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● *Original Contribution*

# AXIAL-SHEAR STRAIN ELASTOGRAPHY FOR BREAST LESION CLASSIFICATION: FURTHER RESULTS FROM *IN VIVO* DATA

ARUN K. THITTAI,* JOSE-MIGUEL YAMAL,† LOUISE M. MOBBS,‡ CHRISTINA M. KRAEMER-CHANT,‡ SRINIVASA CHEKURI,* BRIAN S. GARRA,‡ and JONATHAN OPHIR*

*Department of Diagnostic and Interventional Imaging, The University of Texas Medical School, Houston, TX; †Division of Biostatistics, The University of Texas School of Public Health, Houston, TX; and ‡Department of Radiology, Fletcher Allen Health Care, Burlington, VT

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**Abstract—The purpose of this work was to investigate the potential of the normalized axial-shear strain area (NASSA) feature, derived from axial-shear strain elastograms (ASSE), for breast lesion classification of fibroadenoma and cancer. This study consisted of previously acquired *in vivo* digital radiofrequency data of breast lesions. A total of 33 biopsy-proven malignant tumors and 30 fibroadenoma cases were included in the study, which involved three observers blinded to the original BIRADS-ultrasound scores. The observers outlined the lesions on the sonograms. The ASSEs were segmented and color-overlaid on the sonograms, and the NASSA feature from the ASSE was computed semi-automatically. Receiver operating characteristic (ROC) curves were then generated and the area under the curve (AUC) was calculated for each observer performance. A logistic regression classifier was built to compare the improvement in the AUC when using BIRADS scores plus NASSA values as opposed to BIRADS scores alone. BIRADS score ROC had an AUC of 0.89 (95% CI = 0.81 to 0.97). In comparison, the average of the AUC for all the three observers using ASSE feature alone was 0.84. However, the AUC increased to 0.94 (average of 3 observers) when BIRADS score and ASSE feature were combined. The results demonstrate that the NASSA feature derived from ASSE has the potential to improve BIRADS breast lesion classification of fibroadenoma and malignant tumors. (E-mail: Arun.K.Thittai@uth.tmc.edu)** © **2011 World Federation for Ultrasound in Medicine & Biology.**

***Key Words:*** **Breast lesions, Axial strain, Axial-shear strain, Benign, Cancer, Classification, Elastography, Fibroadenoma, Ultrasound.**

## INTRODUCTION

Ultrasound (US) elastography was introduced by Ophir et al. (1991) as a technique to image the stiffness variation in soft tissues. The technique involves acquiring US (radiofrequency [RF]/envelope) signals from an imaging plane before and after a small quasi-static compression. Typically, the pre- and postcompression frames are processed to generate images of local strain, commonly known as *elastograms.* When the elastogram depicts axial strain values, it is referred to as an *axial strain elastogram* (Ophir et al. 1999).

Based on the axial strain elastograms alone, elastography has been shown to be useful in a wide variety of clinical applications including breast lesion classification (Céspedes et al. 1993; Hiltawsky et al. 2001). The use of elastography for the reduction of the rate of unnecessary breast biopsies has been demonstrated by several groups (Garra et al. 1997; Regner et al. 2006; Barr 2006; Itoh et al. 2006; Cho et al. 2008). Most of these reports have used the size discrepancy between sonographic and elastographic lesion appearance, along with/without strain contrast measures (Garra et al. 1997; Regner et al. 2006; Barr 2006; Burnside et al. 2007). Some of them have used a scoring system based on strain distribution patterns (Itoh et al. 2006; Cho et al. 2008).

However, these measures from axial strain elastograms exploit only the size discrepancy between the sonographic and elastographic images of the tumor, which exists only in malignant cases. Nevertheless, it is also well documented in the literature that benign fibroadenomas are typically mobile (implying loosely-bonded to the host tissue) compared with malignant tumors,

Address correspondence to: Arun K. Thittai, Ph.D., The University of Texas Medical School, Department of Diagnostic and Interventional Imaging, Ultrasonics Laboratory, 6431 Fannin St., Houston, TX 77030. E-mail: Arun.K.Thittai@uth.tmc.edu

which tend to be well adhered (firmly bonded) to the host tissue (Fry 1954; Ueno et al. 1988; Bamber et al. 1988). Therefore, it is reasonable to hypothesize that additional information regarding the bonding conditions near lesion boundaries has the potential to improve the performance of the current standard of practice in breast lesion classification by US.

