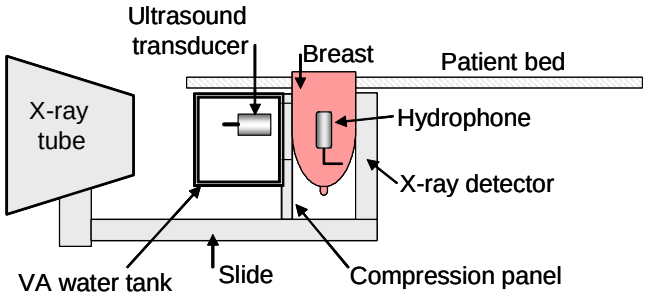

Figure 2: Combined VA-mammography system. The breast is sandwiched between the back panel (x-ray detector), and a sliding compression panel that keeps the breast slightly compressed and fixed for mammography and/or VA scanning. The transducer is moved away during mammography.

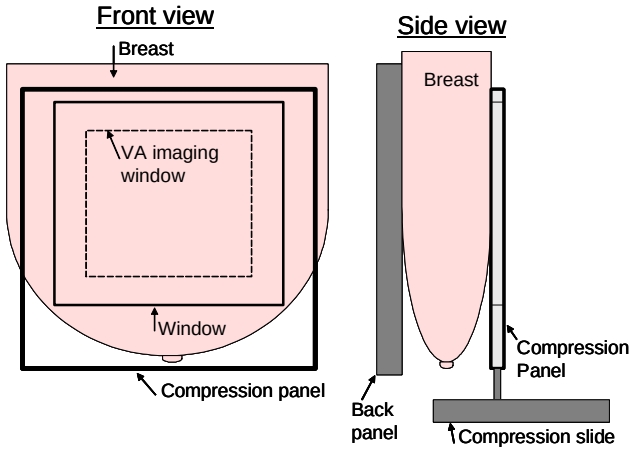

Figure 3: Breast position with respect to the compression panel. The panel has an 8x8 cm window covered with latex sheet. The VA scan is conducted within a 5x5 cm area (*imaging window*) within the latex window.

ISSN: 1727-1983

Figure 4. is a picture of combined VA and mammography system in our laboratory with a patient lied on the examination bed. The entire system in installed in an acoustically insulated room.

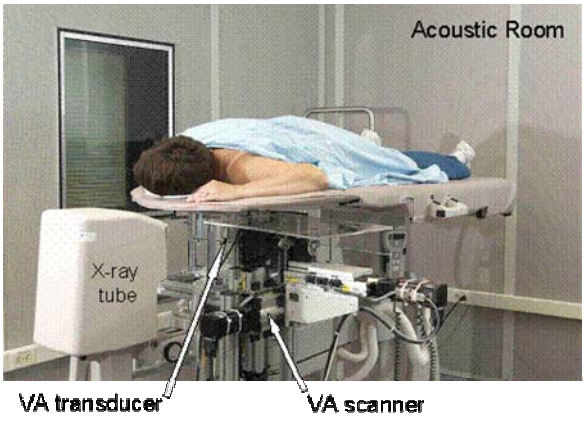

Figure 4: Combined VA and mammography system. The patient lies on the examination bed with the breast hanging down through a hole. The breast is slightly compressed between a compression panel and back-panel. The entire system in installed in an acoustically insulated room.

Results

Vibro-acoustography images of breast tissue samples, one with MC and the other one with calcified artery are shown in figures (5 and 6).

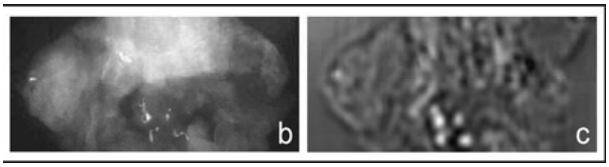

Figure 5: Left x-ray of a breast tissue specimen with a MC on right corner and a cluster of MC on lower middle part of the specimen, on the right VA image of this tissue clearly shows the calcification on both sites.

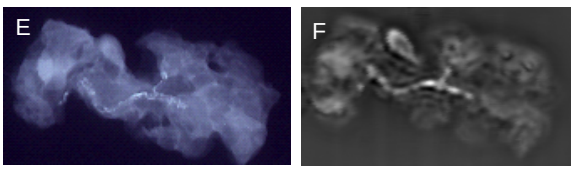

Figure 6: E= x-ray mammography of a breast tissue specimen, F=Vibro-acoustography of the same tissue, Calcified artery can be seen clearly on both images.

Vibro-acoustography scans of the left breast of a subject in the coronal position are shown in Fig. 7. These images cover a 5x5 cm area taken at the depth of 2.5 cm (left image) and 3 cm (right image) from the skin. The calcification (diameter approximately 1 mm) is seen in the left image as a bright spot in the top-left quadrant of the image on the left. The presence of this calcification was proven by mammography. Tissue structure is visible especially in the right image with remarkable contrast. The background in the left image is darker because the image brightness is adjusted to show the calcification which happens to be much brighter than the soft tissue. These images was acquired at frequency Δf = 50 kHz. The scan time was about 7 minutes.

