QUALITY ASSURANCE (QA) PHANTOM FOR GRAY-SCALE ULTRASOUND SCANNERS

♦ MANY DIFFERENT PHANTOMS AND METHODS FOR MANY DECADES
   -- DISCOURAGING TO CLINICAL PERSONNEL

♦ RECENT 4-YEAR STUDY* AT MAYO CLINIC
   ASSESSED MINIMUM NEEDED PARAMETERS

   -- 45 SCANNERS & 265 DIFFERENT TRANSDUCERS

THREE PARAMETERS WORTH MONITORING FOR ARRAY TRANSDUCERS:

1. ELEMENT OR CHANNEL FAILURE (EOCF)
2. MAXIMUM DEPTH OF PENETRATION (DOP)
3. DISTANCE MEASUREMENT ACCURACY (DMA)
   --- DMA IMPORTANT FOR OBSTETRICS
LINEAR ARRAYS AND PHASED ARRAYS
-- FLAT SCANNING WINDOW OK

CURVED ARRAYS (CONVEX ARRAYS) -- RADII OF CURVATURE 0.5 cm TO 7 cm

-- NEED CURVED SCANNING WINDOW FOR CONTACT OVER ENTIRE EMITTING SURFACE

TO DETERMINE VALUES FOR ALL 3 PARAMETERS, NEED:

1. SCANNING WINDOWS WITH BROAD RANGE OF RADII OF CURVATURE
2. TISSUE-MIMICKING (TM) MATERIAL WITH 1540 m/s AND TISSUE-LIKE ATTENUATION AND ECHOGENICITY
PROTOTYPE QA PHANTOM FOR ALL THREE PARAMETERS

-- PHYSICAL PROPERTIES --

♦ PROPAGATION SPEED OF 1540 m/s

♦ ATTENUATION COEFFICIENT ÷ FREQUENCY
  ≈ 0.5 dB/cm/MHz

♦ TWO CONICAL SCANNING WINDOWS & ONE FLAT WINDOW
  -- COMPLETE CONTACT OF ANY SHAPE EMITTING SURFACE WITH WINDOW

♦ 8 PARALLEL NYLON FIBERS FOR DISTANCE MEASUREMENT ACCURACY
ONE SIDE HAS CONICAL SCANNING WINDOW FOR SMALLER ROC VALUES

PHANTOM TURNED OVER TO ACCESS CONICAL WINDOW FOR LARGER ROC VALUES

◆ PLASTIC-COATED ALUMINUM FOIL WINDOWS SUPPRESS DESICCATION -- HEAVIER FORM (WHITE) LINES ENTIRE BOX

◆ FLEXIBLE WINDOWS AND TM MATERIAL

◆ CORK LAYERS PREVENT BENCH TOP SLIP
END VIEW OF QA PHANTOM SHOWING
POSITIONS OF 8 PARALLEL FIBERS
FOR DISTANCE MEASUREMENT ACCURACY TEST
Element or Channel Failure

Convex array average of 3 images obtained while moving the transducer perpendicular to the scan plane

-- 3 adjacent array elements inactivated simulating dead elements

Average of about 100 images while moving transducer

-- shadowing is more apparent
Image of 8 fibers using a 1 cm ROC convex array with about 120 degree sector angle.

If scanning window were flat and water-filled scanning well used, there would be distance measurement errors due to refraction at the window.
Vertical distance measurement error is negligible

Horizontal measurement error is \((87.4 - 90)/90 \times 100 = -2.8\%\)
MAXIMUM DEPTH OF PENETRATION ASSESSMENT

-- Average of 590 frames acquired during continuous translation perpendicular to the image planes
Average of about 590 frames while holding transducer in air
Beyond transducer ring down

-- only electronic noise is averaged
Mean pixel values over 5-mm depth intervals

1) phantom case
2) in-air case
3) in-air case times \((2)^{1/2}\)

Green and red curves intersect at 16.1 cm = maximum DOP \(\Leftrightarrow\) SNR of 1
PERFORMANCE TESTING FOR ANY SHAPE TRANSDUCER VIA DETECTABILITY OF ANECHOIC SPHERES

♦ THREE PHANTOMS:

1) 2 mm DIAMETER SPHERES FOR HIGHER FREQUENCIES (7-15 MHz)
2) 3.2 mm DIAMETER SPHERES FOR LOWER FREQUENCIES (2-7 MHz)
3) 4 mm DIAMETER SPHERES FOR LOWER FREQUENCIES

