GE HealthCare

cSound ADAPT:

Continuous beamforming optimization, adapting to patient anatomy and probe position

White Paper

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cSound ADAPT

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Introduction

Cardiac medical staff currently face an unprecedented workload. As both cardiovascular heart disease[1] and accessibility to healthcare increase, pressure on cardiologists, echocardiologists and sonographers is mounting. Staff burnout, and consequently staff shortages, is on the rise[2,3].

GE HealthCare's research and development has a strong track record of making the lives of healthcare practitioners easier by bringing them the latest advancements in image quality via software beamforming with cSound.

Building on cSound's breakthrough technology, with its flexible and powerful software image former and a unique XDclear™ 2D active matrix array technology, GE HealthCare now introduces cSound ADAPT.

cSound ADAPT corrects for distortions of the ultrasound wavefront introduced while propagating through the thoracic wall, which in turn may bring a meaningful support to the operator in getting a useful image faster. By adjusting the beamforming adaptively at different probe positions and different patient anatomy, cSound ADAPT may improve image quality (i.e. resolution and contrast) compared to traditional ultrasound reconstruction techniques, and help operators from all level of experience to potentially reduce examination time and effort. It is technology in the service of the echo operator.

The complex interaction of sound in the human body

Each patient is different as anyone working in medical ultrasound can attest. Even the best ultrasound system may fall short when used on a very difficult-to-scan patient. This is especially true in echocardiography where clinicians have accepted that there is a large variation in image quality among their daily patients.

Suboptimal image quality is still a major challenge for cardiovascular ultrasound imaging. There are many potential consequences of reduced image quality: reduced confidence in providing a proper diagnosis, longer examination times, repeated exams, increased muscular strain for the operator, more discomfort for the patient because of increased probe pressure, as well as costly and potential referrals for additional examinations.

Based on **30 years** of research

Over the last 30 years, the scientific community has worked to understand the root causes of image quality degradations in medical ultrasound. One of the major contributors is the assumption, used in most, if not all, ultrasound systems, that sound propagates at the same speed in all human tissue. If the ultrasound propagation speed were constant, then echoes from each point in the human body would arrive at the probe surface as a perfect spherical wave. This idealization is, however, not correct. There is a wide variation of the speed at which sound propagates in the different tissues that constitute the human body wall (see table 1, figure 1).

Tissue	Sound speed (m/s)
Water	1480
Blood	1560
Muscle	1600
Fat	1460
Cartilage	1640
Bone	4080

Table 1: sound travels at different speeds in the different tissues of the body wall.

Figure 1: Different tissues in human body wall.
Credit image: https://quizlet.com/ca/298139932/inferior-view-of-transverse-section-of-thoracic-cavity-diagram/

The wavefront of the echoes arriving at the probe often deviate significantly from the assumed spherical form. This in turn compromises image reconstruction, leading to suboptimal image quality. A structure containing a large degree of inhomogeneities is called an aberrating layer. Figure 2 illustrates the impact of such a layer on the ultrasound waveforms reflected towards the probe.

What makes a patient challenging to image?

It is sometimes difficult to guess if your ultrasound system will struggle to provide a correct image on a given patient, or whether this same patient will have an excellent acoustic window. Here are four of the main physical mechanisms known to degrade ultrasound image quality:

- Reverberations are due to multiple scattering of the ultrasound waves around strong spatial heterogeneities, like the body walls or the lungs. Reverberations appear as bright clouds of noise added to the imaged structures
- Absorption denotes the phenomenon in which ultrasound waves are converted to heat, reducing the amplitude of the received ultrasound echoes. The loss in penetration is stronger for higher frequencies and for certain tissue types
- Acoustic shadowing is characterized by a strongly attenuated signal, mostly observed below structures through which sound fails to propagate, such as bone, calcifications, lungs, and medical devices in patient body (such as artificial valves)
- Aberrations are caused by spatial variations in the ultrasound propagation velocity in tissue and degrades the focusing of the ultrasound beams, reducing the resolution in the images

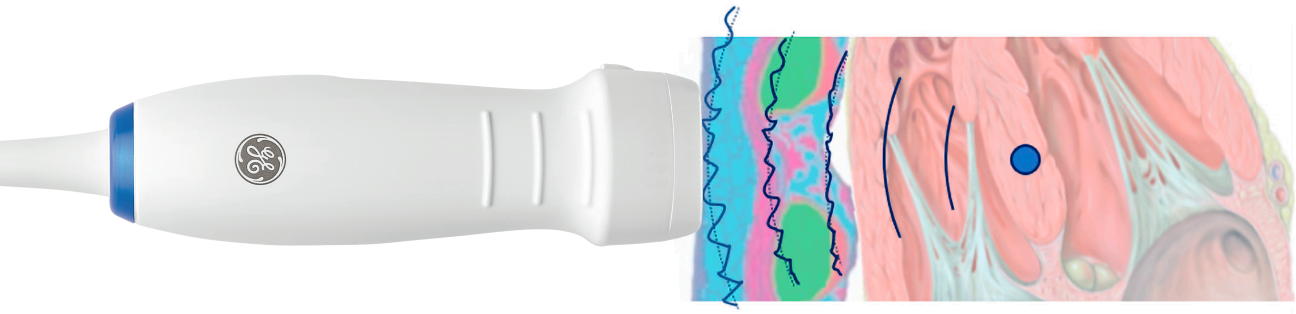


Figure 2: ultrasound propagates at different speeds through each structure.

