Ultrasound Diagnostic Systems Contributing to Advancements in Noninvasive Examinations with Reduced Burden on Patients

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Ultrasound diagnostic systems are employed for diagnostic imaging in many medical institutions due to their advantage of real-time, noninvasive examinations without X-ray exposure. Toshiba Medical Systems Corporation (TMSC) has been developing advanced image processing technologies and ultrasound probe sensor technologies for ultrasound diagnostic systems. These include a shear wave elastography (SWE) technology that displays images showing the hardness of living tissue and the Superb Micro-Vascular Imaging (SMI) technology that extracts blood flow without requiring a contrast medium, for the diagnosis of liver and other abdominal diseases, as well as an ultrasound laparoscopic transducer technology for the support of surgery and inspection of therapeutic effects. The Aplio series ultrasound diagnostic systems incorporating these technologies have come into widespread use in clinical practice.

1. Introduction

Diagnostic ultrasound systems are used to acquire two-dimensional (2D) diagnostic images in a wide range of clinical applications, such as fetal diagnosis, abdominal diagnosis, and cardiac diagnosis.

Toshiba Medical Systems Corporation (TMSC) has developed numerous technologies that support ultrasound diagnosis for abdominal diseases, breast diseases, and cardiac diseases and thereby reduce the burden on patients. These technologies have been incorporated in diagnostic ultrasound systems in the Aplio series (Figure 1). (Some of the newer technologies were incorporated in 2014.)

2. SWE: Visualization of tissue stiffness

Palpation is still used in clinical practice as a basic technique to evaluate tissue stiffness in spite of the availability of various advanced diagnostic techniques. For example, when breast cancer, liver inflammation, or liver fibrosis is suspected, palpation is generally performed as the primary examination. However, evaluation of tissue stiffness by palpation depends on the subjective judgment of the physician, and quantitative assessment is therefore difficult. In recent years, we have developed a SWE technology that makes it possible to visualize information related to stiffness by using the differences in the propagation characteristics of shear waves in tissues of different stiffnesses. SWE enables reproducible diagnostic imaging of tissue elasticity. The elasticity of the tissue is evaluated with the probe held still, without compressing the tissue. The results are therefore independent of interoperator variations, such as the degree of compression applied using the probe. SWE is now drawing attention as a diagnostic method that can enable definitive diagnosis without the need for invasive pathological procedures such as biopsies.

Our unique SWE technology uses the acoustic radiation force to create the tissue displacement that generates the shear wave. Ultrasound pulse signals for detect-
ing shear waves are repeatedly sent and received, and the time variation of the displacement on each scanning line, which is obtained from the Doppler effect of the echo signals, is observed in order to estimate the shear wave speed. The required acoustic radiation force can be generated by a conventional ultrasound probe. Thus no additional parts are required and there is no increase in system size. In addition, operation is simple.

Examples of images acquired using this function are shown in Figure 2. The images in the upper row of the figure show a phantom(*)1 in which a stiffer target is included in a substrate with uniform stiffness. The left image is a shear wave speed image, the center image is an elasticity image in which the shear wave speed is converted into the elastic modulus, and the right image is a propagation image used to confirm whether shear waves are generated and propagated as expected. The stiffer region in the center of the phantom can be clearly seen in the images in Figures 2 (a) and (b). In the propagation image, propagation is displayed by depicting the position of the wave front of the shear wave (which is observed at certain intervals) using contour lines. Since the propagation speed of shear waves increases as tissue stiffness increases, the distance between contour lines is wider in regions with greater tissue stiffness, and is narrower in regions with lower tissue stiffness (greater tissue softness). In the example of Figure 2 (c), the distance between the contour lines is wider at the center of image, which corresponds to the stiff target in the phantom.

While uniform shear wave speed images are desirable, they are not always seen in clinical practice because the human body consists of various different types of tissues of different stiffnesses. This sometimes makes it difficult to judge whether the obtained results are reliable, especially in cases where mottled images are displayed, as in the example in Figure 2 (d). When the propagation of the shear wave generated by the acoustic radiation force is ideal, parallel progress of the wave front is observed. However, if ideal shear waves are not generated by the applied acoustic radiation force or horizontal propagation of shear waves is not observed due to complicated structures, the contour lines become distorted. The lower row of Figure 2 shows examples of images of a phantom with uniform stiffness. Note that the contour lines in the propagation image (Figure 2 (f)) are distorted in deep regions. This indicates that the intensity of the acoustic radiation force is not sufficient in deep regions, which implies that appropriate shear waves were not generated. As described above, in SWE, the reliability of the shear wave speed image and the elasticity image can be confirmed by observing the propagation image.

