MAGNETOMOTIVE ULTRASOUND ELASTOGRAPHY: PRELIMINARY EVALUATION IN PHANTOM

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Abstract: ***Colorectal cancer (CRC) is the third most common malignant neoplasm worldwide and early diagnosis reduces morbidity. The standard preventive exams methods are uncomfortable for the patient, invasive, and /or are ionizing. Here, we evaluate the potential of magneto-motive ultrasound (MMUS) as a new, minimally invasive CRC screening technique. We developed a hybrid transducer (comprised of an ultrasound probe and a magnetic coil system) to construct relative elastography maps in a paraffin phantom with isoechoic inclusions. The electromagnetic component of our system manipulated ferromagnetic fluid located inside of our synthetic colon, and the captured ultrasound images were used to produce relative elastography maps. The MMUS images reveal by otherwise invisible structures based on differences in stiffness. Ultrasound elastography (relative) images by MMUs technique complements usual preventive CRC exams, is minimally invasive, has relative low cost when compared with others image methods. Also is fast diagnose and more comfortable for patient which prevents withdrawal of the screening.***

Keywords: Magnetomotive**,** Elastography, Ultrasound, Magnetism, cancer, colon.

Introduction

Globally, colorectal cancer (CRC) is the third most common cancer [1]–[3] and the fourth leading cause of cancer-related deaths [4]. Often, this detrimental disease originates as benign polyps. These polyps can increase in size and eventually become malignant, with the potential to invade through the bowel wall and metastasize to distant sites in the body. Vigilant colorectal screenings are vital because CRCs are more curable in their early stages [5]. In addition, CRCs metastasize can be prevented by early detection polyps' growth in the colon walls.

Currently, there are several clinical CRC screening techniques, including: stool tests, exfoliated DNA tests, computed tomographic colonography (CTc), optical colonoscopy, and endoscopic ultrasound [6]. The stool test looks for occult blood or abnormal DNA as indicators of cancer. Stool-based CRC screening has limited test sensitivity (incomplete specimen collection and inadequate processing), and cannot detect some kind of CRC when it developed inner colon wall [5]. The CTcs or virtual colonoscopy is a less invasive imaging technique and provides both 2-D and 3-D images. However CTcs have high associated costs, no uniform results, risk colon perforation, low sensitivity for significant adenomas, and use of ionizing radiation [7], [8]. Of these screening technique, the most commonly used is optical colonoscopy (or simply colonoscopy). Colonoscopy has several limitations (dietary preparation, uncomfortable procedure, sedation); it is non-infallible "gold standard" (miss rate for large adenomas is 6% to 12% and for cancer is about 5%) [5].

Ultrasound elastographic evaluation of early tumors may improve the distinction between malignant and benign lesions, and hence decrease the requirement for repeated endoscopic examination and biopsy [6], [9]. However, conventional colorectal ultrasound elastography uses an endoscopic probe which has a limited field of view, is uncomfortable to the patient, and can injure colon walls or adenomatous polyps [10].

Recent studies have showed a hybrid system (HS) (Ultrasound and Biosusceptometric techniques) as potential tool to evaluate gastrointestinal system (GS). This system implements MMUS, where a magnetic field gradient from the Alternate Current Biosusceptometer (ACB) coils pulls a ferromagnetic fluid located inside of the GS, and ultrasound on the outside of the patient is used to detect the resulting displacements [11]–[13] [14], [15]. These micro displacements are then converted to relative elasticity [16], which can highlight CRCs inner wall. The magnetic fluid can reach depth colon region, is more comfortable than endoscopic probe and it can move around polyps without damage them. In this study, we evaluated the potential of our hybrid system to make elasticity image - using magnetic stress - to detect lesions in colon walls.

