TG-128: Quality Assurance for Prostate Brachytherapy Ultrasound

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Outline

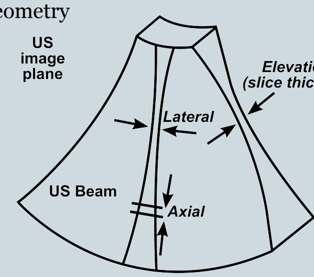
- Ultrasound physics
- Equipment
- TG128 tests
- Tolerances
- Time estimates
- Materials

Report

- “AAPM Task Group 128: Quality assurance tests for prostate brachytherapy ultrasound systems”. Medical Physics, Vol. 35, No. 12, December 2008, pages 5471-5489.
- The report is available on the Publications page of the AAPM web site.

Ultrasound physics

- Beam geometry



Ultrasound Physics

- Wavelength (axial resolution)

$$\lambda = \frac{c}{f}$$

where f = ultrasound frequency
c = speed of sound in the tissue

Material	Velocity (m/s)
Air	330
Water	1497
Bone	3500
Fat	1440
Blood	1570
Soft tissue	1540

Ultrasound Physics

- Acoustic Impedance

$$Z = c \times \rho$$

where ρ = tissue density
c = speed of sound in the tissue

- Sound Pressure Attenuation

$$P(Z,f) \propto e^{-\alpha(f)Z}$$

where α = attenuation coeffiecient
f = ultrasound frequency

Ultrasound Physics

- Sound Power Reflection Coefficient

$$\alpha_r = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$$

Z_1 = 3500 (bone)
Z_2 = 1540 (soft tissue)
$\alpha_r = 0.15$

Z_1 = 1450 (fat)
Z_2 = 1540 (soft tissue)
$\alpha_r = 0.0009$

Ultrasound physics

- The attenuation coefficient for a typical clinical tissue density and ultrasound frequency is 0.5 dB/cm/MHz.

$$\frac{P}{P_o} = 0.5 \text{ dB/cm/MHz} \times 3 \text{ MHz} \times 5 \text{ cm} \times 2$$
$$= 15 \text{ dB} = \boxed{0.03}$$

$$\frac{P}{P_o} = 0.5 \text{ dB/cm/MHz} \times 6 \text{ MHz} \times 5 \text{ cm} \times 2$$
$$= 30 \text{ dB} = \boxed{0.001}$$

Ultrasound Physics

- So why would you ever use 6 MHz?

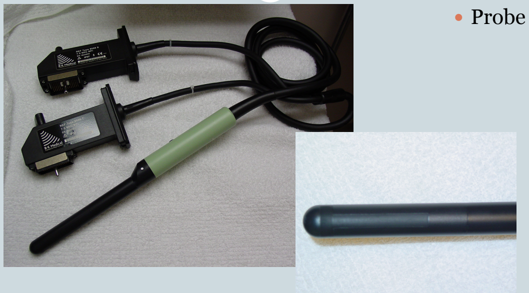
$$\lambda = \frac{c}{f}$$

- You can't measure smaller than your probe

$$\lambda = \frac{1540 \text{ m/S}}{3 \text{ MHz}} = 0.5 \text{ mm}$$

$$\lambda = \frac{1540 \text{ m/S}}{6 \text{ MHz}} = 0.3 \text{ mm}$$

US equipment



- Probe

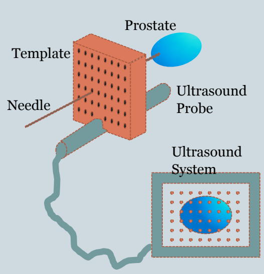
US equipment

- System

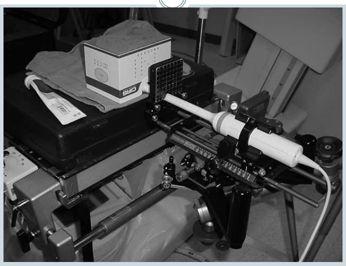
Prostate Brachytherapy US QA

Complete QA will include:

- Ultrasound unit
- Needle template
- Treatment planning system
- Fluoroscope
- CT for post implant



Setup for Phantom Measurements



Clinical perspective, but coupling gel can leak out

Setup for Phantom Measurements

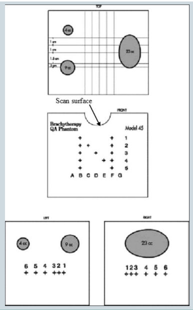
Coupling gel stays in place, but image can be confusing

QC Testing

- Limit inter-observer variability
- Ideally performed by a single individual
- If multiple people, train for consistency

