SHORT COMMUNICATION

Initial clinical experience of an ultrasonic strain imaging system with novel noise-masking capability

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ABSTRACT. Quasistatic strain imaging is a form of elastography that can produce qualitative images of tissue stiffness with only software modifications to conventional ultrasound hardware. Unlike current commercial offerings, the novel strain-imaging system that is the subject of this paper displays regions of signal decorrelation using an overlaid colour mask and can also produce three-dimensional (3D) strain images. In illustrative studies of the breast, testis and thyroid, the colour mask is seen to reduce the potential to misinterpret noise as meaningful stiffness information, and also helps to differentiate cystic and solid lesions. High-quality imaging of the testis *in vivo* demonstrates that 3D strain imaging is feasible.

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The term elastography refers to a range of techniques that attempt to measure tissue stiffness, which has long been recognised as a useful indicator of disease. The general principle is to image the tissue deformation induced by some sort of applied mechanical stress. Stiff lesions deform less than their surroundings and are often readily apparent in the resulting elastograms. The mechanical stress can be applied in a number of ways, ranging from external palpation [1] to internal acoustic radiation force [2]. The deformation can be measured using imaging modalities as diverse as magnetic resonance imaging [3] and ultrasound [4]. The subject of this paper is freehand quasistatic ultrasonic strain imaging, in which the deformation is induced by manually pressing on the transducer and then measured by analysing the consequent echo signals. Although this is a qualitative technique that is fundamentally incapable of measuring absolute tissue stiffness, it is appealing in that it requires only conventional ultrasound scanning hardware, with all processing performed on the echo signals by software. A number of manufacturers have recently started to offer this sort of elastography on their flagship machines.

Figure 1 summarises the principles of quasistatic strain imaging. Two B-mode images are acquired, with a small amount of tissue deformation being induced in the second image by gently pressing on the transducer. The pre- and post-deformation radio frequency (RF) echo signals are compared, and matches established between a fine grid of windows in the two frames (for clarity, only one pair of matching windows is shown in Figure 1). This matching process allows the tissue displacement

(Figure 1a) to be estimated along each vertical line of the image (A-line). The displacement can be differentiated to obtain an estimate of strain (Figure 1b), a measure of how much the tissue has deformed locally. Finally, a strain image (Figure 1c) is constructed by displaying the strain data on a greyscale for each A-line. In Figure 1, note that the displacement increases with depth throughout the soft tissue except in the stiff rectangular region. This area is characterised by low strain and is conventionally displayed as a dark area in a greyscale strain image (Figure 1c).

Quasistatic strain imaging relies on faithful matching of RF data windows between the pre- and post-deformation frames. This requires the same features to be evident in the corresponding windows: in other words, the two sets of signals need to correlate. However, decorrelation can occur for a number of reasons, and this introduces noise into the strain images that is distracting at best and confusing at worst. The principal causes of decorrelation are signal attenuation, out-of-plane tissue displacement and incoherent scatterer motion within fluids: such factors are essentially unavoidable in practice.

This paper describes the initial clinical experience of an experimental patented [5–7] strain-imaging system (Stradwin; Medical Imaging Group, Department of Engineering, University of Cambridge, UK) that displays the strain images in a way that makes it clear where decorrelation has occurred [8, 9]. Strain is displayed in greyscale, with a red colour wash masking out regions that are affected by signal decorrelation. The correlation measure is also used to combine adroitly data from more than two frames, producing a persistent strain image of superior quality and stability. These innovations, and the ability to produce three-dimensional (3D) strain images [10], distinguish this system from current commercial products.

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Figure 1. Principles of quasistatic strain imaging. The ellipsoidal structure has the same stiffness as the background whereas the rectangular structure is stiffer.

Methods and materials

All two-dimensional (2D) studies were performed using a T3000 ultrasound system (Terason Ultrasound, Burlington, MA, USA) with a 12L5V linear array transducer. The 3D study was performed using an RSP6-12 3D transducer (GE Healthcare, Chalfont St. Giles, UK) interfaced to a Diasus (Dynamic Imaging, Livingstone, UK) ultrasound machine. RF echo data were transferred to a PC running STRADWIN Medical Imaging Group, Cambridge University software for real-time display of B-mode and strain images. All diagnoses were verified by biopsy or, in the case of the breast cyst, by aspiration. Informed consent was obtained from all subjects. The study was approved by the Cambridgeshire 3 Research Ethics Committee (references 07/H0306/90 and 07/H0306/92).

Selected cases

Three examples from diverse anatomical sites serve to illustrate the basic properties of strain images. In Figure 2, the B-mode image of the breast shows the typical appearance of an invasive carcinoma, with

marked posterior acoustic shadowing. What is less apparent is the adjacent intraductal extension, which is more obvious in the strain image: lighter shades indicate high deformation (soft) whereas darker shades indicate low deformation (stiff). In the strain image, the red wash masks noise, which in this case is caused by signal attenuation in the posterior shadow of the lesion towards the bottom of the frame. In Figure 3, the B-mode image demonstrates a heterogeneous echogenic mass in the right lobe of the thyroid that was subsequently proven to be a follicular adenoma. Elastography images match the B-mode appearances despite challenges posed by respiratory motion and adjacent vascular pulsation. There is the danger that noise in the unmasked strain image might be misinterpreted as meaningful information. The red mask correctly obscures regions of poor signal correlation, in this case associated with blood within the carotid artery and shadowing from tracheal cartilage. Finally, the strain image in Figure 4 demonstrates a normal testis with a predominantly homogeneous strain pattern and a focal area of increased stiffness at the testicular mediastinum. The bright white perimeter is characteristic of slip (*i.e.* high deformation) at the interface between the visceral and parietal layers of

Figure 2. Invasive breast carcinoma with ductal carcinoma *in situ* (DCIS). (a) B-mode image. (b) Unmasked strain image. (c) Masked strain image. The adjacent intraductal extension (arrow) is more obvious in the strain image: lighter shades indicate high deformation (soft) whereas darker shades indicate low deformation (stiff). In (c), the red wash masks noise, which in this case is caused by signal attenuation in the posterior shadow of the lesion and towards the bottom of the frame.

