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TECHNOLOGY COLUMN

Ultrasound – a Revolution in the Making

The evolution of ultrasound is transforming the delivery of healthcare in virtually all corners of the world. As the technological equipment gets smaller, its impact grows, with new applications and greater usability widening the reach of this versatile healthcare tool.
Ultrasound is finding its way into more hands, expanding from imaging professionals and imaging centers to clinicians working at the patient's bedside. As a result, ultrasound is helping to overcome one of medicine's greatest challenges: to see inside the body in real time. As the stethoscope lets one "hear" inside the body, ultrasound adds immediate "sight" into a patient, right at the point of care.
Technological innovation is the spark behind this shift.

By:
Omar Ishrak
President and Chief Executive Officer of GE Healthcare Systems

GE Healthcare
Pollards Wood
Nightingales Lane
Chalfont St. Giles,
England

GE imagination at work

With advances in computer electronics, ultrasound is becoming miniaturized, more affordable, easier to use, and capable of exceptional image quality and performance. Replacing hardware with software-driven capabilities in ultrasound has enabled highly advanced features to be migrated across programmable product platforms. This software architecture supports a breadth of ultrasound applications on increasingly smaller scanners, from real-time diagnostic data to visualizing needle guidance for interventional procedures.

Multiple areas of global healthcare are in need of practical point-of-care imaging, including emergency medicine and critical care, image-guided procedures, rural medicine, and primary care. Simultaneously, technological advances are making ultrasound affordable and accessible to more users in more places. This "push–pull" dynamic is driving a new model of healthcare in which the expanded use of ultrasound is leading to improved patient care and a more cost-effective global healthcare system.

Three Technological Trends

Medical imaging has been cost prohibitive and unavailable in many regions of the world, leaving billions of people without adequate healthcare. Ultrasound was not capable of overcoming this challenge until recently. Today, three technological trends – software-driven platforms, miniaturization, and intuitive interfaces – are working together synergistically to evolve ultrasound into an affordable, high-performance imaging tool that is accessible to more patients and providers worldwide.

Software-driven platforms: improving performance down the line

With the shift from hardware-based to software-based technology, capabilities that exist on high-end ultrasound systems can be easily migrated across a range of units. Thus, today's smaller units can provide exceptional image quality and performance features that one used to expect only on larger console systems. (Reference Fig. 1). This is improving the versatility and affordability of high-performance ultrasound in multiple fields of medicine.

Spatial compounding was one of the first instances of capability migration. This acquisition and processing technique enhances tissue and border differentiation. Developed on premium console platforms about 10 years ago, compounding software is available today on lower cost laptop-style systems, including some specialized for regional nerve blocks.

Four-dimensional ultrasound – the ability to see moving three-dimensional images – revolutionized fetal applica-

