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Ultrasound Elastography: Development of Novel Technologies and Standardization

超音波エラストグラフィ：新技術の開発と標準化に向けて

Tsuyoshi Shiina (Graduate School of Medicine, Kyoto University)
椎名　毅（京都大学大学院 医学研究科）

1. Introduction

Ultrasound elastography has been developed as a modality which provides novel diagnostic information regarding tissue stiffness by replacing the conventional palpation which was used for breast examination. Recently elastography has a wider application than breast cancer diagnosis, such as arteriosclerosis, chronic hepatitis, myocardial diseases and monitoring for therapy by HIFU. Ten years have passed since the first practical equipment of elastography has been released by a Japanese manufacture in 2003 and the clinical utility was demonstrated. Nowadays each company provides equipment which can offer elastography. Furthermore, the apparently different elasticity imaging methods are available, which has created a potentially confusing situation for clinical users.

As a result, major societies of medical ultrasonics are beginning to focus on creating a set of guidelines on clinical use of ultrasound elasography, with the goal of helping users to understand the different methods, and, to provide guidance as to the appropriate uses, applications, and limitations of each method.

2. Principle and classification of elastography

2. 1. Measured physical quantity

Elastic properties of tissues such as Young's modulus E, can be estimated in the following two ways according to the directly-measured quantities;

Strain imaging: Measure strain ε by externally applying stress σ, and calculate E using the following equation.

$$E=\sigma/\varepsilon \qquad (1)$$

However, in practice, instead of elastic modulus, strain is used by assuming that stress is uniform since it is difficult to know the stress within the body.

Shear wave imaging: Measure the propagation speed c_S after propagating shear waves and calculate E or G by

$$E \fallingdotseq 3G = 3\rho c_s^2 \qquad (2)$$

Here, we assume that incompressible medium, constant density, homogeneity, and isotropy are satisfied. Thus, Young's modulus will be equal to about three times of the shear modulus.

2.2 Excitation methods

Both of the above methods require external excitation (compression or vibration) to produce the reaction such as deformation or shear wave propagation, and physical quantity such as strain and propagation speed are measured by using ultrasound to estimate elasticity. Excitation methods can be classified into (A) manual compression (using hand or cardiovascular pulsation), (B) acoustic radiation force impulse, and (C) mechanical vibration and impulse.

2.3 Classification of elastography methods

There are two major methods based on types of measured physical quantities and three ways to apply external excitation. Therefore, elastography is classified as shown in Table 1. As far as methods to be integrated into clinical practice, they are categorized into four groups as follows,

Stain elastography: Strain induced by quasi-static methods such as manual compression or cardiovascular pulsation is measured, and the distribution of strain or displacement within ROI is displayed.

ARFI(acoustic radiation force impulse) imaging: A focused acoustic radiation force 'push' pulse is used to deform the tissue. The resulting tissue displacement is monitored.

Shear wave elastography：Acoustic radiation force is used to generate shear waves within the organ of interest. Distribution of speed or elastic modulus converted is displayed.

Transient elastography: Mechanical impulse or vibrating 'punch' is used to generate shear waves. At present, commercialized technology is specialized for measuring stiffness of liver tissues and not for imaging.

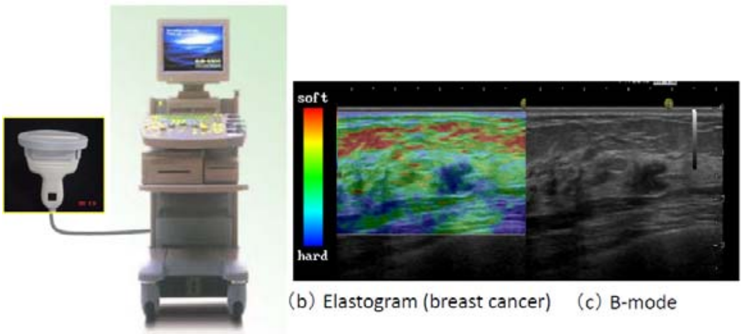
3. Development of practical system of ultrasound elastography

When very slight pressure is applied to tissue with a probe in the beam direction, the majority of the

E-mail address: shiina@hs.med.kyoto-u.ac.jp

Table.1　Classification of various elastography methods (JUSM guidelines).

Elastography methods a)Measured physical quantity b)Output Excitation methods	**Strain imaging** a)Strain (displacement) b)Geometric measures Strain ratio, E/B size ratio	**Shear wave imaging** a)Shear wave speed b)Shear wave speed Young's modulus
(A)Manual compression	**Strain elastography**	N/A
(B)Acoustic radiation force impulse	**ARFI Imaging**	**Shear wave elastography**
(C)Mechanical vibration and impulse	N/A	**Transient elastography**



(a)　First practical ultrasound elastography equipmrnt which was released for breast examination in 2003　(Real-Time Tissue Elastography , Hitachi Aloka Ltd.)

Fig. 1 Practical application of strain elastography

displacement will be in the direction of the propagation of the ultrasound pulse, and the tissue deformation can be approximated using a 1D spring model. Displacement at each site in the beam direction of the tissue is then calculated. This is obtained by calculating the correlation between the echo signal before and after compression. Next, strain is obtained by spatial differential of displacement. In actuality, many technologies must be developed before it will be available for clinical application.

A combined autocorrelation method (CAM) that combines the merits of the phase difference detection method and the spatial correlation method was developed by Shiina[1,2], which achieves high speed, high accuracy, and a wide dynamic range for detecting displacement, consequently, the method is suitable to actual manual compression. As a result of the collaboration with a manufacture, the first equipment based of the CAM that was put to practical use in 2003 as shown in Fig. 1. Its efficacy was demonstrated in the diagnosis of breast cancer tumors together with elasticity score, which was proposed at the same time [3], and is currently being used in various fields of clinical medicine.

4. Movement of making Guidelines

Nowadays, the most widely available commercial elastography methods are strain imaging. However, imaging methods differ slightly among manufacturers, which results in different image characteristics, for example spatial and temporal resolution and different recommended measurement conditions. In addition, many manufacturers have recently provided a shear wave-based method, which provide stiffness images based on shear wave propagation speed. Each method of elastography is designed on the basis of assumptions of measurement conditions and tissue properties. Thus we need to know the basic principles of elastography methods and the physics of tissue elastic properties to enable appropriate use of each piece of equipment and to obtain more precise diagnostic information from elastography. From this perspective, major societies of medical ultrasonics, such as WFUMB, EFSUM and JSUM are beginning to form guidelines to support practice of ultrasound elastography[4].

4. Conclusion

Tissue elasticity imaging further improves the value of ultrasonography by combining the characteristic features of ultrasound, i.e., noninvasiveness, real-time capability, and ease of use, with the ability to provide new diagnostic information related to tissue characterization. On the other hand, it is still an evolving technology with much technical potential for clinical application in the future including expanding its scope of application, quantification, treatment support, etc. One might anticipate that it will further evolve in the future and attain a position as an indispensable mode of ultrasound imaging.

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