Credit image: Robert Waag, Simulation of ultrasonic pulse propagation, distortion, and attenuation in the human chest wall, T. D. Mast, L. M. Hinkelman, L. A. Metlay, J. M. Orr, R. C. Waag, J. Acoust. Soc. Am. 106(6), 1999. https://www.researchgate.net/publication/51361465_Simulation_of_ultrasonic_pulse_propagation_distortion_and_attenuation_in_the_human_chest_wall

Aberrated wavefronts have a characteristic impact on the image: bright structures become weaker and laterally enlarged, while weaker tissues are obscured. This results in a blurred image with reduced contrast and potentially geometric distortions, much as the image of an object viewed through obscure glass is distorted (see figure 3).

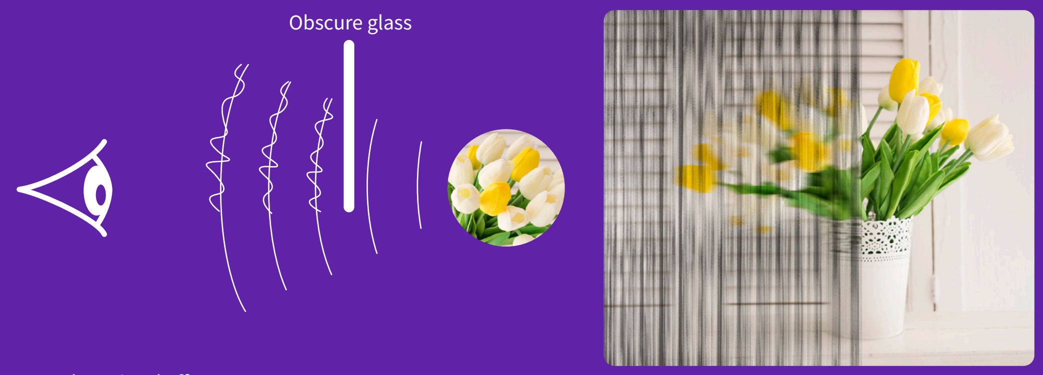


Figure 3: Obscure glass visual effect.

In echocardiography, the thoracic wall is often a significant aberrating layer. The thoracic wall has a complex layered structure composed of skin, adipose tissue, bones (ribs and sternum), intercostal muscles, cartilage, extra-pleural fat, and neurovascular bundles. Ultrasound propagates at different speeds through each of these bone and soft-tissue structures, and this results in distorted wavefronts.

To reduce the impact of aberrations from the thoracic wall on image quality, clinicians will position the probe on the patient to find the location with a sufficiently wide intercostal space. The operator will then typically apply pressure to compress the thoracic wall, to push the ribs apart and to compress the aberrating layer between the probe and the heart. This is only a partial solution, however, and adds to patient discomfort (figure 4).

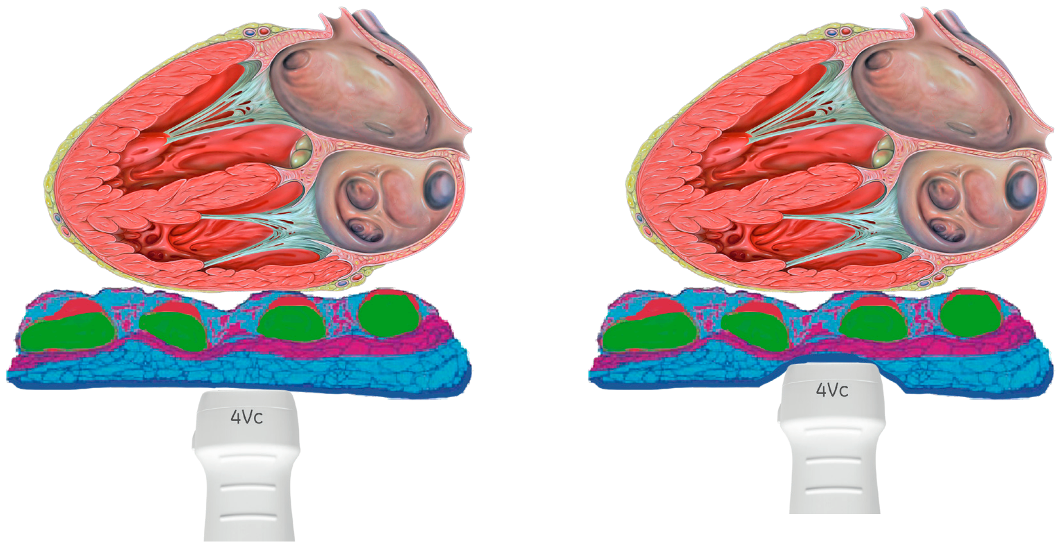


Figure 4: illustration of probe against body compression to move tissue from probe and closer to heart to facilitate scanning.