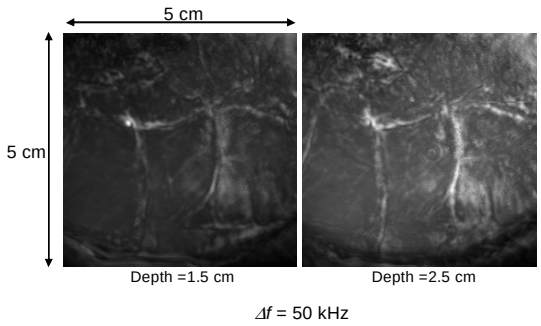

Figure 7: *In-vivo* VA images of a breast.

This preliminary result demonstrates one can produce high contrast *in vivo* images at ultrasound intensities within the FDA guideline (720 mW/cm^2). These results also demonstrate that vibro-acoustography has enough resolution and contrast to show both microcalcifications and the soft tissue.

Discussion

An ideal breast imaging device must be able to image both calcifications and soft tissue. It must also offer enough resolution and sensitivity for detection of microcalcifications. The experimental *in vitro* and *in vivo* studies have demonstrated that vibro-acoustography has such capabilities. The spatial resolution can be improved by using transducer with higher center frequency. However, one must take into account the increase in tissue attenuation. The scanning speed may be improved by using array transducers to steer the beam electronically.

Further investigation is needed to fully explore the potentials of vibro-acoustography for *in vivo* breast imaging. A number of considerations must be taken into account before implementing vibro-acoustography for clinical applications. For example, the coupling between the transducer and the breast must be suitable for clinical practice. Another consideration is the scanning time. This time may be too long for routine clinical applications. The scanning time must be short enough to avoid excess patient discomfort during imaging. A clinical vibro-acoustography system may be implemented based on contact array transducers. That is, instead of using a two-element confocal transducer used in the present study, an ultrasound transducer

ISSN: 1727-1983

comprising of two two-dimensional arrays may be employed to produce the two intersecting beams needed for vibro-acoustography. The two beams from the arrays can be focused at a common focal point and steered rapidly across a given plane within the breast. These methods are currently being studied [13].

Conclusions

Vibro-acoustography has potential to provide newer information in breast imaging. The encouraging results from *in vitro* and *in vivo* experiments suggest further development of vibro-acoustography may lead to a new clinical breast imaging modality.

References

[1] ABELOFF, M. D., LICHTER, A. S., NIEDERHUBER, J. E, et al. (2000): 'Breast'. In: M. D. Abeloff (ED): 'Clinical Oncology', Churchill Livingstone, New York, chap. 75, 2nd Ed., pp. 2051-2138

[2] LESTER, SC., CORTAN, RS. (1999): 'The Breast'. In: Cortan RS., Kumar V. , Collin T., (EDs): 'Robins pathologic basis of diseases', 6th ed. W.B. Saunders,1093-1117

[3] FATEMI M., AND GREENLEAF J. F. (1998): 'Ultrasound stimulated vibro-acoustic spectroscope', *Science*, vol. 280, pp. 82-85

[4] FATEMI M., AND GREENLEAF J. F. (1999): 'Vibro-acoustography': An imaging modality based on ultrasound stimulated acoustic emission', *Proc. Natl. Acad. Sci. USA.*, vol. 96, pp. 6603-6608

[5] GREENLEAF, J. F., EHMAN, R. L., FATEMI, M., et al. (1998): 'Imaging elastic properties of tissue', in: Duck FA, Baker AC, Starritt HZ, eds: 'Ultrasound in Medicine', (Medical Science Series). Institute of Physics Publishing, Bristol, England, pp 263-277

[6] FATEMI M., AND GREENLEAF J. F. (2000): 'Probing the dynamics of tissue at low frequencies with the radiation force of ultrasound', *Phys. Med. Biol.*, vol. 45, pp. 1449-1464

[7] FATEMI M., MANDUCA A., AND GREENLEAF J. F. (2003): 'Imaging elastic properties of biological tissues by low-frequency harmonic vibration', *Proc of IEEE*, vol. 91, no. 10, pp. 1503-1517

[8] FATEMI M., AND. GREENLEAF J. F. (2002): 'Imaging the viscoelastic properties of tissue' in *Topics in Applied Physic,* M. Fink, J-P. Montagner, and A. Tourin, Eds., Springer, Verlog, Heidelberg, Berlin, vol. 84, pp. 257-275

[9] FATEMI M., AND GREENLEAF J. F. (2000): 'Imaging and evaluating the elastic properties of biological tissues', *BMUS Bulletin* (The British Medical Ultrasound Society), vol., no. 4, pp. 16 and 18

[10] FATEMI M., WOLD L. E., ALIZAD A., AND GREENLEAF J. F. (2002): 'Vibro-acoustic tissue mammography', *IEEE Trans. Med. Imag*. 21(1), 1-8

[11] ALIZAD A., FATEMI M., WOLD L. E., AND GREENLEAF J. F. (2004): 'Performance of vibro-acoustography in detecting of microcalcifications in excised human breast tissue: a study on 74 breast tissue samples', *IEEE Trans. Med. Imag*. 23(3), 307-31

[12] ALIZAD A, WHALEY D. H., GREENLEAF J. F., AND FATEMI M. (2005): 'Potential applications of vibro-acoustography in breast imaging', *Technology in Cancer Research and Treatment,* Vol. 4(2), 151-8

[13] SILVA G. T., GREENLEAF J. F., AND FATEMI M. (2004): 'Linear array Beamforming for vibro-acoustography: a numerical simulation study', *Ultrasonic Imaging,* 25:1-17

ISSN: 1727-1983