Key Performance Parameters of a Contemporary Diagnostic Ultrasound Transducer

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A recently published paper in the *European Journal of Echocardiography* entitled "High Incidence of Defective Ultrasound Transducers in Use in Routine Clinical Practice" by Mattias Martensson, et al, focused on the testing of 676 transducers located at 32 hospitals that were currently being used to obtain diagnostic information. [1] Probes were tested using a commercially available device that examines various performance parameters of each crystal that make up the array (also referred to as an acoustic stack).[2] A graphic of the test display is shown in Figure 1. The results of their testing of the 676 probes showed that almost 40% of the probes had some form of performance inhibiting problem ranging from dead or weak elements, breaks in the cable wires, to delaminating lenses. The paper also contained a clinical case study where a suspected patent ductus arterious (PDA) was missed because of a then unknown defect in the transducer (the patient was re-scanned at a later time with a known good probe and the PDA was easily visualized). Diagnostic ultrasound is generally considered a "safe" imaging modality because of its non-ionizing radiation conductance. However, if the transducer (also known as a probe or scanhead) being used is not performing optimally due to some unrecognized problem, and subsequently leads to missing pathology or understating the degree of pathology, then it is in fact not as safe an imaging modality as we might have previously thought.

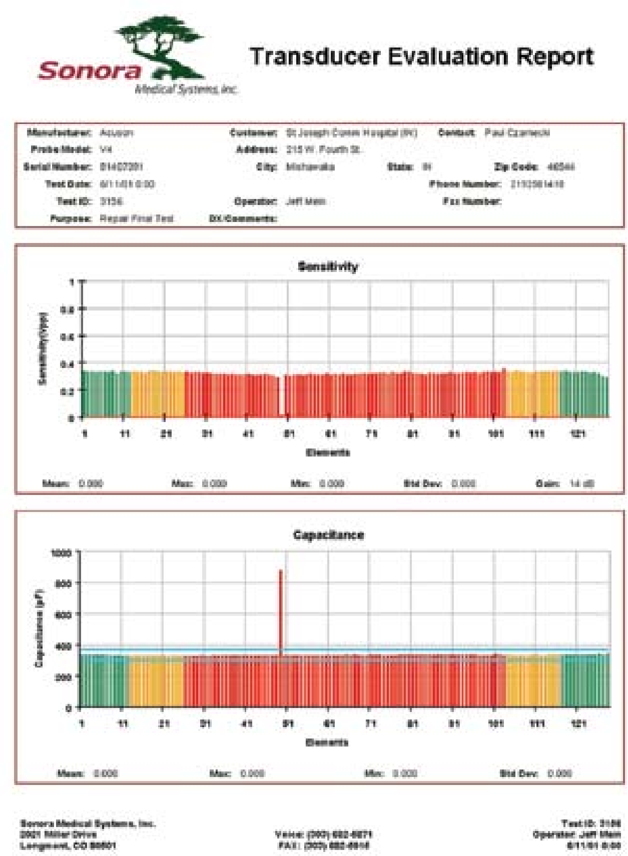

Figure 1. Tranducer testing report.

Given the mounting evidence seen in the literature that it is clinically unwise to use transducers without first knowing their operational condition, what are the key performance parameters associated with contemporary multi-element composite transducers and how can they be tested by clinical engineers to ensure the transducer is operating both safely and effectively? Before addressing that question we should take a step back and look at the basic construction of an array and how the array is actually excited by the ultrasound system for use in the two basic modes of ultrasound: B-mode imaging and Doppler (Doppler includes all derivative modes such as color flow, pulsed wave, and continuous wave).

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Contemporary composite arrays are composed of: 1) a piezoelectric (PZ) material that provides the necessary transduction of mechanical to electrical energy and vice versa, and 2) a supporting polymer that isolates the

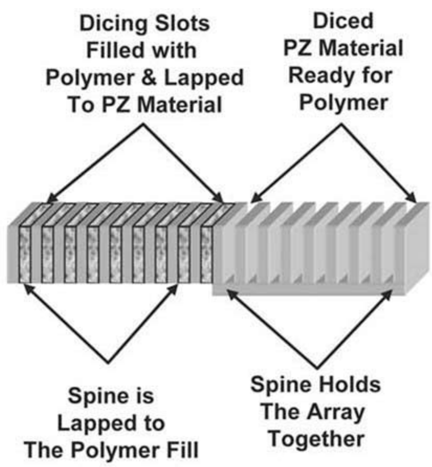

Figure 2. Array configuation.

element while shaping the mechanical and electrical properties of the PZ elements. Typical general imaging linear and curved linear arrays have between 128 and 192 elements. It is the physical distribution of PZ and polymer that makes the array and specifies its behavior. The array construction following a specific design depends on the well-developed "dicing and filling" techniques used in today's transducer manufacturing. Construction begins with a block of PZ material that is "diced" to form PZ elements held by a common spine. The diced regions are then filled with polymer. The final configuration is obtained by lapping the array "front" and "back" to remove polymer on the face and the PZ spine on the back and to set the array center operating frequency (Figure 2).

Although not an exhaustive analysis the following acoustic performance parameters of an array tend to have the most impact on the quality of the transmitted and received echo signals.