Credit image: de Robert Waag. Simulation of ultrasonic pulse propagation, distortion, and attenuation in the human chest wall, T. D. Mast, L. M. Hinkelman, L. A. Metlay, J. M. Orr, R. C. Waag, J. Acoust. Soc. Am. 106(6), 1999.

cSound: the ultrasound platform designed for technological breakthroughs

In 2015, GE HealthCare's cardiovascular imaging team released the Vivid E95, providing clinicians with an unprecedent leap in image quality. This technological breakthrough was made possible thanks to the cSound architecture, which allows for a new level of versatility, flexibility and processing power in image acquisition, reconstruction and visualization.

The main component in the cSound platform is a fully configurable software image former. To run this software, the Vivid E95 is equipped with multiple GPUs. Unlike inexpensive gaming boards, the professional grade GPUs used in the Vivid E95 are designed to reliably handle 100% utilization over prolonged periods. One of the main benefits of the cSound implementation on Vivid E95 is that we can leverage new, more powerful and more power efficient GPUs as they enter the market. Each new generation of GPU brings new opportunities for implementing more powerful algorithms. In 2022, the GPUs embarked on the Vivid E95 combine a processing power which is about 15 times more powerful than the first Vivid E95 release in 2015, with the additional possibility to run artificial intelligence networks.

In 2016, GE HealthCare launched the 4Vc-D probe, providing an ergonomically efficient one-probe workflow that combined break-through image quality in 2D, Color Flow and Doppler with ultra-high volume rates in 4D.

Aberration is by nature a 3D phenomenon, and accurate corrections of wavefront aberrations cannot be achieved with conventional 1D or 1.5D transducers. The 4Vc-D probe is built on a unique XDclear 2D array technology and has the highest element count of the cardiovascular ultrasound industry. This allows for the estimation and correction of aberration delays with the resolution needed to improve the image.

Today, 20 years after Wayne Rigby's pioneering work, and thanks to 2D array technology and the flexibility and processing power offered by the cSound architecture, GE HealthCare is proud to introduce cSound ADAPT imaging on the 4Vc-D transducer.

Did you know?

In 2000, a team at GE HealthCare researchers led by Wayne Rigby demonstrated, for the first time, that correcting for ultrasound wavefront distortions could improve images of human subjects. The team modified a GE HealthCare LOGIQ 700 imager so that the signals from every element in a custom multi-row probe could be processed in a rack of 60 processors (a precursor of today's GPU-based software imagers). Corrections to the beamforming time delays were calculated to compensate for the distortion in the ultrasound wavefronts created by the abdominal wall and sent back to the LOGIQ 700. Today, such calculations can be performed many times faster by the GE HealthCare Vivid E95.

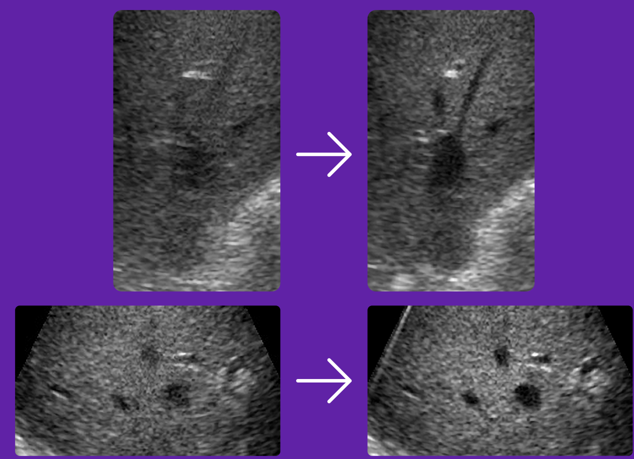


Figure 5: light waves are disturbed upon entering earth's atmosphere

A technology inspired by the stars

Like ultrasound energy traversing the human body, light from stars propagates across the universe as waves. These light waves travel through space mostly undisturbed (see figure 5), but when entering the Earth's atmosphere, atmospheric turbulence distort the arrival time of these wavefronts. The effect is a distortion and twinkling of the image acquired by telescopes. These optical aberrations blur the finest image details of the cosmos, a challenge for astronomers ever since they first built telescopes.

To reduce the effect of aberrations on ground-based telescopes, astronomers have developed telescopes with adaptive optics. This method uses sophisticated, deformable mirrors controlled by computers that can correct in real-time for the distortion caused by the turbulence of the Earth's atmosphere.

With the introduction of adaptive optics in the late 1990's, astronomers have been able to observe finer details of much fainter astronomical objects than would otherwise be possible from the ground, making the images obtained almost as sharp as those taken in space (see figure 6).

