

# *ADVANCEMENTS IN USG TECHNOLOGY*

# HARMONIC IMAGING

- Harmonic frequencies are integral multiples of the frequencies contained in an ultrasound pulse (a  $f$  MHz, upon interaction with a medium, will contain high-frequency harmonics of  $2f, 3f, 4f$  and so on, etc.)
- These higher frequencies arise through the vibration of encapsulated gas bubbles used as ultrasound contrast agents or with the nonlinear propagation of the ultrasound as it travels through tissues.
- Harmonic imaging enhances contrast agent imaging by using a low-frequency incident pulse and tuning the receiver (using a multi frequency transducer) to higher-frequency harmonics.
- For harmonic imaging, longer spatial pulse lengths are often used to achieve a higher transducer Q factor.
- Improve the sensitivity to the ultrasound contrast agent.

- Body wall region close to transducer → less harmonics.
- At depth → less harmonics (increasing attenuation of higher order harmonics). Strongest harmonics at greatest pressure amplitudes (near pulse center).
- Resultant effect → at near surface good rejection of artifacts & clutter from multiple pulse reflections.
- Most useful in technically difficult patients i. e. thick & complicated body wall structures.
- Conventional imaging → hazy image (distortion of the transmitted beam by shallow surface layers or to reverberations between the skin and ribs). The distortions and reverberations consist entirely of us energy at the fundamental frequency.



## ○ Peculiarities of harmonic image:

- Increase signal-to-noise ratio with better interpretation of image.
- Superior lateral & elevational resolution as compared to the fundamental images.
- Removal of clutter and haze with more clear and defined image due to side-lobe level reduction in the second harmonic beam. Harmonic beams are narrower with lower side-lobe levels than fundamental ones.



### Conventional



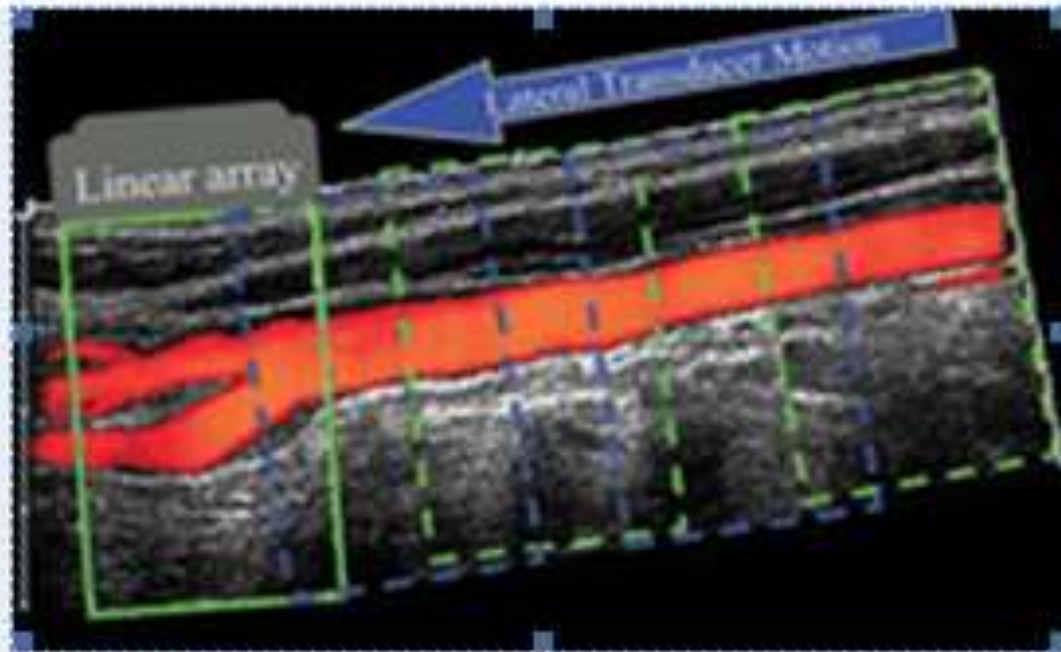
### Harmonic



■ **FIGURE 14-48** Conventional (**left**) and harmonic image (**right**) of the kidney demonstrate the improved image quality of the harmonic image from reduced echo clutter, increased contrast, and resolution. (Images provided by Dr. Kiran Jain, MD, University of California Davis Health System).

## EXTENDED FOV IMAGING

- The transducer is slowly translated laterally across the large anatomic region of interest.
- During this motion, multiple images are acquired from many transducer positions.
- The proper relative positions of the multiple images are determined in the regions of overlap between successive images.
- The registered image data are accumulated in a large image buffer and then combined to form the complete large FOV image
- Can be used to view whole course of vessels.

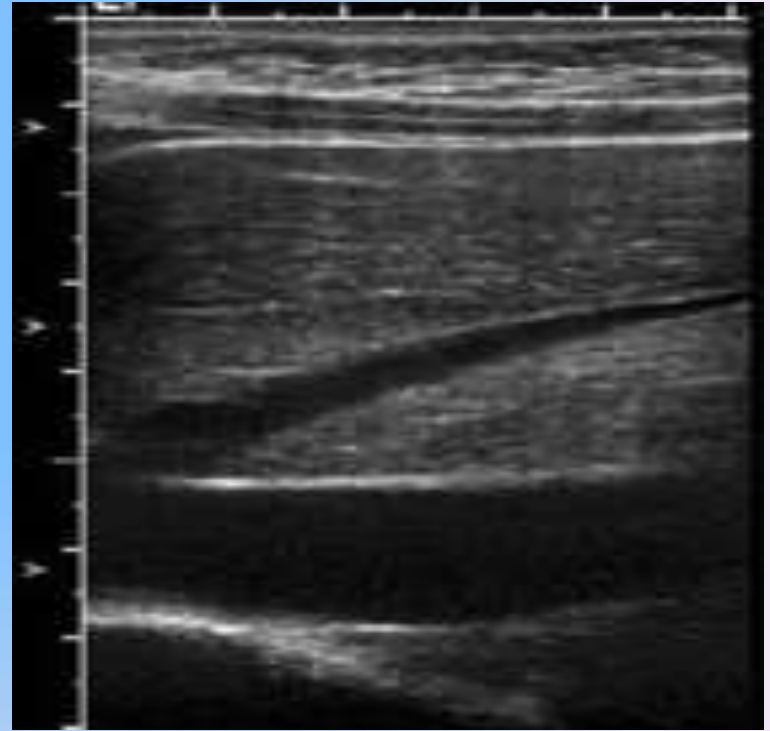
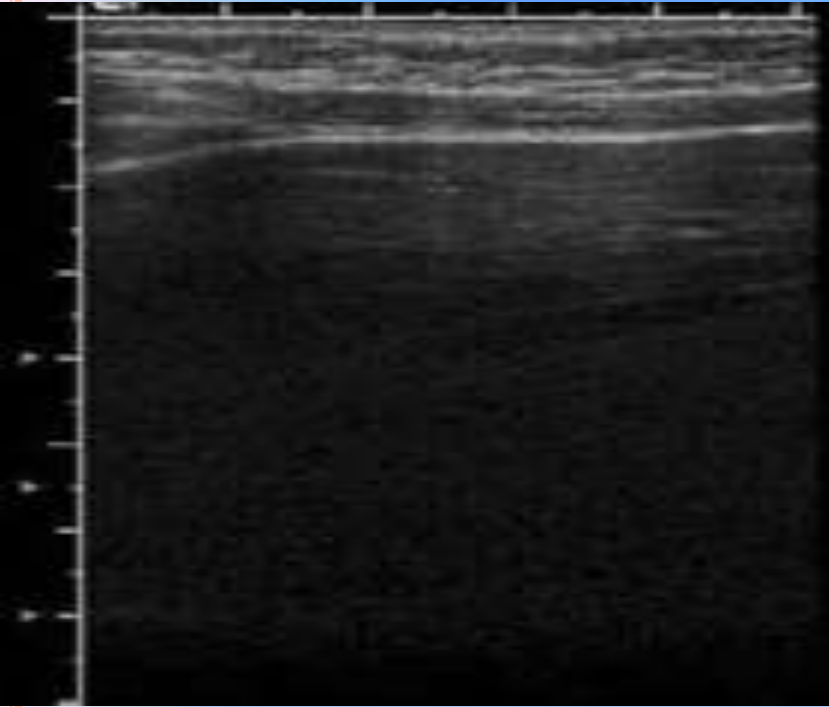


