Intensity-Modulated and Image-Guided Radiation Treatment

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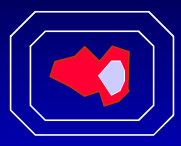
Outline

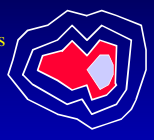
- Multi-modality imaging in radiation oncology
- Intensity-modulated radiation treatment
- Image-guided radiation treatment
  - New devices and technologies

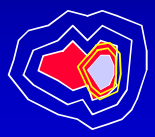
Conformal Radiation Treatment



conventional treatment (rectangular dose distribution)

conformal (dose matches target shape)





bioanatomic IMRT (dose matches target shape and biology)

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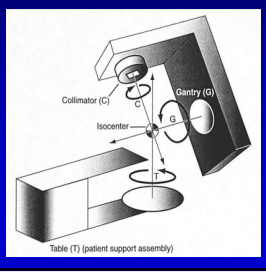
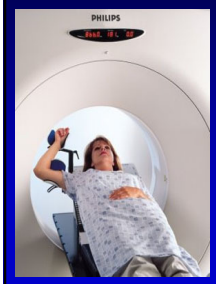
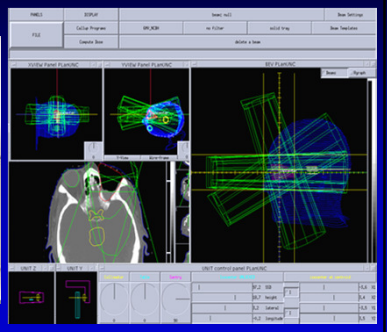
The Electron Linear Accelerator
and
Radiation Treatment Geometry
Six Degrees of Freedom about the Isocenter
3 rotations, 3 translations, 1 mm radius precision



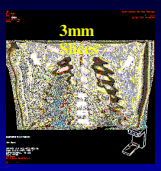
CT Simulation and Treatment Planning
CT + Positioning + 3D RTP Software

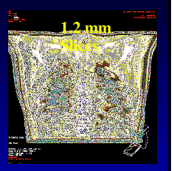


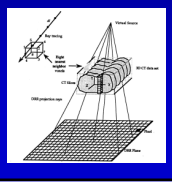


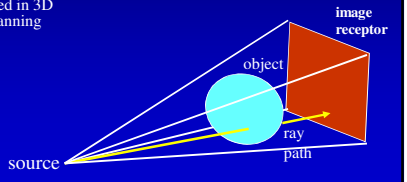
The Digitally Reconstructed Radiograph

- 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

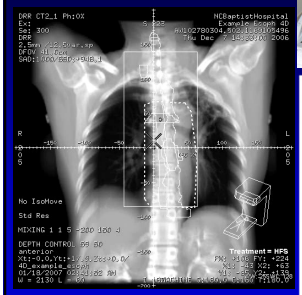


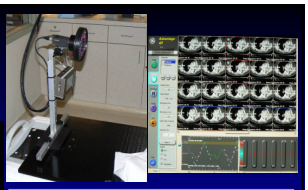


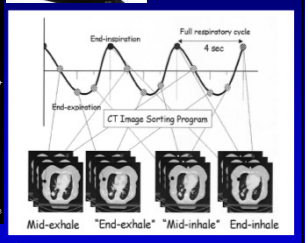




4D CT Imaging





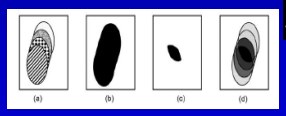


Courtesy of WT Kearns, Wake Forest Univ

Underberg et al., IJROBP, 60, 2004

4D CT for Targeting

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



Underberg et al., IJROBP, 2005

69 yo male, T1 NSCLC
CCCWFU 62306 - RFA + RT

Courtesy of WT Kearns, Wake Forest Univ

PET in Oncology

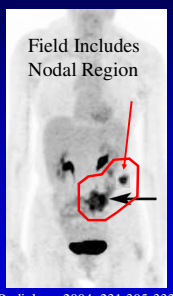
Colon Cancer: Possible Treatment Fields

PET in Oncology

- Diagnosis – less common
- **Staging - yes**
- Target Definition
  - Radiation treatment
  - Other "targeted" therapy
- Re-staging – yes
- Treatment Evaluation