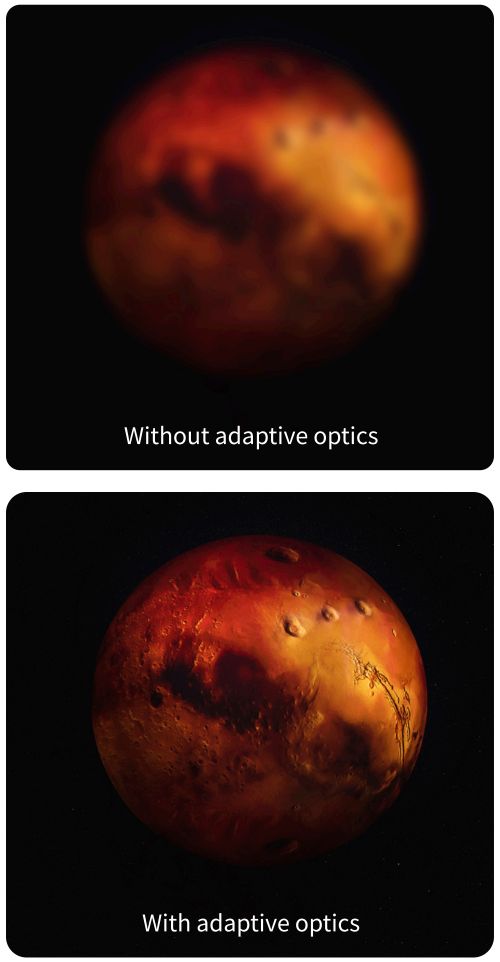


Figure 6: adaptive optics effect illustration

cSound ADAPT

Introducing cSound ADAPT

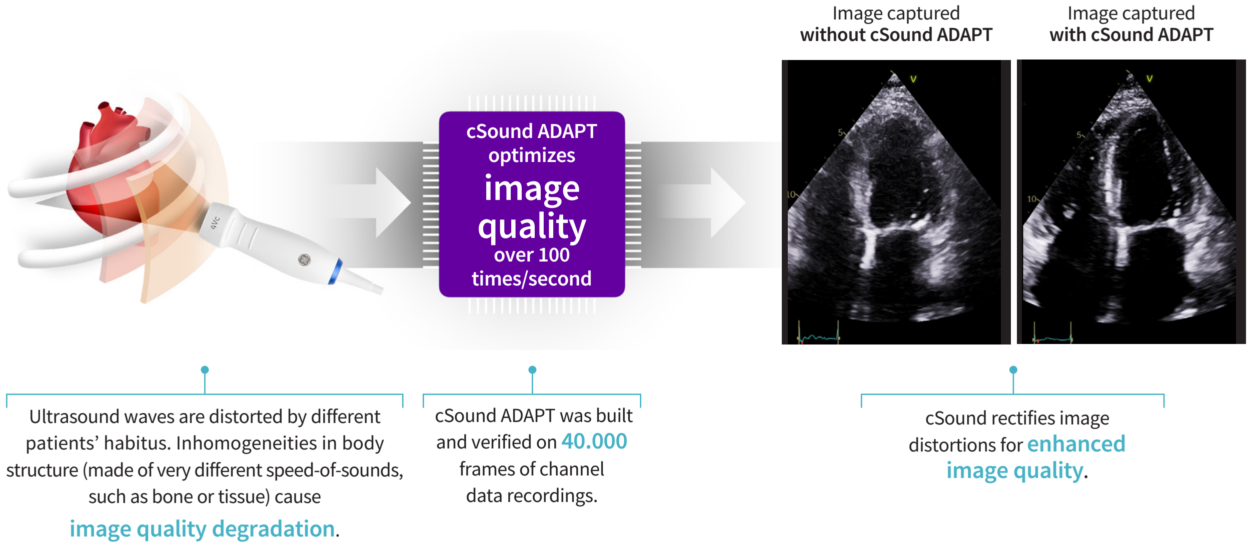
Ultrasound images are created by sampling the ultrasound wavefront across the transducer aperture, then delaying and summing those sampled signals. The signal delays are calculated using an idealized model of the sound propagation in the human body. Aberrations distort the wavefront as it propagates through the thoracic wall, which degrades the image calculated using the idealized propagation model. The cSound ADAPT algorithm on the Vivid E95 continuously estimates and corrects for this wavefront distortion.

Aberrations depend on the properties of the tissue through which the ultrasound beam propagates: its position, shape, and sound speed. For cardiac imaging, the aberrations vary not only with the position of the probe on the patient's chest but also with the movement of the tissue in the thorax caused by the beating heart.

cSound ADAPT analyzes the 4Vc-D transducer channel signals several hundreds of times per second, so that imaging with the 4Vc-D transducer is optimized, in every location, in real-time.