Axial strain is one of the nine strain tensors that describe deformation in 3-D. We have shown that in addition to axial strain, it may be feasible to image another strain tensor in the form of axial-shear strain (ThitaiKumar et al. 2007). Note that the total shear strain, as defined in eqn (1), is the sum of the axial-shear (first-term) and lateral-shear strain component.

$$\varepsilon_{x,y} = \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right), \quad (1)$$

where ($u$, $v$) are the lateral and axial displacement components along the $x$- (lateral direction) and $y$- (axial direction) axes, respectively.

The ultrasonic estimation of the lateral-shear strain is noisy compared with the estimation of the axial-shear component (ThitaiKumar et al. 2005). This fundamental limitation as a result of suboptimal sampling between US array beams also affects traditional elastography and sonography. However, we have shown that imaging the axial-shear component alone results in quality images of an independent constitutive tissue parameter that relates directly to shear strain. The image depicting the axial-shear strain was referred to as axial-shear strain elastogram (ASSE). We demonstrated recently that the axial-shear strain distribution pattern around an inclusion is directly influenced by the bonding at the inclusion-background boundary using simulations, gelatin-phantom experiments and breast lesions *in vivo* (ThitaiKumar et al. 2007). The *normalized axial-shear strain area* (NASSA) near the inclusion-background boundary is a feature that could be used to identify the boundary-bonding conditions (ThitaiKumar et al. 2007, 2008). Results from the initial feasibility study that evaluated the potential of this feature to differentiate between benign and malignant tumors in the breast are encouraging (ThitaiKumar et al. 2008). However, the initial feasibility study was restricted to a small number of *in vivo* cases ($n$ = 21) that precluded a detailed statistical analysis.

In this paper, we report on a larger follow-up study done to investigate the potential of the NASSA feature to classify breast lesions into fibroadenoma and cancer, and therefore reduce unnecessary benign breast biopsies. We include the results of a statistical analysis performed to assess the improvement in the BIRADS-based breast lesion classification as a result of the addition of NASSA.

## MATERIALS AND METHODS

### In vivo *data*

We used *in vivo* digital RF data of breast lesions that were acquired at the University of Vermont by Dr. Garra's group (1997). The patient study was HIPAA-compliant and had appropriate institutional review board approval. Informed consent was obtained from all participating patients, who were informed that the RF data collected would be used at a later time for the creation of *elastograms*. The sonograms used in this study were reconstructed from the selected RF frames. Patients with a BIRADS score of ≥4 and were scheduled for a biopsy participated in elastographic data acquisition. In addition, patients with BIRADS score 3 who elected to undergo a biopsy were also included. The elastographic data were acquired using a Philips HDI-1000 US scanner (Philips Healthcare, Andover, MA, USA) operating at 5 MHz center frequency. The setup consisted of a precision digital motor system for controlled compressions. The acquisition protocol involved multicompression with step sizes of 0.25%, up to a maximum total compression of 5% (Varghese et al. 1998). For each *in vivo* case, six acquisitions (three each in two orthogonal planes) were acquired. Thus, we had the option to use scan data from more than one scan plane per case. Note that we only reprocessed the archived data and no new data acquisition was done in the present study.

We had a total of 134 pathologically confirmed cases in our database comprising 35 malignant and 99 benign cases. Among the benign cases, we had several "normal fibrocystic changes" and other benign conditions such as complex cysts and 33 fibroadenomas. For this (blinded) observer study, only patients with biopsy-proven fibroadenoma or cancer were included. This was because previously reported simulation and phantom studies (ThitaiKumar et al. 2007) used boundary conditions that modeled fibroadenomas and cancers. In addition, we noticed from simulations (not published) that the axial-shear strain feature reported in the literature (ThitaiKumar et al. 2007) is technically valid only if the lesion is located at a depth that is at least one lesion diameter below the surface of compression, because of inadequate surrounding tissue availability near the proximal lesion boundaries. By removing those cases where the lesion was located close (less than one diameter) to the surface of compression, we were left with 30 of the 35 malignant cases and with all 33 fibroadenoma cases for this study.

### *ASSE generation, display and feature of interest*

The precompression and temporally stretched post-compression RF signals were processed to obtain ASSEs using algorithms detailed elsewhere (Céspedes et al.