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● *Original Contribution*

ELASTOGRAPHIC IMAGE QUALITY *VS.* TISSUE MOTION *IN VIVO*

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Abstract—Elastography is a noninvasive method of imaging tissue elasticity using standard ultrasound equipment. In conventional elastography, axial strain elastograms are generated by cross-correlating pre- and postcompression digitized radio frequency (RF) echo frames acquired from the tissue before and after a small uniaxial compression, respectively. The time elapsed between the pre- and the postcompression frames is referred to as the interframe interval. For *in vivo* elastography, the interframe interval is critical because uncontrolled physiologic motion such as heartbeat, muscle motion, respiration and blood flow introduce interframe decorrelation that reduces the quality of elastograms. To obtain a measure of this decorrelation, *in vivo* experimental data (from human livers and thyroids) at various interframe intervals were obtained from 20 healthy subjects. To further examine the effect of the different interframe intervals on the elastographic image quality, the experimental data were also used in combination with elastographic simulation data. The deterioration of elastographic image quality was objectively evaluated by computing the area under the strain filter (SF) at a given resolution. The experimental results of this study demonstrate a statistical exponential behavior of the temporal decay of the echo signal cross-correlation amplitudes from the *in vivo* tissues due to uncontrollable motion. The results also indicate that the dynamic range and height of the SF are reduced at increased interframe intervals, suggesting that good objective image quality may be achieved provided only that a high frame rate is maintained in elastographic applications. (E-mail: Jonathan.Ophir@uth.tmc.edu). **© 2006 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Cross-correlation, Decorrelation, Elastography, Liver, Image quality, *In vivo*, Inter-frame interval, Strain filter, Thyroid, Ultrasound.**

INTRODUCTION

Elastography is a noninvasive method of imaging soft-tissue elasticity using ultrasound (Ophir et al. 1991; Céspedes 1993; Ophir et al. 1999). Pathologic changes are known to be related to tissue stiffness (Ophir et al. 1991). Many cancers are found as hard nodules (Anderson 1953) but they may not be detectable with conventional ultrasound because the echogenic properties of the normal and pathologic tissues may be similar (Garra et al. 1997). The echogenic properties of tissues and their stiffness are, in general, uncorrelated and hence elastograms may allow detection and possibly classification of ultrasonically occult diseases.

In conventional elastography, axial strain elastograms are generated by cross-correlating two sets of RF data, the precompression and postcompression frames (Céspedes 1993). The precompression frame is obtained after making contact with the tissue, whereas the postcompression frame is obtained after applying a small axial compression to the tissue. Local tissue displacements are usually estimated using time-delay estimation (TDE) techniques (Céspedes and Ophir 1993). Local tissue strains are then obtained as the gradient of the time-delay estimates (Céspedes 1993). The time interval between the two frames of data is referred to as the interframe interval (τ).

There are numerous sources of interframe decorrelation that corrupt the performance of the TDE algorithms, ultimately resulting in a reduced objective quality of the elastogram. Nonuniform compression (Ponnekanti et al. 1993), out-of-plane motion (Konofagou et al. 2000; Patil 2005), nonuniform and/or nonslip boundary conditions (Ponnekanti et al. 1992), orientation of the transducers relative to the direction of compression (resulting

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in depth-dependent decorrelation (Narayana and Ophir 1983), strain-dependence of the noise in elastograms (Varghese and Ophir 1997a; Varghese and Ophir 1998), frequency-dependent attenuation (Varghese and Ophir 1997b) and the uncontrolled and unwanted transducer motion introduced by the operator are some of the main sources of decorrelation in elastography. In addition to these, *in vivo* elastography is also faced with physiologic motion such as heartbeat, respiration, blood flow and uncontrolled muscle motion.