Node Negative

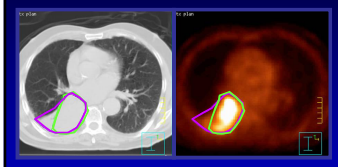
Node Positive



Adapted from Rohren, Turkington, Coleman: Radiology 2004; 231:305-332

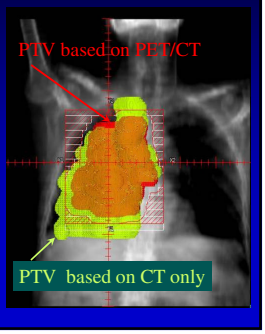
Secondary Impact: Target Definition

PET may decrease or increase target volumes compared to CT-only



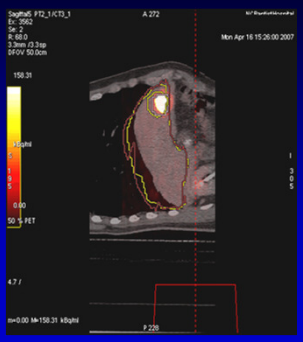
CT: Purple PET/CT: Green

Changes in target outline translate to reduced treatment field size



Courtesy of K Mah, Univ Toronto, Sunnybrook

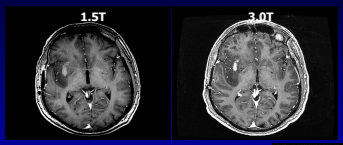
4D PET-CT: Liver

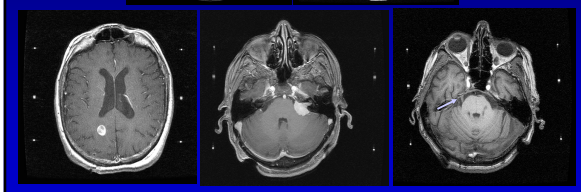


Courtesy of WT Kearns, Wake Forest Univ

Magnetic Resonance Imaging: Simulation and Treatment Planning

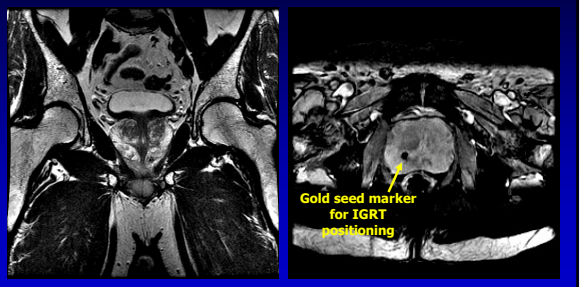
Courtesy of EG Shaw, Wake Forest Univ





Brain Metastasis Acoustic Neuroma Trigeminal Neuralgia

Prostate MR Imaging for RTP



Courtesy of EG Shaw, Wake Forest Univ

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

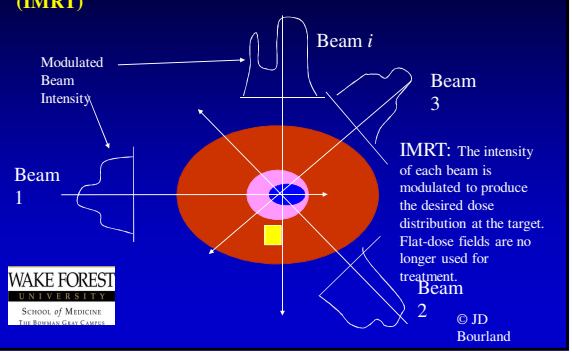
See
then
Treat
then
See
then
Treat
(and so on …)

adaptive

- 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?

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.

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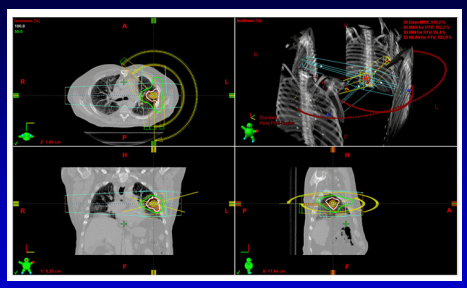
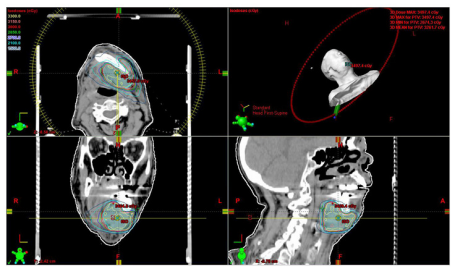
Intensity Modulated Arc Radiotherapy