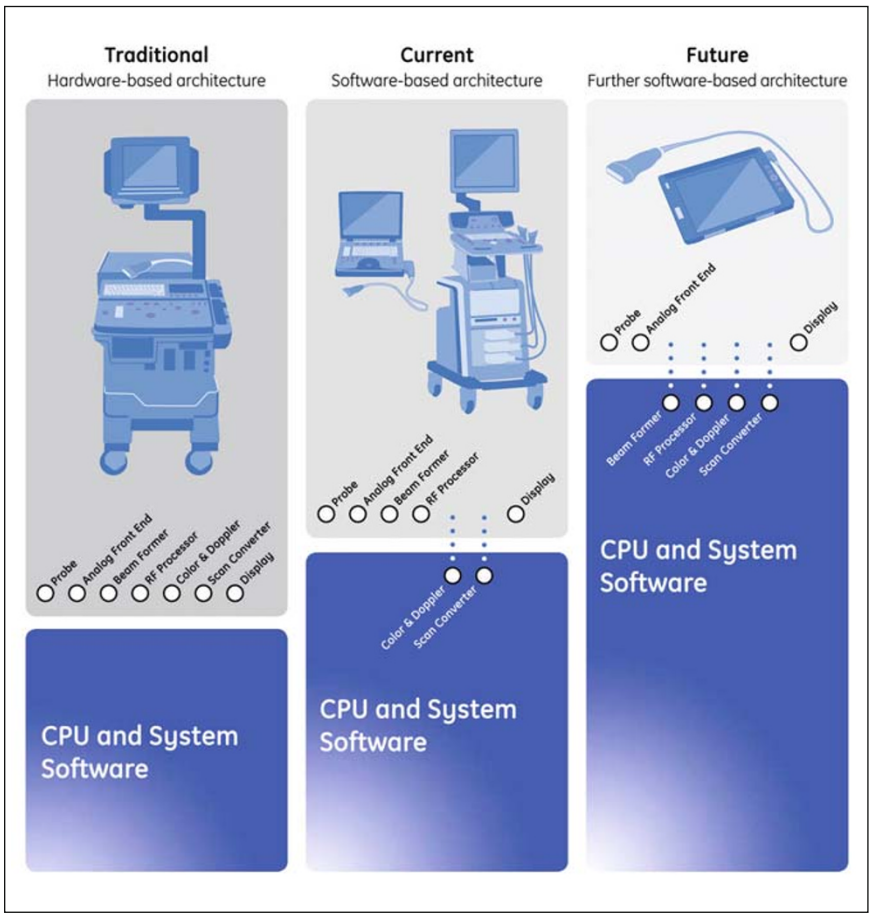

Fig. 1 - Evolution of Ultrasound. The transition from hardware to software architectures usually occurs in steps, not all at once. Benefits include lower manufacturing cost, scalable feature migration across products and higher performance with smaller size

tions on high-performance ultrasound systems. Today, that capability has moved to compact platforms and is expanding into new application areas, such as musculoskeletal and orthopedic imaging and needle guidance.

Software that automates obstetric measurements may be available on a range of ultrasound platforms in the future. Today, most users take measurements during the fetal scan of the head, femur, abdomen, length, and circumference. If we put fetal data within a standard growth chart according to demographic differences, fetal growth abnormalities could be identified automatically via software. Such a capability could have a tremendous impact on prenatal health care in rural settings.

Future software advancements will likely focus on developing dedicated ultrasound units for specific care areas and simplifying system operation. Software-based ultrasound systems are highly programmable. Advances in user interfaces and touch-screen controls will help make scanners increasingly intuitive to operate, even for healthcare providers new to ultrasound.

Miniaturization: riding the technology wave from consumer electronics

One of the advantages of portable systems is the ability to reach patients in challenging settings, whether in terms of geography (remote areas) or urgency (emergency medicine and surgery).

Lower-cost consumer components such as processing chips, flat displays, and batteries are enabling many kinds of electronics to become smaller, lighter, and less expensive. Computers that once cost several thousand dollars now have a price tag under $500, and many offer even higher performance in terms of speed and memory than the earlier, more expensive versions. In a similar fashion, the global availability of ultrasound system components is helping to reduce the size and cost of scanners.

Improvements in battery technology are resulting in smaller and lighter batteries with longer life. This is the key to portability – lightweight systems that can continue scanning on battery power when moved from room to room or location to location, or during a power outage. Looking ahead, we envision a day when "green energy" comes to ultrasound. Portable scanners with integrated solar cells may be able to convert the sun's energy into electricity to provide direct power and charge backup batteries, enabling rural users to be less dependent on the power grids in their regions.

Communications are also being transformed by advances in consumer electronics. Consider cellular connectivity. According to a 2009 United Nations report, mobile phones are now the communication technology of choice worldwide, particularly in poor countries. There are an estimated 4.1 billion cell phone subscriptions globally, according to the report, and developing countries account for about two thirds of the cell phones in use.[1] The ubiquity of cellular towers and equipment offers considerable potential to support telemedicine and tele-education around ultrasound imaging.

Many portable ultrasound scanners now have wireless local area network (LAN) capabilities for communication within hospital settings. This technology may be the key to enabling healthcare providers in developing regions to get diagnostic overreads on ultrasound exams. Training programs delivered

wirelessly could speed the development of essential imaging skills and further the adoption of ultrasound – increasing access to more patients.

