High-quality/High-resolution Digital Ultrasound Diagnostic Scanner

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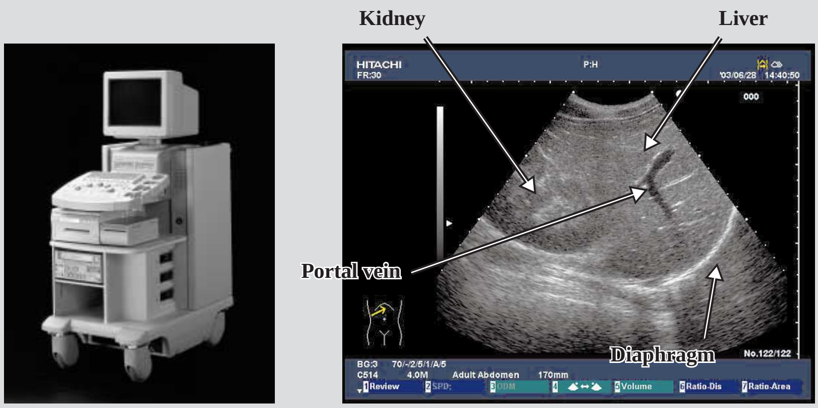
OVERVIEW: Ultrasound diagnostic scanners have gained broad acceptance in a wide range of diagnostic fields because they are able to make observations inside the body safely and in real time. In keeping with the developments in signal processing technology and semiconductor technologies, resolution and other functions were dramatically improved through the use of digital ultrasound scanners developed in the late 1980s. In terms of ultrasound imaging technologies as well, the quality of images was increased and the scope of applications expanded through the use of superior imaging technologies and ultrasound contrast agents. Hitachi Medical Corporation has developed a digital ultrasound device which is equipped with an electrical compound function and the high-speed moving image adaptive filter, with the goal of contributing further to medical treatments by improving image quality. The ultrasound endoscope, which was created using fine processing technologies, is ideally suited to gastrointestinal tract examinations. Hitachi Medical Corporation is also developing new imaging technologies such as tissue elastic imaging, and plans to incorporate these technologies into new equipment in the future.

INTRODUCTION

ULTRASOUND diagnostic scanners emit ultrasound (roughly 2-15 MHz) into the body, and use the signals from the sound waves that bounce back from the interface between tissues (referred to here as “echo”) to obtain images and blood flow speed information.

Research into the use of ultrasound in medical diagnosis began in the 1940s with research conducted by K.T. Dussik et al. At that time, a method called the A mode (amplitude mode) was used to observe echo as a wave, but the scope of applications was limited. In the late 1950s, a technology was developed to create images by converting echo waves into an intensity, and in the 1970s, an electronic scanning ultrasound scanner was released, in which multiple ultrasound transducers were arranged in an array, and these elements were switched electronically to achieve scanning. This ultrasound scanner came to be used in



(a) External view of the digital ultrasound diagnostic scanner

(b) Abdominal image of a healthy individual

Fig. 1—External View of Digital Ultrasound Diagnostic Scanner and Abdominal Image of Healthy Individual (right).
Using the digital ultrasound diagnostic scanner, an image has been created of the liver and the portal vein, a large vein that carries blood from the stomach and the intestines into the liver (image on right). The segment below the liver, imaged using a high echo level, is the diaphragm.

a wide range of diagnostic fields, including abdominal, obstetrics and gynecology, and cardiac diagnostics, because it is safe, non-invasive, and provides real-time images[1].

In the latter half of the 1980s, with the development of electronic digital ultrasound diagnostic devices, image quality improved dramatically, and these devices came to be used in orthopedics and other new fields. In recent years, these devices are evolving even further, undergoing a transition from "diagnosis of existence," such as checking for the presence of lesions, to "diagnosis of identification," which provides even greater support for effective diagnoses.