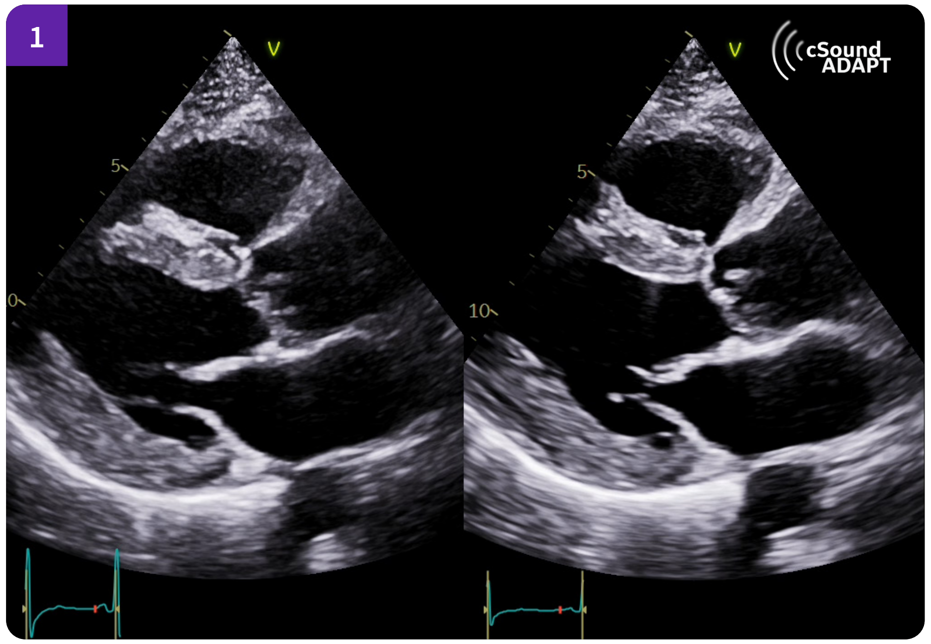
An algorithm backed-up by 40,000 images

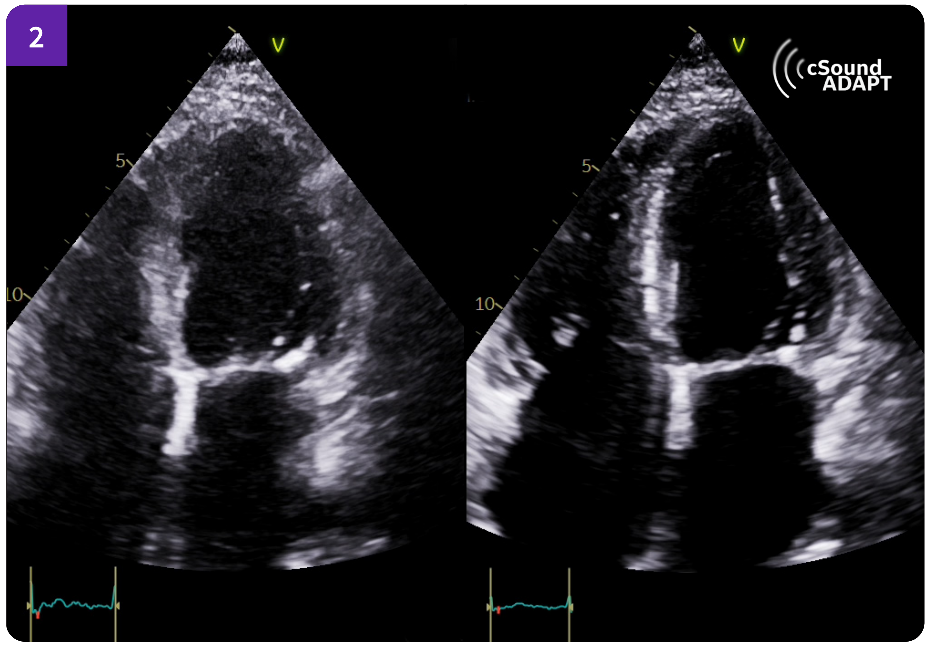
cSound ADAPT was developed in close collaboration with researchers at the Centre for Innovative Ultrasound Solutions, Norwegian University of Science and Technology, and the St. Olavs Hospital, Trondheim, a historical center of excellence for ultrasound imaging. The technology was built and verified on a very large database of forty thousand frames of channel data recordings acquired in the clinic.



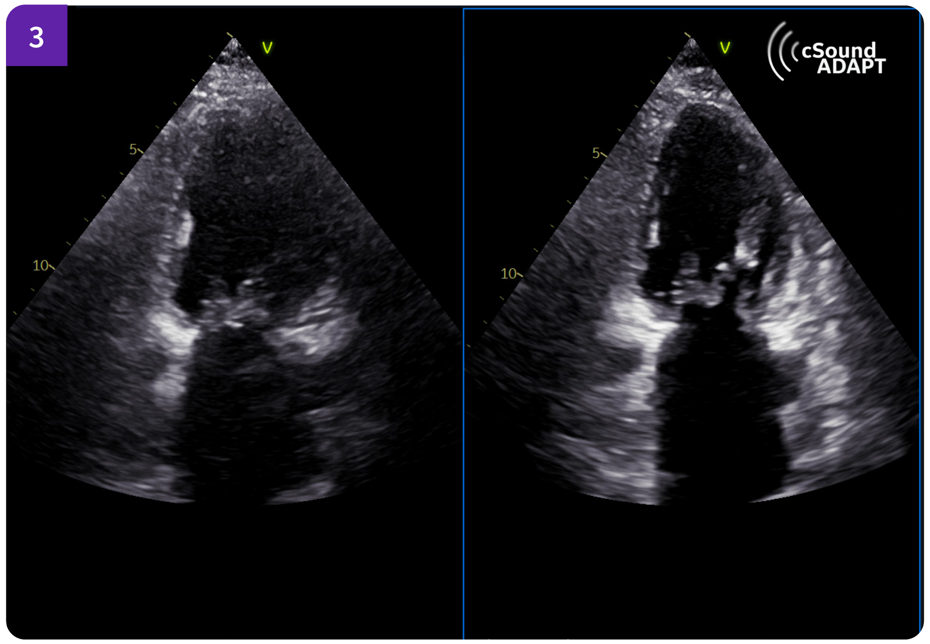
cSound ADAPT in action – clinical images