Figure 3. Follicular adenoma of the thyroid. (a) B-mode image. (b) Unmasked strain image. (c) Masked strain image. The B-mode image demonstrates a heterogeneous echogenic mass in the right lobe of the thyroid that was subsequently proven to be a follicular adenoma. The red mask correctly obscures regions of poor signal correlation, in this case associated with blood within the carotid artery and shadowing from tracheal cartilage.

Figure 4. Transverse section through the testis. (a) B-mode image. (b) Unmasked strain image. (c) Masked strain image. There is a focal area of increased stiffness (arrow) at the testicular mediastinum. The bright white perimeter is characteristic of slip (*i.e.* high deformation) at the interface between the visceral and parietal layers of the tunica vaginalis. The mask covers areas where the signal is heavily attenuated.

Figure 5. Three-dimensional strain imaging of the testis. (a) B-mode image. (b) Unmasked strain image. (c) Masked strain image. In each case, the top left image is in the B-scan plane, the bottom two are orthogonal reslices, and the top right is a composite showing all three planes.

Figure 6. Breast cyst. (a) B-mode image. (b) Unmasked strain image. (c) Masked strain image. The B-mode image shows a small hypoanechoic breast lesion with marked posterior acoustic enhancement. The strain image confirms a stiff lesion but the colour wash masks the fluid within the cyst wall.

the tunica vaginalis. The mask covers areas where the signal is heavily attenuated.

The additional value of strain imaging is not restricted to 2D acquisition. 3D strain imaging is possible using specialised transducers, but the scanning protocol is more challenging because tissue motion needs to remain coherent over the full 3D volume and throughout the few seconds it takes to acquire the data. Figure 5 shows an example of high-quality 3D strain images of the testis.

Three further examples illustrate the potential utility of the colour mask in aiding diagnosis (Figures 6, 7 and 8). In Figures 6 and 7, the B-mode images show small hypoanechoic breast lesions with marked posterior acoustic enhancement. Differentiation between cysts and solid benign fibroadenomas is not always straightforward. The corresponding strain images confirm stiff lesions in both instances, but the colour wash masks the fluid within the cyst wall. There is no colour wash over the fibroadenoma (indicated in Figure 7), which retains the expected characteristics of stiffness in the strain image. Scatterer motion is not coherent between pre- and post-deformation frames in lesions containing fluid. The colour wash is therefore able to distinguish between cystic and solid lesions.

In Figure 8, the B-mode image shows a typical irregular lobulated hypoechoic breast mass suspicious of a carcinoma. The unmasked strain image shows a corresponding stiff irregular lesion, but addition of the colour wash shows an unexpected area of masking in the centre of the lesion. Core biopsy confirmed an aggressive Grade 3 ductal carcinoma with extensive central necrosis. The masked region is caused by incoherent scatterer motion, most likely corresponding to the necrotic region. The information provided by the colour wash may therefore help in targeting biopsy.

Discussion

The clinical relevance of ultrasonic strain imaging has yet to be established. In a recent evidence-based review [11], only transient ultrasound elastography (a quantitative technique that does not produce an image, but instead measures point stiffness) emerged as a clinically proven technique for assessing liver fibrosis. For breast imaging, the conclusion was that ultrasound elastography “may prove to be a useful addition... perhaps serving as an adjunct to conventional ultrasound, rather than a

Figure 7. Suspected fibroadenoma in the breast. (a) B-mode image. (b) Unmasked strain image. (c) Masked strain image. The B-mode image shows a small hypoanechoic breast lesion (arrow) with marked posterior acoustic enhancement. The strain image confirms a stiff lesion with no colour wash, suggesting the absence of any fluid.

Figure 8. Invasive breast carcinoma. (a) B-mode image. (b) Unmasked strain image. (c) Masked strain image. The B-mode image shows a typical irregular lobulated hypoechoic breast mass. The unmasked strain image shows a corresponding stiff irregular lesion, but addition of the colour wash shows an unexpected area of masking in the centre of the lesion. Core biopsy confirmed an aggressive Grade 3 ductal carcinoma with extensive central necrosis. The masked region is caused by incoherent scatterer motion, most likely corresponding to the necrotic region.

replacement for it, but further research is needed.” Only “limited evidence” was found for ultrasound elastography’s utility in prostate, endoscopic and vascular imaging. It is therefore still early days for this technology, but the commitment of the major equipment manufacturers suggests that its utility will eventually be proven.

In this context, the cases presented here demonstrate the potential advantages of masked images over more conventional ways of visualising strain data. Without masking, regions of noisy strain data are prone to misinterpretation, and differentiating fluid-filled and necrotic lesions is less straightforward. Masked display could be added to any strain-imaging system with only minor software modifications. Finally, 3D strain imaging has been shown to be feasible *in vivo* and might offer advantages in establishing the shape and extent of lesions prior to surgical or radiotherapeutic intervention.

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