Courtesy of Varian Medical Systems

Intensity Modulated Arc Radiotherapy



Courtesy of Varian Medical Systems

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
(and so on …)

adaptive

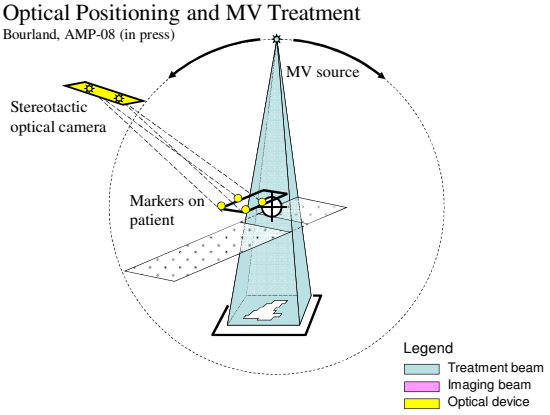
- See
  - How well – target localization?
    - Specificity/sensitivity?
    - Modality?
    - Anatomy, biology?
  - How often?
    - Once, weekly?
    - Per fraction?
- Treat
  - Verification of target hit?
  - Matched to imaging?
    - Static, dynamic, contrast?
  - Readily interpretable?

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

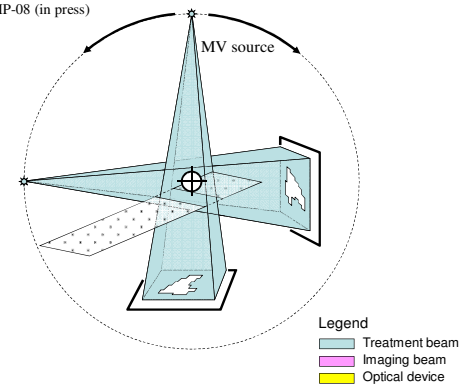
Optical Positioning and MV Treatment

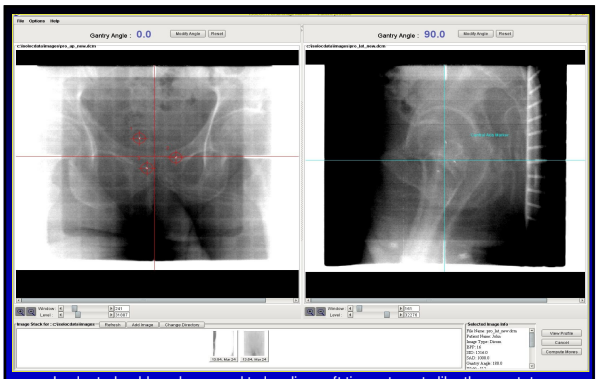
Bourland, AMP-08 (in press)



Orthogonal MV Imaging (EPID) and MV Treatment

Bourland, AMP-08 (in press)