Some of the sources of decorrelation mentioned above can be reduced to acceptable levels by using well-established techniques. For example, nonuniform compression, orientation of transducer and operator-induced motion can be controlled by fixing the transducer to a frame that allows precise control of the applied motion. Lateral and elevational motion that results from the axial compression can be corrected by using suitable correction algorithms (Kallel et al. 1997; Konofagou et al. 1999; Srinivasan et al. 2002b; Srinivasan et al. 2002c). However, when *in vivo* studies are considered, the interframe decorrelation is primarily caused by physiologic sources, which are never completely controllable and can only be reduced and monitored (Konofagou et al. 2002; Céspedes et al. 2000). This decorrelation due to physiologic uncontrollable factors corrupts the performance of elastography and imposes practical limitations for possible *in vivo* elastographic applications (Souchon 2004). To understand the performance limits of elastography *in vivo*, it is necessary to study the effects of these factors on the attainable image quality of the elastograms.

It is noteworthy that the effect of uncontrollable motion may be reduced if the time interval between the pre- and postcompression frames is less than the time required for these factors to cause significant undesirable tissue motion in the tissue region that is being imaged. However, many practical factors limit the shortest interframe interval that can be used. Among these factors is the finite speed of sound in tissue and instrumentation limitations. Furthermore, recent elastographic applications are aimed at depicting the time-dependent mechanical behavior of tissues (Righetti et al. 2004; Righetti et al. 2005). For future applications of these new elastographic methodologies to tissues *in vivo*, it is very important to know the maximum allowable interframe interval before decorrelation occurs (Righetti 2005). In this work, we investigated the effect of different interframe intervals on the obtainable elastographic image quality. *In vivo* experimental data were obtained from human livers and thyroids of 20 healthy subjects at various interframe intervals. The experimental data were then used in combination with elastographic imaging simulations to quantify the deterioration of elastographic image quality by computing the area under the strain filter (SF) at a given resolution, which has been previously shown to be an objective global image quality measure (Srinivasan et al. 2002d). Finally, curves relating the interframe interval and the quality of the elastogram were obtained. Thus, this study elucidates the statistical tradeoffs between image quality and interframe delays in a noisy tissue environment *in vivo*.

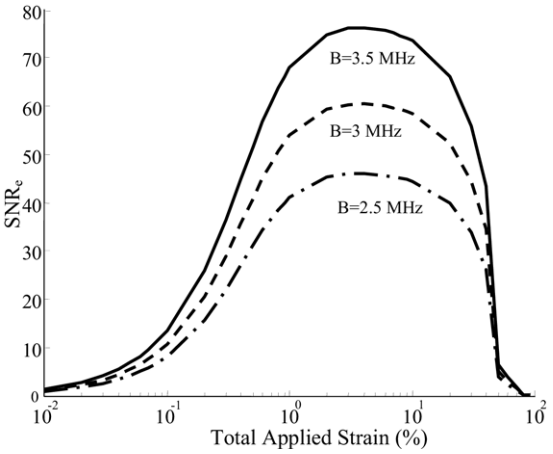

Fig. 1. Strain filter plotted for different bandwidths.

METHODS

The strain filter

Axial strain can be obtained from the displacement gradient obtained from matching segments of the pre- and postcompression RF A-lines separated by Δt (Céspedes 1993; Ophir et al. 1991). Increased strain results in increased decorrelation between the adjacent A-line segments. Strain estimates for strains larger than 5% suffer from decorrelation due to stretching artifacts, and for very small strains the system noise (SNR_s) corrupts the estimates (Varghese and Ophir 1997a). Hence, there exists an intermediate limited range of strains for which the elastographic SNR (SNR_e) is high. The SNR_e in elastography is defined as

$$SNR_e = \frac{\mu_s}{\sigma_s}, \quad (1)$$

where μ_s is the mean of the estimated strain and σ_s is the standard deviation of the estimated strain. The behavior of SNR_e in the strain domain is similar in shape to a band-pass filter, and is known as the strain filter (SF) (Varghese and Ophir 1997a). Typical SFs as a function of the tissue strains are shown in Fig. 1 for three different bandwidths. Figure 1 shows that the height and the width of the SF increase at increased bandwidths (Varghese and Ophir 1997a; Srinivasan et al. 2003).