Here, we will provide an outline of digital ultrasound scanners, and discuss the digital ultrasound diagnostic scanner developed by Hitachi Medical Corporation, as well as new technologies currently under development (see Fig. 1).

OUTLINE OF ULTRASOUND DIAGNOSTICS

In ultrasound diagnostics, an ultrasound probe that sends and receives ultrasound is placed against the examination region (see Fig. 2).

There are a number of commonly used test modes, including:

Fig. 2—During Ultrasound Diagnosis.
The examiner places the probe against the region on the patient's body to be diagnosed.

Fig. 3—Longitudinal Section Image of Fetus's Head (B mode).
The fetus's nose and mouth are clearly imaged; it can be observed that the fetus is bringing its hand to its mouth.

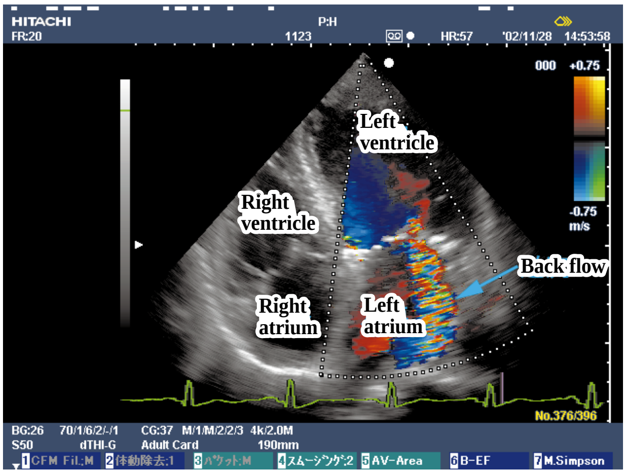


Fig. 4—Image of Four Cavities at Cardiac Apex (Color Doppler Mode).
This is an image created for observation of blood flow in color Doppler mode, by detecting blood flow and then allocating colors to different flows. Back flow due to mitral valve insufficiency can be observed.

(1) B mode (Brightness mode; for observing the shape of organs),
(2) M mode (Motion mode; for observing the movement of the heart's valves, etc.),
(3) Doppler mode (for observing the speed of blood flow), and
(4) color Doppler mode (for observing blood flow using color coding according to speed and direction).

Diagnoses are conducted by selecting and combining these methods depending on the goal and the examination region. Ultrasound can also be used to observe fetuses (see Fig. 3) because it is noninvasive, or in the diagnosis of circulatory organs because it enables observations inside the body in real time. In the regions surrounding circulatory organs, M mode, Doppler mode, and color Doppler mode are often used because they enable observations of the heart's movements and the state of blood flow (see Fig. 4).

Noise was reduced and contrast resolution improved through the development of a technology called the tissue harmonic imaging, in which imaging is achieved using the harmonic components of echoes generated through the nonlinearity of living bodies. The contrast harmonic imaging, which combines this harmonic imaging with ultrasound contrast agents, is extremely effective in imaging tumors inside the liver and observing tumor feeding vessels based on an imaging technology that uses a second harmonic component from the contrast agent. The contrast harmonic imaging has come to be indispensable

Photo provided by Dr. S. Tanaka of the Osaka Medical Center of Cancer and Cardiovascular Diseases

Fig. 5—Image of Metastatic Liver Cancer (Contrast Harmonic Imaging).
An example of imaging using ultrasound contrast agents: because the contrast agent is absorbed in normal liver tissue, the imaging appears white. The cancerous segments, however, do not absorb the contrast agents, so the imaging appears darker than the surrounding areas.