The possibilities may extend even further. Computer engineers at Washington University in St. Louis, MO, USA, recently reported the development of universal serial bus (USB)-based ultrasound probes that are compatible with smartphone technology,[2] an advance that will bear watching in the years ahead.

Intuitive technology: increasing ease of use to facilitate wider adoption

Portable ultrasound is becoming indispensable in emergency medicine and critical care for caregivers who have little time to spend adjusting controls or scrolling through multiple menus. Automation of image optimization, calculations, and measurements is imperative in these time-sensitive environments. Other applications, such as interventional and guidance procedures, are also improved by greater speed in optimizing image parameters for streamlining of workflow.

We see technology becoming simpler and more intuitive. More diagnostic protocols are becoming automated, and interfaces have fewer controls. Touch screens, as seen in consumer products, and voice-activated controls will become more common user interfaces in ultrasound.

In addition to reducing exam times, simplicity in design also assists in user training. The more intuitive the design, the more quickly and easily a clinician can learn how to use the system. Ease of adoption will become a critical issue as ultrasound moves closer to the front lines of patient care and more clinicians want to add this capability to their practices.

Ultrasound and the Transformation of Care

A radical transformation in patient care is occurring. The trends of migration, miniaturization, and simplicity are converging to create affordable, high-performance ultrasound imaging tools suited to the needs of specific care areas. Let us look at how ultrasound is changing emergency medicine and critical care, image-guided procedures, rural health, and primary care around the world.

Emergency medicine and critical care

Ultrasound is becoming an indispensable diagnostic tool in the emergency department (ED) and the intensive care unit (ICU), as urgent care specialists and intensivists embrace bedside ultrasound for its ability to provide real-time information on patient status.

As hospitals struggle with issues around cost, wait times, and quality of care in the ED, ultrasound is proving to be an effective and relatively inexpensive method to image patients in real-time and move them quickly out of the ED and to the next step of care.

"The greatest impact of ultrasound is with the critically ill," says Robert Blankenship, M.D., F.A.C.E.P, medical director of St. Vincent Medical Center Northeast and ultrasound director of St. Vincent Emergency Physicians in Indianapolis, IN, USA. "Ultrasound gives me the ability to help diagnose a patient who might die in the next 30 minutes if I don't figure out what's wrong." He points to the large number of emergency patients who present with low blood pressure. "By using ultrasound, I can quickly evaluate the patient's central venous pressure and dramatically shorten the list of possible causes of the hypotension," he says.

Dr. Blankenship recalls a patient in her thirties with low blood pressure and tachycardia. "You would normally suspect a ruptured ectopic pregnancy with a low central venous pressure, but this patient actually had a high central venous pressure," he says. "I quickly scanned her heart and lungs and determined evidence of right-sided heart strain and a wedge-shaped pleural density indicative of a pulmonary embolism. CT confirmed multiple pulmonary emboli. Using ultrasound I was able to quickly determine her hypotension was not due to a ruptured ectopic, pericardial tamponade, or pneumothorax. Traditionally, this would have taken a pregnancy test, an echo, and a chest X-ray. With ultrasound, I was able to evaluate the patient at the bedside in only several minutes."

Dr. Blankenship says that focused assessment with sonography for trauma (FAST) is an important decision-making tool for emergency physicians, enabling them to see bleeding into the peritoneal, pleural, or pericardial spaces that may accompany trauma. The FAST exam is part of the Advanced Trauma Life Support (ATLS) protocol developed by the American College of Surgeons.

"Vascular access is another area that demonstrates the power of ultrasound in emergency care," says Dr. Blankenship. More than 5 million central venous catheters are inserted by physicians each year in the United States, and approximately 15 percent have complications.[3] Studies show that ultrasound can help to reduce the risk of complications and time required for insertion.[4]

"Ultrasound helps change the way we think about patient care and can dramatically decrease the cost of healthcare," says Dr. Blankenship. "Image quality is phenomenal these days. The better the image quality, the easier it is to train people, because they truly are seeing the detail more finely."

In critical care settings, ultrasound is assisting physicians in assessing cardiac function, guiding vascular access procedures, localizing abnormal fluid collection, and assessing for the presence of deep vein thrombosis (DVT).

