# Ultrasound System B-Mode Imaging Performance Comparison

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*Abstract*—**Ultrasound imaging continues to be a technology driven modality resulting in a stream of operational and image quality improvements. It is quite easy to subjectively recognize good images but an unbiased, objective assessment of B-mode image quality requires a more scientific approach. Image quality can be objectively measured using the well accepted criteria which include spatial resolution, contrast resolution, penetration, temporal resolution, image uniformity, and presence of artifacts introduced by image processing technologies. A systematic approach is presented which can logically measure B-mode image quality parameters.**

*Index Terms*—**Beamformer, imageformer, spatial resolution, contrast resolution, temporal resolution, image uniformity, artifacts, ZONE Sonography, Dynamic Transmit Focus**

## I. INTRODUCTION

ULTRASOUND image quality and system performance is a direct function of the technology used to acquire and extract clinical information encoded in the echoes. The displayed image is dependent not only on the technology used but also on the compromisesbetween performance and system cost, size, technology limitations and other design parameters, that invariably engineering departments must make. For these reasons comparison between various systems can easily become very misleading unless strict evaluation protocols are employed so that a true A-to-B comparison can be made. Systemperformance evaluations are performed for principally two reasons:

- Quality assurance to detect potential system problems.
- Comparison between two or more systems when purchasing new equipment.

Quality assurance testing is relatively straight forward and can be performed by service personnel on a periodic basis. Image quality comparison between two systems which often utilize different technologies can be significantly different than normal clinical studies. To perform such evaluations in an objective manner can require different skills and experience than are typical to normal clinical examinations. Some of the best trained people in such evaluations are commercial sonographers who actually perform objective system tests on a daily basis and who certainly know both the technology behind the system and the techniques to get the best performance from a system.

An experienced sonographer or sonologist can generally classify ultrasound images as being clinically acceptable and technically good. Such subjective classification is primarily based on conspicuity of relevant clinical information as well as the use of appropriate field of view, correct settings of imaging controls (gain, DGC, placement of transmit focus, etc.) as well as presence or absence of artifacts. What this paper presents, however, is a series of tests that will allow an objective determination of B-mode image quality.

Ultrasound B-mode image quality is traditionally defined by the following criteria:

- **Spatial resolution** is a measure of minimum spacing between distinguishable point targets which may be simply wire targets in a phantom or perhaps small anatomical objects very close together.
- **Contrast resolution** is a measure of the differentiability of a region of one echogenicity within a region of different echogenicity. This is also closely related to sensitivity which is the ability of an ultrasound system to detect low level echoes. This becomes very important when imaging deeper anatomical structures where noise levels begin to obscure low level echoes.
- **Image uniformity** is the ability to maintain comparable spatial and contrast resolution throughout a large field of view.
- **Temporal resolution** is a measure of the number of independent image frames per unit time. The displayed frame rate is sometimes misleading especially in mixed modes where the displayed image is composed of several acquired frames.

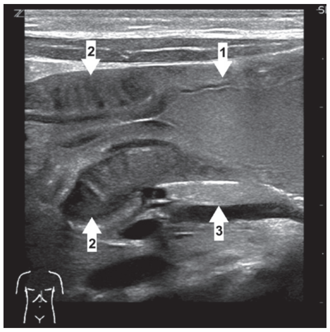
These criteria are conceptually quite simple and self-evident but in practice these parameters can be confounded by personal appearance preferences which are entirely subjective.

The following paragraphs are intended to form a test protocol structure which, if followed, will result in an objective assessment of B-mode imaging capabilities of any general purpose ultrasound system regardless of the fundamental technology employed to form the image. A testing protocol which includes the human body and a commercially available phantom is presented here. It is worth noting that many authorities recommend the use of phantoms as part of a departmental quality assurance program[1].