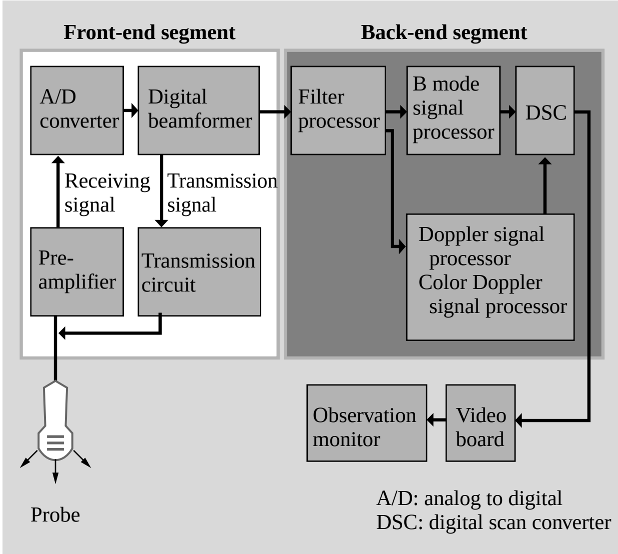


Fig. 6—Overall Block Diagram for Digital Ultrasound Diagnostic Scanner.
The scanner is comprised of a front end segment for receiving the ultrasound signals, and a back-end segment that conducts signal processing and image processing to create images.

particularly in the diagnosis of liver cancer and in judging the effects of cancer treatments (see Fig. 5).

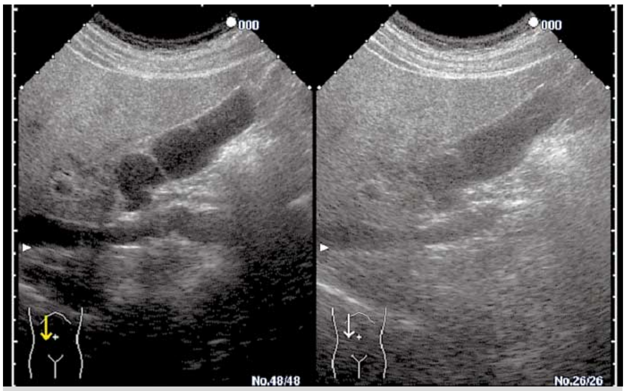
DIGITAL ULTRASOUND DIAGNOSTIC SCANNER

Scanner Configuration

Hitachi’s digital ultrasound diagnostic scanner is divided into front end and back end segments (see Fig. 6). In the front end segment, a group of pulses with a time difference is generated to achieve ultrasound transmission focus; these pulses are supplied to the transducer array via the transmission circuit. The sound waves that are reflected back from the body are received by the transducer array, and then pass through the pre amplifier; they are converted into digital signals by the A/D converter, and reception focus processing is executed. The segment that executes this transmission focus and reception focus is called the beamformer. In conventional scanners, the beamformer was comprised of analog delay lines, but digital scanners employ signal processing technology to achieve delay time control that ensures optimum focus. A delay corresponding to the distance to the reflecting body is digitally added to the signal received by each transducer, and after the signal phases from all channels have been aligned, processing is carried out using addition to achieve optimum reception focus. For the digital ultrasound diagnostic scanner, Hitachi Medical Corporation, in collaboration with Hitachi, Ltd., has developed an ASIC (application specific integrated circuit) for the roughly one million gates (equivalent to about three million transistors) that make up the core of this beamformer segment, thus achieving highly accurate ultrasound focus.

The back-end segment, meanwhile, executes processing to create images and detect blood flow information in response to the signals after reception focus processing, and creates image data to be displayed on the monitor. The ASIC was developed jointly with Hitachi, Ltd. because a filter with sharp cutoff characteristics is needed to eliminate frequency components that are not required for harmonic imaging. After eliminating the unnecessary band using this ASIC, log compression (dynamic range control) and enhancement are executed to enable effective display on the monitor used to observe echo signals for which the dynamic range is 90 dB or more. These signals are then converted into scanning lines by a DSC and sent to the display circuit.

The digital ultrasound diagnostic scanner incorporates FPGA (filed programmable gate array) and DSP (digital signal processor), for which most of the circuits are programmable, so it is possible to add functions to the scanner or make modifications without making changes to the hardware. For this reason, the diagnostic scanner can respond quickly to diversifying market needs.