Yanick Beaulieu, M.D., F.R.C.P.C., assistant professor at Université de Montréal, is a cardiologist, echocardiographer and intensivist at Hôpital Sacré-Coeur de Montréal, as well as director of the hospital's Bedside Ultrasound Curriculum in Québec, Canada.

"Ultrasound will likely become a fundamental part of daily practice. Evidence will show it to be absolutely essential in

patient care, not only for cardiac imaging, but for catheter placement and DVT assessment," says Dr. Beaulieu.

He remembers one case in particular. A patient had a hematoma at the site of a groin puncture from cardiac catheterization. The hematoma was getting bigger and the patient became unconscious with a faint pulse. Thinking it was a heart attack, staff intubated the patient and rushed him to the cardiac cath room. Dr. Beaulieu did a quick echo and saw a very small hyperdynamic heart. Behind the patient's abdomen was a massive hematoma – no heart attack. The patient was transfused and returned home in a couple of weeks.

"A simple bedside scanner led to a completely different kind of therapy," he says. "I wouldn't practice without ultrasound. It's my belief that ultrasound is a best practice in urgent care." Education, he says, will drive the acceptance of ultrasound in critical care and other care areas and, as a result, "the generation that begins to practice in the next 10 years will have this as second nature."

Guidance procedures

Procedure guidance is another area of ultrasound growth. The ability to clearly visualize the needle and to differentiate anatomy can help clinicians improve outcomes and avoid complications. Ultrasound has proven to support minimally invasive surgeries and procedures, such as central line placements, by helping clinicians decrease needle sticks and avoid hematomas and pneumothorax. Ultrasound also helps avoid puncturing of arteries, which can lead to stroke and other major complications.

Brandon Winchester, M.D., is an assistant professor of anesthesiology at Duke University School of Medicine in Durham, NC, USA. He uses ultrasound in his daily practice for central line placements as well as for regional nerve blocks. "Anesthesia is a target-rich environment for ultrasound," he says. "In some cases, our procedure time has decreased by as much as 50 percent."

One memorable case, he says, involved a kidney transplant patient. "He was a difficult peripheral IV stick, so during a recent emergency room visit, preparations were made for a central line via the right internal jugular (IJ) vein. After five blind sticks by two doctors, this procedure was aborted in favor of a subclavian central line. Weeks later in the OR, it was immediately clear when we put the ultrasound probe on the patient's neck that the right internal jugular vein had clotted off. A central line was instead placed in the left IJ vein, and an impossible right IJ stick was averted. A complication was avoided without the needle ever puncturing the skin."

For peripheral nerve blocks, ultrasound can help physicians visualize the nerve, the needle and local anesthetic spread for prolonged pain control, according to Dr. Winchester. Traditionally, a nerve stimulator is necessary to locate nerves with blind landmark-based nerve blocks. Nerve stimulation can be very painful to the patient. With ultrasound to guide the procedure, nerve stimulation may not be necessary and therefore severe pain to the patient can be avoided, he says.

"We use ultrasound to place nerve blocks for orthopedic procedures every day," Dr. Winchester says. "In one case, a 60-year-old man presented with a painful ruptured quadriceps muscle. It was clear that a technique utilizing femoral nerve stimulation would cause him severe discomfort. Instead, we performed an ultrasound-guided femoral nerve catheter without nerve stimulation. The femoral nerve was visualized directly, a small catheter was placed adjacent to the nerve, and local anesthesia was injected through the catheter. Proper spread was confirmed with direct ultrasound visualization. The patient experienced minimal procedure-related discomfort, and the nerve block completely eliminated the patient's quadriceps pain."

Simple user interfaces, high-performance imaging, small footprints, clean ability, and the mobility to move the unit from room to room will continue to coalesce into devices uniquely suited for guidance procedures.