Materials and methods

Hybrid System

The hybrid system transducer is composed of a ACB [11], [13] and an ultrasonic probe EC9-5/10 microconvex (Ultrasonix - British Columbia, Canada) placed in the center of the ACB coils [12]. The ultrasound system (Sonix RP, Ultrasonix, British

Columbia, Canada) was used to acquire the radio frequency (RF) signals from the phantom. In this experiment, we used only the ACB excitation coil to pull the ferromagnetic fluid. The coil was powered by an HP 33120A signal generator (Agilent Technologies Inc., Santa Clara, CA) connected to amplifier (DYNAMIC 20000 Ω2 H, Ciclotron Indústria Eletrônica Ltda, SP, Brazil). At a distance of 5 cm from the transducer (20ms pulse width), the measured magnetic field gradient and intensity were ~0.26 T/m and ~14mT, respectively.

Phantom

The tissue-mimicking materials were formed from paraffin-gel wax (Gel Candle, São Paulo, Brazil) [17]. The phantom had a cylindrical cavity (4 cm diameter) filled with a ferromagnetic fluid to mimic colon region. This fluid consisted of ferrite particles (diameter between 37 and 70 µm; TH 50, Thornton Electronics, Vinhedo, SP, Brazil) mixed with yogurt (Chandelle, Nestle SA, Vevey, Switzerland) at concentration of 20% by mass. Spherical inclusions were constructed by doping the paraffin-gel with paraffin-wax. The inclusions (~11 mm diameter and ~2 times stiffer than base material) were placed above the synthetic colon, like as lesions inner colon wall, as showed in Figure 1. In this study, we used only central inclusions (labeled A and B).

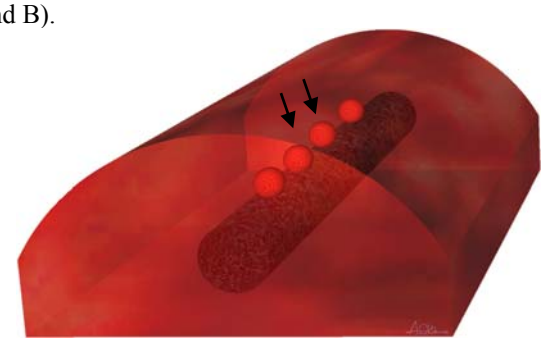

Figure 1 : Colon phantom with four spherical inclusions located above a cylindrical cavity. A and B were central inclusions (arrows).

Experiment

The hybrid transducer was fixed on a 2D axis system (non-magnetic) and placed over the phantom (Figure 2). With the ultrasound probe in constant contact with phantom, the signal generator and Sonix RP was synchronized during the magnetic pull. Elastography maps were generated from the ultrasound RF data during post-processing.

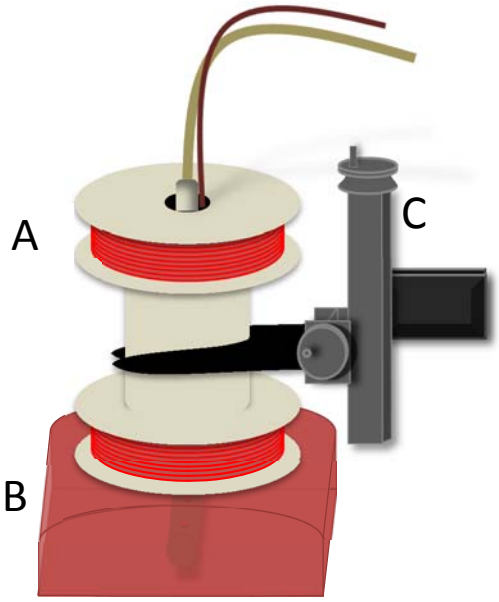

Figure 2: Experimental setup illustrating the hybrid transducer (A), the colon phantom (B), and the 2D axis (C).

Results

As shown in Figure 3, the inclusions and colon phantom background were nearly isoechoic. The red arrow in Figure 3 indicates the location of the harder inclusion and the yellow arrow indicates the location of the ferromagnetic fluid filled synthetic colon.

