"SONO-ELASTICITY" IMAGES DERIVED FROM ULTRASOUND SIGNALS IN MECHANICALLY VIBRATED TARGETS

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An approach has been developed for detecting the "stiffness," or elastic constants of tissues. Externally applied vibration at low frequencies (20-1000Hz) sets up vibrations within soft tissues, and Doppler ultrasound is used to map out the vibrations over regions of interest. The results are displayed in grey scale format and are termed "sono-elasticity images". These novel images may be useful for detecting tumors in the prostate, breast, and other organs.

KEY WORDS: Ultrasound, Tissue Characterization, Doppler, Tumors, Prostate, Cancer

DISCUSSION

Cancers of the prostate have traditionally been detected by digital palpatation which identifies increased stiffness (modulus of elasticity, hardness) of the abnormal tissue. Grey scale ultrasound is insensitive to stiffness as an imaging parameter and often fails to reveal the extent or existence of a prostate cancer. Recent developments in technology and understanding have improved the diagnostic efficacy of transrectal ultrasound for detection of early prostate cancer, but even when coupled with digital rectal examination, a significant percentage of existing carcinomas may not be recognized. This allegation is based on the lower detection rates for transrectal ultrasound and digital rectal examination in screening populations (0.1-4%) as compared to autopsy series prevalance rates of approximately 30%. Recent reports suggest that early cancers of the prostate may be characterized as hypoechoic areas in the peripheral zone of the prostate (1). Others suggest that the more advanced lesions have varied appearances ranging from hypo to hyperechoic with some even showing combinations of both (2, 3). Our transrectal ultrasound experience from patients with palpable cancers (which include moderate to advanced disease), suggests a varied non-specific grey scale appearance as well, despite the uniform impression that they are all firm on digital palpation.

Recent studies imply potential for curability of carcinoma of the prostate if it is detected before it reaches 1.3 cm^3 in volume (4) (presuming a spherical tumor, this corresponds to a 1.3 cm diameter). It is suggested that biologically active carcinomas alter the supporting prostate stroma resulting in an increased modulus of elasticity which may be detected as a region of stiffness or hardness on digitial rectal examination. Since not all lesions are within the range of the examining finger, nor are all lesions palpable for a variety of reasons, a sensitive and objective method for detecting abnormal regional elasticity should lead to improved detection of carcinoma of the prostate. The purpose of this research is to incorporate tissue stiffness features into ultrasound images (sono-elasticity). The concept is that stiff tissues (cancers) will respond differently to an applied mechanical vibration than normal tissues.

This approach combines external mechanical stimulation of target tissues with Doppler ultrasound to improve lesion detection, provided the lesion presents an altered region of elasticity. Stimulation of target tissues by a controlled mechanical vibration causes regions of different elasticity to respond with different displacements and velocities. The idea of characterizing tissue from the motion or mechanical response is not new but has had only limited evaluation (5-10). Ultrasound detection schemes have utilized correlations between A-lines to detect motion of cardiovascular origin, and visual analysis of M-mode waveforms have been performed to detect motion for a 1.5 Hz external vibration source. None of these techniques have reached clinical maturity because of a number of difficulties. The A-line or M-mode techniques rely primarily on echoes from speckle regions, with few discrete specular reflections available to demonstrate motion unequivocally. The changes in speckle pattern resulting from motion of the sample volumes are complex and can be difficult to interpret. The correlations may suffer from patient motion caused by respiration and other body movements. The use of cardiovascular pulses to generate internal motion is problematic because the "source function", the radial expansion of arteries, is generally of uncertain strength, and has unknown coupling to the surrounding tissues. The pulsatile movements near the arteries can be submillimeter in extent, which is well below the resolution of conventional A-line or M-mode techniques.

In comparison, the approach embodied in the present research employs variable frequency, external, periodic pulsations and incorporates range-gated Doppler ultrasound to detect the periodic movements of tissue. The advantages can be summarized as follows:

i) External periodic pulsation applied to a specimen provides a known stimulus which can be easily recognized as distinct from other velocity (noise) sources. Sensitive coherent signal detection schemes may then be applied to improve signal-to-noise ratios if indicated.

ii) The Doppler detection technique is capable of resolving much smaller displacements than A-mode or M-mode techniques. This results from the fact that Doppler ultrasound measures velocity (displacement times frequency for sinusoidal motion) compared with techniques which measure displacement only. At "high" frequency (1 KHz) mechanical vibration, a conventional 2 MHz Doppler ultrasound time-frequency display is capable of resolving excursions (sinusoidal displacements) on the order of 0.06 mm (11). Thus, very small vibrations in deep tissues can be measured.

iii) The Doppler detection technique is sensitive in regions of low speckle, as well as regions with specular reflectors. For example, color coded Doppler blood flow images are derived from regions where conventional B-scan images show extremely low reflectivity.

iv) Doppler ultrasound combined with mechanical stimulation is relatively insensitive to respiratory and other gross tissue movements. This results from the examiners ability to identify the sinusoidal Doppler ultrasound output at a given known frequency of external vibration so that motions which are not periodic at the driven frequency can be ignored.

v) A variable frequency approach maximizes the likelihood of detecting differences between normal tissue and tumor with concomitant altered elasticity, because of the possibilities of exciting "mechanical resonances". The mechanical properties of tissue include a high degree of damping, and thus, strong resonance behavior (high Q) should not be encountered. Nonetheless, the ability to change stimulation frequency may add additional information concerning the frequency dependent response of a region, and this information can be compared with theoretical and experimental results to estimate the regions' mechanical properties.

As a result of these advantages, the combined external vibration/Doppler ultrasound detection approach appears to be a leading candidate for determining the elastic properties of discrete regions of tissue, which may permit early detection of prostate tumors and other focal abnormalities in soft tissue.

Preliminary work using 18 Hz mechanical vibratory system and pulsed Doppler detection has resulted in generation of prototype images of stiffness obtained from a sponge model containing a "tumor" nodule of altered stiffness. Diminished vibratory motion in the nodule is clearly evident. In another investigation, gelatin blocks of different stiffness demonstrated recognizable differences in motion of contained reflectors as well as differences in propagation of the low frequency mechanical energy transmission. These preliminary results indicate that tissue stiffness can be incorporated into grey scale ultrasound imaging (12).

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