Featured Articles

Diagnostic Ultrasound System for Care Cycle Innovation

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OVERVIEW: Diagnostic ultrasound systems play an important role in all four stages of the healthcare cycle, namely prevention and checkup, screening and diagnosis, therapy and treatment, and prognosis and elderly care. Hitachi is working on new initiatives for all of these stages. These include the diagnosis of hardening of the arteries in the prevention and checkup stage; increasing the throughput of prevention, checkup, screening, and diagnosis and providing probes to assist with this aim; functions and special probes designed to facilitate treatment procedures; and devices for both primary treatment and in-home healthcare for the prognosis and elderly care stage.

INTRODUCTION

THANKS to their small size, low cost, and portability, diagnostic ultrasound systems are used in a variety of different healthcare fields across the care cycle, with their use of ultrasound making them a very safe and non-invasive method for realtime medical imaging.

These characteristics have led to their use primarily for abdominal and cardiovascular applications and obstetrics, however with recent improvements in performance and function they have also come to be used often for applications like orthopedics, the treatment of rheumatism, and first aid.

Diagnostic ultrasound systems are also recognized for their potential use as small and inexpensive basic diagnostic tools, playing a role in policies of nations around the world that seek to control increases in healthcare expenditures driven by the growth and aging of the population and increased prevalence of lifestyle diseases.

This article describes how diagnostic ultrasound systems are being used in the care cycle, including new initiatives in this field being undertaken by Hitachi.

DIAGNOSTIC ULTRASOUND SYSTEMS AND THE CARE CYCLE

Principles and Components of Diagnostic Ultrasound Systems

Diagnostic ultrasound systems transmit an ultrasound signal into the body and generate images from the amplitude, phase, frequency shift, and other features of the signal reflected back from internal tissue. A system consists of a diagnostic unit that controls ultrasound transmission and reception, performs image processing, and houses the video monitor, and a probe that is held in direct contact with the body being scanned and acts as a transducer (it converts an electrical signal into ultrasound and converts the reflected ultrasound signal back into an electrical signal) (see Fig. 1).

Diagnostic ultrasound systems generate ultrasound in frequencies that range between about 1 and 18 MHz. While ultrasound is good at passing through and imaging body tissue, it is not as effective on bone or air, making it important when imaging to

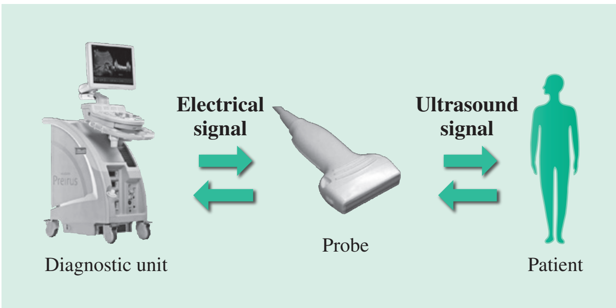


Fig. 1—Principles and Components of Diagnostic Ultrasound Systems.
Diagnostic ultrasound systems consist of a diagnostic unit that controls ultrasound transmission and reception and performs image processing, and a probe that converts between electrical and ultrasound signals.

avoid areas like the ribs or lungs. The frequency is selected based on factors such as the location being scanned or the characteristics of the tissue. High-frequency ultrasound, for example, has high resolution but is strongly attenuated, and therefore it is used for imaging tissue that is close to the surface. Low-frequency ultrasound, on the other hand, is less attenuated and so is used when imaging deeper tissue.

A wide range of probes are available for imaging different parts of the body. Examples include the phased array probes with a small end piece that are used to image the heart from between the ribs, convex probes (so called because of their convex end piece) used to push aside bodily gases to perform abdominal imaging, and linear probes that provide excellent adhesion for imaging superficial tissue. There are also numerous special purpose probes such as the internal probes used in obstetrics and urology and those fitted with a needle for taking biopsies (tissue samples).

