GE Healthcare

Invenia ABUS Imaging Architecture

Ultrasound imaging architecture for the breast screening environment

Costas Simopoulos, PhD, GE Healthcare

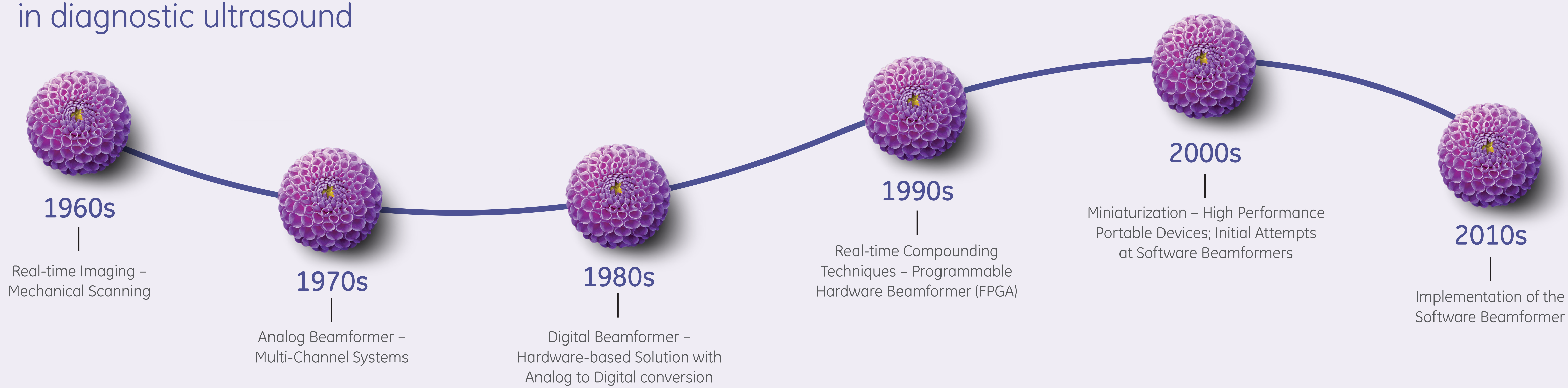
Abstract

Ultrasound is a proven breast imaging tool for breast cancer diagnosis. However, operator dependence and long acquisition times have limited the ability to incorporate traditional hand-held ultrasound (HHUS) into new applications like breast cancer screening programs. Further, many automated breast ultrasound units do not have specific indications for supplemental breast cancer screening.

These limitations are addressed by the Invenia™ ABUS (Automated Breast Ultrasound) system through the implementation of its advanced Invenia imaging architecture. Developed for the high-volume breast screening environment, GE Healthcare's Invenia Imaging Architecture has the ability to insonify a large volume, such as the breast, in a reduced number of transmissions, resulting in the rapid acquisition of high quality volumetric data.

Invenia ABUS imaging involves the transmission of wide beams. The electrical signals recorded from multiple transmissions of wide beams are coherently compounded retrospectively to generate high image quality and high frame rates. Enabled by the computing power of modern multicore computer processors such as Graphics Processor Units (GPU), coherent compounding eliminates focal zones and generates a virtual focus everywhere for uniform image quality throughout the volume. The result is improved consistency, reproducibility, and sensitivity of whole breast ultrasound.

Evolution of the beamformer in diagnostic ultrasound



Introduction

Since the implementation of routine screening mammography, there has been a 30% reduction in breast cancer mortality.[1] While mammography remains the gold standard for detecting breast cancer, research has shown[2] that it is not equally effective in all women. Mammography is likely to detect cancer in a fatty breast in most cases; however, as breast density increases, the likelihood of a cancer being detected is reduced. In women with dense breast tissue, mammography can miss up to one third of breast cancers in dense breasts.[2] This leads to a delay in diagnosis and a worse prognosis for women with dense breast tissue.

Ultrasound is a proven diagnostic tool in breast imaging. With its non-invasive, non-ionizing radiation, real-time and economical nature, ultrasound has potential to be an important screening modality as an adjunct to mammography. However, the limitations of traditional hand-held ultrasound (HHUS), which include operator dependent variability and long acquisition times, make it unwieldy for broad-scale breast cancer screening. Further, most automated breast ultrasound devices do not have supplemental breast screening indications.

