Intensity-Modulated and Image-Guided Radiation Treatment

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Outline

• Multi-modality imaging in radiation oncology
• Intensity-modulated radiation treatment
• Image-guided radiation treatment
  – New devices and technologies

Conformal Radiation Treatment

conventional treatment
(rectangular dose distribution)

bioanatomic IMRT
(dose matches target shape and biology)
The Electron Linear Accelerator and Radiation Treatment Geometry
Six Degrees of Freedom about the Isocenter
3 rotations, 3 translations, 1 mm radius precision

CT Simulation and Treatment Planning
CT + Positioning + 3D RTP Software

The Digitally Reconstructed Radiograph
- DRR - a computerized ray trace through a CT 3D digital dataset – a secondary image
- Attenuation properties of material are modeled
- Source and image receptor treated as ideal
- Very important step of verification for the virtual simulation process used in 3D radiation treatment planning
4D CT Imaging

4D CT for Targeting

- Gate the target
  - Select Phases
- Define the margins (ITV)
  - Max Intensity Projection (MIP)
  - Ave-IP
  - Min-IP
  - Phases

PET in Oncology

Colon Cancer: Possible Treatment Fields

Node Negative
- Simple Field

Node Positive
- Field includes Nodal Region

Adapted from Roben, Turkington, Coleman: Radiology 2004, 231:305-332
Secondary Impact: Target Definition
PET may decrease or increase target volumes compared to CT-only

CT: Purple  PET/CT: Green
Changes in target outline translate to reduced treatment field size

PTV based on PET/CT
PTV based on CT only

Courtesy of K Mah, Univ Toronto, Sunnybrook

4D PET-CT: Liver

Courtesy of WT Kearns, Wake Forest Univ

Magnetic Resonance Imaging: Simulation and Treatment Planning

Courtesy of EG Shaw, Wake Forest Univ

Brain Metastasis  Acoustic Neuroma  Trigeminal Neuralgia
Prostate MR Imaging for RTP

Imaging in Radiation Oncology
Treatment Verification

- Electronic Portal Imaging Devices (EPID)
- Image-Guided Radiation Treatment (IGRT)
  - Real-time visualization of target during treatment
  - Imaging and treatment devices in the same room

Electronic Portal Imaging (Digital Megavoltage Imaging)

- Linear accelerator
- Flat panel electronic portal image receptor
- Amorphous silicon
- About 256 x 512 pixels
- Multi-layered receptor “sandwich”
The Radiation Targeting Issue

See then Treat then See then Treat (and so on …)

- See
  - How well - target localization?
  - Specificity/sensitivity?
  - Modality?
  - Anatomy, biology?

- Treat
  - How often?
  - Once, weekly?
  - Per fraction?

- Adaptive

Intensity Modulated Radiation Treatment

(IMRT)

IMRT: The intensity of each beam is modulated to produce the desired dose distribution at the target. Flat-dose fields are no longer used for treatment.

Intensity Modulated Arc Radiotherapy

Courtesy of Varian Medical Systems
Intensity Modulated Arc Radiotherapy

IMRT Summary

• The inverse answer to dose conformation, for concave targets and OAR avoidance
• Multiple implementations: small/large leaf widths, binary/continuous leaf motion, step-&-shoot, dynamic MLC, and now in dynamic arc format
• Constraints are for dose to adjacent tissues as well as device electromechanical/radiological limits
• Opportunities for 4D implementations – gating and target tracking
• Secret to efficiency is to treat as much solid angle as possible at any one time

The Radiation Targeting Issue

See then Treat then See then Treat then Treat adaptive (and so on …)

• See
  – How well - target localization?
  • Specificity/sensitivity?
  • Modality?
  • Anatomy, biology?
  – How often?
  • Once, weekly?
  • Per fraction?
• Treat
  – Verification of target hit?
  – Matched to imaging?
  • Static, dynamic, contrast?
  – Readily interpretable?
Image-Guided Radiation Treatment

- 3D-CRT (image-based)
- Stereotactic radiosurgery: Gamma unit or Linac
- US-guided EBRT prostate target-of-the-day
- CT-guided EBRT target-of-the-day: adaptive
- MR-guided EBRT target-of-the-day: adaptive
- IGRT for prostate brachytherapy (seeds, HDR)
- 4D CT and Gated Treatment (respiratory)
- Cone-beam CT (near) real-time verification (IGRT)
- Real-time image registration (EPID + DRR + CBCT)
- A growing variety of hybrid devices

Optical Positioning and MV Treatment
Bourland, AMP-08 (in press)

Orthogonal MV Imaging (EPID) and MV Treatment
Bourland, AMP-08 (in press)
Implanted gold markers used to localize soft tissue targets like the prostate. Without markers, bony anatomy can be accurately aligned, but not the prostate itself.

At WFUBMC, this software has been used to improve localization for prostate, head and neck, and paraspinal cancers.

Bourland, AMP-08 (in press)
kV Bi-Planar Fluoroscopy and Robotic MV Treatment
Bourland, AMP-08 (in press)

In-Room CT On Rails and MV Cone-Beam Treatment
Bourland, AMP-08 (in press)

MV Fan-Beam CT and MV Fan-Beam Treatment
Bourland, AMP-08 (in press)
kV Cone-Beam CT and MV Treatment
Bourland, AMP-08 (in press)

Legend
- Treatment beam
- Imaging beam
- Optical device

MV Cone-Beam CT and MV Treatment
Bourland, AMP-08 (in press)

Legend
- Treatment beam
- Imaging beam
- Optical device

Vendor IGRT Implementations

### Hybrid IGRT Technologies

<table>
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<th>Treatment Device</th>
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### Summary: IMRT and IGRT

- **“Static”** imaging: diagnosis and staging, treatment simulation, planning, verification and treatment evaluation
- Multi-modality imaging is common: provides anatomical/structural and biological character of radiation targets and normal tissues
- **“Real-Time”** imaging now used for treatment simulation and planning (4D CT, 4D PET, 4D MR) – also, provided during treatment

### Summary: IMRT and IGRT

- IMRT maturing: large solid angle at any one time – eg, arc modulated radiotherapy
- “Real-Time” imaging used for in-room treatment verification: IGRT – efficiency will increase to enable real-time imaging, perhaps with simultaneous imaging and treatment
- Hybrid (bi-mode, tri-mode) imaging, remote monitoring, and treatment devices being developed and installed for dedicated radiation treatment
  - Compatibility, safety, and implementation aspects

**Hybrid IGRT device development ➔ rapid growth!**
• Work supported in part by research grants from North Carolina Baptist Hospital, Varian Medical Systems, and GE Healthcare
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