

Chapter 4

Biomedical Application of Multimodal Ultrasound Microscope

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ABSTRACT

High frequency ultrasound imaging has evolved from the classical acoustic microscope to the multimodal ultrasound microscope, which is available for quantitative C-mode, surface acoustic impedance mode, and three-dimensional (3D)-mode imaging. This evolution has realized both quantitative parametric imaging and easier observation. Quantitative C-mode represents two-dimensional sound speed distribution and is realized by frequency-domain analysis of a single pulse by a high-speed digitizer. Because the square of sound speed is proportional to tissue elasticity, sound speed imaging provides biomechanical information about the tissue. Surface acoustic impedance mode has been used to image fresh brain tissue. High-frequency 3D-mode imaging has been used to visualize the 3D structure of dermis sebaceous glands.

INTRODUCTION

High resolution biomedical imaging using high-frequency ultrasound is possible because both wavelength and beam width are inversely proportional to ultrasonic frequency. Routine echography in health care or gynecology uses several MHz ultrasound and its resolution is approximately 0.5 mm. Ultrasound microscopes (UM) use 100 MHz

or higher frequency ultrasound. The resolutions achieved by 100 MHz and 1 GHz ultrasound are 15 and 1.5 microns, respectively; this level of detail enables cellular imaging.

UM introduced a new form of contrast that is based on the mechanical properties of what is being imaged. There are three major advantages of UM compared with other forms of microscopy, such as optical, electron and atomic force. First, UM can be applied to simple histopathological examinations because it does not require any

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special staining techniques. The contrast observed in UM images depends on the acoustic properties (i.e., density, stiffness, and attenuation) and topographic contour of the tissue.

Second, microscopic acoustic properties obtained with high frequency ultrasound can be used for assessing echo intensity and texture in clinical echography with lower frequency ultrasound. Density ρ and sound speed c determine the characteristic acoustic impedance Z of the material as

$$Z = \rho c .$$

On the assumption that the interface between two fluid-like media is infinite and plane, the relative reflected sound power in dB can be determined by the specific acoustic impedance of each medium as

$$dB = 10 \log_{10} \frac{P_r}{P_i} = 10 \log_{10} \frac{(Z_a - Z_b)^2}{(Z_a + Z_b)^2},$$

where P_r is the sound power reflected at the interface, P_i is the incident sound power, Z_a is the acoustic impedance of medium a , and Z_b is the acoustic impedance of medium b .

Third, UM data can be used as basic data for assessing tissue and cell biomechanics. This is particularly useful for microscopic targets where direct mechanical measurements cannot be applied. In its simplest form, the relationship between sound speed and the elastic bulk modulus of liquid-like media is

$$c = \sqrt{\frac{K}{\rho}},$$

where c is sound speed, K is the elastic bulk modulus, and ρ is the density.

As a biological soft tissue may be considered a liquid-like material, this equation can be applied to assess its elastic properties. Recent biomechanical

studies have suggested that the mechanical properties of tissues may not be sufficiently similar to liquids and should be treated as soft solid materials. However, the acoustical relationships of solid materials can also be described by the following equation if the material is assumed to be isotropic.

$$c = \sqrt{\frac{E(1 - \sigma)}{\rho(1 + \sigma)(1 - 2\sigma)}},$$

where c is sound speed, E is Young's modulus, σ is Poisson's ratio, and ρ is the density.

The above equation shows that Young's modulus of tissue and sound speed are closely related.

Soft materials are sometimes considered to be viscoelastic materials. In these cases, viscosity is also derived from acoustic properties, although it is a complicated procedure (Mikhailov, I. G., Soloviev, V. A., Syrnikov, Y. P., 1964).

$$\alpha = \frac{2f^2 \pi^2}{3\rho c^3} \left(\eta_v + \frac{4}{3} \eta_s \right),$$

where α is the absorption, f is the frequency, η_v is the volumetric viscosity, η_s is the shear viscosity, ρ is the density, and c is sound speed.

Recently, computer technological advances and high frequency engineering allowed us to develop a multimodal ultrasound microscope that enabled C-mode, surface acoustic impedance mode and three-dimensional (3D) mode. Figure 1 shows the schematic illustration of imaging planes obtained with each mode.

MAIN FOCUS OF THE CHAPTER

Instrumentation of Multimodal Ultrasound Microscope

Figure 2 shows the block diagram of the multimodal ultrasound microscope (Saijo, Y., 2007).

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