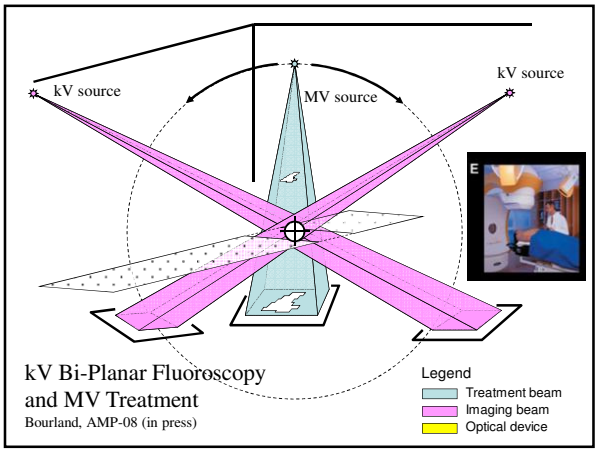


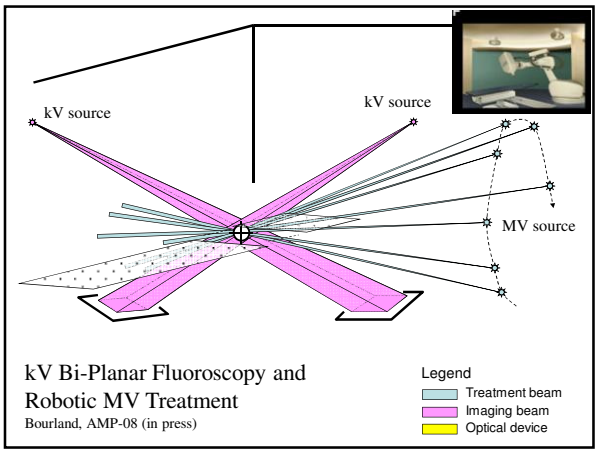
Implanted gold markers used to localize soft tissue targets like the prostate. Without markers, bony anatomy can be accurately aligned, but not the prostate itself.

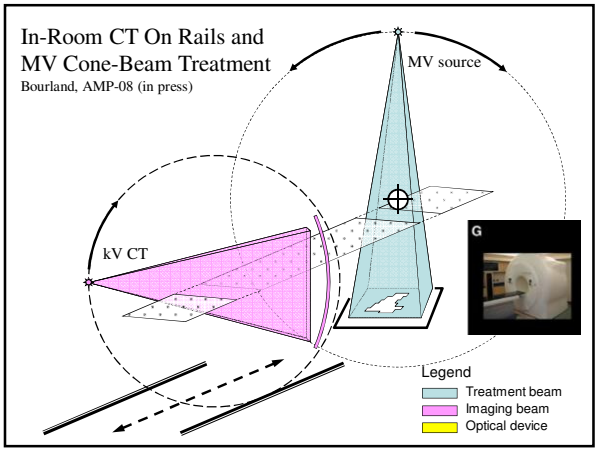
Courtesy of CJ Hampton, Wake Forest Univ

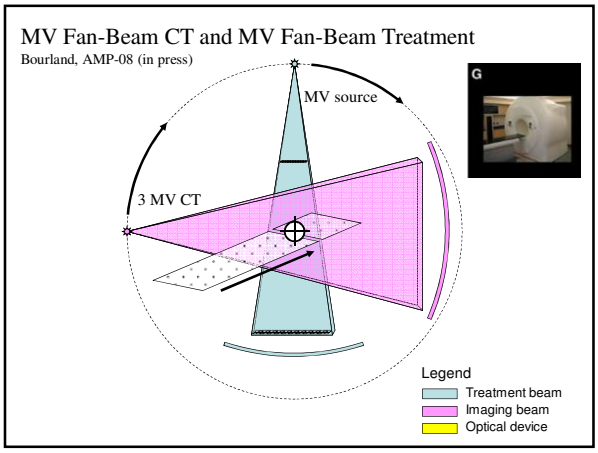
At WFUBMC, this software has been used to improve localization for prostate, head and neck, and paraspinal cancers.

Courtesy of CJ Hampton, Wake Forest Univ



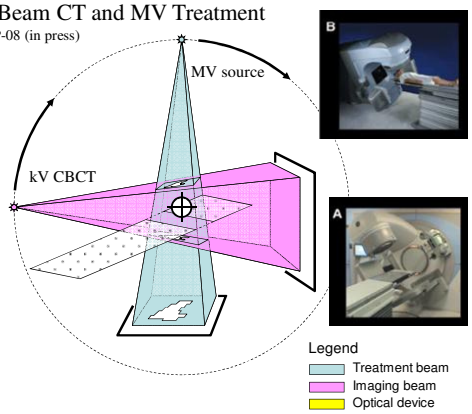

kV source
kV source
MV source
kV Bi-Planar Fluoroscopy and
Robotic MV Treatment
Bourland, AMP-08 (in press)
Legend
Treatment beam
Imaging beam
Optical device


In-Room CT On Rails and
MV Cone-Beam Treatment
Bourland, AMP-08 (in press)
MV source
kV CT
G
Legend
Treatment beam
Imaging beam
Optical device


MV Fan-Beam CT and MV Fan-Beam Treatment
Bourland, AMP-08 (in press)
MV source
3 MV CT
G
Legend
Treatment beam
Imaging beam
Optical device

