Recent and future developments in diagnostic ultrasound technology

Despite the fact that diagnostic ultrasound is an older imaging modality compared to MRI and PET, it is very intriguing to see that it continues to expand as a field and offer numerous applications. In the past decade, several leaps have been made with the advent of faster computer processors, contrast agents, the utilisation of nonlinear wave propagation, cutting-edge signal and image processing techniques and complex transducer architecture, to name a few. In this section, a short overview of the key techniques that can routinely be used on ultrasound machines in the future, if not already, is provided.

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Contrast agents and harmonic imaging

One of the main problems with the standard use of ultrasound arises from high attenuation in some tissues and especially small vessels and blood cavities. In order to overcome this limitation, contrast agents are routinely used. Contrast agents are typically microspheres of encapsulated gas or liquid coated by a shell, usually albumin. Due to the high impedance mismatch created by the gas or liquid contained, the resulting backscatter generated by the contrast agents is a lot higher than that of the blood echoes.

An alternative method to generating higher backscatter due to the increased impedance mismatch is based on the harmonics generated by the bubble's interaction with the ultrasonic wave. The bubble vibration also generates harmonics above and below the fundamental frequency, with the second harmonic possibly exceeding the first harmonic. In other words, the contrast agent introduces non-linear backscattering properties into the medium where it lies. Several processes of filtering out undesired echoes from stationary media surrounding the region, where flow characteristics are assessed, result to weakening of the overall signal at the fundamental frequency. Therefore, since residual harmonics will result from moving scatterers, motion characteristics can all be obtained from the higher harmonic echoes, after using a high-pass filter and filtering out the fundamental frequency spectrum that also contains the undesired stationary echoes.

Another method for distilling the harmonic echo information is the more widely used phase or pulse inversion method, in which two pulses (instead of one) are sequentially transmitted with their phases reversed. Upon reception, the echoes resulting from the two pulses are then added and only the higher harmonics remain.

Despite the fact that the idea of contrast agent use originated for applications in the case of blood flow, the same type of approach can be applied in the case of soft tissues as well. After being injected into the bloodstream, the contrast agents can also appear and remain on the tissues and offer the same advantages of motion detection and characterisation as in the case of blood flow. However, it turns out that contrast agents are not always needed for imaging of tissues at higher harmonics, especially since tissue scattering can be up to two orders of magnitude higher than blood scattering. The nonlinear wave characteristic of the tissues themselves is, thus, sufficient in itself to allow imaging of tissues, despite the resulting higher attenuation at those frequencies. The avoidance of patient discomfort following contrast agent injection is one of the major advantages of this approach in tissues.

Imaging using the harmonic approach (whether with or without contrast agents) is generally known as harmonic imaging. Compared to the standard approach, harmonic imaging in tissues offers the ability to distinguish between noise and fluid-filled structures, e.g. cysts and the gall bladder. In addition, harmonic imaging allows for better edge definition in structures and, thus, it is generally known to increase image clarity, mainly due to the much smaller influence of the transmitted pulse to the received spectrum. Harmonic imaging is now available in most commercially available ultrasound systems. One of the main requirements for harmonic imaging is the large bandwidth of the transducer at receive so as to allow reception of the higher frequency components. This brings into very good agreement with the higher resolution requirements for diagnostic imaging.

Elasticity Imaging

Another field that has emerged out of ultrasonic imaging in the past decade is elasticity imaging. Its premise is built on two proven facts: a) that significant differences between mechanical properties of several tissue components exist and b) that the information contained in the coherent scattering, or speckle, is sufficient to depict these differences following an external or internal mechanical stimulus. For example, in the breast, not only is the hardness of fat different than that of glandular tissue, but, most importantly, the hardness of normal glandular tissue is different than tumorous tissue (benign or malignant) by up to one order of magnitude. This is also the reason why palpation has been proven a crucial tool in the detection of cancer.

The second observation is based on the fact that coherent echoes can be tracked while or after the tissue in question undergoes motion and/or deformation caused by the mechanical stimulus. Speckle tracking techniques are also used here for the motion estimation. In fact, Doppler techniques were initially applied in order to track motion during vibration (Sonoelastography or Sonoelastostigraphy). Parameters, such as velocity and strain, are estimated and imaged in conjunction with the mechanical property of the underlying tissue. The higher the velocity or strain estimated the softer the material and vice versa.

Due to the vast impact that these techniques could have in imaging and characterisation of tissues, a variety of very promising methods have been recently developed spanning from handheld and real-time application of elastography to elastic modulus maps based on the wavelength of propagation through different tissues following an applied stimulus (Transient Elastography) and the use of the internal radiation force resulting from the pressure of the beam itself to locally displace (e.g., Acoustic Radiation Force Imaging and Radiation Force Elastography) or vibrate (e.g., Ultrasound-Stimulated Vibroacousto-graphy and Harmonic Motion Imaging) the underlying tissue and measure its resulting response.

The elasticity imaging techniques have not been proven as readily applicable clinically as those for harmonic imaging due to the more complicated combination of tissue mechanics and processing during deformation. However, all these techniques are now in the process of being incorporated into standard clinical ultrasound scanners. For example, Hitachi Medical Systems recently introduced the first clinical scanner (Hi VISION 8500) for real-time elastography in the detection of breast cancer. Several other manufacturers are also in the final stages of development and integration of such elasticity imaging technology. Future clinical applications of elasticity imaging are currently being investigated for the detection of cardiovascular disease, joint disease, atherosclerosis (RF or HIFU) monitoring and vascular plaque detection.

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3D short-axis echocardiogram depicting the right and left ventricles (EKG gated). [Image obtained using HP Sonos 7500 and courtesy of Todd Fulperwitz and Shunichi Homma (New York Presbyterian Hospital, New York, NY)].

3D Imaging

Clinical ultrasound scanners have recently expanded to 3D imaging in several clinical applications, especially cardiology and obstetrics. This is due to the advancement in faster data processing and compact transducer design, namely 2D arrays, where beams are generated in all three planes. For cardiology applications, several clinical scanners, such as the HP Sonos 7500 and the GE Vivid 7, are routinely used by cardiologists in the clinic. Recently, the GE Vivid 7 Precision was the first scanner to achieve 3D scanning of the heart in real time, i.e. without requiring a breath-hold.

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