The Phantom

- CIRS Model 45 phantom.
  - Used here for illustrative purposes only; no endorsement is implied.
  - Wires spaced at known intervals
  - Volumetric objects.
- TG128 report recommends a phantom design, but no manufacturer has implemented it yet

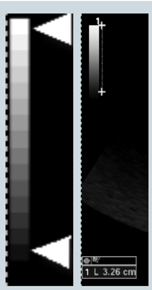


Test 1: Grayscale visibility

- Monitor must be adjusted appropriately for optimal visibility
- Calibration and brightness can drift over time
- Phosphors can fade

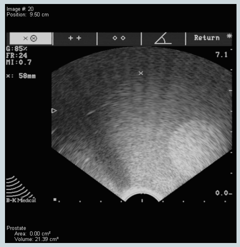
Test 1: Grayscale visibility

- Locate the gray scale strip on the side of the ultrasound screen.
- Depending on the type of strip, count the number of gray levels or measure the length of the gradation.



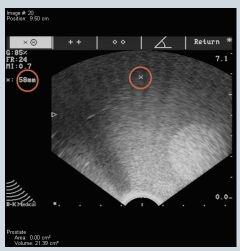
Test 2: Depth of penetration

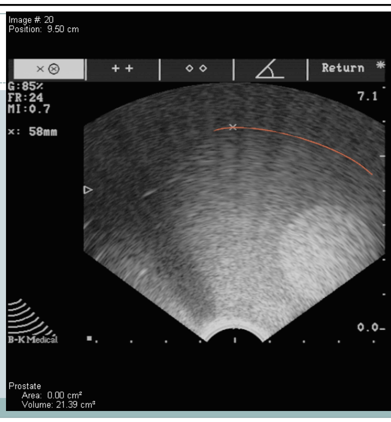
- Reduced depth of penetration can reduce visibility of anterior capsule border
- Any increase in system noise will reduce depth of penetration
- Dead transducer elements (reducing signal) will also reduce depth of penetration



Test 2: Depth of penetration

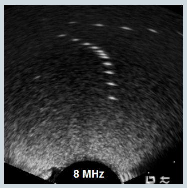
- Find a relatively homogeneous region in the phantom.
- Using the digital calipers, determine the maximum depth that the static ultrasound speckle pattern of the phantom can be clearly distinguished from the dynamic electronic noise.





Test 3: Spatial resolution

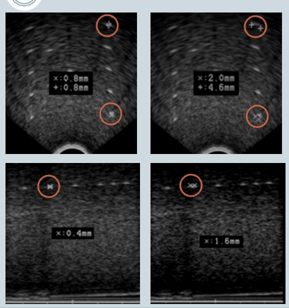
- Negatively impacted by
  - Poor probe condition
  - Problems with pulse formation circuit boards
  - Problems with pulse send/receive circuit boards



5 mm
4 mm
3 mm
2 mm
1 mm

Test 3: Spatial resolution

- Find a region of the phantom having single filament targets at various depths.
- Measure the dimensions of the filament image in both the axial and lateral directions.
  - These dimensions are effectively the axial and lateral resolution limits.
- Switch the probe to the orthogonal direction and repeat

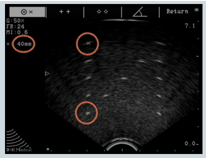


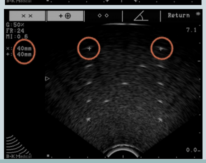
Test 4: Distance measurement accuracy

- Distance determined by pixel size and pixel calibration
- Pixel depth determined by range equation
  - Differences from 1540 m/S sound speed will lead to errors in distance measurement
- Lateral distance calibration determined by FOV and pixel calibration.
- Errors can stem from image processing board and other circuitry

Test 4: Distance measurement accuracy

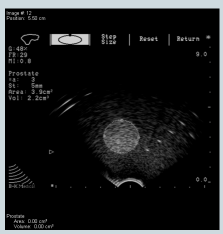
- *Axial measurement:*
  - Align a column of fiber targets near to the center of the image, if possible. Freeze the image.
  - Using the electronic calipers, measure the distance between the most proximal and the most distal targets.
- *Lateral measurement:*
  - Repeat using a row of targets, measuring most lateral targets.