Extended FOV color flow image of the carotid artery.

## CODED PULSE EXCITATION

- Short, highly focused ultrasound pulses that optimize spatial resolution are generally obtained at higher frequencies.
- Higher frequency-more attenuation.
- Coded ultrasound pulses are a potential means of overcoming this limitation, providing good penetration at the higher frequencies necessary for high spatial resolution.
- The coded pulses are produced with a very specific, characteristic shape, and the resulting echoes will have a similar shape.
- These pulse shape locations may be determined with a tight spatial tolerance and are assumed to correspond to the locations of reflective structures in the body.
- The end result is an image with good echo signal and good spatial resolution at large depths.





Conventional B-mode and coded pulse US images of the liver. The spatial resolution of the coded pulse image is very comparable with that of the 13-MHz conventional image . However, the useful imaging depth is about 7.5 cm for the coded pulse image compared with only about 2.8 cm for the conventional image.



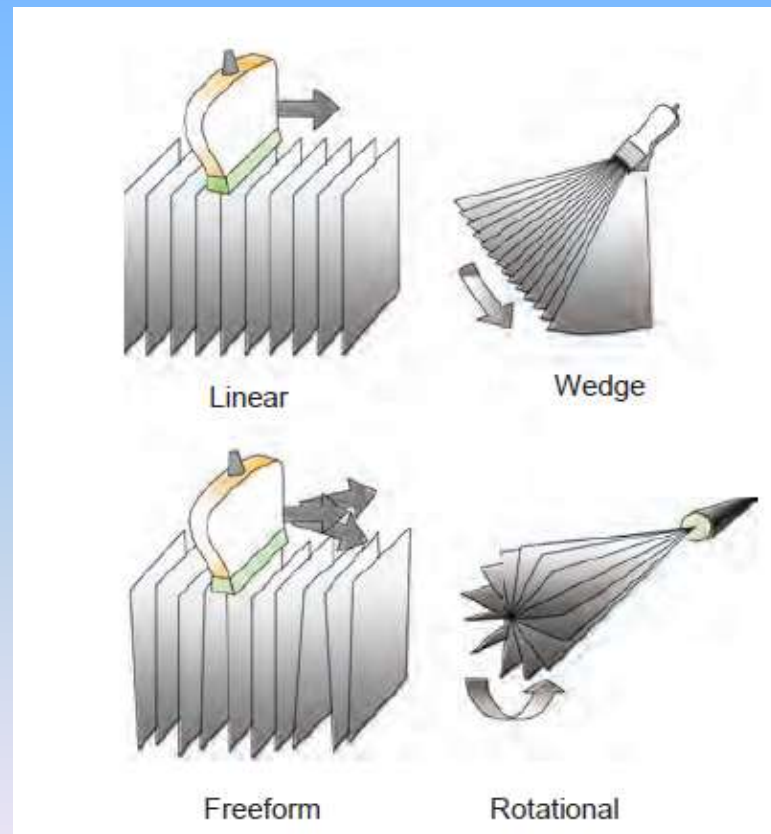
## 3D US

- 3D ultrasound imaging acquires 2D tomographic image data in a series of individual B-scans of a volume of tissue.
- Forming the 3D dataset requires location of each individual 2D image using known acquisition geometries.
- 3D ultrasound works by taking thousand of slices in a series (called volume of echoes) the volume are then digitally stored and shaded to produce 3D images that look more life like.



Volume sampling can be achieved in several ways with a transducer array:

- (1) linear translation,
- (2) freeform motion with external localizers to a reference position,
- (3) rocking motion, and
- (4) rotation of the scan



# 4D ULTRASOUND

- 4D Ultrasound represents the difference between video and a still photograph.
- Through this technology, three-dimensional image is continuously updated, providing a "live action" view.
- The entirely digital platform and very fast processors cope with the large volume of data required to reconstruct 3D images again and again, giving the impression of a moving image.
- 4D Ultrasound takes multiple 2-dimensional ultrasound images, creates a 3-dimensional image and adds the element of time to the process. The result: live action images of any internal anatomy.



Chewing



Firstwhinge



Sleepy

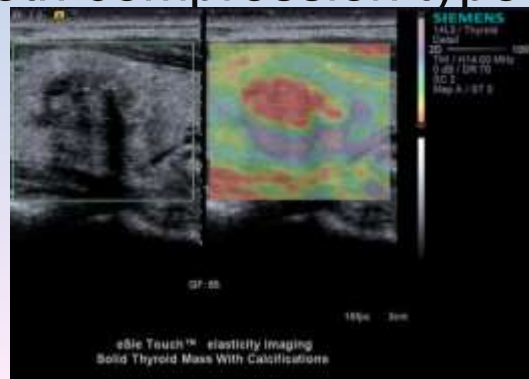


Smiling

# ELASTOGRAPHY

- Stiffness and compliance of different tissue can be assessed .
- A set of digital RF echo data from ROI is obtained and the tissue is then compressed usually by transducer and further set of RF echo data obtained.
- This is then cross correlated with initial data and any changes in arrival time of pulses from equivalent volume of tissue can be obtained.
- An estimate of local tissue strain can be assessed and from this the degree of tissue stiffness can be assessed.
- Tissue stiffness is described by the Young modulus expressed in kilopascals ( $E = 3\gamma C^2$ ).
- The elastography methods are based on a common approach: measurement of deformation induced in a tissue by a force.

