Image Quality Through Ultrasound-Compatible Cylinders for Transvaginal Ultrasound-Guided High-Dose-Rate Brachytherapy

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Purpose

To evaluate how ultrasound images are affected when captured through a hollowed sonolucent sheath designed for 3D transvaginal ultrasound (3DTVUS) guidance in gynecologic high-dose-rate brachytherapy.

Background

- 3DTVUS system developed at the University of Western Ontario[(1)] (Figure 2a)
- **3D image reconstructed from 2D sagittal images**
- Transvaginal images acquired through sonolucent sheath because:
  - Rigid cylinder required to fix transperineal templates
  - Outer dimensions match 3cm dia. clinical cylinder; 3DTVUS images anatomically matched to treatment scenario
  - Sonolucent material minimizes ultrasound attenuation
- Effect of sheath on images requires characterization

Methods

- Sonolucent sheath constructed in-house:
  - Material: RT-18 grade TPX™ plastic[(2)]
  - Speed of sound: ~2090m/s [(3)]
  - Inner/outer diameters: 22.1mm/30.0mm
- Bi-plane transrectal probe
- Acquisition settings: 9MHz, 50% gain, maximum depth
- Imaged the CIRS Model 045A Brachytherapy QA Phantom (Figure 1)
- Adapted AAPM TG-128[(4)] prostate ultrasound QA recommendations
  - Baseline without sheath ('sheath-out')
  - Comparison with sheath ('sheath-in')

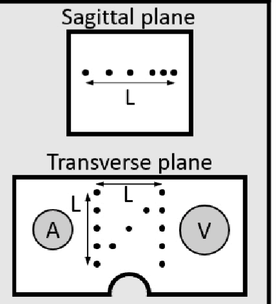

Figure 1: Schematic of CIRS phantom sagittal and transverse planes, with spaced wires and contrast volumes. L=40.0mm, A=5.23cm², and V=20.0cm³.

Results and Discussion

- **All tests in sagittal image plane passed TG-128 tolerances[(4)]**
- Depth of penetration (#2), measured as phantom cavity edge to noise edge, was reduced by 4.0mm due to physical thickness of sheath
- Lateral resolution (#3) degraded in transverse images (see Figure 2), but not in sagittal images
- Sheath has little effect on area and volume measurements
- Air bubbles for sheath-in images can be problematic, must be careful when inserting probe into sheath
- Transverse image degradation not of concern since 3DTVUS images are reconstructed from 2D sagittal images

Table 1 – Adapted TG-128 tests comparing sheath-out and sheath-in images

TG-128 Test #	Test	Baseline (sheath-out)	Measured (sheath-in)	Difference*	TG-128 Tolerance
2	Depth of penetration	56.9 mm	52.9 mm	-4.0 mm	10 mm
3	Axial resolution – transverse	0.4 mm	0.3 mm	-0.1 mm	1 mm
	Lateral resolution (near) – transverse	1.5 mm	2.7 mm	1.2 mm	1 mm
	Lateral resolution (far) – transverse	4.0 mm	6.0 mm	2.0 mm	1 mm
	Axial resolution – sagittal	0.6 mm	0.3 mm	-0.3 mm	1 mm
	Lateral resolution – sagittal	1.8 mm	2.1 mm	0.3 mm	1 mm
4	Axial scaling (40 mm) – transverse	40.0 mm	39.6 mm	-0.4 mm	2 mm / 2%
	Lateral scaling (40 mm) – transverse	40.3 mm	40.3 mm	0 mm	3 mm / 3%
	Lateral scaling (40 mm) – sagittal	40.1 mm	40.0 mm	-0.1 mm	3 mm / 3%
5	Area measurement (5.23 cm^2)	5.31 cm^2	5.32 cm^2	0.2%	5%
6	Volume measurement (20.0 cm^3)	20.9 cm^3	20.8 cm^3	-0.5%	5%

*Green = within tolerance, yellow = outside tolerance

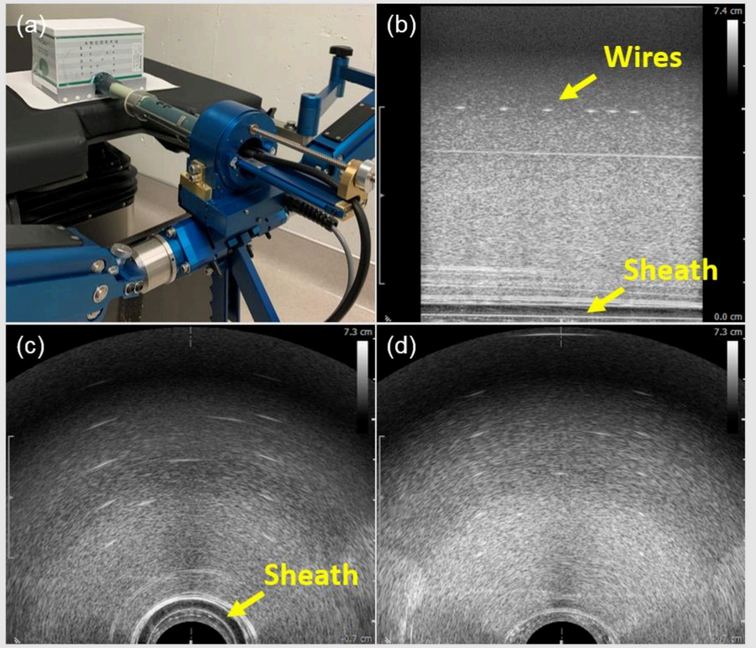

Figure 2:
(a) 3DTVUS system secured to bed rails, with probe and sheath inserted in CIRS QA Phantom
(b) Sheath-in sagittal image showing wires used for axial and lateral resolution tests. Little observable differences seen compared to sheath-out.
(c) Sheath-in and (d) sheath-out transverse images which show that lateral resolution degraded with the addition of the sheath

Conclusion

Sagittal images acquired with and without the sonolucent sheath are within adapted TG-128 tolerances. Future work includes patient studies evaluating use of 3DTVUS-based workflows in both intracavitary and interstitial gynecologic high-dose-rate brachytherapy.

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