(a) Image using harmonic imaging **(b) Image using conventional B mode**

Fig. 7—Image of Gallbladder.
With the Harmonic Imaging shown in (a), the gallbladder wall is clearly imaged, and the noise within the gallbladder has been reduced, enabling easier, more accurate diagnosis.

Advantages of Digital Ultrasound Diagnostic Scanner

Following are some of the advantages that have been obtained by introducing a digital beamformer, which is the heart of the scanner.

(1) High image quality

Beamformers that used conventional analog delay lines presented a number of issues, including signal cross talk and wave deformation, as well as variance in delay time accuracy. The introduction of a digital beamformer enables focus control close to the theoretical value, thus improving image quality and deeper area sensitivity.

(2) High frame rate

The digital beamformer can process signals received from several directions simultaneously, and so can generate multiple ultrasound beams with a single reception. This allows the image frame rate to be increased.

(3) Harmonic imaging

By using a filter with sharp cutoff characteristics that were difficult to attain with analog filters, we have achieved practical applications of harmonic imaging that creates images of only the second harmonic component. In this way, we have substantially reduced ultrasound artifacts, and made it possible to obtain images with good SN (signal-to-noise) ratio (see Fig. 7).

CHALLENGE OF BETTER IMAGE QUALITY

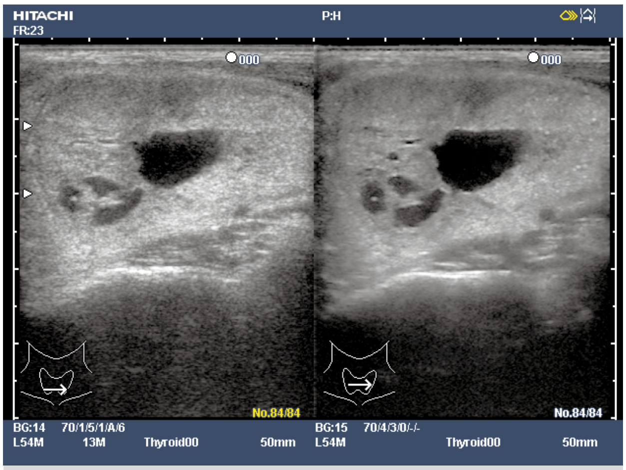
Real-time Compound Function

When there is a strong reflecting object or absorbing object inside a living body, the ultrasound does not pass through that object, and a low-echo region is created behind that object, where the ultrasound beam does not reach. Another problem that arises is that when a puncture is made below the ultrasound guide, if the angle of the puncture needle is parallel with the ultrasound transmission direction, then it is difficult to image the needle. We have thus developed an electrical compound function that will assist in resolving these issues.

This function is a technology that sends and receives ultrasound beams from a variety of angles when the image is taken, and combines these beams. With additional processing of multiple images from different angles, we have been able to improve detectability of the low-echo region and visibility of the puncture needle, as well as the SN ratio of the ultrasound image and contrast resolution.

High-speed Moving Image Adaptive Filter

In order to achieve higher image quality than was possible in the past, we have developed the high-speed moving image adaptive filter, which uses a high-speed computation processor to conduct real-time computations. The adaptive filter technology first compares the target pixels with the surrounding pixels, and then averages or emphasizes the image based on the results of this comparison. Blood vessels, muscles, and other structures cover a broad range of pixels, but "speckle noise," which is unique to ultrasound images,



(a) Image using conventional B mode **(b) Image using electrical compound and adaptive filter function**

Photo provided by Dr. N. Fukunari, Ito Hospital

Fig. 8—Image of Thyroid Gland.
In (b), the tissue inside the thyroid gland is shown in much more detail, so the gland is imaged with greater clarity.

displays a characteristic pattern, and is comparatively localized. Using this characteristic, the connection between structures in a living body is improved, and at the same time speckle noise is eliminated (see Fig. 8).

