Quality Assurance of Ultrasound Imaging in Radiation Therapy

Zuofeng Li, D.Sc.
Murty S. Goddu, Ph.D.
Washington University
St. Louis, Missouri
Typical Applications of Ultrasound Imaging in Radiation Therapy

• Prostate brachytherapy
  – Low dose rate permanent seed implant and high dose rate remote afterloading implant
    • Ultrasound images with software template overlay used for target definition and treatment planning

• Ultrasound-imaging-guided external beam radiation therapy
  – Real-time ultrasound images of targets and organs at risk correlated to their counterparts in treatment planning CT images for accurate patient positioning in external beam radiation therapy

• Breast brachytherapy
  – Ultrasound used to identify targets and organs at risk, and to guide insertion of treatment catheters
    • Standard ultrasound QA tests sufficient
Ultrasound Imaging for Prostate Brachytherapy (HDR and LDR)

- Acquisition of transverse and/or sagittal prostate images for treatment planning (volume study)
- Segmentation of prostate, urethra, bladder, and rectum as well as calculation of their volumes
- Re-production of volume study ultrasound images for real-time guidance
- Template overlay on ultrasound image must correlate with physical template used for needle insertion guidance
Ultrasound-Guided Prostate Brachytherapy

- Low dose rate permanent seed implant
- High dose rate remote-afterloading brachytherapy
Components of Ultrasound-Guided Prostate Brachytherapy

• Ultrasound imager
  – A portable unit with software template overlay as well as contouring and volume calculation capabilities

• Template/Stepper system
  – Allows guidance of needle insertion as well as accurate positioning of ultrasound transducer relative to prostate organ

• Stabilizer/stand system
  – Mechanical support mounted on the floor or OR table side rails to improve stability of ultrasound probe and template/stepper system, and to improve needle insertion accuracy

• Treatment planning system
  – Capability to import ultrasound images for treatment planning
Image Quality of TRUS Unit

Poor image quality directly affect accuracy of target determination.
Purposes of Testing:

- TRUS unit must provide adequate image quality for delineation of prostate, seminal vesicles, urethra, and rectum
- TRUS unit must maintain adequate geometric accuracy in delineation of imaged objects
- TRUS unit, together with implant-specific attachments, must maintain position accuracy of source placement
Testing of Image Quality

- Image uniformity - qualitative
- Vertical and horizontal distance accuracy in homogeneous medium - quantitative
- Axial and lateral resolution - quantitative
- Maximum depth of view - not important for prostate brachytherapy
- Anechoic object imaging
Testing of Geometric Accuracy

• Prostate training phantom used
  – Vertical and horizontal distance measurement accuracy in heterogeneous medium: Direct measurement
  – Agreement of grid points with needle template holes: Direct measurement
  – Stepping distance accuracy: Direct measurement
  – Volume calculation accuracy: Comparison with volume calculated from CT scans of the same phantom
CIRS Prostate Training Phantom
Orthogonal Views of Fused TRUS and CT Images
TRUS calculation of prostate volume in prostate phantom agrees with treatment planning computer calculation to within 1%

TRUS measurement of prostate dimensions agree with treatment planning computer measurements to within 2 mm in AP and lateral directions, 3 mm in superior-inferior direction. CT spacing = 3mm
Agreement of Grid Point with Needle Template Holes - Fusion with CT image

Fusion of TRUS images with CT images verifies geometric accuracy throughout the scanned region.
Agreement of Grid Point with Needle Template Holes

Grid position adjustable on TRUS unit (ACUSON)

Agreement verified through the length of prostate (probe tilt not fixed on TRUS unit)

Grid dimension dependent on depth of view setting
Prostate Brachytherapy QA Phantom (CIRS model 045)
Daily Ultrasound QA for Prostate Implant

- A custom phantom used to check geometry accuracy on the day of treatment: *Matic et al, Med. Phys. 27(1), 2000*
  - 2 mm geometry accuracy tolerance

Out of tolerance

Within tolerance

Jul 27, 2004

AAPM 2004 Annual Meeting
Ultrasound Imaging Guidance for External Beam Radiation Therapy

Bladder, prostate, and rectum contours transferred from treatment planning system not aligned with ultrasound image.

Bladder, prostate, and rectum contours aligned with ultrasound image following patient re-positioning.

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Nomos BAT- Components

- Ultrasound based Localization System
- Ultrasound probe is fixed to an articulated arm
  - High precision - position tracking robotic arm
- Docking stations:
  - Cart cradle
  - Gantry Cradle – Isocenter Registration
  - Couch Cradle – Patient Positioning
- Customized software used for Imaging and Localization
ZMed - SonArray
US based Image Guided Patient Positioning System

High-resolution infrared camera
Detects passive and active fiducials

SonoSite Ultrasound:
- Portable
- 3.5MHz abd. probe
CMS I-Beam System

- An 3D-Ultrasound based Stereotactic Localization System
- Is designed to use it on a daily basis for prostate localization
- Does not require any permanent hardware mounting in treatment rooms
- It is on wheels for its use in multiple tx. Rooms
I-Beam Components

Compact ultrasound system:
- System on a chip technology
- 128 channel linear array transducer

Integrated camera and US probe
- Free-hand probe allows ease of scanning
- Passive localization target placed in the wedge or block tray
- Machine Vision’s Coordinate position technology
I-Beam: How does it Work?

- “Target” image captured by camera
- I-Beam’s Image registration software converts target image into a point matrix that supports geometric calculation
- Large white square used to calculate camera distance, rotation angle, etc.
- Unique pattern on target along with patient’s ‘treatment position information’ allows software to establish patient orientation (patient coordinate system)
- Calibration process defines isocenter and registers live US images to isocenter coordinate system
I-Beam System: Calibration

• Accurate calibration important for any localization
• Calibration phantom has wires crossing at 6 points
  - Align phantom to room lasers
  - Scan phantom to capture 3D-volume

• After calibration:
  - Isocenter location determined
  - Allows registration of real-time US images to treatment Room co-ordinate system
I-Beam System: Calibration
I-Beam: QA Tests

• Ultrasound Image Quality / Configuration
  - Standard US Image quality tests performed
• Calibration Accuracy
• Alignment accuracy in all 3 dimensions
I-Beam: Calibration Check

- CT scan calibration phantom with fiducial markers at 0,0,0
  - Set isocenter in treatment planning system to fiducial marks
  - 2mm x 2mm box contours were created at all six calibration points
  - Transfer plan to I-Beam system and verify calibration points under US imaging
  - US the phantom using I-Beam system
Localization Accuracy: US vs. CT

- Verify prostate location by CT and I-Beam on the same table

**Test Process:**
- CT scan phantom
- Contour prostate, bladder & Rectum
- Set isocenter and mark phantom
- Export the plan to I-Beam system
- Scan phantom with I-Beam
I-Beam: Alignment Accuracy

- Translate phantom to a known distance
- I-Beam scanned and aligned the images with contours
- Determined the shifts predicted by I-Beam system
- Translated the couch per I-Beam recommendations
- Rescanned the phantom to confirm its position

Alignment accuracy better than 2 mm in most cases
I-Beam: Daily QA

- Translate phantom to a known distance
- Determine shifts predicted by I-Beam system
- Align images and translate treatment couch per I-Beam recommendations
- Rescan phantom to confirm isocenter location
Summary

• QA of ultrasound imaging devices for radiation therapy introduces unique challenges and requirements
• Geometry and positional accuracy tests must be devised for each individual applications
• Test phantoms customized for each individual applications
• Standard image quality QA tests often sufficient
• QA of ultrasound imaging in radiation therapy remains an evolving area of development