Chapter XXIV
Nonlinear Ultrasound
Radiation–Force Elastography

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ABSTRACT

“Elastography” or “elasticity imaging” can be defined as the science and methodology of estimating the mechanical properties of a medium (including soft tissue). In this chapter, an overview of elastography and its relation to tissue pathology will be presented. The basic principles of the static and dynamic methods will be described with special emphasis on the dynamic methods that rely on the acoustic radiation force of ultrasound. Of interest are the low-frequency narrowband shear waves that can be generated by a modulated radiation force produced by the interference of two continuous-wave (CW) ultrasound beams of slightly different frequencies. The advantages of using narrowband shear waves to estimate the viscoelastic properties of tissue will be discussed. Furthermore, an implementation of the inverse-problem approach will be presented and it will be shown how harmonic maps of the local shear modulus and viscosity can be reconstructed based on both the fundamental and higher-harmonic components of the propagated narrowband shear waves.

INTRODUCTION

The elasticity of soft tissues depends, to a large extent, on their molecular building blocks (fat, collagen, etc.), and on the microscopic and macroscopic structural organization of these blocks (Fung, 1981). Pathological changes are generally correlated with local changes in tissue stiffness (Figure 1). Many cancers, such as scirrhous carcinoma of the breast, liver metastases, prostatic carcinoma, and thyroid cancer, appear as extremely hard nodules (Anderson, 1984).
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Other types of breast cancers (e.g. intraductal and papillary carcinoma) are soft (Ariel, 1987). Other diseases involve fatty and/or collagenous deposits, which increase or decrease tissue elasticity. The standard medical practice of soft tissue palpation is based on qualitative assessment of the low-frequency stiffness of tissue and has been used for centuries by physicians to distinguish between normal and diseased tissues. Palpation is sometimes used to assess organs such as the liver, and it is not uncommon for surgeons at the time of laparotomy to palpate tumors that were not detected preoperatively using conventional imaging methods, such as Ultrasound, Computer Tomography (CT), or Magnetic Resonance Imaging (MRI), since none of these modalities currently provides the type of information elicited by palpation.

In many cases, despite the difference in stiffness, the small size of a pathological lesion and/or its location deep in the body, preclude its detection and evaluation by palpation. In general, the lesion may or may not possess acoustic backscatter properties, which would make it detectable using ultrasound. For example, tumors of the prostate or the breast could be invisible or barely visible

Figure 1. (a) Sonogram and (b) elastogram of an in-vivo benign breast tumour (fibroadenoma) and (c) sonogram and (d) elastogram of an in-vivo malignant breast tumour (invasive ductal carcinoma). Note that black indicates stiff and white indicates soft tissue. Adapted version, reprinted from Ultrasonics, 38, Konofagou (2000), pp. 400-404, ©2000, with permission from Elsevier.
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