- Elastography is therefore an application, which produces the force coupled with a measurement system for the deformities caused by the force.
- There are several types of forces or applications:
  - static compression induced externally by manual compression or internally by organ motion (heart, vessel, breathing);
  - dynamic compression induced with a continuous vibration at a given frequency;
  - impulse compression (transient vibration): induced externally by a transient mechanical impulse (FibroScan<sup>®</sup>) or internally by an ultrasound impulse (ARFI, SWE), both compression types producing shear waves.



# ELASTOGRAPHY TECHNIQUES

## ○ Impulse elastography:

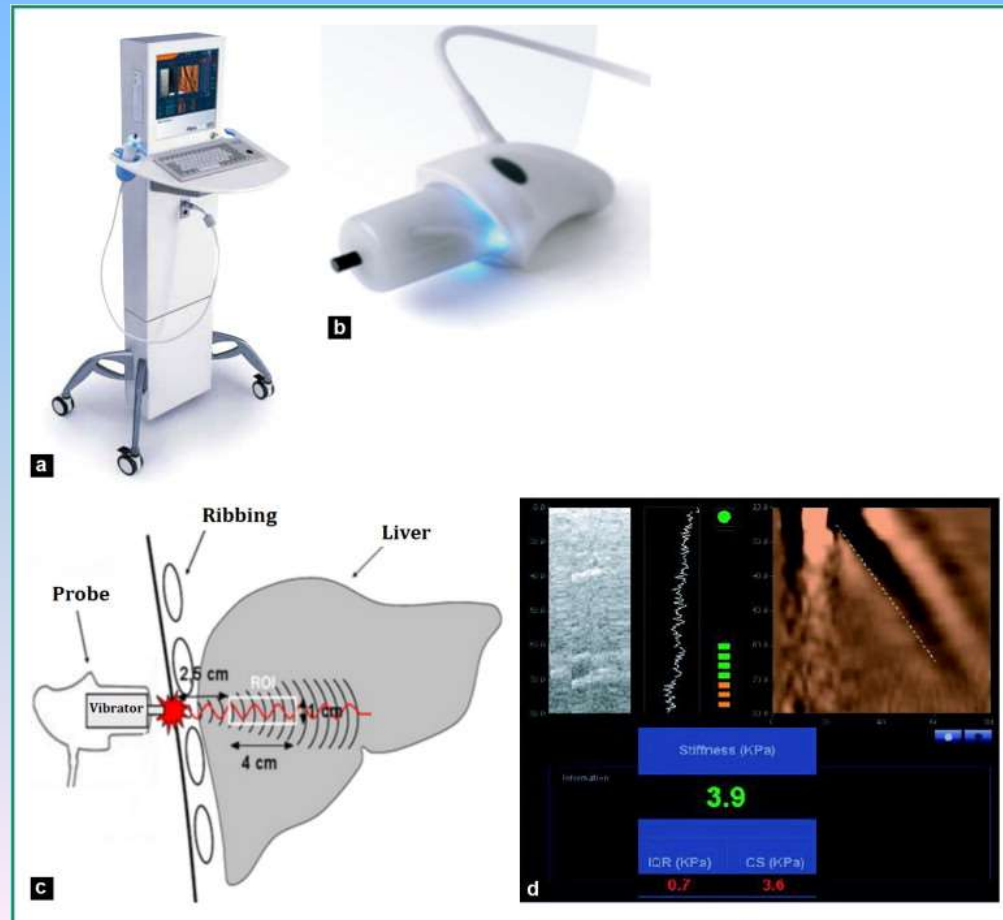
- Uses an external mechanical device (FibroScan) or an internal acoustic radiation force (ARFI and SWE) to induce shear waves in the tissue to be explored.
- Shear wave propagation velocity ( $V_s$ ) is then measured in m/s using ultrasound imaging in the tissue being studied in order to assess its stiffness.

## ○ Uni-dimensional transient elastography: FibroScan

- Developed around 10 years ago
- Based on shear wave, which is generated by an external mechanical impulse and whose speed is measured by an ultrasound one-dimensional probe.
- The one-dimensional probe (3.5 MHz) is mounted along the axis of an electro-dynamic transducer (vibrator).



- The FibroScan<sup>®</sup> estimates liver stiffness by measuring the velocity of elastic shear waves in the liver parenchyma generated by the mechanical push.
- The propagation velocity is directly related to the stiffness of the medium, defined by the Young modulus.
- Stiff tissues exhibit higher shear wave velocities than soft tissues.

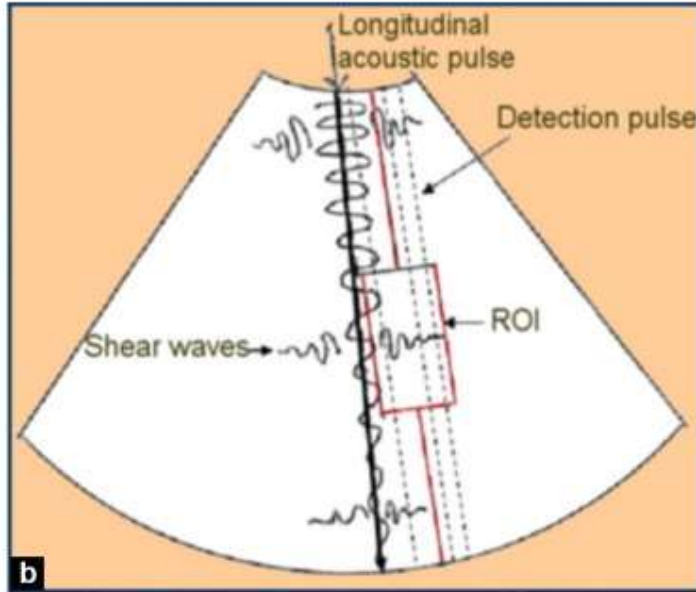


## ○ Acoustic Radiation Force Impulse (ARFI) Imaging mode elastography:

- A new method for quantifying mechanical properties of tissue, without manual compression, by measuring the shear wave velocity induced by acoustic radiation and propagating in the tissue.
- Developed by Siemens.
- Provides a single uni-dimensional measurement of tissue elasticity like the FibroScan, although the measurement area can be positioned on a two-dimensional Bmode image.
- The region is a  $1 \times 0.5$  cm rectangular, which can be freely moved in the two-dimensional Bmode image to a maximum depth of 8 cm from the skin plane.
- The measurement is expressed in m/s, expressing shear wave speed, travelling perpendicular to the shear wave source.
- The technique has been implemented on the ultrasound probe designed for abdominal imaging.