In order to succeed in a screening capacity, an imaging system must meet several specific criteria that cannot be met with the traditional hand-held transducer ultrasound imaging systems. First and foremost, it must be capable of volume imaging with a large field of view and high frame rate so that the entire breast can be imaged in a single scan. It is paramount that the amount of time required for scanning is short, otherwise the system is not practical for typical screening workloads. Pushing the boundaries of the classic compromise between image quality and frame rate, a screening ultrasound system must deliver images with high resolution, contrast, and uniformity that make it highly sensitive and selective to cancerous lesions.

Invenia Imaging Architecture was developed for the high-volume, breast cancer screening environment. The unique requirements for breast cancer screening led to important innovations being incorporated in the Invenia ABUS system.

Evolution of the beamformer in diagnostic ultrasound

Introduced into clinical practice in the 1960s, ultrasound has become a reliable, cost-effective tool for diagnostic applications. Early ultrasound systems had single element transducers that created a single focused beam. 2D images were created by repeated sweeps of the imaged region, see figure 1. Next generation ultrasound systems used multi element-transducers which utilized beamformers to create focused beams, see figure 2. The beamformer is an electronic component of an ultrasound imaging system that calculates the precise timing of excitation of each element so that the combined effect of all the elements results in a focused beam. This was a major step in image quality as beams focused at a various depths, instead of the fixed focus of the single element transducer, could now be created. However, beams with a different focus must be transmitted in sequence and the additional time required is to the detriment of frame rate.

The hardware-based beamformers evolved from analog to digital in the 1980-90s, enabling clinicians to adjust various parameters to create images that maximized diagnostic information. Today another leap in image quality is being driven by the availability of affordable, massively parallel, computer processors. The implementation of software beamforming on these processors supports image improvements and cost-effective upgrades not possible with previous hardware-based architectures.

Barriers to achieving optimal screening workflow with traditional ultrasound

Traditional B-Mode ultrasound imaging involves the sequential transmission of focused narrow beams, where each beam is displaced slightly from the previous one to create one 2D image frame. Breast ultrasound imaging demands higher resolution for the early detection of small breast cancers. To acquire high resolution images, the number of beams must be large, which in turn reduces the frame rate. The problem is compounded for 3D volumetric imaging, as with whole breast ultrasound, where a large number of frames have to be collected as each frame corresponds to one slice in the 3D image. As a result, the large number of transmitted beams required for the acquisition of a large volume, results in long image acquisition times and does not provide the efficient workflow required to support the screening environment.

In addition, image uniformity is not achieved in conventional ultrasound systems where narrow beams are only truly narrow within a small range around the focus of the beam. This region, where the beam is narrow, is known as the depth of field, see figure 3. The narrow focus results in better image resolution; however, the depth of field also gets smaller as it scales with the square of the resolution. The consequence of a narrow focus is a greatly reduced depth of field that results in an image that is sharp only around a small band known as the focal zone. In a traditional ultrasound system this phenomenon is remedied by multiple transmissions of beams focused at different depths.

The multiple focal zones are stitched together to form the complete image. Even with multiple focal zones, uniformity is only partially achieved. The boundaries of the individual focal zones are prone to artifacts. When used for diagnostic evaluation with real-time imaging, the number of transmit foci and their location can be customized to characterize specific lesions. However, with screening breast ultrasonography, the images are not viewed in real-time and, therefore, an area of concern identified at the time of interpretation cannot be improved by re-adjusting the transmit focus.

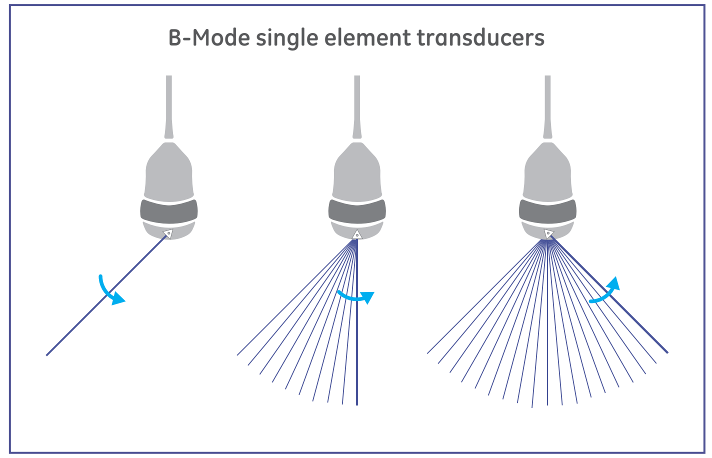


Figure 1. Early ultrasound systems had single element transducers that created a single focused beam. The 2D image was created by the transducer's oscillatory motion, which made the beam repeatedly sweep through the imaging plane.