General Aspects of Array Performance

For array systems there are two primary drivers of transducer performance that must be considered: (1) pulse shape and (2) any parameter that effects the coherent summation of the signals to and from the array elements.

- **Pulse Shape:** There are two critical measures of the pulse shape: at the –6 decibel (dB) point and at the –20dB point. A short –6dB pulse length gives rise to good range resolution, however it is the –20dB pulse length that determines many of the important parameters of perceived image quality such as contrast resolution. Due to the relatively large variation in the reflection coefficient of structures within the body (>40dB), a long –20dB response can act to hide important low-level echo reflectors. Additionally, a long ring-down can create an effective fogging of the image, greatly reducing contrast sensitivity.
- **Parameters that Effect Coherent Summation:**
  a) Variations in the impulse response of each transducer element across the array
  b) Variations in element bandwidth
  c) Variations in element band-shape

Crosstalk affects both the pulse shape as well as coherent summation. Crosstalk is an example of an array performance parameter that is actually more important to good Doppler than imaging. In-phase crosstalk is especially harmful to continuous wave (CW) Doppler. This is because in the CW Doppler mode, half of the array is transmitting while the other half is receiving. Even a small in-phase crosstalk will coherently add resulting in a large interference signal that ultimately degrades the performance of the receive processor. Out-of-phase crosstalk will distort the shape of the main lobe and introduce an unwanted side lobe.

Uniform Sensitivity of Each Element

Ideally, the impulse response of each transducer element within an array should be identical (i.e., uniform sensitivity). In such a case, the coherent sum of all the elements would simply be a larger rendition of the response of a single element. Additionally, identical array element response would provide the optimal spatial impulse response afforded by a particular beamformer design.[3] Unfortunately, array elements cannot be so constructed and variations will exist. The key in array design and construction is to minimize the variation. In the design of transducer arrays, engineers look to avoid two basic problems related to array element-to-element variation: 1) periodicity in element response across the array, and 2) random variations.

Given that even carefully designed arrays will exhibit some form of both No. 1 and No. 2 above, an array with one or more dead elements will represent an amplified version of the problem and will impact clinical performance. Periodic variations will cause unwanted side-lobe structure, while random variations will cause an overall increase in the background structure of the system's beam pattern (spatial point response). The system beamformer is designed under the assumption that the array that it will be driving is functioning at its optimal design level. Therefore, when the array is compromised with dead and or weak elements, either randomly located within the array or contiguous within the array, the ultrasound system's overall performance level is also compromised. It has long been known that side lobes cause the most problems with the Doppler signal used to detect blood flow, thus causing erroneous velocity measurements.[4]

20dB Pulse Width (Length)

This performance parameter has the greatest impact upon the contrast sensitivity of the image. There should be limited variability demonstrated by individual elements across the array. A long -20dB response can easily hide important low-level reflectors, as well as creating an effective "fogging" of the image thereby greatly reducing contrast sensitivity. Every manufacturer will have slightly different specifications for this parameter, but in general the average array pulse length should be less than four cycles long.

Center Frequency of the Array

Most modern transducer designs are broadband in nature and usually have a range expressed concerning their frequency, for example a Philips C5-1 curved array implies an operating bandwidth between 1 megahertz (MHz)to 5MHz at the –6dB points. The center frequency is calculated by identifying the upper frequency and lower frequency –6dB points on the measured frequency spectrum, and dividing that number by two. This calculation assumes a well-behaved pulse shape, which, in the presence of defective elements will not be the case. If the center frequency is too low, the axial resolution may be worse. If it is too high, the array may not have sufficient penetration. A shift in the measured center frequency of any given array away from that measured on known good in-kind arrays may be an indirect measure of a defective array. Additionally, in certain probes when the backing material separates from the acoustic stack, variations in center frequency from element to element may occur.

Fractional Bandwidth

The primary benefit of wide bandwidth to imaging is the ability to run at high frequencies in the near field and low frequencies in the far field. Lower ultrasound frequencies also benefit virtually every Doppler mode (e.g., CW, pulsed wave and color flow). Modern ultrasound systems utilize tracking filters to selectively receive signals so that echoes from other frequencies don't clutter the image. Otherwise, wide band frequency response would make for a noisy cluttered image. Current transducer designs generally produce bandwidths in excess of 70%. Fractional bandwidth variation across the array is important in that it might negatively impact the pulse shape and phase of the acoustic signal. Typically, designers specify a fractional bandwidth variation across the array of 5% or less. All things being equal, bandwidth is a key contributor to the overall tissue contrast resolution seen in the image. Transducer-wide bandwidth response is also essential for high-quality harmonic imaging performance. Dead and weak elements will negatively impact the overall fractional bandwidth of the transducer thus compromising clinical performance.

Conclusion

It is essential for hospitals to have in place an evidence-based quality assurance program if they are using contemporary diagnostic ultrasound systems in a quantitative manner.[5] Additionally, as a commercially available test device can provide the necessary quantitative and repeatable measures of each of the transducer design parameters outlined in this article, it is possible now for the clinical engineer to bring that technology in-house and verify that the transducer being used meet factory specifications. As more evidence is presented on transducer safety and clinical efficacy from hospitals around the world, it is becoming increasingly clear that assuming ultrasound is safe simply because it is non-ionizing radiation is a false and potentially unsafe assumption. ■

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