Ultrasound in Med. & Biol., Vol. ■■, No. ■■, pp. ■■–■■, 2017

0301-5629/$ - see front matter

https://doi.org/10.1016/j.ultrasmedbio.2017.06.018

● *Original Contribution*

SPECIFIC ULTRASOUND DATA ACQUISITION FOR TISSUE MOTION AND STRAIN ESTIMATION: INITIAL RESULTS

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(*Received* 20 *October* 2016; *revised* 14 *June* 2017; *in final form* 19 *June* 2017)

Abstract—Ultrasound applications such as elastography can benefit from 3-D data acquisition and processing. In this article, we describe a specific ultrasound probe, designed to acquire series of three adjacent imaging planes over time. This data acquisition makes it possible to consider the out-of-plane motion that can occur at the central plane during medium scanning, and is proposed with the aim of improving the results of strain imaging. In this first study, experiments were conducted on phantoms, and controlled axial and elevational displacements were applied to the probe using a motorized system. Radiofrequency ultrasound data were acquired at a 40-MHz sampling frequency with an Ultrasonix ultrasound scanner, and processed using a 3-D motion estimation method. For each of the 2-D regions of interest of the central plane in pre-compression data, a 3-D search was run to determine its corresponding version in post-compression data, with this search taking into account the region-of-interest deformation model chosen. The results obtained with the proposed ultrasound data acquisition and strain estimation were compared with results from a classic approach and illustrate the improvement produced by considering the medium's local displacements in elevation, with notably an increase in the mean correlation coefficients achieved. (E-mail: elisabeth.brusseau@creatis.insa-lyon.fr)

Key Words: **Elastography, Strain imaging, Multiplane acquisition, Ultrasound.**

INTRODUCTION

Ultrasound elastography refers to ultrasound-based imaging techniques dedicated to the investigation of the mechanical properties of biological tissues *in vivo* (Bamber et al. 2013; Parker et al. 2011). Strain imaging consists of the slow compression of tissues with, for example, the ultrasound probe and collection of the corresponding pre- and post-compression ultrasound data from which the tissue strain is estimated (Ophir et al. 1991; Varghese 2009). Strain imaging has been reported to be helpful in distinguishing regions differing in stiffness within a medium, and its evaluation as a diagnostic tool has already been the subject of many studies (Cosgrove et al. 2013; Gong et al. 2011; Itoh et al. 2006; Lyshchik et al. 2005; Taylor et al. 2011).

To estimate the medium strain, various 1-D and 2-D approaches have been developed (Chen et al. 2009; Liu et al. 2009; Maurice et al. 2004; Pellot-Barakat et al. 2004; Pesavento et al. 1999; Ophir et al. 1991; Shi and Varghese 2007; Zahiri-Azar and Salcudean 2006). Compared with 1-D techniques that restrict the analysis of tissue motion to axial displacements only (*i.e.,* along A-lines), 2-D methods additionally consider the lateral motion experienced by the tissues with compression. A limitation of these 2-D techniques remains that they ignore the out-of-plane motion, and significant elevational motion will corrupt the estimation of tissue displacement and strain. Improved results can be obtained by adopting a 3-D approach from volumetric ultrasound data, as already reported in some published work (Awad and Yen 2007; Booi et al. 2006; Deprez et al. 2009; Fisher et al. 2010; Hendriks et al. 2016).

Diverse transducers and scanning strategies can be used to acquire 3-D radiofrequency (RF) ultrasound data for strain imaging. The fact that both pre- and

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post-deformation data need to be captured contributes to the variety of the experiments conducted. Indeed, in some cases, the use of specific equipment is required to maintain the examined medium compressed while performing data acquisition. In the next two paragraphs, the discussion is focused more on the ultrasound probes used and the strategies adopted to acquire volumetric data for strain imaging, bearing in mind that additional devices may be needed for data collection.

