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● *Original Contribution*

SPATIAL COMPOUNDING TECHNIQUE TO OBTAIN ROTATION ELASTOGRAM: A FEASIBILITY STUDY

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Abstract—The perception of stiffness and slipperiness of a breast mass on palpation is used by physicians to assess the level of suspicion of a lesion as being malignant or benign. However, most current ultrasound elastography imaging methods provide only stiffness-related information. There is no existing approach that provides information about the local rigid body rotation undergone by only a loosely bonded, asymmetrically oriented lesion subjected to a small quasi-static compression. The inherent poor lateral resolution in ultrasound imaging poses a limitation in estimating the local rigid body rotation. Several techniques have been reported in the literature to improve the lateral resolution in ultrasound imaging, and among them is spatial compounding. In this study, we explore the feasibility of obtaining better-quality rotation elastograms with spatial compounding through simulations using Field II and experiments on tissue-mimicking phantoms. The phantom was subjected to axial compression (~1%–2%) from the top, and the angular axial and lateral displacement estimates were obtained using a multilevel 2-D displacement tracking algorithm at different insonification angles. A rotation elastogram (RE) was obtained by taking half of the difference between the lateral gradient of the axial displacement estimates and the axial gradient of the lateral displacement estimates. Contrast-to-noise ratio was used to quantify the improvements in quality of RE. Contrast-to-noise ratio values were calculated by varying the maximum steering angle and the incremental angle, and its effects on RE quality were evaluated. Both simulation and experimental results corroborated and indicated a significant improvement in the quality of RE using compounding technique. (E-mail: akthittai@iitm.ac.in) © 2017 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Axial displacement, Axial shear strain elastogram, Breast lesion, Fibroadenoma, Lateral displacement, Malignant lesion, Rotation elastogram, Spatial compounding.**

INTRODUCTION

Breast cancer is one of the most common cancers among women worldwide, with nearly 1.7 million new cases diagnosed in 2012 (the second most common cancer overall). This represents 12% of all new cancer cases and 25% of all cancers in women (Ferlay et al. 2014).

Stiffness changes in soft tissue are generally correlated with pathologic changes. On palpation, most cancers feel much stiffer and firmly bonded to their surrounding host tissue compared with benign (*e.g.,* fibroadenoma in the breast) lesions. Specifically, it has been observed that benign fibroadenoma tends to slip, whereas malignant lesions do not, in response to small quasi-static compression (Bamber et al. 1988; Chen et al. 1995; Fry 1954; Garra et al. 1997; Ueno 1986). In many cases, despite the difference in stiffness and/or mobility, the small size of the lesions makes their detection difficult. Location deep inside the body also impedes detection and evaluation using traditional manual palpation (Ophir et al. 2002). Inspired by this art of palpation, several ultrasound (US) elastography techniques have become available over the last two decades for use in the non-invasive determination of tissue stiffness. Quasi-static elastography, acoustic radiation force impulse imaging and shear wave elastography are three of the different elastography techniques, which differ from each other in the perturbation technique used to deform the tissue (Ophir et al. 2011; Parker et al. 2011; Sarvazyan et al. 2011). All of these methods are now available in many commercial scanners worldwide, but they have mostly exploited only the contrast resulting from the changes in stiffness of the underlying

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tissue. The practice of quasi-static ultrasound elastography is based on the estimation of axial (along the direction of insonification) tissue displacements and strain through analysis of radiofrequency (RF) (or envelope) signals obtained before and after a small quasi-static axial compression (~1%).

In the last few years, the application of quasi-static elastography has been extended beyond use of only the axial and lateral components of the normal strain tensor. It has been found that estimation and imaging of the local axial shear strain distribution convey information on the bonding of a lesion with the surrounding tissue (Thitaikumar et al. 2007, 2008). However, there is practically no method available at present to directly estimate and visualize the local rigid body rotation undergone by a loosely bonded asymmetrically oriented lesion when it is subjected to a small quasi-static compression.

It has been reported that there exists a fundamental relationship between the bonding at an inclusion–background boundary and the axial-shear strain distribution near it (Galaz et al. 2009; Rao et al. 2007; Thitaikumar et al. 2007, 2008). Normalized axial-shear strain area near the inclusion–background boundary is one of the features identified from the axial-shear strain elastogram (ASSE) that is indicative of a bonding condition at the boundary (Thitaikumar et al. 2007, 2008). Further, nonzero axial-shear strain values inside the inclusion, referred to as "fill-in," occurs in the case of loosely bonded asymmetrically oriented inclusion and is interpreted as a surrogate of the possible rigid body rotation of the inclusion (Galaz et al. 2009; Thittai et al. 2010, 2012). Hence, a rotation elastogram (RE), defined as an image of the local rigid body rotation of the target tissue under quasi-static compression, was hypothesized to contribute additional useful to differentiate benign from malignant breast lesions (Thittai et al. 2012). The rotation tensor is given by the equation (Timoshenko and Goodier 1970)

$$Wx,y(\text{rotation}) = 0.5\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) \tag{1}$$

where u is lateral displacement, and v is axial displacement. However, estimation of the rotation tensor is limited by the inherent poor lateral displacement tracking precision of US. Righetti et al. (2002) reported that the lateral resolution in elastography is proportional to the beamwidth of the US transducer, provided that consecutive A-lines are not separated by more than one beamwidth. It has also been reported that the spatial compounding technique can provide better lateral resolution compared with conventional ultrasound imaging (He et al. 1997). In the spatial compounding method, the echogenicity information on the underlying tissue is obtained from several different angles of insonification and combined to produce a single image. Averaging of images obtained from multiple angles of insonification reduces the random noise in the compounded B-mode image to yield better-quality images compared with the uncompounded B-mode image (He et al. 1997). The lateral resolution is improved because the compounded image is generated from a number of insonification angles, making the likelihood greater that one of the angles will be perpendicular to a specular reflector. Spatial compounding technique has also been found to reduce many image artifacts inherent in conventional B-mode imaging.

Spatial-angular compounding for elastography was introduced by Techavipoo et al. (2004) to reduce noise artifacts in elastograms. Spatial-angular compounding averages multiple strain estimates around the same region of interest (ROI) acquired from different insonification angles. The results presented by Techavipoo et al. (2004) illustrate an improvement in the obtained elastographic signal-to-noise ratio (SNR_e) and contrast-to-noise ratio (CNR_e) with angular compounding. In their work, however, RF echo signals at different angular insonification directions were acquired by translating a phased-array ultrasound transducer in the lateral direction, which is time consuming and subject to measurement errors caused by transducer positioning. Another disadvantage of using phased-array transducers is that the data sets need to be rearranged during off-line analysis so that the A-lines along the same angle from all the sector images can be grouped together to form RF frames at that specified angle.

Rao et al. (2007) performed spatial-angular compounding for elastographic imaging using beam steering on a linear-array transducer. Here, pre- and post-compression RF echo signals are acquired at different beam steering angles before and after application of quasi-static compression, respectively. Angular elastograms estimated at different angles were weighted and then averaged to generate a compounded axial strain elastogram.

To summarize, over the last decade, spatial compounding approaches have been adapted to elastography by quite a few groups (Hansen et al. 2010; Rao and Varghese 2006; Rao et al. 2007; Zahiri-Azar et al. 2011; Xu and Varghese 2013; Techavipoo et al. 2004). Most of these articles have described an improvement in the quality of axial strain elastograms through use of the spatial compounding technique, whereas a few (Hansen et al. 2010; Rao et al. 2007; Techavipoo et al. 2004) have described improvement in lateral displacement tracking quality.

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