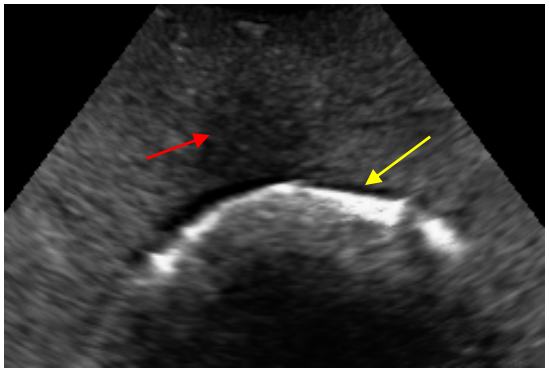

Figure 3: Colon phantom B-mode image using a microconvex probe with central frequency of 9MHz. The red arrows show inclusion (up – tumor) and cylindrical cavity (down - colon tube).

In addition to RF data, we also acquired B-mode images to give an anatomical reference to the relative elastography maps. Figure 4 shows images before and during magnetic pulse. In the elastography map, red indicates a hard structure, while blue indicates softer normal tissues

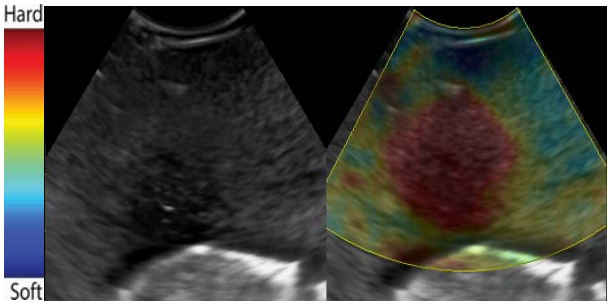

Figure 4: Colon phantom elastography image using a microconvex probe with central frequency of 9MHz. B-mode image (right) and relative elastography map overlaid B-mode (left) of inclusion "A".

Table 1: Inclusions diameter (lateral and axial) measured from elastography maps using Matlab® (The MathWorks, Inc., Natick, Massachusetts, United States) software.

Inclusion	Lateral (mm)	Axial (mm)
A	11.6±0.2	10.2±0.1
B	11.9±0.2	10.3±0.2

Lesion size and shape are important prognostic factors to plan biopsy or therapies [18]–[20]. We measured the lateral and axial diameter of two different inclusions (A and B) using the elastography map (Table 1).

Discussion

B-mode imaging alone cannot distinguish hard and soft tissues [21]–[23]. Although the inclusions were faintly visible in the B-mode image (Figure 3), it is very challenging to determine its true boundaries. The elastography images (Figure 4) shows clear inclusion boundaries, which can be used for diagnosis.

Using the elastography maps, the measured inclusion diameters were similar to the actual values (Table 1). The axial dimension was measured smaller than the lateral because of small physical distortions generated from the magnetic pull. The relative elastography maps showed the inclusion boundaries (diagnostic parameter), distinguished different stiffness, and had accuracy to determine inclusion size and shape.

Conclusion

The magnetic force induced by HT coils produced significant strain on paraffin phantom. However, the magnetic field needs to be increased for *in vivo* experiments, because some colon segments are deeper than 5 cm.

In an *in vivo* application of this technique, we will insert magnetic fluid in colon tube and attract it to region of interest with a continuum magnetic field from the ACB coil. After this, a pulsed magnetic field will induce stress-strain on the colon wall. This procedure uses no ionizing radiation, has low cost when comparing with CTc and MRA, and can complement other clinical CRC screening techniques. However, we need more studies – about magnetic fluid interactions and application procedure - to enhance and optimize the technique before *in vivo* application. One enhancement will be the ACB use to quantifier magnetic force to generate an absolute elastography image in order to avoid biopsy procedure in some cases.

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