DEVELOPMENT OF HIGH-DEFINITION ULTRASOUND ENDOSCOPE

Optical endoscopes are widely used in the diagnosis of gastrointestinal tracts. When diagnosing tumors, however, while a grasp of the invasion level and the spread of lesions is important in determining treatment measures, the optical endoscope only observes the surface shape of the lesion in the gastrointestinal tract, so it is difficult to determine the layer structure. In this situation, an ultrasound endoscope is useful because it is capable of providing a cross-sectional (tomographic) view of the lesion. The invasion depth attained by the ultrasound far exceeds the wall of the gastrointestinal tract, enabling applications with organs that are difficult to observe from the body surface due to the effects of gas in the gastrointestinal tract. Another advantage is that there are no effects on the skin or muscle, so even higher frequency ultrasound can be adopted, making it possible to obtain images with higher resolution. In the past, ultrasound endoscopes adopted a "mechanical radial method" in which a single ultrasound transducer was rotated mechanically, but this method presented the following problems:

(1) Regions near the endoscope were susceptible to audio noise due to multiple ultrasound echoing, making observation of the lesion difficult.

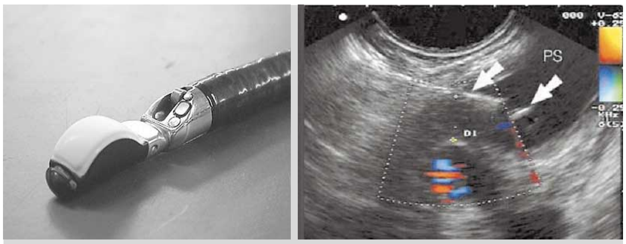
(2) Rotation caused vibrations, which reduced resolution.

(3) When using mechanical rotation, the direction of transmission and reception could not be adjusted freely, so the Doppler mode and the color Doppler mode could not be used.

In addition to the issues noted above, the size of ultrasound endoscopes was severely limited in comparison to external devices because of their applications. For example, if the aperture is limited, there is a significant effect on resolution and invasion depth.

In order to resolve these issues, we developed an ultrasound endoscope in collaboration with PENTAX Corporation that features a convex style and an electronic radial method.

Fig. 9 shows PENTAX Corporation's ultrasound endoscope, which features a 10 R, 6.5 MHz scanning segment, and an image taken during the puncture period. The ultrasound endoscope enables the puncture to be made while monitoring the ultrasound image via the working channel. Because scanning is conducted electronically, the user can also observe blood flow using Doppler mode or color Doppler mode.



(a) External view of the ultrasound endoscope **(b) Color Doppler image during puncture period**

(b) photo provided by Dr. M. Giovannini, Institut Paoli-Calmettes

Fig. 9—Ultrasound Endoscope and Image of Puncture.
In (b), the puncture needle is indicated by the arrow.

Fig. 10—External View of Electronic Radial Ultrasound Endoscope.
An optical system is placed at the tip, enabling imaging in a wide field covering 270 degrees around the head.

Fig. 10 shows PENTAX Corporation's electronic radial scanning ultrasound endoscope. In the ultrasound endoscope, an optical scanning system has been placed at the tip of the head, such that ultrasound images can be obtained in a wide field covering 270 degrees around the head. Once again, because the scanning is conducted electronically, blood flow can be observed using Doppler mode or color Doppler mode.