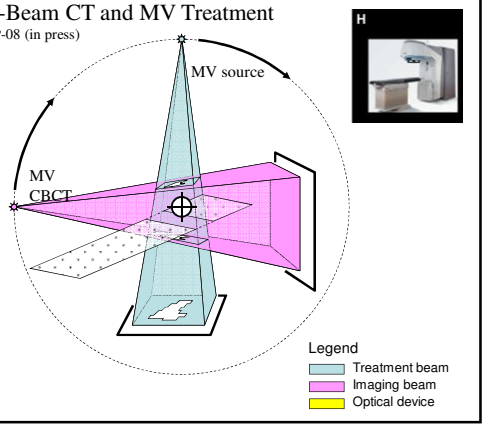
kV Cone-Beam CT and MV Treatment

Bourland, AMP-08 (in press)

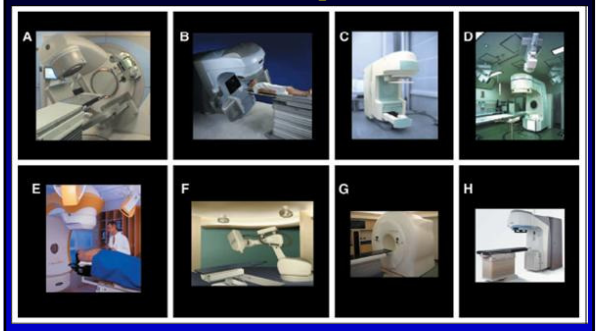


MV Cone-Beam CT and MV Treatment

Bourland, AMP-08 (in press)



Vendor IGRT Implementations

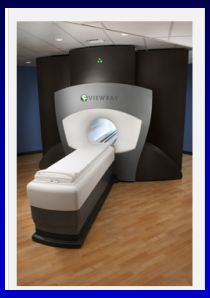


Dawson LA, Jaffray DA. Advances in image-guided radiation therapy. J Clin Oncol. 2007 Mar 10;25(8):938-46.

VERO - Very Large Bore MV + CBCT

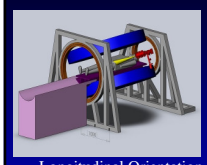
Courtesy BrainLab AG and Mitsubishi Heavy Industries, Ltd

Gamma + MRI

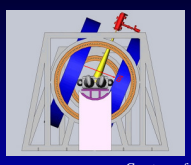


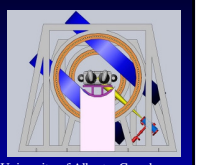
Courtesy Viewray, Inc

MR + Linear Acclerator

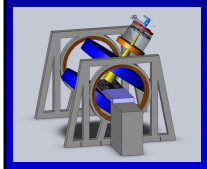


Longitudinal Orientation

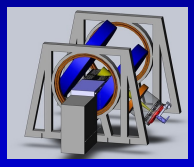


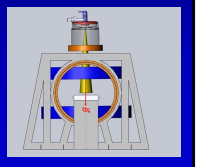


Courtesy of University of Alberta, Canada



Transverse Orientation





Courtesy of University of Alberta, Canada

Hybrid IGRT Technologies

Treatment Device →

Imaging Device ↓

	Gamma RadSurg	MV x rays Linac	MV x rays robotic	Brachy	HiFUS
US		X	?		
Optical		X	X		
Remote Send		X	X		
Fiducial Markers		X	X	X	
CT		X		?	
PET-CT		X			
MV FBCT		X			
kV CBCT	X	X		X	
MV CBCT		X			
Stereo XR		X	X	X	
MRI	X	X		X	X
SPECT/NM		X			

Summary: IMRT and IGRT

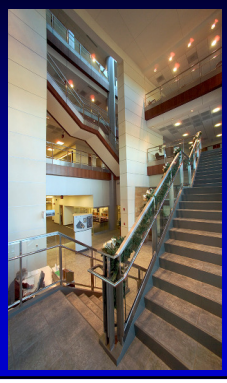
- "Static" imaging: diagnosis and staging, treatment simulation, planning, verification and treatment evaluation
- Multi-modality imaging is common: provides anatomical/structural and biological character of radiation targets and normal tissues
- "Real-Time" imaging now used for treatment simulation 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!

Wake Forest Baptist Medical Center



Acknowledgements

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- Bill Kearns, Wake Forest University
- Carnell Hampton, Wake Forest University
- Edward Shaw, Wake Forest University