Rural health

Improving healthcare in remote regions of the world is imperative. The statistics are staggering. For example, women die of pregnancy-related causes at a rate of about one a minute, with 99 percent of those deaths occurring in developing countries, primarily in Africa and southern Asia.[5] Infant mortality rates exceed 100 per 1,000 births in a number of African countries.[6] According to experts in rural healthcare, X-ray and ultrasound are some of the key diagnostic imaging modalities that can improve care, with the ability to meet over 90 percent of the imaging needs of the population.[7]

Dr. Yang Yujiang, director of the ultrasound department at Hanjiashu Township Hospital of Tianjin, China, has been scanning for 17 years. He says that one case that exemplifies the value of ultrasound for maternal–infant care in rural areas was a routine exam of an expectant mother who was asymptomatic 10 weeks into her pregnancy. Dr. Yang saw several lymph cysts around the baby's neck, a rare abnormality. Surgery confirmed the diagnosis. "Fetal lymph cysts aren't easy to find with other methods. Ultrasound is the easy and low-cost way to diagnose fetal abnormalities at an early stage" Dr. Yang says.

Dr. Hao Jianjun, director of the ultrasound department for Yangqu County Hospital of Shanxi Province, China, uses ultrasound for gynecology patients. He recalls one patient with an ovarian cyst who had not been able to conceive for 2 years. Using ultrasound, Dr. Hao was able to diagnose a right oviduct hydrocele. After referral to gynecology specialists and surgery, the diagnosis was confirmed, and 1 year later, the patient was pregnant.

In addition to OB and gynecological (GYN) applications, Drs. Yang and Hao

use ultrasound for imaging the liver and gall bladder, as well as breast, thyroid, cardiac, vascular, and small parts exams. Both doctors have used ultrasound for about 20 years and have seen a nearly three-fold increase in the number of ultrasound exams per day.

Another remote area in which ultrasound plays a key role is the district of Achham in western Nepal. According to physicians who care for patients in this hilly, remote region, compact ultrasound is a valuable triage tool. "The trip to the nearest medical center can take 24 to 36 hours on a bus," says Stephen C. Morris, M.D., emergency medicine resident PGY-IV at Yale-New Haven Hospital, New Haven, CT, USA. "Avoiding an unnecessary trip is almost as critical as determining who is sick enough to require the arduous transportation."

The Yale Department of Emergency Medicine supports the Nyaya Health initiative, which provides essential public health services in the Achham region. Ultrasound is particularly important for maternal care in rural regions, says Christopher Moore, M.D., assistant professor of emergency medicine at Yale-New Haven Hospital.

Dr. Morris cites the case of a 21-year old expectant mother. "The patient had been collecting dead branches for firewood and fell from a tree," he says. "She was in pain and in emotional distress. We were able to assess the pregnancy by date and fetal heart sounds, and determine that she had no obvious placental abruption. We also determined there was no free peritoneal fluid, a negative FAST exam, and no pneumothorax or pericardial effusion. We watched her overnight and re-evaluated with repeat abdominal and OB ultrasounds in the morning. Both were normal. As a result, we could keep her in the community and avoid an arduous trip, relieving her and her family. That gives you a sense of the value of ultrasound."

There is a need to develop ultrasound systems with specifications for rural health: durable, reliable, and highly portable. Two other technology benefits – intuitive interfaces with displays tailored to local languages and connectivity through telemedicine – will be critical in rural healthcare.

Duncan Smith-Rohrberg Maru, Ph.D., a member of the Yale School of Medicine Medical Scientist Training Program and cofounder of Nyaya Health, emphasizes the need for systems designed for rugged conditions. "Electricity is quite unreliable and we don't have capability to buy large inverters or battery systems. To have an ultrasound machine that you can literally plug into a wall socket and recharge like a laptop computer is incredibly important," he says. "Then there are transportation costs. A large ultrasound machine can be very expensive to ship to a remote region like ours. We need ultrasound that is small and easy to maintain."

Primary care

Even though primary care is the front line of medicine and draws the largest population of physicians[8], it is the furthest from the widespread use of ultrasound. In the United States, for example, ultrasound is rarely used in primary care. Even globally, this field is in a very early phase of adoption. However, new doors are opening through medical school and other ultrasound education programs.

Dr. S. Suresh, head of the department of fetal medicine and director of MediScan Systems Diagnostic Ultrasound Research and Training Centre in Chennai, India, has used ultrasound for 27 years. He believes that low-cost intuitive systems can help solve a critical challenge – enabling clinicians to achieve good image quality despite limited experience with scanning.