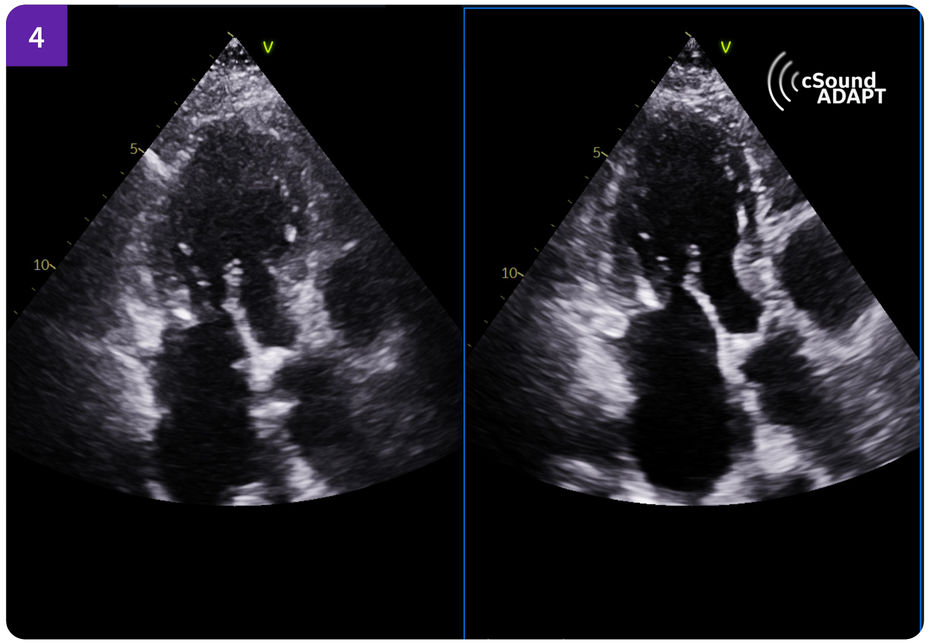
The cSound ADAPT algorithm on the Vivid E95 continuously estimates and corrects for aberrated wavefront distortion. The clinical images below show side-by-side examples. Each pair of images was acquired on the same patient scanned by the same operator, using the same 4Vc-D probe, in the same session.