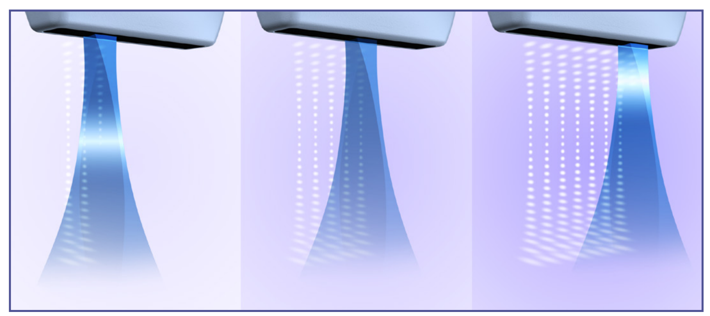


Figure 2. Linear Arrays, Multi-element Transducer. In order to create focused beams with these transducers a beamformer is required, which calculates the precise timing of excitation of each element. The combined effect of all the elements is a focused beam as illustrated.

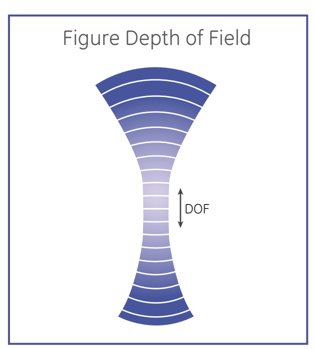


Figure 3. Depiction of a focused beam indicating the Depth of Field (DOF).

Software beamformer designed for volumetric breast imaging

The advent of high of high performance massively parallel processors such as the Graphic Processing Units (GPU) used in high end computers allowed the implementation of beamformers purely in software. The image improvements possible with the software beamformer are not easily achievable with a hardware-based architecture. At this point a clarification is in order. Beamformers are used in creating transmit (physical) beams as well as reconstructing the received signals into a virtual "receive" beam. The two beamformers are separate. The transmitted beams and their steering is done by the "transmit" beamformer. In the following the term "software beamformer" refers to the "receive" beamformer. A block diagram comparing the receive beamformer of a conventional ultrasound imaging system and the software beamformer is shown in figure 4.

