Source Localization in Brachytherapy

Part I: Radiographic Methods

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Methods of Source Localization

- Plain Radiographs (Films) or Amorphosilicon Imaging
- Autoradiographs for HDR and Intravascular Brachytherapy
- CT: Diagnostic and CT-simulators
- Ultrasound: Intraoperative Permanent Prostate Implants
- Fluoroscopy (simulators or C-arms)
- Cone-Beam CT (Acuity Simulator)
- MRI: Dubois, Bice, and Prestidge 1997, 2001
- Mechanical (Nucletron) and Optical (Varian) for HDR
- Other Non-Radiographic Methods: EM tracking
Traditional Methods

- Orthogonal Films (e.g. AP and Lat.)
- Couch Stereo-Shift
- Gantry Stereo-Shift
- Multi-film methods for prostate seeds

Not the state of the art but still could be used
Source Localization using Orthogonal Films

X-ray Tube 1

X-ray Tube 2

Film 1

Film 2

$F_1$

$F_2$

$X$

$Z$

$I$

$S$

$x$

$z$

$X_1$

$Z_2$
Orthogonal Films

- Total number of seeds
- Seed orientation and clusters
- Implant location with respect to the bony anatomy
- Chest X-ray after permanent prostate implant
Magnification for Orthogonal Beams

\[ M_1 = \frac{F_1 F_2 + x_1 z_2}{(F_1 F_2 + x_1^{(r)} z_2) / M_1^{(r)} + F_2 (z_2^{(r)} - z_2) / M_2^{(r)}} \]

\[ M_2 = \frac{F_1 F_2 + x_1 z_2}{(F_1 F_2 + x_1 z_2^{(r)}) / M_2^{(r)} - F_1 (x_1^{(r)} - x_1) / M_1^{(r)}} \]

Formulas allow to determine magnification factors for the films and the source positions.
Source S localization using stereoshift
Source Localization using Stereo-Shift

\[ z_s = SFD \cdot \frac{(SFD - z_f) \cdot (x_2 - x_1) - s \cdot z_f}{(SFD - z_f) \cdot (x_2 - x_1) - s \cdot SFD} \]

\[ M = \frac{SFD - z_s}{SFD} \]

Source position and film magnification found from a pair of radiographs taken with a stereo-shift.
Automatic Reconstruction using Plain Radiographs

- Amols and Rosen 1981
- Altschuler, Findlay, and Epperson 1983
- Biggs and Kelley 1983
- Rosenthal and Nath 1983
- Stock et al. 1995
- Todor et al. 2002

Up to 5% of the seeds could be mismatched if the number of seeds is large
Autoradiographs

- HDR QA: dwell locations with respect to “dummies”
- Intravascular QA: source length, uniformity, and location
- HDR dwell locations in some applicators

Performed with Ready-Pack or GAFChromic film
CT-Based Reconstruction

• Advantages:
  – 3D picture
  – Organ Visualization
  – DVH calculation
  – Allows [semi]automatic contouring and localization

• Disadvantages:
  – Requires CT
  – CT Gantry Size and Clearance
  – Artifacts
  – Special Applicators Needed
  – Localization Accuracy
Auto Contouring for Prostate HDR

- High-contrast objects (bones, outer contour) can be automatically outlined.
- Catheters can be automatically recognized.
3D Reconstruction of HDR Catheters

3D view with catheters and the patient’s anatomy
HDR Dwell Positions on CT-Based Plan

- Dwell positions of the HDR source can be automatically entered based on the catheter location and length
Catheter Reconstruction

Positions of the catheters with respect to the patient’s anatomy allows to decide which catheters should be used.
Various imaging tools allow to visualize the dose distribution as a cloud or a surface.
Brachytherapy of Head and Neck

CT-based planning can be used for most of the sites
Use of mammosite applicator requires precise imaging.

- Radiation source port pathway
- Multilumen, silicone catheter
- Variable 4 to 5 cm balloon
- Single source dwell position
Mammosite Localization

Check of the form and position of the balloon
Prostate HDR Brachytherapy
CT Slice Thickness and Partial Volume Effect

Too thick CT slices reduce the accuracy of the location and volume determination, while too thin slices increase the seed double-registration.
Problems in CT-based Prostate Postimplant Analysis

- Double-registration (up to 40% for 3-mm contiguous slices)
- Seed clusterization (multiple seeds at one location)
- Seed location depends on its orientation
- Localization accuracy
- Imaging Artifacts (star patterns, dark lines connecting different seeds)

Recommended by the AAPM for post-implant analysis
Automatic Seed Localization

- D. Brinkmann and R. Kline, 1997
- Li et al. 2001
- Liu et al. 2003
- Holupka et al. 2004
- Commercial Programs (Varian, Nucletron, et al.)