**a**



**b**

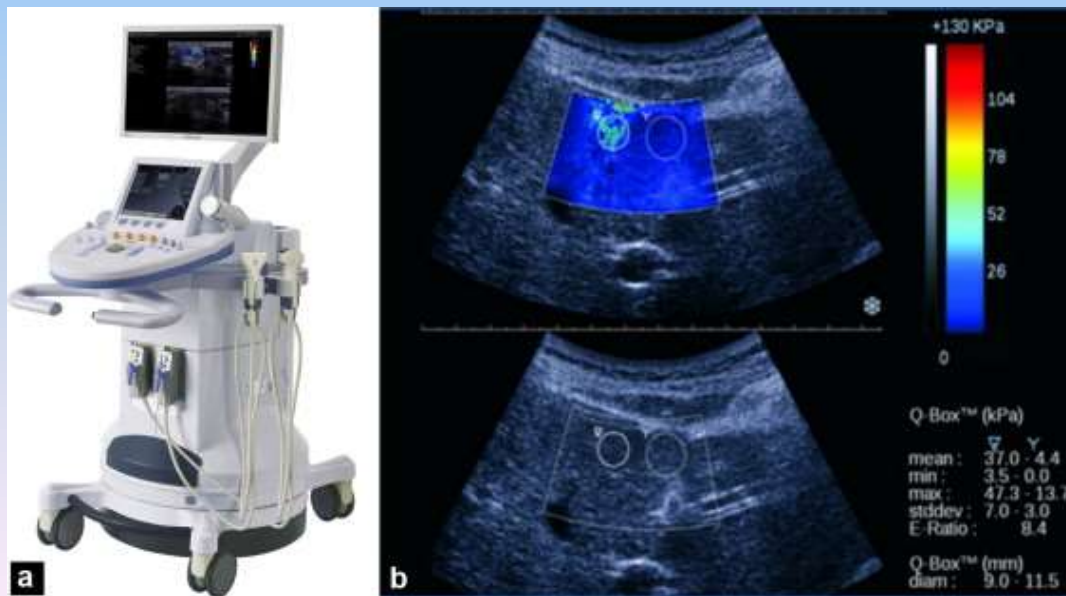


**c**

## ○ Shear Wave Elastography (SWE):

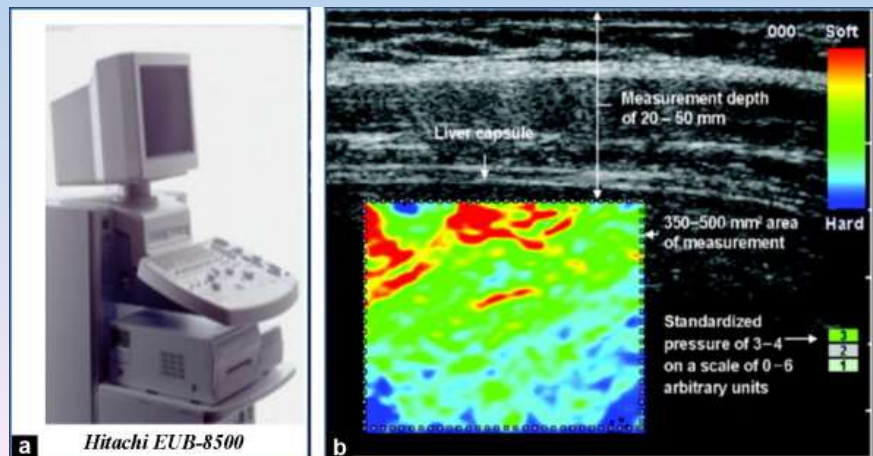
- Was introduced in 2005.
- Relies on the measurement of the shear wave propagation speed in soft tissue; like ARFI, does not require an external vibrator to generate the shear wave. Based on the generation of a radiation force in the tissue to create the shear wave.
- The ultrasound probe produces a very localized radiation force deep in the tissue of interest that induces a shear wave, which then propagates from this focal point.
- Several focal points are then generated almost simultaneously, in a line perpendicular to the surface of the patient's skin.
- This creates a conical shear wave front, which sweeps the image plane, on both sides of the focal point. The progression of the shear wave is captured by the very rapid acquisition of ultrasound images (up to 20,000 images per second), called UltraFast Imaging.

- A high-speed acquisition is necessary to capture the shear wave as it moves at a speed in the order of 1 to 10 m/s.
- Comparison of two consecutive ultrasound images allows the measurement of displacements induced by the shear wave and creates a “movie” showing the propagation of the shear wave whose local speed is intrinsically linked to elasticity.
- The propagation speed of the shear wave is then estimated from the movie that is created and a two-dimensional color map is displayed, for which each color codes either the shear wave speed in meters per second (m/s), or the elasticity of the medium in kilopascals (kPa).
- This color map is accompanied by an anatomic reference gray scale (or B-mode) image. This quantitative imaging technique is a real-time imaging mode.



## ○ Static elastography:

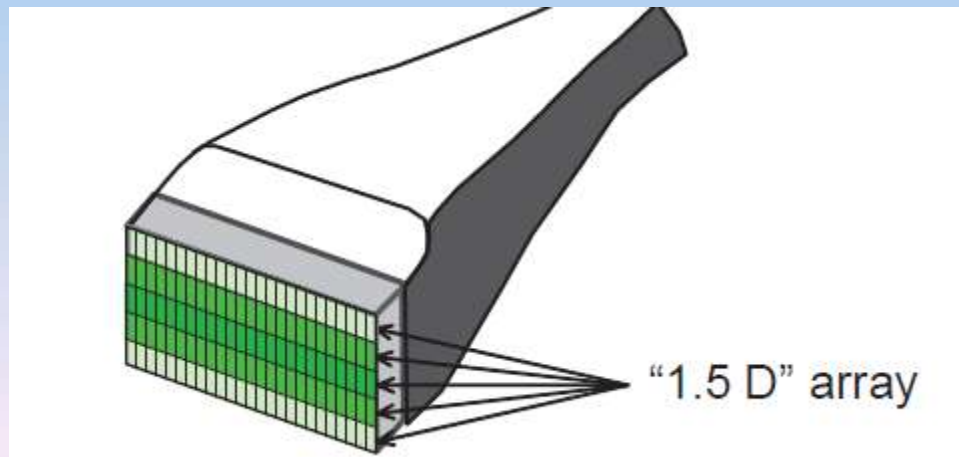
- Developed by Hitachi.
- The operator manually applies gentle pressure with the ultrasound probe in order to induce in the underlying tissues a deformation.
- Only the deformed tissue subject to the manual compression is measured, rather than a direct measurement of elasticity. The deformation is considered to be inversely proportional to elasticity.
- A color map of tissue elasticity is obtained: this is a qualitative approach. In more recent systems, the deformation of the liver parenchyma as a result of vascular beating or respiration alone has also been used.