Role of Diagnostic Ultrasound Systems at Each Stage of the Care Cycle

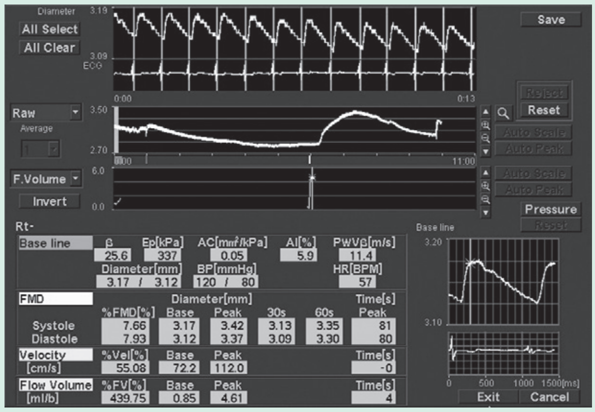
This section describes the role of diagnostic ultrasound systems at each stage of the care cycle (prevention and checkup, screening and diagnosis, therapy and treatment, and prognosis and elderly care), and their potential enhancements. Being a form of diagnostic imaging system, naturally there is also strong demand for improvements in image quality.

The public is familiar with diagnostic ultrasound systems in the prevention and checkup stage through their use in complete medical checkups. The normal practice is for a specialist technician to operate the system and record the imaging data, and for a doctor to then use this data for diagnosis. As this involves scanning large numbers of patients and handling large quantities of data, throughput is an important issue.

There is also a high degree of familiarity with their use in screening and diagnosis, which includes the specific tests ordered after a complete medical checkup or progress checks during pregnancy. The former require higher image quality to improve diagnostic performance and support functions for such procedures as elastography, which displays tissue stiffness, and as with the prevention and checkup stage, there is also a need for throughput because of the large number of patients that are scanned. The latter, pregnancy progress checks, require measurement functions for checking fetal development.

While the use of diagnostic ultrasound systems in the treatment stage may seem unlikely, they are in fact used in supporting roles such as when placing a probe directly on the affected organ during open surgery to verify the location of a tumor. This requires probes with various different shapes and features to suit specific uses.

Uses in the prognosis and elderly care stage including post-operative checks and in-home care. For use by practitioners involved in primary healthcare who are unfamiliar with diagnostic ultrasound, the requirements for this phase include small, lightweight devices that are highly portable and simple to operate.



FMD: flow mediated dilatation

Fig. 2—FMD Analysis.
FMD can detect arteriosclerosis at an early stage by assessing the function of the inner linings of blood vessels.

INITIATIVES FOR PREVENTION & CHECKUP —EARLY DIAGNOSIS OF HARDENING OF THE ARTERIES—

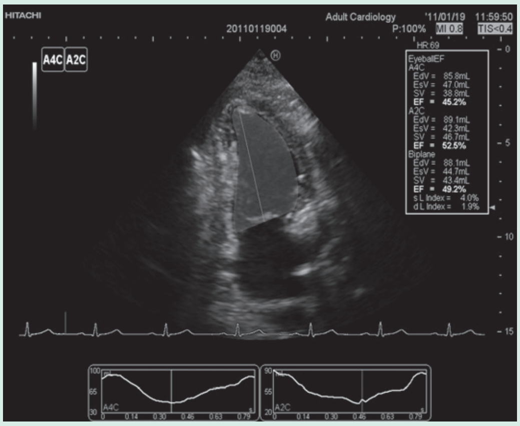
As diagnostic ultrasound is mainly used for the morphological imaging of tissue, it can be difficult to identify lesions that do not produce morphological changes.

In arteriosclerotic disease (hardening of the arteries), for example, the usual means of diagnosis is to identify the morphological changes associated with the hypertrophy of arterial walls due to the buildup of plaque. However, arteries harden and lose their elasticity before hypertrophy is present. If this loss of elasticity can be identified, then earlier diagnosis will become possible.

Assessing the elasticity of arterial walls requires highly accurate measurement of the contraction of arteries in time with the heartbeat, a feat that is achieved by a technique that tracks the phase of the high-frequency ultrasound signal. Hitachi has utilized this technique to develop flow-mediated dilatation (FMD) analysis, which can assess the function of the inner linings of blood vessels even before the arterial wall loses its elasticity (see Fig. 2). This technique is recognized as having the potential to contribute to preventive medicine through the early diagnosis of arteriosclerosis.