## II. EVALUATING SPATIAL RESOLUTION

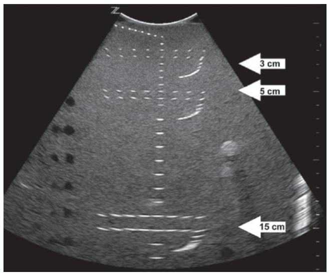
Spatial resolution is typically measured at specific depths, say 3, 5 or 15 cm. The reason for this is that the majority of ultrasound systems utilize older beamformer technology which focuses the ultrasound beam at one point only but spatial resolution should be measured at all depths since one cannot predict where lesions or other inhomogeneities will belocated in clinical settings. It is important to note, however, that spatial resolution (and uniformity) can be improved through techniques such as sequential focusing which unfortunately compromises temporal resolution. The objective in any evaluation must be to make sure that any of the image quality criteria are not compromised. Any compromise will favor one system and therefore bias the evaluation. It is worth pointing out that a new technology has been developed called Zone Sonography™ Technology (ZST), which enables continuous focusing throughout the field of view and optimizes image formation parameters to compensate for sound speed variations from patient to patient.

**1[a]** Sagittal section through the kidney with a septated upper pole cyst. Note fine spatial resolution of the septae and fibers of psoas muscle posteriorly.

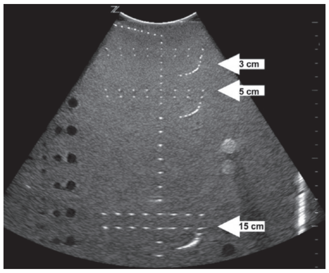


**1[b]** Pediatric stomach and pylorus using 20 MHz resolution. Note fine tissue layers of the stomach (arrow 1) and muscle fibers of the pyloric ring muscle (arrows 2). Pancreatic tissue is seen posteriorly (arrow3).

This is important to remember that in a beamformer system, resolution is optimized only at the point of focus, while in the ZST system, resolution is optimized throughout the field of view. In addition, in a ZST system, the image is formed at the patient's unique tissue sound speed while beamformer technology utilizes an assumed tissue sound speed of 1540m/s for all tissue within the field of view. Spatial resolution is probably easiest to measure using a resolution phantom where the pin targets are embedded in tissue mimicking material, which typically should have an attenuation coefficient of 0.5dB/cm-MHz. System settings should be optimized so that both the "tissue" and the pin targets are visible. Resolution is determined by measuring the spacing between adjacent targets



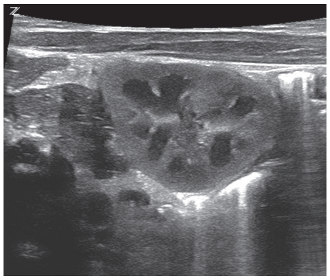
**1[c]** Pin targets embedded in a tissue mimicking material shows spatial resolution at 3, 5, and 15cm depth (arrows) without sound speed compensation.



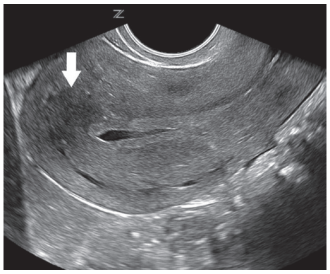
**1[d]** Pin targets embedded in a tissue mimicking material shows spatial resolution at 3, 5, and 15cm depth (arrows) with sound speed compensation.

## III. EVALUATING CONTRAST RESOLUTION

Contrast resolution is defined as the ability of a system to differentiate an area of one echogenicity within an area of another echogenicity. This differentiation is of critical value in identifying tissue differences and typically these are very low level echoes, typically in the 40-60dB range when measured on a beamplot. Phantoms are available to assess contrast resolution but the human body can be an easier and a very accurate test object. The objective here is to find a patient who will present some tissue surrounded by other tissue with a slightly different echogenicity. This may prove to be difficult and a simpler solution suggests itself. Imaging a large field of view and looking for structures, normal or abnormal, in the far field is much more practical. Technically difficult to image patients, often with a Body Mass Index (BMI) significantly greater than 25 are a potential pool of candidates to choose from. Comparing the conspicuity of information on the far field is a good indicator of system's contrast resolution as well as penetration. Other targets such as a thyroid where often very subtle lesions can be found, can also act as "living phantoms." Additional areas include very bright structures adjacent to medium to low level echoes.



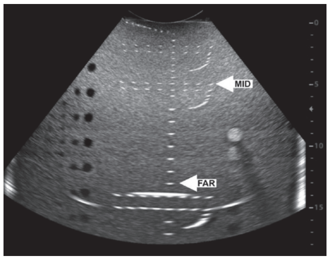
**2[a]** Axial section through a pediatric kidney demonstrating exquisite contrast resolution between renal medulla (pyramids) and cortex.