# TRANSDUCER DEVELOPMENTS

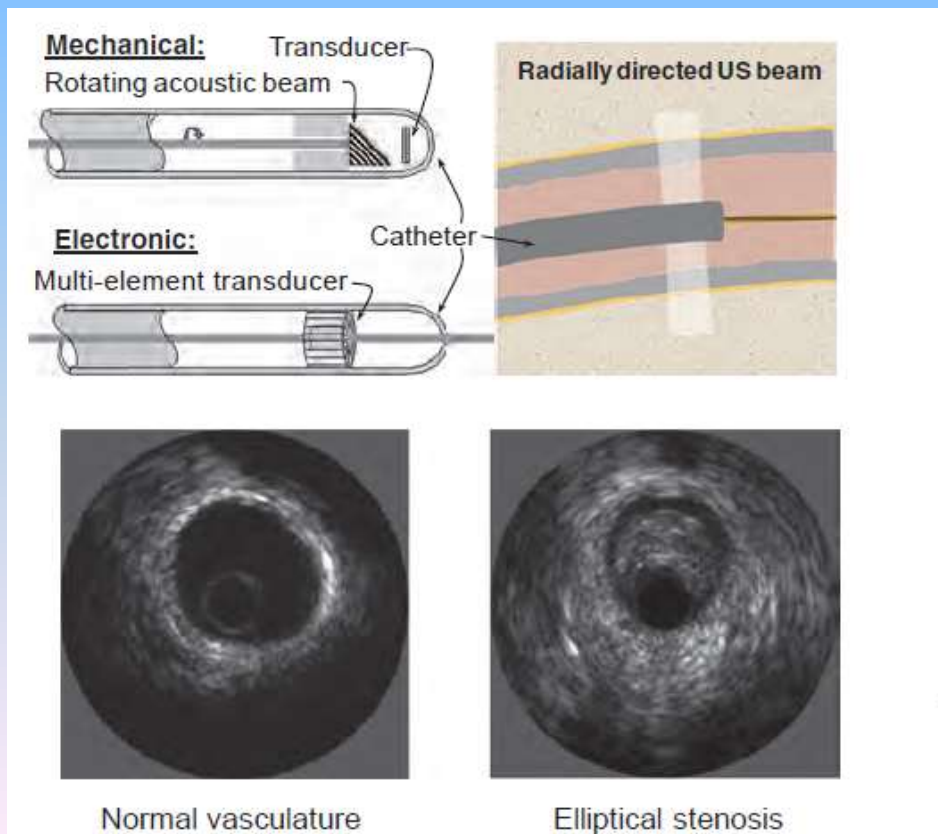
## ○ Multiement array transducers:

- Possible for US beam focus and steer electronically, different group of elements can be used for different tasks e.g pulse doppler.
- Beam can be manipulated in two direction thus improving resolution.
- Now days 2D array are available possible for volume scan(3D and 4D possible)



## ○ Small sized transducers:

- Can be mounted on catheter to pass into coronary arteries.
- Specialized transducer like trans rectal and TVS(endo cavity).





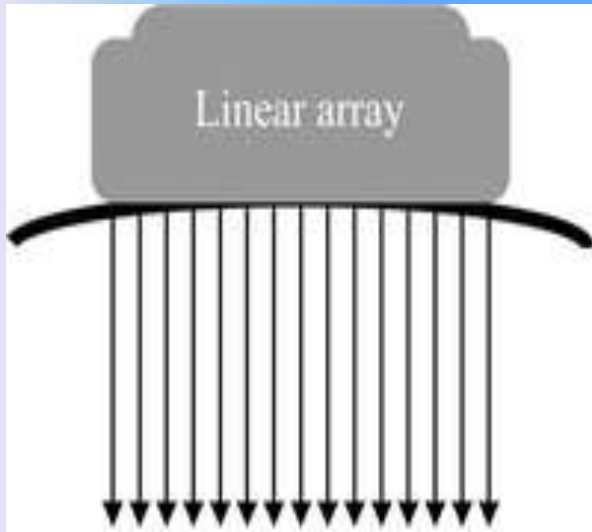
# ECHO-ENHANCING AGENT

- Most agents comprised of encapsulated microbubbles of 3 to 5 micrometer diameter containing air, nitrogen, or insoluble gaseous compounds such as perfluorocarbons.
- Encapsulation materials, such as human albumin, provide a container for the gas to maintain stability for a reasonable time in the vasculature after injection.
- Response of US to microbubble depends on acoustic power.
  - At low power (MI -0.1-0.3) they reflect and scatter Us.
  - At moderate power (MI abt 0.5) they resonate frequency of US.
  - At high power (MI-0.7-0.8) microbubble oscillate nonlinear fashion and production of harmonic signal which are specific to agent .
  - More than this power micro bubble disrupted and burst.