3 SMI: Visualization of extremely low velocity blood flow

3.1 SMI technique

This blood-flow imaging technique, which was originally developed to map cardiac blood flow velocities in 2D, has been employed to observe blood flow in abdominal and peripheral blood vessels. For examinations of blood flow in the abdomen and peripheral blood vessels, a power Doppler method with high sensitivity and low angle dependence is also used. Advanced Dynamic Flow (ADF), in which resolution is improved by performing wideband transmission/reception, can also be employed.

Visualization of finer and lower velocity blood flows is desired in clinical practice. It is difficult to observe extremely low flow velocities, because motion artifacts(*)2 tend to cover the entire image when the velocity range is lowered to near the velocity of tissue movement. In addition, scanning for blood flow imaging is difficult because the frame rate is lower for blood flow imaging than for B mode(*)3 imaging.

SMI, featured in Aplio 500, is a new imaging method that allows visualization of extremely low velocity blood

(*)1 Model mimicking body tissues, which is used for diagnostic training and diagnostic system evaluation

(*)2 Noise in a diagnostic ultrasound image caused by patient movement

(*)3 Basic diagnostic ultrasound image generation mode in which the brightness levels correspond to the amplitudes of the reflected ultrasound waves
flows, which are normally hidden by motion artifacts, by removing the motion artifacts after analyzing their characteristics. Blood flows are depicted at a high frame rate by optimizing the units for scanning and signal processing separately (Figure 3), facilitating stress-free scanning and detection of transient changes in blood flow. With SMI, the visualization of blood flows is close to that in contrast-enhanced examinations. If an ultrasound contrast medium is actually used, visualization of even smaller blood flows is possible. SMI is therefore expected to enable the development of new diagnostic applications related to blood flow.

3.2 Reduction of burden of diagnostic process on pediatric patients

The advantages of the use of SMI in pediatric diagnosis include: (1) it allows observation of fine blood flows without the use of contrast medium (which requires percutaneous injection) and (2) the high frame rates and reduced artifacts allow examination to be performed in a shorter period, which is particularly useful in pediatric patients, who tend to be active. Figure 4 shows an example of a blood flow image of the renal cortex of a 17-day-old infant obtained by SMI. As can be seen in the figure, even peripheral blood vessels are visualized without the use of contrast medium.

SMI is also useful in the evaluation of regurgitant flow from the bladder into the ureters for pediatric patients with signs of urinary tract infection (UTI). SMI is a greatly preferable alternative to invasive contrast-enhanced X-ray bladder examinations that use a urinary catheter, which would otherwise be required to detect if there is regurgitant flow from the bladder into the ureters. Since it is necessary to observe the urination pattern under physiological conditions, the use of sedatives is not recommended. Therefore contrast-enhanced X-ray bladder examinations would need to be performed without sedation, and the procedure could be painful, especially for pediatric patients.

Figure 5 shows images for a case in which the blood flow in the renal pelvis is detected using SMI for a pediatric patient who has been undergoing treatment for UTI. No anatomical defects that could explain the cause of UTI could be found in this patient. However, SMI allowed non-invasive, pain-free detection of blood flow in the renal pelvis toward the kidney (not the bladder), providing diagnostic information quickly. Compared with conventional color Doppler, images with better resolution, a higher frame rate, and reduced artifacts can be acquired using SMI, allowing the detection of whether or not there is blood flow in a short period of time. SMI thus reduces the need for invasive procedures such as a contrast-enhanced X-ray examination of the bladder, and therefore contributes to reducing the burden of the diagnostic process on pediatric patients.
4. **BEAM: Reduction of burden of biopsy procedures**

The widespread use of diagnostic ultrasound systems and improvements in their diagnostic capabilities have also contributed to expansion of the range of clinical applications. Examples of such clinical applications include ultrasound-guided puncture procedures, which have expanded from biopsy (extraction of tissues and cells for pathological diagnosis) to treatment procedures such as drainage (to remove unwanted intracavitary fluid) and percutaneous ethanol injection therapy (PEIT). A needle navigation imaging method called BEAM (biopsy enhancement auto mode), which enhances safety and provides technical and procedural assistance for the operator, is discussed in this section.

Ultrasound-guided puncture procedures are excellent in terms of reducing the exposure dose of the patient, and they allow simple real-time examination. Needle navigation enhances safety and reduces the time required for such procedures, because it allows the operator to accurately determine the tissues and organs around the puncture target.