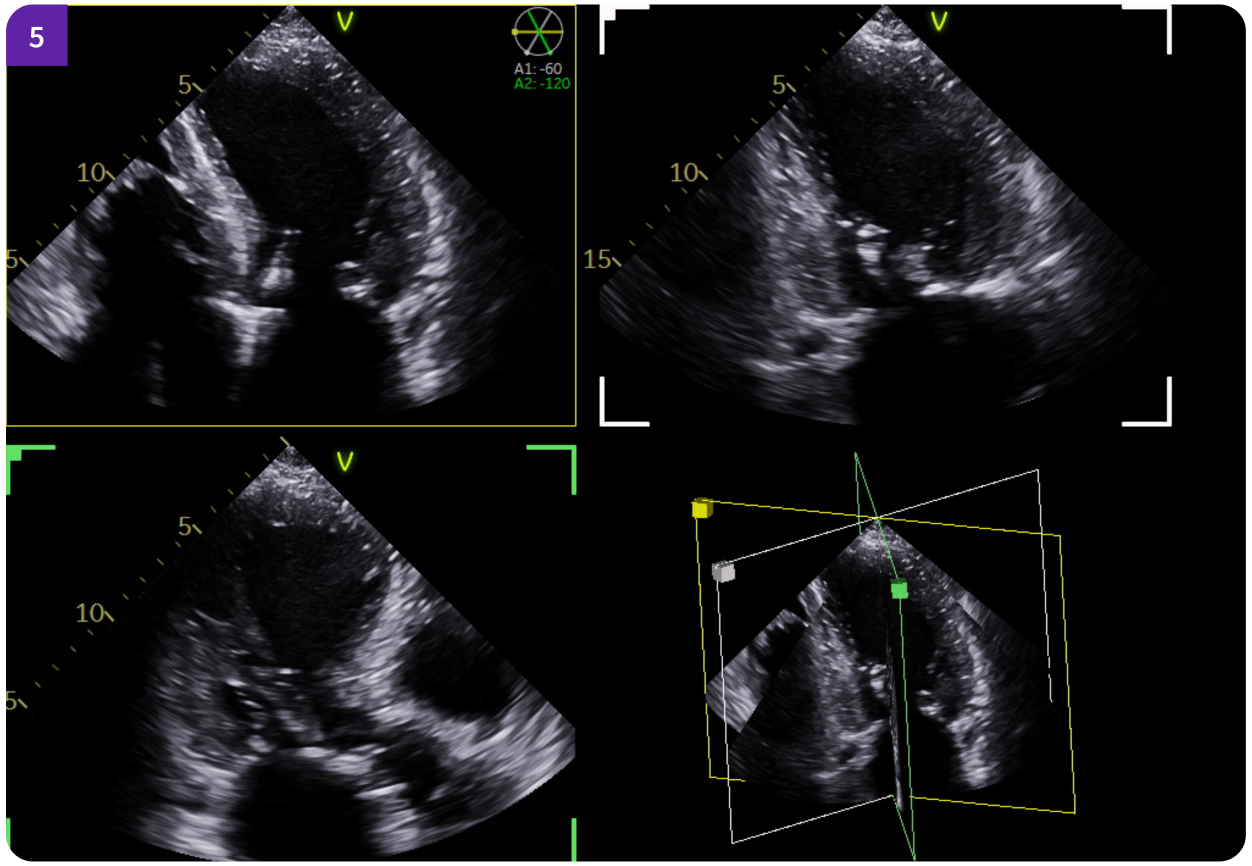


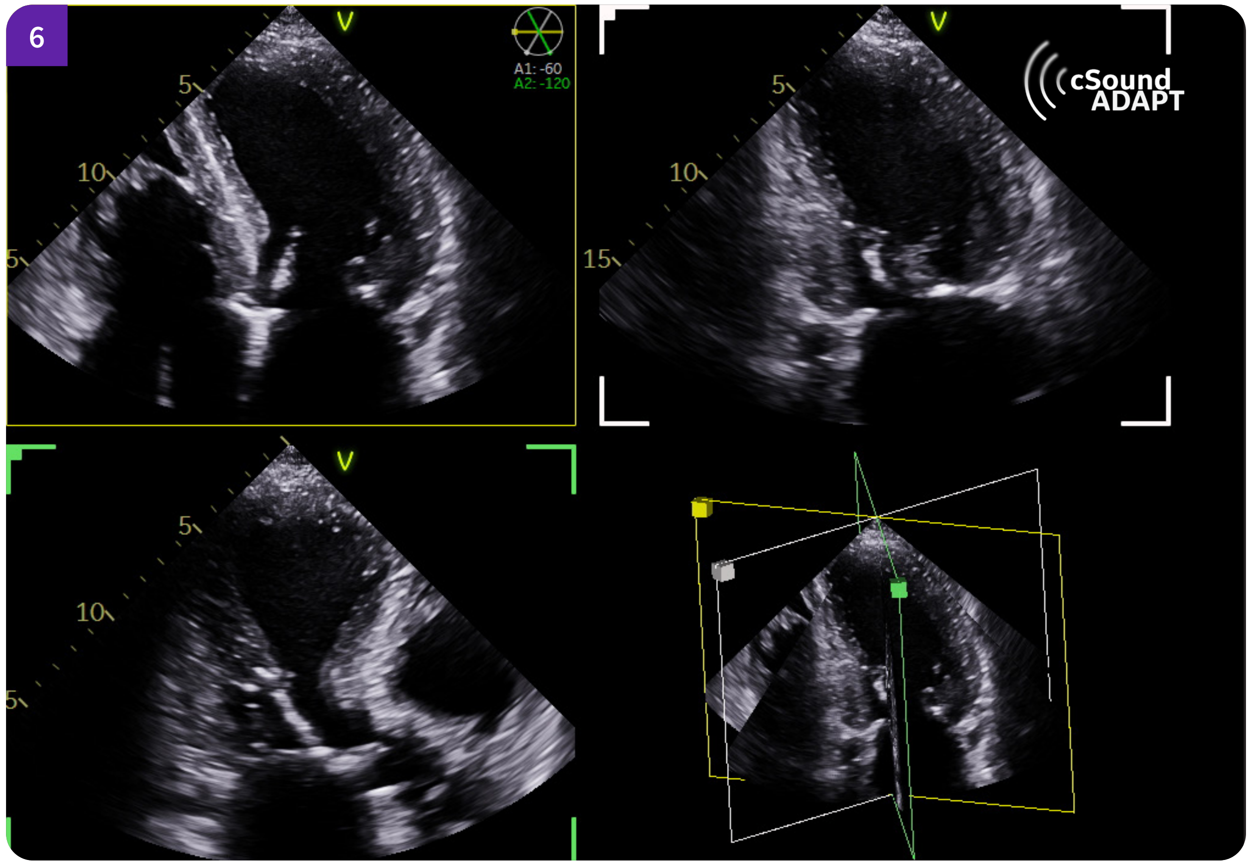
1. Comparison of a Parasternal Long Axis view (PLAX) acquired using the previous Vivid Ultra Edition release and with cSound ADAPT, available with 2022 release.
2. Comparison of a 4 Chamber view (4CH) acquired using the previous Vivid Ultra Edition release and with cSound ADAPT, available with 2022 release.





3. Comparison of a 2 Chamber view (2CH) acquired using the previous Vivid Ultra Edition release and with cSound ADAPT, available with 2022 release.
4. Comparison of an Apical Long Axis view (ALAX) acquired using the previous Vivid Ultra Edition release and with cSound ADAPT, available with 2022 release.





