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● *Original Contribution*

A NOVEL ELASTOGRAPHIC FRAME QUALITY INDICATOR AND ITS USE IN AUTOMATIC REPRESENTATIVE-FRAME SELECTION FROM A CINE LOOP

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Abstract—This study was aimed at developing a method for automatically selecting a few representative frames from several hundred axial-shear strain elastogram frames typically obtained during *freehand* compression elastography of the breast *in vivo*. This may also alleviate some inter-observer variations that arise at least partly because of differences in selection of representative frames from a cine loop for evaluation and feature extraction. In addition to the correlation coefficient and frame-average axial strain that have been previously used as quality indicators for axial strain elastograms, we incorporated the angle of compression, which has unique effects on axial-shear strain elastogram interpretation. These identified quality factors were computed for every frame in the elastographic cine loop. The algorithm identifies the section having N contiguous frames (N = 10) that possess the highest cumulative quality scores from the cine loop as the one containing representative frames. Data for total of 40 biopsy-proven malignant or benign breast lesions *in vivo* were part of this study. The performance of the automated algorithm was evaluated by comparing its selection against that by trained radiologists. The observer- identified frame that consisted of a sonogram, axial strain elastogram and axial-shear strain elastogram was compared with the respective images in the frames of the algorithm-identified section using cross-correlation as a similarity measure. It was observed that there was, on average (~standard deviation), 82.2% (~2.2%), 83.4% (~3.8%) and 78.4% (~3.6%) correlation between corresponding images of the observer-selected and algorithm-selected frames, respectively. The results indicate that the automatic frame selection method described here may provide an objective way to select a representative frame while saving time for the radiologist. Furthermore, the frame quality metric described and used here can be displayed in real time as feedback to guide elastographic data acquisition and for training purposes. (E-mail: akthittai@iitm.ac.in) © 2016 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Axial strain elastogram, Axial-shear strain elastogram, Elastography, Angle of compression, Normalized axial-shear strain area, Frame quality indicator, Representative frame, Real-time feedback.**

INTRODUCTION

Quasi-static ultrasound elastography was introduced as a technique for imaging the mechanical properties of the soft tissues (Ophir et al. 1991). Elastography has developed rapidly in the last decade and is currently implemented in most commercial ultrasound scanners (Balleyguier et al. 2013). The fundamental principle governing elastography is as follows: When a tissue medium is deformed, all elements in the medium are subject to the resultant strain. If certain elements of the tissue under study differ in stiffness parameters from other tissues, the resultant strain in those tissue elements will be higher or lower than that of the other elements. Specifically, the strain level in harder regions of the tissue will be lower than those in softer regions of the tissue (Ophir et al. 1999). Most often, the term *strain elastogram* is synonymously used to refer only to the image of the axial strain distribution.

It has, however, been found that when an inhomogeneous elastic material, such as a stiff lesion in a softer background, is subjected to uni-axial compression, shear strains are generated at and near the boundaries between the inhomogeneities and the background. The magnitude and spatial variation of these shear strains depend mostly on the degree of bonding at the inclusion–background interface, the orientation of the inclusion–background interface with respect to the direction of compression, the stiffness contrast between the inclusion and the background and the level of axial compression applied

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(Knight et al. 2002; Twiss and Moores 1992). It was reported in a series of publications that even by imaging only the axial-shear strain component of the total shear strain, information related to the degree of bonding between the inclusion and the background can be reliably obtained (Thitaikumar et al. 2007a, 2007b; Thittai et al. 2011, 2012). The image of the axial-shear strain distribution, defined as the axial-shear strain elastogram (ASSE), which is computed as a lateral derivative of axial displacement (Thitaikumar et al. 2007b), has been reported to be useful for *in vivo* breast lesion classification into benign and malignant (Thitaikumar et al. 2008; Thittai et al. 2011). However, most of the *in vivo* feasibility studies have used data obtained from controlled compression and not the more practical *freehand* compression technique (Xia et al. 2014; Xia and Thittai 2015).