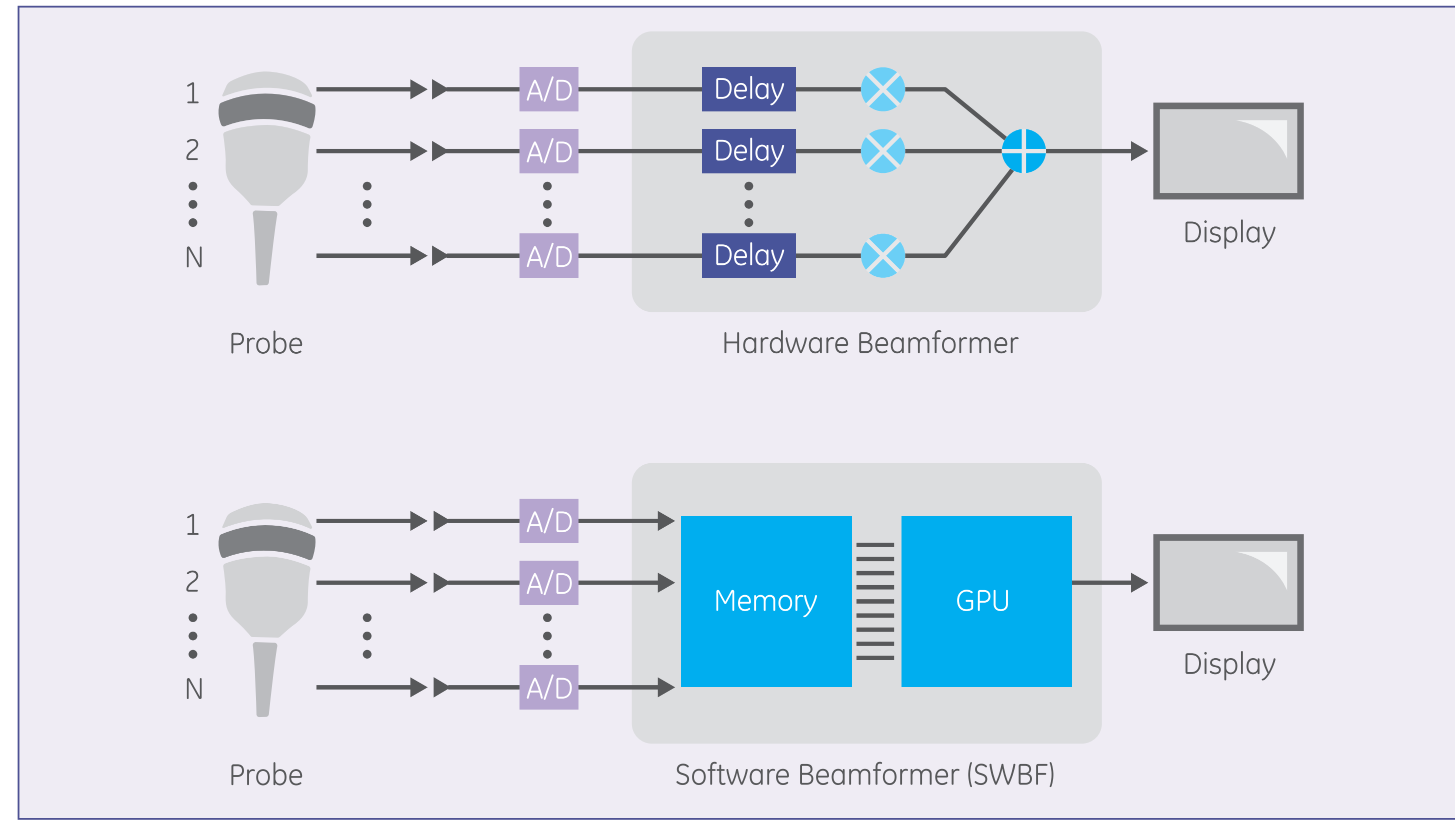


Figure 4. Conventional Beamformer vs. Software Beamformer. The conventional beamformer (top) consists of an electronic device that combines the signals from the transducer elements to create the displayed image. The software beamformer (bottom) is not a specific device but uses the memory and the processor or graphic card of a computer, thus enabling the implementation of more advanced beamforming techniques as explained in the text.

Implementation of Invenia Imaging Architecture for breast screening

The imaging architecture of the Invenia ABUS system has the ability to reconstruct 3 million pixels a second at high frame rates to compute a full 3D breast volume from one single sweep. Processing more data than traditional ultrasound systems enables the acquisition of breast volumes that are at least three times larger than what is achievable with traditional hand held ultrasound.

Wide beams insonify a large area in a single transmission

The architecture of the Invenia ABUS system resolves the constraints of uniformity and frame rate of conventional ultrasound by utilizing a technology innovation known as coherent compounding. Coherent compounding is combined with wide beams, that insonify a large volume in a single transmission, to create images with a large field of view from a linear array with a large aperture.

Focal point at every pixel

The wide beams do not have a focal point within the imaged area. Normally this would create images with poor resolution and contrast. In order to compensate for the lack of a narrow focus in the transmitted beam we make use of the following observation. The ultrasound waves in a transmit beam converge at the focus from different directions see figure 5. Based on this observation, multiple unfocused or wide beams steered at slightly different angles are transmitted, see figures 6 and 7. As a result, the ultrasound waves insonify a particular point in space from multiple directions, albeit at different times. This is not an issue because the electrical signals from the echoes of their individual transmissions are saved in computer memory and can be combined together in a coherent way so that a virtual transmit focus can be reconstructed at any location in the image. The computer memory where the electrical signals received from all the individual transmissions are recorded constitutes a central component of the software beamformer.