5-6. Comparison of a Triplane view acquired using the previous Vivid Ultra Edition release and with cSound ADAPT, available with 2022 release.

Clinical pilot trial

Trondheim University Hospital and The Norwegian University of Science and Technology (NTNU) in Trondheim, Norway conducted a pilot trial to validate the clinical potential of cSound Adapt. The local ethics committee approved the study, and the Clinic of Cardiology at the hospital consecutively recruited 22 patients (11 women and 11 men). Patients who were hemodynamically unstable, had arrhythmia, or lacked competence to consent were excluded.

For each patient, one cineloop containing one heart cycle was recorded using the Vivid E95 scanner with the 4Vc-D probe for five standard 2D views: parasternal long axis (PLAX), parasternal short axis (PSAX), apical four chamber (A4C), apical two chamber (A2C), and apical long axis (ALAX). This resulted in a total of 116 cineloops. Images were stored both with and without cSound Adapt generated from the exact same acquisition, using a specialized protocol.

Since cSound is a software image former, it allows for the calculation of image quality metrics from the data acquired before image formation. In this trial, a metric was devised and calculated to measure how much the arriving echoes to each element in the 4Vc-D probe deviates from the theoretically perfect spherical form. An increase in this metric indicates reduced deviation and consequently improved alignment of echoes during beamforming. Figure 7 shows a box plot of the relative increase in this metric for the different cardiac views recorded in the trial. As shown, the metric improved for all images and the median value improved by more than 50% for all cardiac views.

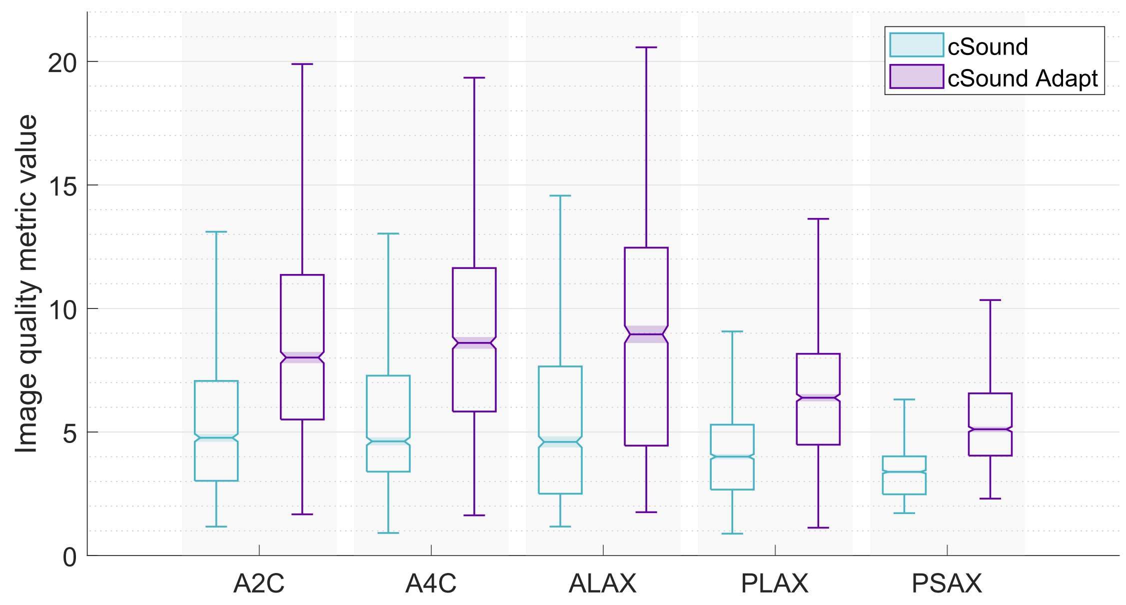


Figure 7: Box plot of the image quality metric with/without processing with cSound Adapt as a function of cardiac view.

Four cardiologists evaluated 116 image cases in a blinded and left-right-randomized side-by-side evaluation. They preferred the cSound Adapt images in 97% of the cases, noting that the cSound Adapt images appeared sharper with better contrast, and the structures such as valve leaflets, chordae, and the endocardial borders appeared narrower and more clearly defined.

In summary, the results of this pilot trial shows that clinicians prefer cSound Adapt in almost all cases, and that this aligns with an increase in the image quality metric. The findings suggest that cSound Adapt has significant potential for aberration correction in cardiovascular ultrasound imaging.

Conclusion

With an increasing workload pressure on cardiology medical staff today, and image quality at the heart of quality, improvements on 2D and 4D in ”easy to scan” patients are not enough to further boost diagnosis confidence.

GE HealthCare is proud to bring to market cSound ADAPT, developed to improve image quality by addressing a decades-long problem for the echolab scientific community – counteracting phase front aberrations derived from patient body habitus, one of the root causes of image quality degradation in medical ultrasound.

Through our collaboration with prestigious academic institutions, the cSound ADAPT technology was created and was verified on forty thousand image data sets, optimizing the image hundreds of times per second even in challenging situations.

References

*Sound ADAPT is exclusively available for the Vivid™ E95.

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