To obtain data volumes, a first approach consists of using a 1-D array that is moved either automatically or manually (Bharat et al. 2008; Booi et al. 2006; Deprez et al. 2009; Foroughi et al. 2012; Hendriks et al. 2016; Huang et al. 2015; Lindop et al. 2006; Sayed et al. 2013). One-dimensional arrays provide 2-D images of a medium, and acquisition of volumetric data requires a displacement in elevation of this array. This displacement can be automatic, as with the probes dedicated to 3-D imaging (referred to as 4-D imaging probes when also considering time), for which mechanical sweeping is an integral part of probe functioning (Bharat et al. 2008; Foroughi et al. 2012; Sayed et al. 2013). These transducers, such as the Ultrasonix 4DC7-3/40 (Ultrasonix Medical Corporation, Richmond, BC, Canada), are designed to produce data volumes, rotating (“wobbling”) the 1-D array to scan the different planes. Volumes thus acquired have well-defined characteristics, but the angular sweeping of the array results in non-uniform spatial scanning and, therefore, sampling. Other studies have proposed volumetric data acquisition through the automated translation of a 1-D array attached to a dedicated motorized device. Whereas experiments conducted with phantoms are not subjected to particular constraints, in terms of time or motorized system for example, application to patients requires appropriate equipment. For the examination of breast lesions, Booi et al. (2006) experimented with a system in which the ultrasound transducer was positioned on a stand-alone mammography-mimicking unit that contained four motors, two translating the transducer carriage and two controlling the compression paddle movements. Also developed for breast applications is the automated breast volume scanner (Acuson S2000 ABVS, Siemens Medical Solutions, Mountain View, CA, USA), which basically consists of a 768-element transducer (14L5BV probe) that is automatically displaced over the breast to reconstruct its volume. Hendriks et al. (2016) investigated the use of an ABVS-like system with different scanning protocols for breast elastography in a phantom study. Finally, the displacement in elevation of the 1-D array can also be done manually, the probe being moved by the operator without any trajectory guiding element (Lindop et al. 2006) or along a linear sliding track (Huang et al. 2015). Reconstructing a volume then requires tracking the position of the probe during scanning, which can be achieved, for instance, by means of an optical system, such as the NDI Polaris system employed in Lindop et al. (2006).

For the acquisition of ultrasound volumetric data, 2-D arrays can be used as well, obviating the need for mechanical movement of the probe. In a study published in 2007, 3-D data for elastography were acquired using a prototype sparse 2-D array (Awad and Yen 2007). In Fisher et al. (2010), RF data volumes were collected with a prototype 2-D capacitive micromachined ultrasonic transducer (CMUT).

Acquisition of volumetric data allows but does not necessarily imply the application of a 3-D estimation method. Two-dimensional and even 1-D techniques can also be implemented to process 3-D ultrasound data and produce volumes of tissue strain. Three-dimensional strain data offer the possibility of better visualizing the shape of the lesions (than a single elastogram) and are helpful in lesion volume assessment. However, when the medium elevational motion is taken into consideration during elastogram computation, improved results can be produced in comparison with those obtained by restricting the analysis to in-plane motion (Awad and Yen 2007; Booi et al. 2006; Deprez et al. 2009; Fisher et al. 2010; Hendriks et al. 2016). In Deprez et al. (2009) for instance, results from simulated data were presented where the axial strain image produced by a 2-D method was so noisy that a stiff spherical inclusion could not even be identified, whereas the elastogram computed with a 3-D technique clearly brought out this inclusion. With another simulated data set, for which a spherical inclusion remained detectable with a 2-D approach, there was an increase in the mean correlation coefficients achieved during elastogram computation, from 0.64 to 0.79, when considering elevational displacements. Finally, in Awad and Yen (2007), interest in a 3-D over a 2-D approach was examined in terms not only of motion estimation, but also of beamforming. The combinations of 2-D or 3-D beamforming with 2-D or 3-D motion tracking were studied through phantom experiments, and the different elastograms resulting from the four possible processing combinations were compared in terms of the elastographic contrast-to-noise ratio, the elastographic signal-to-noise ratio and strain contrast. The best results were observed with 3-D processing, involving 3-D beamforming and 3-D motion estimation. The authors also underlined the improvement in contrast-to-noise ratios achieved by switching from a 2-D to a 3-D motion estimation technique, whatever beamforming was employed. For example, ratios increased roughly from 2–2.5 to 3–3.5 for a 9-mm sphere within a phantom.

In everyday clinical practice, an ultrasound examination is performed by freely moving the probe; that is, the operator holds the transducer and displaces it, as desired,