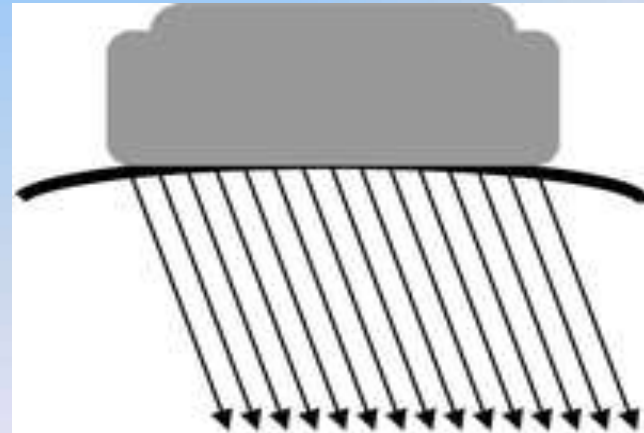
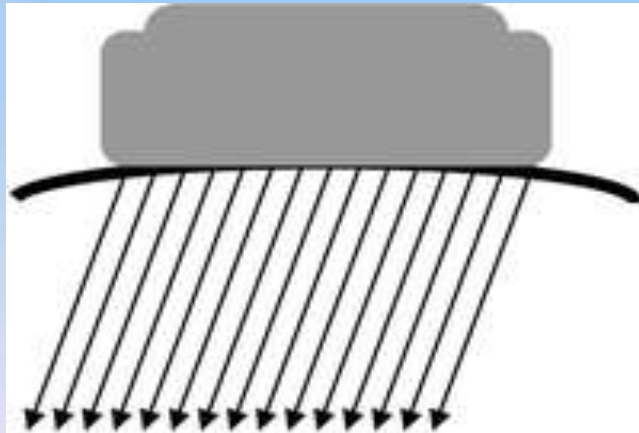
# SPATIAL COMPOUND IMAGING

- Aims to improve image quality by averaging several coplanar ultrasound frames into a single image.
- **Mechanism:**
- Repeated us beam steering in same tissue by an array transducer using parallel beams oriented in different directions → echoes from multiple acquisition of same tissue → averaged → single composite image.
- Multiple beams for same tissue (vs one beam in conventional B-mode imaging) hence more time for data acquisition & reduced frame rate.





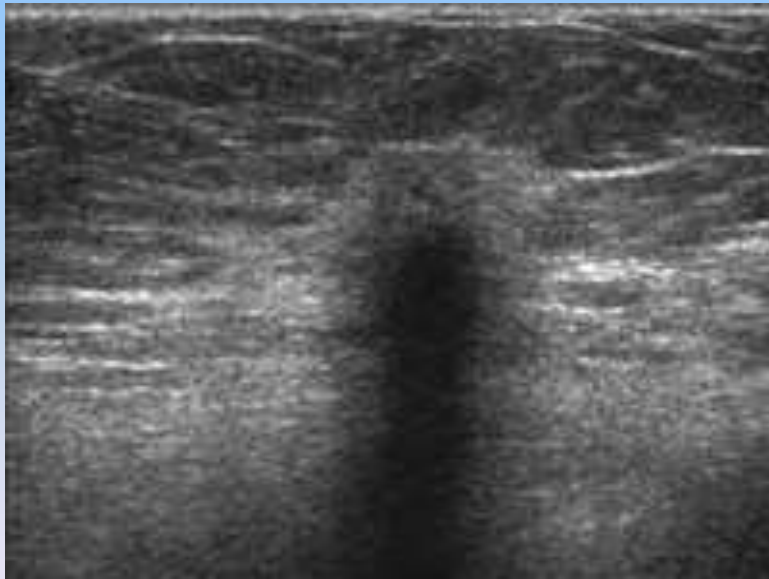
set of us beam lines for conventional imaging



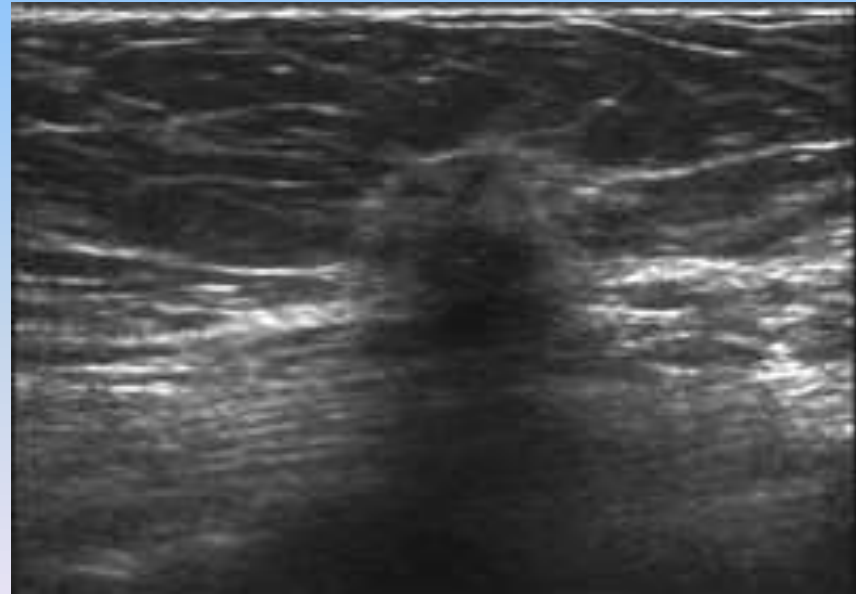
Two additional set of us beam lines for spatial compound imaging. Upto nine sets are used.

## ○ Advantages of compound imaging:

- greater spatial details of lesions and tissue in the FOV with decreased image graininess (due to speckle). Speckle varies with beam line direction, averaging echoes from different directions average out and smooth the speckle with less grainy image.
- Improved contrast & margin definition.
- Reduction of enhancement & shadowing artifacts.