One new development is the 3D ultrasound image from the ultrasound endoscope. Fig. 11 shows a 3D image of a theloncus tumor in the pancreatic duct. In this 3D image, the diaphragm and nodule inside the tumor are clearly imaged, and it is possible to observe the relationship between the tumor and the main pancreatic duct more clearly. In the future, we plan to achieve 3D displays of ultrasound endoscope images that incorporate hemodynamics, thus contributing to

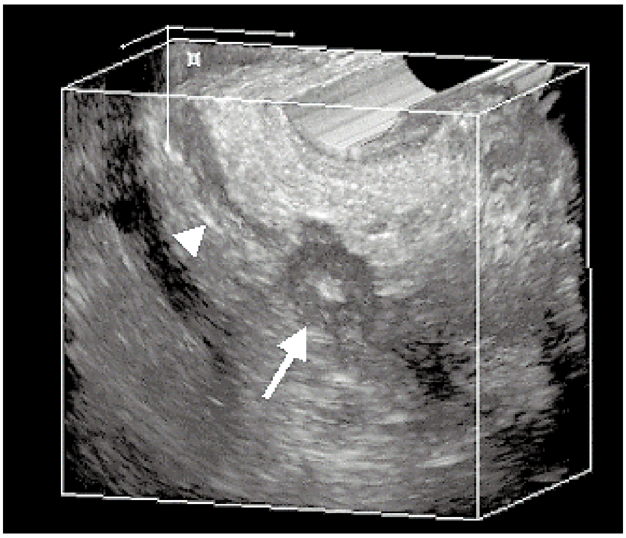
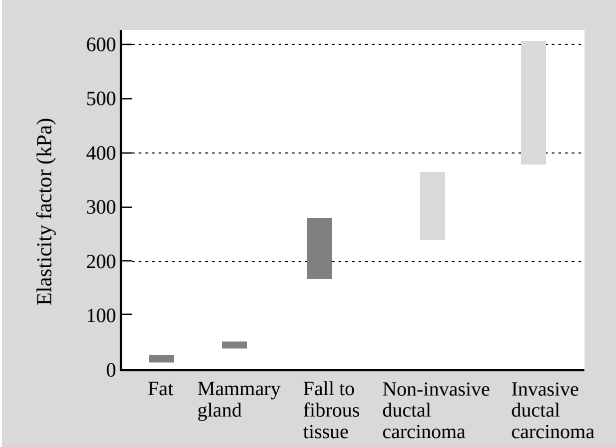


Photo provided by Dr. Y. Hirooka of Nagoya University Graduate School of Medicine

Fig. 11—Image of Theloncus Tumor in Pancreatic Duct.
The diaphragm and nodule inside the tumor are clearly imaged.



Source: T.A. Krouskop, et al.; Ultrasonic Imaging (1998)

Fig. 12—Hardness of Breast Tissue.
The Y-axis is the elasticity factor; larger values indicate increasing hardness.

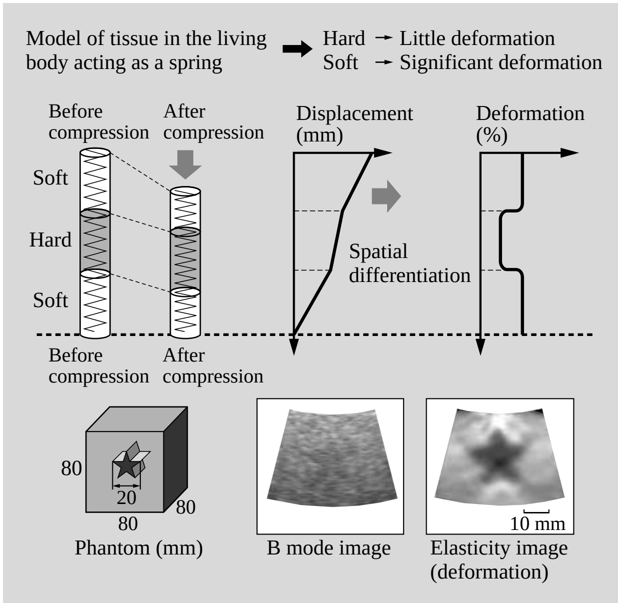


Fig. 13—Principle of Tissue Elastic Imaging.
An image is created with a focus on deformation during compression: soft tissue shows significant deformation, while hard tissue shows little deformation.

the further proliferation and development of ultrasound endoscope examinations.