INITIATIVES FOR PREVENTION & CHECKUP AND SCREENING & DIAGNOSIS —IMPROVING THROUGHPUT—

The functional support provided by diagnostic ultrasound systems plays an important role in increasing their throughput when used for examinations. The main steps in an ultrasound examination are scanning with the probe (hereinafter, “scanning”) to obtain a cross-sectional image of the area of interest and performing measurements on this image. As many aspects of ultrasound examination images are patient-dependent, there are also difficulties in interpretation, including such things as not being able to correctly identify lesions unless the image quality is adjusted properly during scanning. While recent systems offer an extensive range of image adjustment parameters that can compensate for individual differences between patients, adjusting these parameters takes a lot of work. Automatic optimization functions have been provided to minimize this workload by making the appropriate adjustments automatically based on the signal reflected back from the patient.



EF: ejection fraction

Fig. 3—Automatic EF Measurement Function.
This function can calculate cardiac output in realtime by using a realtime analysis of the shape of the heart chamber to perform precise tracing.

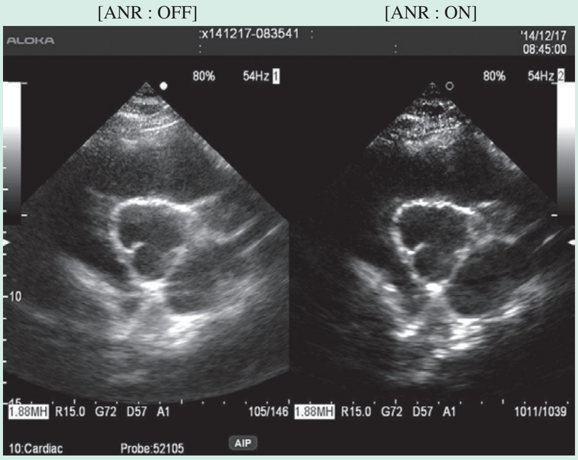
Automatic optimization functions include automatically compensating for patient differences in factors such as attenuation or the amplitude of the reflected signal, and making it possible to observe blood flow rates by setting the appropriate velocity range based on the condition of the patient and the location being imaged when using Doppler mode. These functions can reduce the amount of effort the operator needs to put into adjusting the image.

While diagnostic ultrasound systems resolve images by focusing the ultrasound in accordance with the depth below the skin, this assumes that the speed of sound in tissue is a constant value. However, because the actual speed of sound varies between patients and in different parts of the body, it is not uncommon for the spatial resolution of images to decline due to an inability to correctly focus the ultrasound. Accordingly, improved resolution can be achieved by estimating the speed of sound in the tissue being scanned and using this as a basis for automatic optimization.

Another important aspect of automation that Hitachi is working on is automatic measurement. For example, manually tracing the borders of cardiac blood vessels on images to estimate heart capacity places a heavy workload on the operator. However, when considering how to automate this tracing process, one problem is that it is not possible to identify blood vessel borders from variations in image brightness alone because of the difficulty of tracing out the entire heart at once. Automatic measurement functions for calculating cardiac output in realtime are capable of highly accurate tracing because they perform a realtime analysis of the shape of the heart chamber (see Fig. 3).

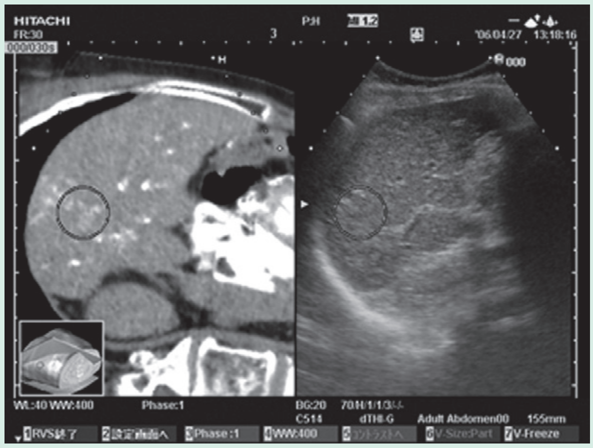
As the quick and accurate identification of lesions is also important for improving the throughput of ultrasound examinations, along with making image adjustment faster (as described above), there is a need to provide images in which lesions are easily visible. Internal organs imaged by diagnostic ultrasound systems frequently have speckle (ultrasound interference) patterns. As this hinders the identification of edges or structures, it has led to the adoption in recent years of adaptive image processing techniques such as HI REZ (high-resolution imaging) with functions that include identifying and highlighting edges or structures and reducing speckle patterns.