Conventional image of breast mass



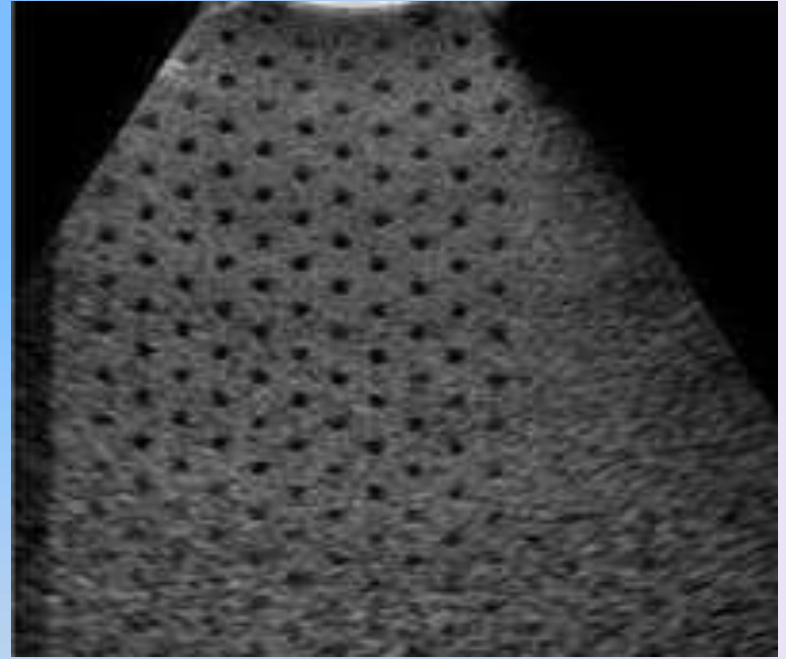
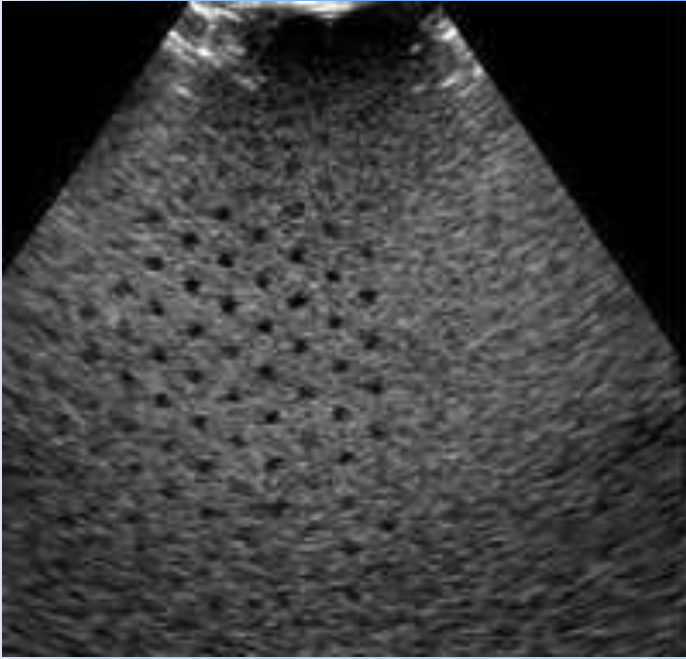
Spatial compound imaging of breast mass



# ELECTRONIC SECTION FOCUSING

- Electronic focusing of US pulse in the lateral direction by transducer arrays produces great benefits compared with mechanical focusing.
- Most transducers in current clinical use still employ mechanical focusing (curved piezoelectric elements or acoustic lenses) in section thickness direction → resultant highly variable section thickness → great difficulty in accurately visualizing small structures.
- Electronic focusing is employed with more than one-dimensional single row of piezoelectric elements {referred to as 1.25D, 1.5D, 1.75D, or full 2D (two-dimensional) arrays} as per the number of element rows and the level of independence with which the individual rows may be excited.
- Full-size, filled 2D array transducers are not yet commercially available, only 1.25D arrays are available.
- The greater the number of rows, the greater the ability for full electronic focusing which provide multiple, user-selectable elevational focusing and more uniform section profiles.





US images of a phantom with small anechoic spheres in conventional B mode & electronic focusing in section thickness direction.



# MINIATURIZATION

- Modern full-size US scanners are relatively portable and inexpensive.
- The general trend toward hardware miniaturization and the use of dedicated integrated circuitry is making possible even smaller and less expensive US scanners, with few (if any) compromises in general image quality and available features.
- This trend toward lower cost and smaller systems has great potential to radically alter the overall role of US in medicine.





Commercially available small US scanners from two vendors. The left scanners are 13.3 in (33.8 cm) tall and weigh 5.7 lb (2.6 kg), whereas the right scanners weigh about 3 lb (1.4 kg). The dedicated electronics module attached to the transducer cable weighs 10 oz (0.3 kg) and is 7.6 in (19.3 cm) long.