Predefined or adjustable threshold, volume rastering, etc.
Varian Automatic Seed Finder
Ultrasound Imaging Commonly Used for Permanent Prostate Implants

• Advantages:
  – Can be performed intraoperatively
  – Allows to visualize prostate, needles, seeds (Davis, 2003: corrugated surface for better visualization), and TURP
  – Allows 3D-image acquisition and live imaging
  – No radiation dose to the patient and personnel

• Disadvantages:
  – Lower resolution and sharpness
  – Lower contrast
  – Spatial distortion (cylindrical coordinates)
Nucletron Sonographic Planning of Oncology Treatments

• Intraoperative 3D-image acquisition
• Live planning with live seed update - handle the difference between plan and treatment situation.
• Integrated real-time planning and post-implant evaluation - see the difference between the planned and the delivered treatment.
• Instant dose calculation to see the effect of needle placement or changes to enable the physician to optimize dose distribution to the actual treatment volume.
• Direct communication with seedSelectron® for immediate delivery of seeds in the most up to date configuration
• see the effect of seed implant procedure, make adjustments and corrections where necessary in the plan – and deliver this optimized treatment
Ultrasound Images of Needles

Surface of some needles and seeds is specially treated to be better seen on the ultrasound.
Prostate gland and pubic arch are seen on the Ultrasound Images
TURP can be also visualized on Ultrasound
A set of ultrasound images of the prostate can be used for the planning of the permanent implant.
Nucletron Ultrasound Planning
Fluoroscopy

• Advantages:
  – Can be used intraoperatively
  – Provides sharper and higher contrast images than US
  – Conventional geometry

• Disadvantages:
  – Ionizing radiation
  – Cannot be used to acquire 3D set of images
  – Does not visualize soft tissues
Fluoroscopy for Source Localization

- Tubic et al. 2001
- Narayan, Cho, and Marks 2002
- Todor et al. 2003, Su et al. 2004

Multiple projections for eliminating the radioactive seeds overlap problem

Intravascular Brachytherapy: dummy and active sources
AP and Lateral Fluoro Images

Additional images at different angles can be used Intraoperatively for evaluation and seed localization.
Fluoro Verification for Each Fraction

First fraction in the morning

Second fraction in the afternoon
Fluoroscopy can be used for mammosite localization
Cone-Beam CT

B. Prestidge, Texas Cancer Clinic, San Antonio, 2004

- Acuity simulator from Varian
- Dedicated brachytherapy suite
- Intraoperative CT
- Large mechanical clearance
- Patient not disturbed
- Verification CT before each fraction
- Scan in treatment position
- Primary or secondary imaging
- Plan and treat under anesthesia
Varian Acuity with Cone Beam CT

 Courtesy of B. Prestidge, Texas Cancer Clinic, San Antonio, 2004
Vaginal Cylinder Cone-Beam CT

Courtesy of B. Prestidge, Texas Cancer Clinic, San Antonio, 2004
Cone-Beam CT for Prostate HDR

Courtesy of B. Prestidge, Texas Cancer Clinic, San Antonio, 2004
Cone-Beam CT of the Prostate Seed Implant

Courtesy of B. Prestidge, Texas Cancer Clinic, San Antonio, 2004
Image Resolution Optimization

Courtesy of B. Prestidge, Texas Cancer Clinic, San Antonio, 2004
Mammosite Cone Beam Imaging

Courtesy of B. Prestidge, Texas Cancer Clinic, San Antonio, 2004
Summary

• Source and target localization are extremely important in brachytherapy.

• Traditional radiographs allow to accurately localize the source but could be labor intensive and less practical.

• CT, Ultrasound, and Fluoroscopy have several advantages and disadvantages and could complement each other.

• New imaging modalities, such as Cone-Beam CT, open new opportunities in the field.

• There are also non-radiographic methods of the source localization.