Recent progress in basic research useful for the interpretation of ultrasound diagnostic images

On the publication of the special feature on recent progress in basic research useful for the interpretation of ultrasound diagnostic images

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Ultrasound diagnosis involves no ionizing radiation exposure, is minimally invasive, and is safe enough to be used for fetal diagnosis. Cross-sectional images in living tissues can be obtained simply by placing an ultrasound probe on the body surface, and ultrasound diagnosis is also excellent for real-time observation of the dynamics of moving tissues such as the heart and blood flow [1]. In addition, since the ultrasound diagnosis apparatus can be miniaturized and examinations at the bedside and at the surgical site can be easily performed, ultrasound diagnosis has become essential in clinical settings.

Technological advances have played a major role in the evolution of ultrasound diagnosis, resulting in the development of many diagnostic modes. The cross-sectional images provided by B-mode imaging, which is the most basic imaging mode of ultrasonic diagnosis, are becoming higher in quality thanks to new image reconstruction technologies including transmit and receive beamforming, apodization, and received echo compounding processing [2–5]. Recently, high-frame-rate imaging technology is being developed to dramatically improve real-time performance. As is well known, the Doppler mode provides imaging of the blood flow velocity distribution and quantitative measurement of the blood flow velocity within a sample volume. The concept of echo tracking used in the Doppler mode is also partially applied to elastography, as described later. The new diagnostic technique elastography provides information about tissue stiffness. In addition to strain imaging, which provides relative stiffness information, there are shear wave elastography (SWE) and transient elastography (TE), which can

quantitatively yield absolute stiffness values. Other modes include the contrast harmonic imaging mode in combination with an ultrasound contrast agent and the tissue harmonic imaging mode, which are based on the extraction of the second harmonic component from the received echo.

Thus, the improvement in the quality of ultrasonic images and the increase in the number of physical parameters that can be quantitatively measured with ultrasound are considered major advances in recent ultrasound diagnostic technology. In particular, the advent of SWE and TE have had a great impact because the elastic modulus can be quantitatively measured at a level applicable to clinical practice. Therefore, doctors and sonographers are approaching the ideal situation where they can make objective diagnoses based on high-quality images and quantitatively measured physical parameters.

On the other hand, with the progress of technology, there are some situations that require careful consideration in the clinical diagnosis to understand the formed images and interpret quantitative measurement values. Backscattered waves affected by various factors in biological tissues return to the probe as echo signals, and the echo signals are used for image formation and quantitative measurement of physical parameters such as blood flow velocity and elastic modulus. Therefore, in addition to the engineering principles of image formation and quantitative measurements, it is essential to understand the acoustic properties and wave propagation characteristics of biological tissues that can affect these results. That is, it is necessary to consider the effect of wave phenomena (e.g., reflection, refraction, scattering, interference, diffraction) caused by fundamental acoustic properties such as speed of sound, acoustic impedance, and wavelength on the formed images and quantitative measurement values [6]. These are not classical research topics but rather ongoing research topics [7]. For example, the effects of the tissue microstructure on formed images and

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quantitative measurements have not been fully elucidated. And these effects need to be discussed together with the principles and limitations of image formation and quantitative measurement. Therefore, in this special feature, topics with respect to ultrasound image formation and typical ultrasound quantitative measurement were selected. With the aim of providing information that can help readers interpret the formed B-mode images and quantitative ultrasound measurements, this special feature includes three review articles that focus on the recent progress in basic research useful for the interpretation of ultrasound diagnostic images.

Dr. Hasegawa described recent advances in technologies to improve the image quality and spatial resolution in B-mode imaging. The basic process for producing B-mode images is beamforming, which affects image quality and spatial resolution. This review article focused on the beamforming in signal reception. It begins with a description of delay-and-sum (DAS) beamforming, which is the most basic received beamforming technology, and includes a description of the latest beamforming technologies such as adaptive imaging and adaptive beamforming. It also explained image quality evaluation methods to confirm the effectiveness of these beamforming technologies. This includes basic metrics such as spatial resolution, contrast, and contrast resolution, as well as recently developed new metrics. Some examples of the results obtained by the methods developed in these studies were also shown. Through this review article, we will be able to get a sense of the future of further improvement in the image quality in B-mode imaging. And this review also contains a detailed explanation of how to evaluate image quality. This explanation will provide useful information to readers for the interpretation and evaluation of formed B-mode images, which is the aim of this special feature.

Dr. Yamaguchi explained the basic concepts and clinical applications of quantitative ultrasound (QUS) technology. Some of the QUS technologies described in this review article include those that have been studied for a long time as tissue characterization. However, there have been significant advances in recent years. This review described typical examples of QUS technology for assessing attenuation, speed of sound, amplitude envelope characteristics, and backscatter coefficient in tissues. And examples of basic and clinical research related to QUS technology were also explained. The author also reviewed the latest research going on to establish the QUS method as a technique for assessing true tissue properties. QUS technology is expected to contribute to the realization of highly accurate diagnosis by quantitatively measuring tissue characteristics. This review points out that the accurate interpretations of the results obtained with the QUS method requires the understanding of the basic theories and limitations of QUS technology. The information provided in this review will help readers understand QUS

technology. The results obtained with QUS technology may also be useful in interpreting ultrasound images in the future. As mentioned in this review article, for the evolution of B-mode image interpretation, it will be important to elucidate the relationship between the micro-level acoustic properties and the macro-level acoustic properties observed in clinical images.

Of course, the technical factors that determine B-mode image quality are also involved in the above-mentioned relationships. As is well known, the factors that determine the texture of B-mode images, including artifacts, are classified as factors associated with the ultrasound diagnosis device and factors related to the acoustic properties of tissues. As inferred from this example, considering factors with respect to the ultrasound device described in the first review article and factors with respect to the acoustic properties of tissues described in this review article together may provide useful information for the interpretation and evaluation of B-mode images, which is the purpose of this special feature.

Dr. Nitta et al. explained the principle of SWE and comprehensive multiple factors that may affect the results of shear wave speed (SWS) and elastic modulus measured and calculated using SWE, which can also be defined as a QUS technology. SWE quantitation and reliability are recent topics and are of great interest in clinical practice. As previously described, factors are classified as physical factors derived from tissue properties that doctors and sonographers cannot control and engineering factors derived from the performance of ultrasound devices such as push pulse intensity and signal processing, and each factor was explained in detail. In terms of physical factors, the propagation characteristics of shear waves; the mechanical properties of tissues including viscoelasticity, nonlinearity, and anisotropy; and the influence of the size and shape of the target tissue were considered. As for engineering factors, the depth of the ROI, the intensity of push pulses, and the influence of signal processing methods were considered. Finally, verification methods such as the measurement accuracy of SWS were described, and the safety of SWE were also mentioned. Although this review article does not provide examples of clinical measurements, it is stated that the aim of this review is not to provide an answer to the interpretation of SWS and elastic modulus values but rather to provide information for readers to formulate and verify the hypothesis for the interpretation.

These three review articles may not always provide quick and direct answers, but approximately 350 references are included. Therefore, I believe that these three articles provide the information necessary for readers to formulate and verify the hypothesis for interpreting ultrasound images and the results of quantitative ultrasound measurements. I also hope that the collaboration between researchers in the engineering and clinical fields will be further promoted to achieve that goal.

Of course, this special feature does not cover everything about the interpretation of ultrasonic diagnostic techniques. For example, this special feature does not include reviews of technical areas such as blood flow measurement and contrast-enhanced ultrasound. Reviews of technical areas that were not included in this special feature should be considered in the future.

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