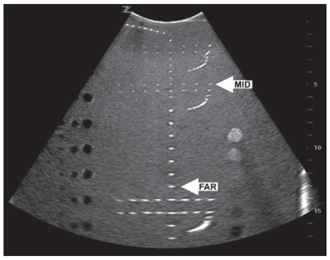
**2[b]** Sagittal endovaginal high contrast resolution image of the uterus demonstrating a subtle intramural fibroid (arrow).

## IV. MEASURING IMAGE UNIFORMITY

Image uniformity measures both spatial and contrast resolution throughout the image field of view. Phantoms are the simplest way to measure spatial resolution and some phantomsmay be able to measure spatial and contrast resolution as well as image uniformity. The simplest way to assess image uniformity is to use a pin phantom where the pins are spaced 1cm apart throughout the image depth. Since virtually all beamformer based systems are focused at a single point the appearance of the pins will be small dots at the best point of focus and gradually they will become more and more laterally elongated away from the best point of focus.

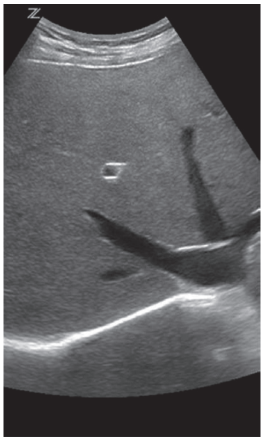


**3[a]** Beamformer image using a tissue equivalent pin phantom demonstrating reduction in image uniformity and elongation of central axis pins in the mid and far fields (arrows).



**3[b]** Same phantom using ZONE Sonography Technology with sound speed compensation. Note integrity of image uniformity throughout the field of view and less divergence of the central axis pins in both mid and far fields (arrows).

One of the major contributing factors to image uniformity degradation is phase aberration caused by the fact that sound speed in tissue is not constant but varies depending on patient body habitus, tissue type, and presence of pathology. As a result, all beamformer based systems are designed to use an assumed tissue sound speed of 1540m/s as a basis for calculating echo location. The reason for this assumption is that beamformer based systems do not have a fast, consistent technology to calculate actual average sound speed in theregion of interest. ZST based systems have that functionality built in so that all images can be formed using actual sound speed in every patient's tissue.

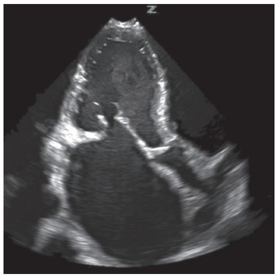


**3[c]** Axial section through the right lobe of the liver without sound speed compensation.

**3[d]** Axial section through the right lobe of the liver with sound speed compensation.

## V. EVALUATING TEMPORAL RESOLUTION

Temporal resolution is a measure of the number of independent image frames acquired per unit time. Although this definition is quite simple it is important not to use the frame rate number often displayed on the image. Different manufacturers may have unique ways of calculating frames per second which may include interpolated frames or more complex methods when spatial compounding is used. The most reliable way is to look for tissue motion artifacts often generated by the heart, pulsating arteries, tissue motion due to breathing or by imaging a fetus which often tend to be very active.



**4** Short frame acquisition times captures mitral valve leaflets especially useful for deep penetration (20cm in this image). Note spontaneous contrast of blood bolus in the left ventricle.

Another way is to judge the image when mixed modes are enabled such as Duplex or Triplex functionality which requires considerable processing time and many manufacturers must sacrifice the number of acquired frames. The most practical way to assess temporal resolution is by scanning a patient.

## VI. TEST PROTOCOL

### System setup

- Use the same patient or phantom for each image quality attribute.
- Transducer frequency: use the highest frequency that will provide correct field of view.
- System settings: adjust all controls to achieve an optimized image.
- Sequential focus settings: System with ZST do not have this functionality. Sequential focus sacrifices temporal resolution and therefore will bias the objectivity of the test
- Depth: For phantom images set depth beyond the deepest pin targets, typically >15cm. (once we specify the phantom, depth can be specified).
- Set system for B-mode only.

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Figure 1[a] courtesy of Dr. Seitz, Karlsruhe.
Figure 1[b] courtesy of Dr. Geier, Heilbronn

### References

[1] American Institute of Ultrasound in Medicine. Routine Quality Assurance for Diagnostic Ultrasound Equipment. Laurel, MD. 2008.