Typically, a sonographer or a radiologist is trained to quickly scan the scout images during ultrasound B-mode scanning in real time and save only those frames of adequate quality for further analysis. However, this becomes a little challenging when quasi-static elastography is practiced with freehand compression because the image quality is a function of inter-frame compression, and therefore, frames over at least a few compression–relaxation cycles may be needed to capture a wider dynamic range of image quality for further evaluation. To address this challenge there have been several efforts, from providing a quality indicator as feedback in real time that is aimed at improving the quality of data acquisition and becoming trained in the process, to having algorithms that select representative frames from stored cine-loop data for off-line analysis (Chang et al. 2011, 2014; Jiang et al. 2006; Lindop et al. 2008). Some of these approaches have already been incorporated into commercial scanners (Calvete et al. 2013; Havre et al. 2008). Note that all of the aforementioned developments refer only to the axial strain elastogram (ASE) that is popularly referred to as an elastogram and is commercially available now. As stated earlier, ASSE is a newer variant in the quasi-static elastography technique that provides additional ability to visualize information regarding the inclusion–background boundary bonding conditions. Naturally, all of the concerns associated with the practice of freehand compression ASE are also applicable to freehand compression ASSE. Next we provide information on the different approaches reported in the literature in the context of ASE. Subsequently, we provide some recent developments reported in relation to ASSE. These provide the context for the work reported in this article.

Prior work has established that image quality factors of ASE, such as signal-to-noise ratio (SNR_e) and contrast-to-noise ratio (CNR_e), are a function of applied strain. It was found that SNR_e and CNR_e exhibit bandpass characteristics in response to applied strain, which has been described in terms of strain filter in the literature (Varghese and Ophir 1997). Another equally important factor that indicates ASE quality is the cross-correlation coefficient, which is obtained with the displacement tracking algorithm. A low value indicates poor displacement estimation, which will in turn lead to a false axial strain value in ASE. Understanding and using these factors in freehand compression elastography has been nontrivial, because even within a case, inter-frame compression can differ and thereby result in differences in representation of ASEs. To address this issue, several approaches have been proposed. Jiang et al. (2006) proposed a method for allocating elastogram quality measurement ranging from zero to one based on the accuracy of displacement tracking and consistency among the consecutive strain images. This quality indicator was envisaged to provide feedback and training for freehand elastography acquisition. They further confirmed the scheme using *in vivo* data for off-line processing. Lindop et al. (2008) introduced a method to assign strain quality measurements as a color overlay on elastograms or ASEs. They developed an adaptive strain normalization method combined with persistence. It was found to produce robust freehand elastograms regardless of angular compression and poor-quality radiofrequency (RF) signals. Xia et al. (2014) proposed a “one prediction–one correction” method that selects pre-compression frames dynamically, such that the pairing frames have a desired axial compression strain level between them (typically set to ~1%). This approach was found to work well on breast data obtained with the real-time freehand compression elastography technique. Recently, Chang et al. (2011, 2014) proposed methods for selecting a representative frame from the cine loop of ASE using SNR_e, CNR_e and the “hard ratio” (*i.e.*, lesion–background strain ratio) as the quality factors. Noticeably, they did not consider the cross-correlation coefficient as one of the explicit quality factors as for other methods discussed earlier.

Recognizing that ASSE is a newer variant of the quasi static-elastography technique, it is not surprising that its quality depends on some of the same parameters that affect the ASE. However, previous studies have reported that deviation from uni-axial compression has significant influence on reliability in interpreting ASSEs (Xia and Thittai 2015). In particular, it was found that non-zero axial-shear strain values inside a lesion (referred to as *fill-in features*) were expected to be present only in ASSEs of loosely bonded tumors (benign tumors of the breast) that are non-normally oriented with respect to the direction of compression and conspicuously absent in malignant breast lesions. However, it was found that even non-normally oriented malignant breast lesions start to exhibit misleading fill-in features when there is excessive deviation from the ideal uni-axial compression (*i.e.*, angle of