There are many artifacts in ultrasound images, such as those caused by multiple reflections or side lobes, and these are also a major factor in poor visibility. One



ANR: acoustic noise reduction

Fig. 4—ANR Function.
The ANR function suppresses artifacts to provide clear images of the aortic valve and surrounding structures.



RVS: Real-time Virtual Sonography CT: computed tomography

Fig. 5—RVS Function.
The RVS function displays marks to indicate the location of the tumor in the CT image on the left and the matching location on the ultrasound image on the right.

way of improving visibility is acoustic noise reduction (ANR), a technique for analyzing the signal received back from the body to selectively minimize artifact signals (see Fig. 4).

INITIATIVES FOR THERAPY AND TREATMENT

In the therapy and treatment stage of the care cycle, diagnostic ultrasound systems are frequently used in supporting roles such as when placing a probe directly on the affected organ during open surgery to verify the location of a tumor. This section describes Real-time Virtual Sonography[*1] (RVS), a treatment support function that Hitachi was the first in the world to commercialize[*2], and also special-purpose probes.

Treatment Support Functions

Uses for diagnostic ultrasound systems in treatment take advantage of their simplicity of operation and realtime performance, with applications that include checking the location and direction of movement of the needle used for radiofrequency ablation (RFA) treatment for liver cancer, and identifying where to implant the radioactive seed used in brachytherapy for prostate cancer.

To simplify these uses even further, Hitachi has led the world in developing the RVS function, which combines realtime ultrasound images with a simultaneous image of the same cross section using a different modality, such as computed tomography (CT) or magnetic resonance imaging (MRI) (see Fig. 5).

RFA treatment uses an ultrasound probe to image the liver from between the ribs as a needle is inserted into the tumor to destroy it using heat. Because RFA positions the probe between the ribs, bone or air can get in the way and prevent the location of the tumor from being identified by ultrasound alone. The RVS function makes the tumor easy to find by augmenting the ultrasound with a CT image.

In addition to CT or MRI images, further improvements to the technique are also being made by incorporating the display of three-dimensional ultrasound data, or by using it in conjunction with a contrast agent. Meanwhile, clinical research is proceeding on expanding its uses to other parts of the body such as breasts, kidneys, and the prostate. The market for the technique is expected to grow in the future.

Special Probes for Assisting Treatment

The section describes surgical probes developed to assist treatment.

In the case of surgery for the removal of a region of tissue designated by pre-surgical planning, a surgical probe provides a realtime view of the designated region to ensure that the tissue removal is performed accurately and also to detect any lesions that were not identified prior to surgery. Probes are available in a wide variety of shapes to suit different surgical

*1 Real-time Virtual Sonography is a trademark of Hitachi Medical Corporation.
*2 Based on research by Hitachi Aloka Medical, Ltd.

techniques and locations. Examples include micro-convex probes that can be held between the fingers, T-shaped linear probes that provide a good cross-section image and can make perforations, and hockey stick probes that can be inserted into narrow locations that are otherwise difficult to access (see Fig. 6).

Another technique of recent years is minimally invasive laparoscopic surgery, which seeks to minimize incisions in the skin and to enable patients to return quickly to a normal life. This involves opening a number of small incisions in the body through which a laparoscope can be inserted by way of a trocar (a pipe that holds the incision open). Hitachi has developed extremely small probes for the specific purpose of imaging organs through a trocar. These include a laparo probe with a transducer (oscillator) in the probe tip that can be manipulated externally to bend in four different directions, and a drop-in probe fitted with fins that can be grasped by forceps (see Fig. 7).

Through the commercialization of these various different surgical probes, Hitachi is helping support the therapy and treatment stage of the care cycle.