"Today, image optimization on most ultrasound equipment is a tough task, and often the end user is not aware of how to achieve this. In India and many other countries, even basic knowledge of ultrasound is lacking," says Dr. Suresh. "The majority of centers need simple ultrasound systems with good image quality. Appropriate technology at affordable cost is the key to extending healthcare to all segments of society and reducing inequality in the delivery of primary care."

Nabor Díaz Rodríguez, M.D., uses ultrasound several days a week in his primary care practice in Ourense, Spain. He is the national coordinator for Grupo de Trabajo de Ecografía within the SEMERGEN Society, an organization of primary care physicians. Dr. Díaz leads the group's ultrasound training for primary care and casualty physicians.

"Ultrasound has helped revolutionize primary care," Dr. Díaz says. "Primary care doctors now can study organic structures without any harm to the patient. This contributes to more accurate diagnoses, 80–90 percent, thanks to the sum of the clinical and physical history of the patient, and the ultrasound findings." As a result, patients can be referred quickly to specialized centers, he says, avoiding risky delays.

He cites a patient who presented at the emergency clinic with hypertension and abnormal echocardiogram (ECG) readings that pointed toward cardiopathology but were inconclusive. Dr. Díaz conducted an abdominal ultrasound scan that revealed an aortic aneurysm, and the patient was referred immediately to the hospital for surgery. "Ultrasound enabled us to detect an asymptomatic aneurysm at a very early stage, which helped save a life," he says.

"The low price and low weight of portable ultrasound machines help primary care managers at public or private hospitals, as well as private clinics, to acquire ultrasound capabilities," says Dr. Díaz. "I believe that in 5 years, all doctors, regardless of specialty, will have ultrasound devices in their practices."

Improving Healthcare through "Disruption"

Harvard Business School professor Clayton Christensen defines disruptive technologies in healthcare as innova-

tions that enable lower-cost venues of care and empower lower-cost caregivers to provide medical services of higher value for patients. Ultrasound – specifically small, portable ultrasound technology used at the point of care – could be considered a true disruptive technology.

Portable ultrasound systems are improving the delivery of healthcare globally – widening access, lowering costs, and improving the quality of outcomes. As these systems become even smaller and easier to use, adoption will increase across all care areas, from the ED to remote rural regions to primary care.

Greater simplicity will accelerate adoption by new users. Intuitive machines targeted to specialized needs will enable a wider range of caregivers to use ultrasound effectively for their patients. Adding wireless transmission and telemedicine will further increase the scope of where ultrasound can be practiced.

From a cost perspective, ultrasound is among the most affordable of imaging technologies. Its demonstrated ability to provide high clinical value for a relatively low cost will help enable ultrasound to align with new models for reimbursement and insurance coverage going forward.

Healthcare faces many challenges. Ultrasound is a tool for change in addressing such issues as access, quality, and cost – and its positive impact is changing the way that healthcare is delivered and experienced worldwide.

References

1 *Developing world embraces mobile phones: UN report*. (2009, March 2). CBCnews.ca. Retrieved June 30, 2009 from http://www.cbc.ca/technology/story/ 2009/03/02/un-telecommunications.html

2 Fitzpatrick, T. (2009) Ultrasound imaging now possible with a smartphone. Retrieved June 30, 2009 from http://news-info.wustl.edu/tips/page/normal/13928.html

3 McGee DC and Gould MK. Current concepts: preventing complications of central venous catheterization. N Engl J Med 2003; 348:1123-33

4 McGee, 1123-33

5 *Maternal mortality figures show limited progress in making motherhood safer* (2007). United National Population Fund Web site. Retrieved June 29, 2009, from http://www.unfpa.org/mothers/statistics.htm

6 United Nations, Department of Economic and Social Affairs, Population Division (2007). World Population Prospects: The 2006 Revision, Highlights, Working Paper No. ESA/P/WP.202

7 Palmer PE (1993) Imaging equipment for small hospitals. Trop Geogr Med 45: 98-102

8 By the Numbers. Annual Resource Guide 2007-2008 edn. Supplement to *Modern Healthcare* (2007, December 24), 30