Test 5: Area measurement accuracy

- Area measurement is central to the implant procedure
- Since area measurement and distance measurement are so closely related, they have similar fault causes



Test 5: Area measurement accuracy

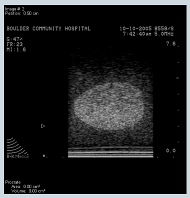
- Scan an object of known dimension such that the ultrasound beam intercepts it normally
- Using the appropriate tool on the ultrasound system, carefully trace the boundary of the object and record the calculated area of the object

Measured area = 3.1

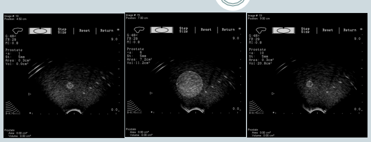
Nominal area = 3.05

Test 6: Volume measurement accuracy

- Complementary to distance and area measurements
- Errors are compounded multiplicatively



Test 6: Volume measurement accuracy



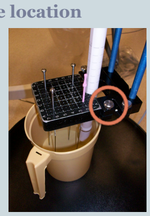
Measured volume: 20.8 cc

Certified volume: 20.6 cc

- Locate the “base” and “apex” of the phantom target; zero the stepper at the base
- Using the typical clinical procedure, perform a volume study
- After contouring the entire target, record the calculated volume

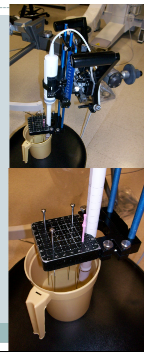
Test 7: Needle template alignment

- Depends on
  - Accuracy of electronic template
  - Distance measurement accuracy
  - **Physical needle template location**



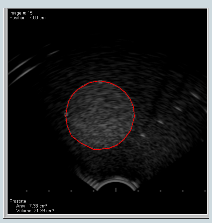
Test 7: Needle template alignment

- Place the probe with the needle template attached vertically in the water bath.
- Place needles at each corner of the needle template and one at the center.
- On the US system, verify that needle flashes in the image correspond to locations of needles on electronic grid overlay.



Test 8: TPS volume accuracy

- Perform a volume study of 3D target in the US phantom
- Import ultrasound images into treatment planning computer
- Retrace contours in treatment planning software
- Compare TPS volume to volume calculated by US system



Variseed volume: 21.4 cc (3.9%)
US Measured volume: 20.8 cc
Certified volume: 20.6 cc

Tolerances

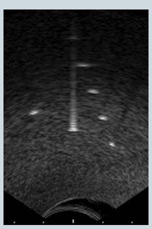
Test #	*Test name*	*Typical duration*
1	Grayscale visibility	Δ > 2 steps or 10% from baseline
2	Depth of penetration	Δ > 1 cm from baseline
3	Axial and lateral resolution	Δ > 1 cm from baseline
4	Axial and lateral distance accuracy	Error > 2 mm or 2%
5	Area measurement accuracy	Error > 3 mm or 3%
6	Volume measurement accuracy	Error > 5%
7	Needle template alignment	Error > 3 mm
8	Treatment planning computer volume accuracy	Error > 5%

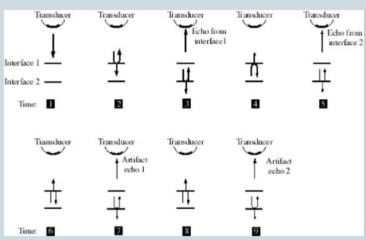
Time Estimates

Test #	*Test name*	*Typical duration*
0	Gather and filling in preliminary information	10 minutes
1	Grayscale visibility	2 minutes
2	Depth of penetration	2 minutes
3	Axial and lateral resolution	1-5 minutes
4	Axial and lateral distance measurement accuracy	5 minutes
5	Area measurement accuracy	5 minutes
6	Volume measurement accuracy	10 minutes
7	Needle template alignment	15 minutes
8	Treatment planning computer volume accuracy	15 minutes
	Total:	**70 minutes**

Ring-down artifact

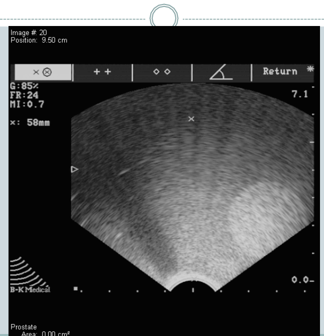
- The signal is reflected multiple times within the needle.





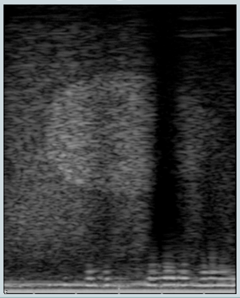
Electronic artifact

Moisture in probe connection



Contact artifact

Poor contact between probe and object



Concluding Remarks

- Each of the tests rely on establishing a set of baseline measurements against which future measurements can be compared.
- The overall time commitment is manageable: the full set of measurements should be performed annually and will take about 90 minutes.