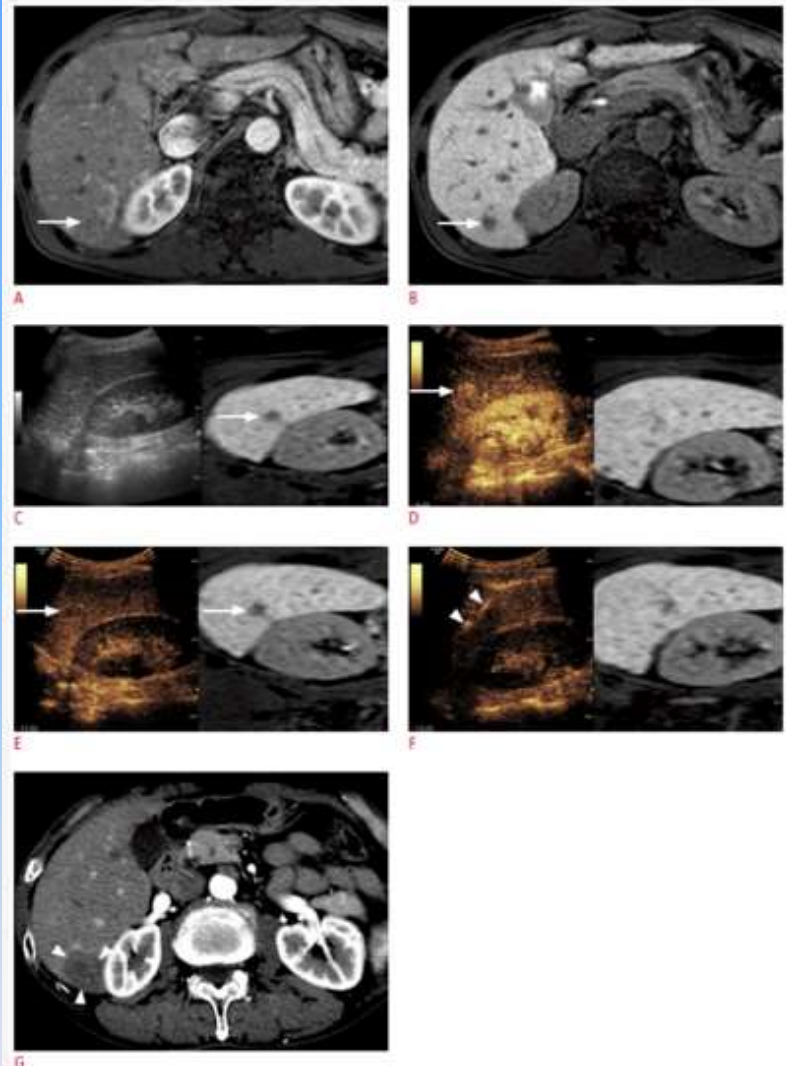




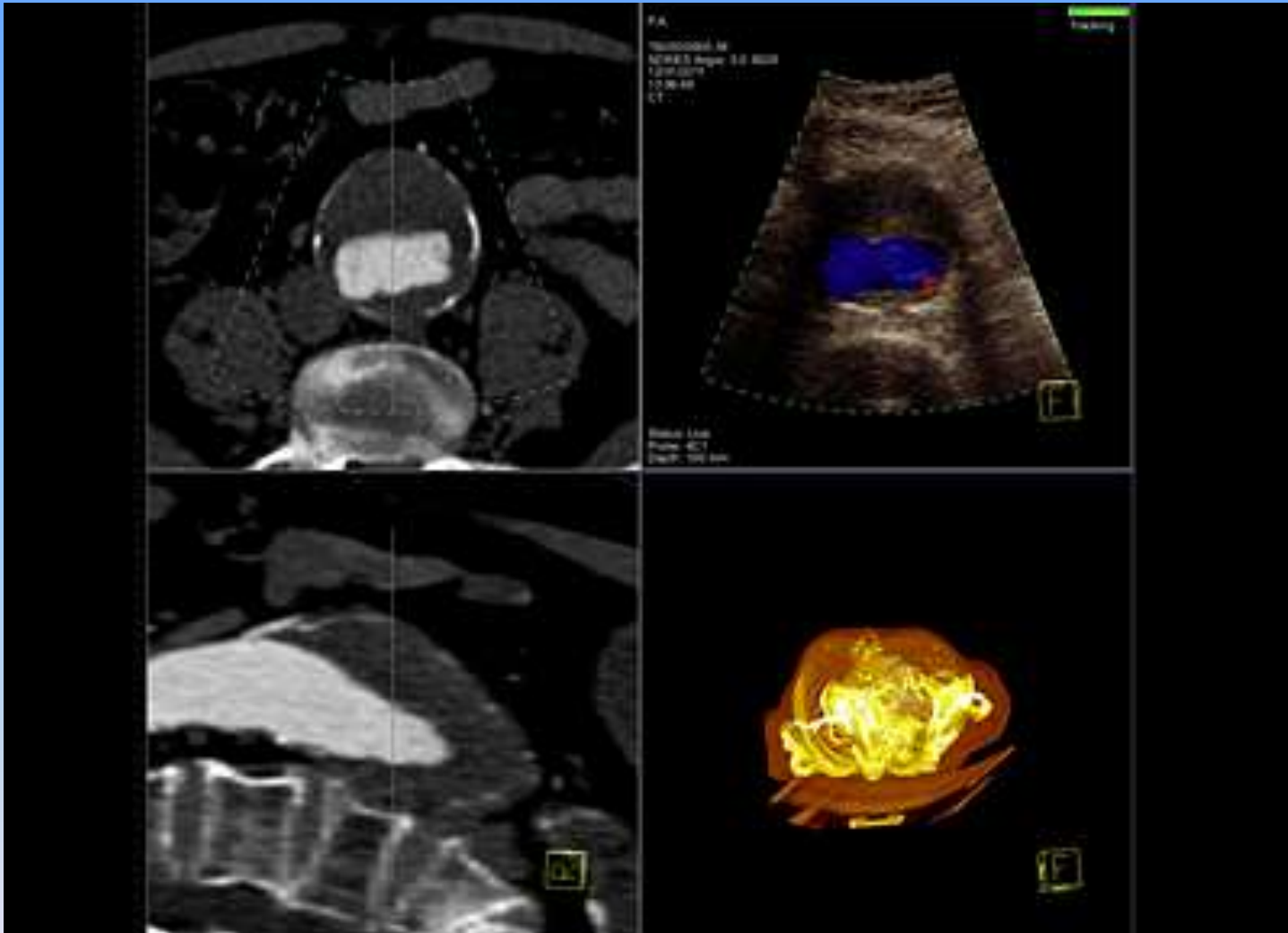
# FUSION TECHNOLOGY

- An emerging technique in the field of abdominal imaging with translation possibilities to neuroradiology.
- Involves co-registered display of live ultrasound with a reference series from another modality, such as CT, MRI or PET.
- As the ultrasound exam is performed the fusion system continuously generates reformatted planes from the reference series matching the oblique imaging planes of the ultrasound transducer.
- The reformatted planes are displayed either as an overlay or side-by-side with the live ultrasound.
- This display enhances interpretation of ultrasound by enabling a direct comparison with the reference images from the same view angle.

- Fusion imaging makes use of a tracking system to localize ultrasound transducers and other devices relative to the patient.
- Optical and electromagnetic systems are available, the latter being most commonly used.
- Various software tools are also used to bring the reference series into alignment with the tracking system for fusion display.
- Tracking sensors are also incorporated into some interventional devices such as introducers and ablation needles, enabling the display of needle location as an overlay on live ultrasound image.
- For the fusion imaging technique, a variety of tracking methods are available, including optical, image-based, and EM tracking.



**Fusion imaging and contrast-enhanced ultrasonography (US)-guided radiofrequency ablation (RFA) of a 1-cm hepatocellular carcinoma (HCC) in a patient with a hepatitis B virus carrier**



# WIRELESS TRANSDUCER



- They feature proprietary ultra-wideband (UWB) wireless radio to help ensure images are transferred at high speeds, with full data integrity and free from interfering with other medical equipment—and all without cables.
- These breakthrough cable-free innovations help provide uninterrupted, hassle-free, real-time imaging that allows you to scan in the position that is comfortable for you and safe for your patient.

# SMARTPHONE ULTRASOUND

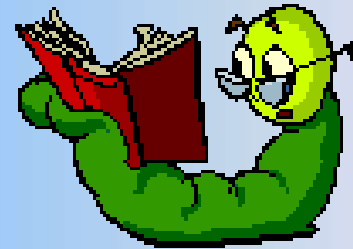
- Inexpensive, which will lead to even wider use, especially in rural and third-world areas
- Widespread use in Emergency Rooms, and in the surgical and medical wards, as well as in office practice
- A great start for diagnosing all types of medical problems, as a screening device, such as vascular problems, gallstones, kidney stones, abdominal masses, and other problems.
- The model shown is a Mobisante which is the world's first smartphone-based ultrasound imaging system, the MobiUS SP1 ultrasound system.



## CONCLUSIONS

- Modern US equipments are based on many of the same fundamental principles employed in the initial devices used for human imaging over 50 years ago.
- USG is relatively inexpensive, portable, safe, and real-time in nature, all of which make it one of the most widely used imaging modalities in medicine.
- B-mode US continues to experience very significant evolution in capability with the US science, technology, and applications are expanding at a brisk pace and are far from mature with exciting developments in future.





## FIND MORE AT:

- *The essential physics of medical imaging; Bushberg JT, Seibert JA et.al.*
- *AAPM/RSNA Physics Tutorial for Residents: Topics in US*
- *Ultrasound elastography in liver; Frulio N, Trilaud H.*
- *Fusion imaging of real-time ultrasonography with CT or MRI; Lee MW*
- <http://e-ultrasonography.com>



# Thank You