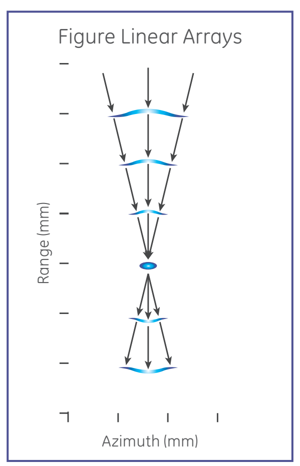


Figure 5. Static Transmit Focus. Note that at the focus, the lines perpendicular to the wavefronts, indicating locally the direction of propagation of the wave, converge towards the focal point.

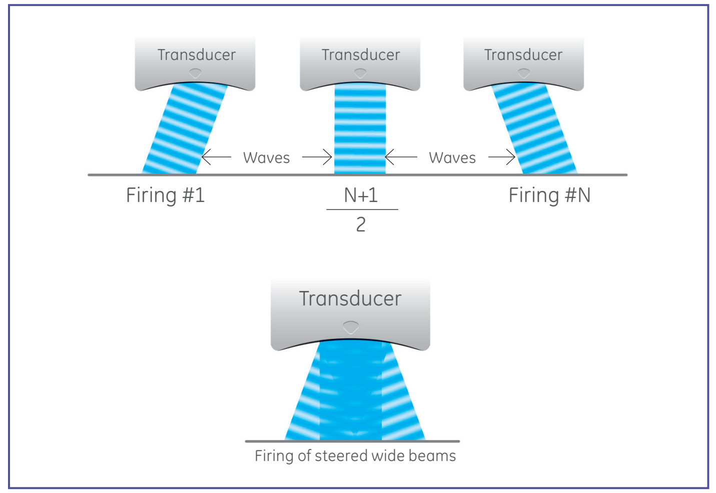


Figure 6. Wide Beams with Multiple Angles: multiply steered wide beams improve resolution. The steered wide beams are fired sequentially and the signals are recorded in the memory of the computer.

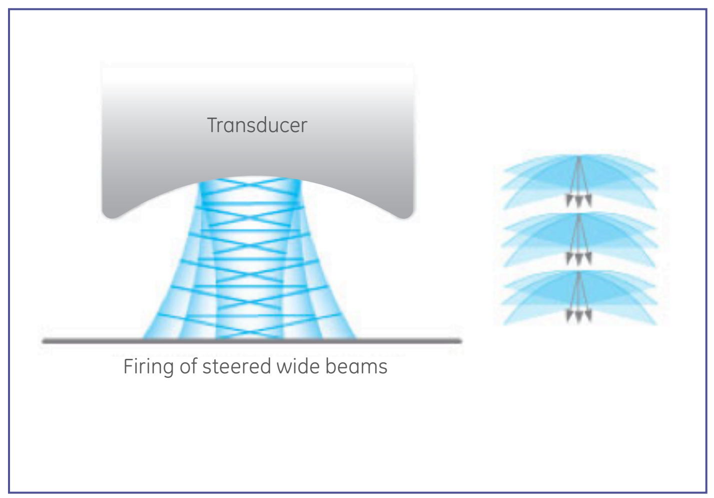


Figure 7. The data from each firing is stored in memory and then rearranged to recreate a focal point at each image pixel. It is not important that the converging wavefronts do not happen simultaneously as in focused transmit beams. However, it is important that the received signals are combined with the appropriate delays from each angle dataset so as to be added coherently to form a virtual transmit focus at each pixel – forming an image of high uniformity and resolution. This is similar to dynamic receive focus in conventional systems where the delays for combining the signals from each element are adjusted continuously with depth. The difference is that in addition to the dynamic receive focus a dynamic transmit focus is also achieved.

Invenia ABUS acquires breast volumes in 30 seconds

The quality of the final image is dependent on the number of the steered transmissions used to create it: the higher the number of steered transmissions, the better a transmit focus is approximated, which leads to better image quality. Despite the increased number of transmissions required for multiple steered wide beams to achieve good image quality, the improvement in frame rate is still 3x compared to imaging with conventionally focused beams.

The Invenia ABUS system uses a 15 cm high-frequency Reverse Curve™ (concave) linear array transducer to acquire a 15.4 cm x 17.0 cm volume. With a depth of up to 5.0 cm, the Invenia ABUS' wide field of view is at least three times larger than any traditional system.