♦ SPHERE ECHO LEVEL < ~32 dB RELATIVE TO BACKGROUND

♦ ATTENUATION COEFFICIENT ÷ FREQUENCY ≈ 0.5 dB/cm/MHz
  FOR BOTH BACKGROUND AND SPHERES

♦ PROPAGATION SPEED = 1540 m/s

♦ ONE FLAT SCANNING WINDOW FOR NEARLY FLAT EMITTING SURFACES, SUCH AS LINEAR ARRAYS

♦ CONICAL SCANNING WINDOWS FOR BROAD RANGE OF RADII OF CURVATURE (ROC'S) OF CONVEX (CURVED) ARRAYS
♦ SPHERES RANDOMLY DISTRIBUTED

♦ PARALLEL REFLECTORS PROVIDE FOR ACCESS TO ENTIRE IMAGE SECTOR OF SECTOR SCANNERS

-- TOTAL INTERNAL REFLECTION OF COMPRESSIONAL WAVES WITH NO MODE CONVERSION BEYOND RAYLIEGH CRITICAL ANGLE

♦ SOFTWARE QUANTIFIES HUMAN-MIMICKING DETECTABILITY OF ANECHOIC SPHERES
Photo of 4-mm sphere phantom

Photo of 2-mm sphere phantom
End view of 4-mm-diameter-sphere phantom

Parallel plate reflectors provide - via total internal reflection - for extension of the image outside of the phantom.
- Two-part mold with 3.2-mm diameter hemispherical depressions
- Mold parts lowered into a bath of molten tissue-mimicking (TM) material and brought together to form 1044 spheres
- 4 sets of alignment pegs and holes
- 8 sets of molds produce more than 8000 spheres
DATA ACQUISITION

♦ Acquire a set of images where the transducer is translated perpendicular to the scan plane by increments of 1/4 of the sphere diameter D

♦ Number of images sufficient for adequate statistics
AUTOMATED DATA ANALYSIS

♦ Computes mean pixel values (MPV's) over square areas with side = 2D/3
  -- centers of MPV's form a square array with spacing D/4
  -- do for all images

♦ Center of each sphere determined within D/8 for each Cartesian coordinate
  -- MPV centered in ith sphere ≡ S_{Li} is "signal" for the ith sphere

♦ Computes Lesion Signal to Noise Ratio (LSNR) for each sphere using MPV's
LSNR for the ith sphere:

\[
\text{LSNR}_i \equiv \frac{S_{Li} - S_{mBi}}{\left[\frac{1}{2}\left(\sigma_L^2 + \sigma_{Bi}^2\right)\right]^{1/2}}
\]

-- \( S_{mBi} \) is the mean of all background MPV's in the image frame within a radius 2D of the sphere center and NOT influenced by the presence of any sphere

-- \( \sigma_{Bi} \) is the standard deviation of all MPV's contributing to \( S_{mBi} \)

-- \( \sigma_L^2 \) is standard deviation of all \( S_{Li} \) values in depth interval \( d \)

-- \( d \) is typically 0.5 or 1.0 cm.

\# LSNR for depth interval \( d \)  \( \equiv \)  LSNR = \( \frac{1}{N} \sum_{i=1}^{N} \text{LSNR}_i \) where \( N \) is the total number of spheres detected in the depth interval \( d \) (including all image frames)
Image of prototype 4-mm sphere phantom using convex array focused at 4 cm

Parallel plane reflectors are perpendicular to the image plane -- alumina on left and plate glass 10 cm to its right

Vertical line of elevated echoes at slightly rough surface of alumina plate
Cropped image with low-level diffuse echoes at the alumina surface removed

Gray-scale map of overlapping MPV's (squares with sides 2D/3)

MPV sites identified with sphere centers

Depiction of 1-cm depth intervals with different levels of gray
Mean LSNR values as a function of depth using 50 images

Number of spheres detected in each 1-cm depth interval
One of 80 parallel linear array images of the 4-mm sphere phantom

Frequency = 4 MHz

Focus at 4 cm

Width of image \( \approx 3.7 \) cm
Three successive images of the 80 separated by $D/4 = 1\text{ mm}$.

The green x's identify the determined centers of the spheres identified with the respective images.

Where there are no x's, the sphere center was identified with a nearby image.
Results using all 80 image frames

Number of spheres detected in each 1-cm depth interval
New phantom with 3.2-mm diameter spheres and twice as many spheres per unit volume (19 July 2012)

3.2 mm half the volume of 4-mm spheres

Larger concentration allows for fewer images to produce adequate statistics
REPRODUCIBILITY STUDY AND COMPARISON FOR DIFFERENT FOCUSING
Multiple foci at 4, 8 & 12 cm

Single focus at 10 cm

detectability vs depth

number of spheres in each 5-mm depth interval
Multiple foci at 4, 8 & 12 cm

Single focus at 4 cm
Single focus at 4 cm

Single focus at 10 cm
Single focus at 4 cm