DEVELOPMENT OF ADVANCED TECHNOLOGIES: TISSUE ELASTIC IMAGING

Tissue elastic imaging is a technology that uses ultrasound to detect the hardness of tissue, and to create images accordingly[2,3]. It is currently under development in joint research with Prof. Tsuyoshi Shiina of the Institute of Information Sciences and Electronics, University of Tsukuba.

As an example, Fig. 12 shows the hardness of breast tissue. It is well known that when breast tissue falls to fibrous tissue and then becomes cancerous, tissue becomes increasingly hard through this process.

If we can detect this hardness and express it as an image, it will be helpful in such processes as the determination of benign/malignancy of tumors and the identification of the invasion area, and thus will be extremely useful in clinical applications. It takes time to learn the skills required for palpitation tests currently used to conduct examinations for breast cancer, and it is difficult to detect tumors measuring 5 mm or less in diameter. In terms of the ability to detect fine calcification, mammography using X-rays is superior to ultrasound, but X-ray mammography is not suited to the imaging of cancer invasion regions. Compared to this method, ultrasound can be considered more useful from the perspective of objectivity through imaging, repeated non-invasive testing, and ease of use during operations.

For operation, the probe is held freely in the operator’s hand, and is pressed against the examination region. In this way, it is possible to detect and image the strain quantity within the living body from the signals before and after pressure is applied.

Fig. 13 illustrates the concept of tissue elastic imaging. When pressure is applied to tissue in a living body, soft segments change shape substantially, while hard segments do not change shape very much. Using this characteristic, displacement at each depth is determined from the echo signals before and after

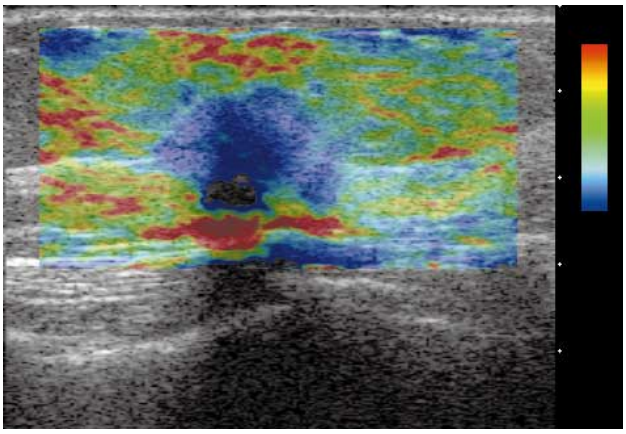


Photo provided by Dr. E. Ueno of Institute of Clinical Medicine University of Tsukuba

Fig. 14—Tissue Elastic Image of Invasive Ductal Carcinoma.
It is difficult to identify the invasion area using a B mode image, but with a tissue elastic image using a color overlay, the size of the cancer can be easily grasped.

pressure is applied, and deformation is calculated from the degree of displacement. Based on the results of this calculation, the relative hardness is calculated assuming that areas showing significant deformation are soft and areas with little deformation are hard, and an image is created accordingly. In image created using this technology is shown in Fig. 14. The tissue elastic image is overlaid on a regular B mode image as a translucent color image, and colors are assigned such that blue indicates hard regions and red indicates soft regions. Here, the invasive ductal carcinoma in the center of the image (blue) is clearly imaged as a hard segment.

CONCLUSIONS

Here, we discussed the digital ultrasound scanner and new technologies that we plan to incorporate into this device.

The digital technologies that form the base of current ultrasound equipment are constantly evolving, and technologies for simulating the physical phenomena of ultrasound are becoming increasingly advanced. The combination of these two factors is likely to further accelerate the pace of improvements to the performance of ultrasound diagnostic equipment.

In the future, Hitachi Group will continue to develop technologies and equipment that will achieve better diagnoses and better treatments, thus contributing to the evolution of the medical field.

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