To acquire a single frame, the Invenia ABUS transducer transmits several groups of steered wide beams displaced from each other by approximately 1 cm so that the entire aperture of the transducer is covered. The volume is created from the cine loop of frames acquired at regular intervals while the transducer moves at a uniform speed in a direction perpendicular to the imaging plane. A volume consists of about 300-400 frames,. Using its advanced architecture, the Invenia ABUS system can acquire each view in approximately 30 seconds. A traditional system would require over 700,000 beams to cover the entire volume compared to approximately 200,000 for the Invenia ABUS. A frame rate improvement of more than 3-times. This is clinically relevant to streamlined workflow in a high-volume screening environment.

Contrast enhancement

The effects of coherent compounding can be further enhanced to provide a significant improvement in image contrast. Even though the virtual transmit beams are narrow, there is some low level energy scatter from surrounding tissue. This low level energy causes otherwise unechoic regions that should appear totally black, like cysts, to be filled with a haze. Known as acoustic clutter, the haze is, in fact, present everywhere, not only within cysts and causes the appearance of faded and flat images. The software beamformer enables the implementation of algorithms that identify the acoustic clutter and eliminate it. This is a unique feature that would otherwise be very difficult to implement using a hardware beamformer. With improved contrast resolution, the Invenia ABUS has the potential to reduce false positives and improve diagnostic confidence when characterizing lesions.

Real-time ABUS exam results for immediate interpretation

3D rendering and reconstruction of the coronal plane is computed in real-time and available for display and interpretation upon completion of the whole breast ABUS exam and saved in a DICOM® file, available at any future point in the course of a patient's care.

The Invenia ABUS system converts the 2D image datasets to multi-planar 3D reconstructed images to facilitate the review of the entire breast volume in three orthogonal planes (coronal, axial, and sagittal). The digital multi-planar 3D display allows the operator to visualize the 3D positions of potential breast abnormalities within the three dimensional anatomy of the breast tissue and to document the location of these abnormalities relative to the nipple, anterior skin surface, posterior chest wall and the conventional clock position. The Invenia ABUS system workstation features a user-friendly interface optimized for viewing breast ultrasound volumes.

Conclusion

The Invenia ABUS (Automated Breast Ultrasound) system is designed to improve the consistency, reproducibility, and sensitivity of whole breast ultrasound, demonstrating a 55% relative increase in invasive cancer detection* (sensitivity) in women with dense breasts without prior breast intervention.[3]

Through the implementation of Invenia Imaging Architecture, the Invenia ABUS system overcomes the limitations of conventional ultrasound to create a focus at every pixel. The result is a uniform and high spatial and contrast resolution image. Clinically, this translates into improved image quality without a reduction in efficiency, making Automated Breast Ultrasound well positioned to address the unique clinical workflow requirements for high-volume breast cancer screening and improve the early detection of breast cancer, in women with dense breasts.

www.gehealthcare.com

GE Healthcare provides transformational medical technologies and services to meet the demand for increased access, enhanced quality and more affordable healthcare around the world. GE (NYSE: GE) works on things that matter – great people and technologies taking on tough challenges. From medical imaging, software & IT, patient monitoring and diagnostics to drug discovery, biopharmaceutical manufacturing technologies and performance improvement solutions, GE Healthcare helps medical professionals deliver great healthcare to their patients.

* Increase in sensitivity was associated with a decrease in overall specificity.

1. Tabár L, Vitak B, Chen TH, et al: Swedish two-county trial: Impact of mammographic screening on breast cancer mortality during 3 decades. Radiology 260:658-663, 2011.
2. Mandelson MT et al. Breast density as a predictor of mammographic detection: comparison of interval- and screen-detected cancers. J Natl Cancer Inst 2000; 92(13): 1081-1087.
3. Brem RF, Tabár L, et.al. Assessing Improvement in Detection of Breast Cancer with Three-dimensional Automated Breast US in Women with Dense Breast Tissue: The SomoInsight Study. Radiology.2015 Mar; 274(3): 663-73

GE Medical Systems Ultrasound & Primary Care Diagnostics, LLC, a General Electric company, doing business as GE Healthcare.

GE Healthcare
9900 Innovation Drive
Wauwatosa, WI 53226
U.S.A.
www.gehealthcare.com

June 2015
JB31235XX