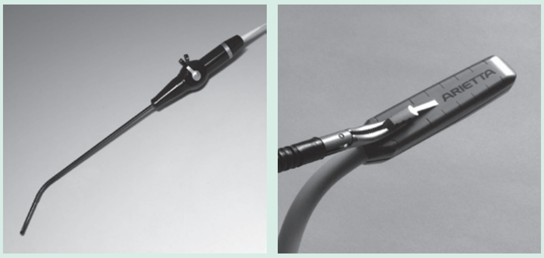
INITIATIVES FOR PROGNOSIS AND ELDERLY CARE

As noted earlier, nations around the world are variously taking steps to improve the quality and efficiency of healthcare as part of policies for controlling increasing medical expenditures. Primary and in-home healthcare play major roles in these measures, areas that operate under different conditions to previous purchasers of diagnostic ultrasound systems, in different environments with different experiences and needs.

Micro-convex probe　Hockey stick probe

T-shaped linear probe (long version)　T-shaped linear probe (short version)

Fig. 6—Special-purpose Probes.
Probes are available in a wide variety of shapes to suit different surgical techniques and locations.



Laparo probe　Drop-in probe

Fig. 7—Probes Designed Specifically for Laparoscopic Surgery.
The probes have a slim design to allow for insertion into the trocars used with laparoscopes and a movable tip.

In addition to considerations of cost and ease-of-use, diagnostic ultrasound systems are recognized for their potential uses in primary and in-home healthcare, which are called on to deal with a wide range of medical conditions under the constraints of limited time and information, by acting as diagnostic imaging systems that provide considerable assistance with diagnosis by augmenting the information obtained by medical practitioners from physical examinations.

To achieve this, systems must be able to deliver imaging performance with simple operation. As noted above, the nature of diagnostic ultrasound systems means they are more influenced than other diagnostic imaging modalities (such as MRI or CT) by the characteristics of the patient and the skill of the operator, often requiring detailed adjustment to obtain good quality images.

Ease of installation is another important consideration for primary healthcare, where the availability of space for a consultation is often limited. While existing hand carried units (HCUs) include small models similar in size to a laptop computer, for various different reasons these still tend to require a dedicated trolley, meaning that the space requirements in practice are little different from a conventional diagnostic ultrasound system.

Hitachi's own Noblus[*3] diagnostic ultrasound system is a compact model that features high image quality and advanced functions. In terms of ease of use and installation, however, it cannot really be described as suitable for primary and in-home healthcare.

*3 Noblus is a trademark of Hitachi Aloka Medical, Ltd.

Hitachi is currently proceeding with development aimed at entering this market and releasing models that can gain a high market share. By utilizing automatic techniques for optimizing imaging to suit individual patients based on know-how built up over many years in how to obtain images suitable for diagnostic use, the resulting systems will deliver solutions to the challenge of combining imaging performance with simple operation, two objectives that at first sight may appear to conflict. Hitachi is also working on design features such as seeking to ensure that systems are available for use when needed but do not get in the way during consultations that may take place in a limited space, such as outpatient healthcare.

FUTURE OUTLOOK—HEALTHCARE IT—

The ability to work with and utilize information technology (IT) will be a major challenge for diagnostic ultrasound systems in the future. Healthcare IT has the potential to dramatically transform the quality and efficiency of medical practice. A survey conducted in the USA found that approximately 72% of the country's doctors made routine use of smartphones and similar devices in their work, a percentage that continues to rise[1].

At a macro level, meanwhile, progress is being made in areas such as the introduction of electronic health records (EHRs) by governments and initiatives for the medical use of artificial intelligence. In order to make the most of diagnostic ultrasound systems in routine healthcare under these changing market conditions, Hitachi believes in the need to consider product development that takes account of systems' affinity with digital tools and allows for future workflow integration with EHRs and other systems, and integration with such technologies as artificial intelligence and the cloud to support diagnosis and other activities.

CONCLUSIONS

This article has described new initiatives Hitachi is pursuing for each stage of the care cycle. Many of these initiatives will help make life easier not only for patients but also for the medical practitioners who use the systems.

Along with improvements in throughput and quality of life (QoL), Hitachi intends in the future to develop and supply customers with products for use in a wide variety of applications at each stage of the care cycle.

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