Two types of ultrasound guidance are used in puncture procedures: out-of-plane guidance, where the needle is advanced perpendicular to the ultrasound plane, or in-plane guidance, where the needle is advanced along the ultrasound plane, allowing the entire needle to be visualized in the image. In out-of-plane guidance, the distance between the probe and the tip of the needle is generally less than that in in-plane guidance; however, because the needle is only visible in the section where it intersects the ultrasound plane, it is necessary to move the ultrasound probe according to the movement of the needle, so that the tip of the needle is always visible in the ultrasound plane. In contrast, in in-plane guidance, since the entire needle is visualized in the ultrasound image, the needle can be advanced and the position of the tip of the needle can be monitored in the image while holding the ultrasound probe still. However, in some cases, depending on the angle of the needle, the image of the needle may become unclear even with the entire needle positioned within the image plane.

BEAM provides improved visualization of the needle in in-plane guidance. The mode can be switched between B-mode and BEAM by one-button operation. BEAM enhances the depiction of the position of the needle in the image by separately performing optimal transmission and reception for visualization of the needle while maintaining high image quality for the background tissues. Both the target and the needle can thus be clearly observed in the images.

As can be seen in Figure 6, the visibility of the puncture needle is improved in the BEAM image by enhancing the needle by displaying it with high intensity. The enhancement level can be adjusted in three steps, and it is possible to set the level according to the diameter of the needle and the region to be examined, so that optimum images are obtained. Needles with smaller diameters can be visualized clearly by setting a high enhancement level, and needles with larger diameters can be visualized clearly without appearing too thick by setting a low enhancement level. To stably visualize the needle in in-plane guidance, the operator must have the skills to be able to position the entire needle within the ultrasound plane. BEAM is a function that helps the operator perform the puncture procedure easily and reduces the time required for the puncture procedure, significantly reducing the burden on the patient.

5. **Ultrasound probe for avoiding burden of open abdominal surgery**

Laparoscopic surgery, which is performed using dedicated devices inserted from small incisions in the patient’s abdominal wall, has gained widespread acceptance as a treatment option that is less invasive than open abdominal surgery. The major advantages of laparoscopic surgery relative to open abdominal surgery include less postoperative wound pain, lower secondary-
infection rate, and quicker recovery. Thus, laparoscopic surgery significantly reduces the burden on the patient.

However, in laparoscopic surgery, the surgeon must understand the entire surgical field from a limited field of view. The surgeon cannot palpate the surgical field and the burden on the surgeon is therefore large. Ultrasound probes play a significant role in helping surgeons understand the surgical field, thereby reducing their burden. Using an ultrasound probe, the surgeon can obtain information such as the position of the tumor and the courses of the blood vessels in the surrounding area. Ultrasound probes are therefore considered to be indispensable in laparoscopic surgery, particularly in laparoscopic resection of the liver, where the risk of bleeding is high.

We have developed the PET-805LA, a new laparoscopic ultrasound probe with the following unique characteristics (Figure 7):

1. The ultrasound probe is light and has an easy-to-handle grip section that allows flexible one-handed operation using the knob, which can be tilted and rotated.
2. Marks indicating the side opposite the ultrasound-emitting surface are provided on the head of the ultrasound probe. The same marks are displayed on the transducer mark at the top of the ultrasound system screen, allowing the position and direction of the ultrasound probe in the abdominal cavity to be easily understood.
3. Biopsy needle insertion point guide notches are provided at five locations on the head of the ultrasound probe to facilitate the puncture procedure.
4. Our unique Differential tissue harmonic imaging (THI) provides high image quality with excellent diagnostic capabilities when it is used in combination.

PET-805LA facilitates quick intra-abdominal diagnosis, helping reduce the burden on both the surgeon and the patient.

6. Conclusion

In this paper, we have discussed the new clinical applications made possible by the technologies incorporated in the Aplio series diagnostic ultrasound systems. In addition to the technologies discussed, Aplio series also allows three-dimensional (3D) scanning for the generation of 3D images and enables diagnosis based on fusion images, which are generated by using images acquired by other modality systems in combination with ultrasound images. It thus facilitates objective diagnosis within a shorter time.

Through further development of diagnostic ultrasound imaging technologies and ultrasound probes, we will continue to contribute to advances in medical care to reduce the burden of patients.

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*In this technique, ultrasound waves with two different frequencies are combined and transmitted, and the difference tone and harmonics in the received signals are used to produce high-quality images with high resolution and reduced noise.*