

Image Guided Radiotherapy Technologies and Processes

Joint ICTP-IAEA International Workshop
Implementation of IGRT
8-12 May 2017

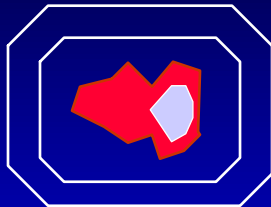
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Winston-Salem, North Carolina, USA
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Outline

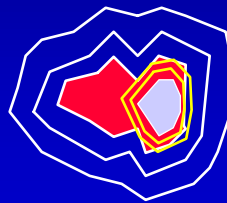
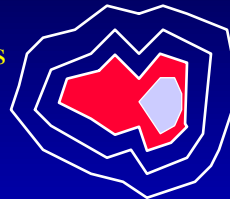
- Radiotherapy imaging and treatment
- Image-guided radiation treatment
 - New devices and technologies
 - Processes in IGRT

Conformal Radiation Treatment



conventional treatment
(rectangular dose
distribution)

conformal
(dose matches
target shape)



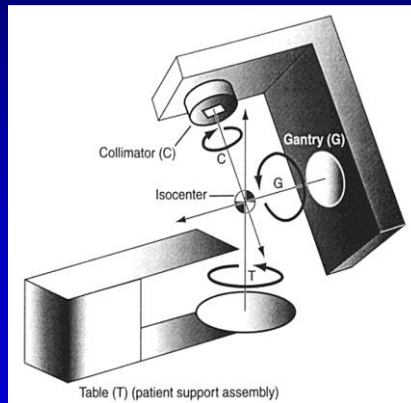
bioanatomic IMRT
(dose matches target
shape and biology)

© JD Bourland

The Electron Linear Accelerator and

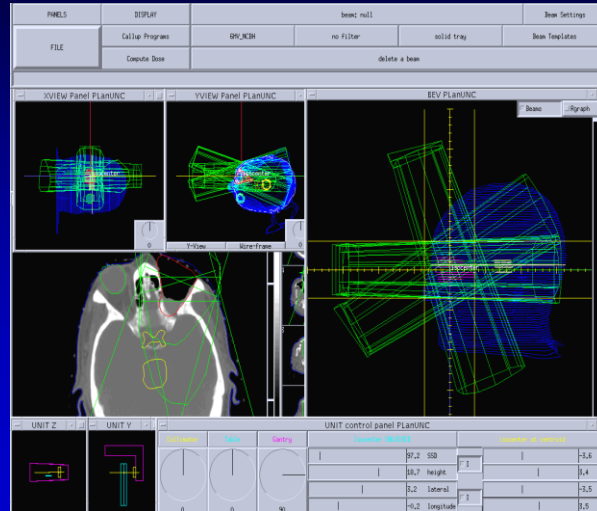
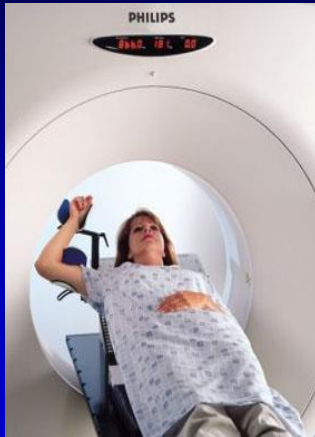
Radiation Treatment Geometry

Six Degrees of Freedom about the Isocenter
3 rotations, 3 translations, 1 mm radius precision



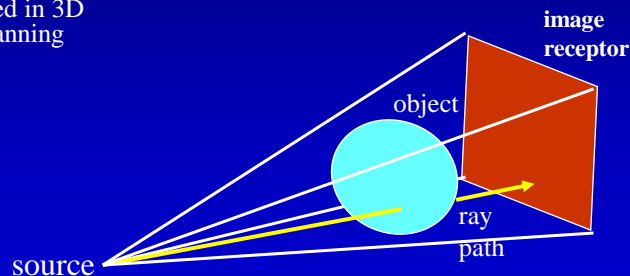
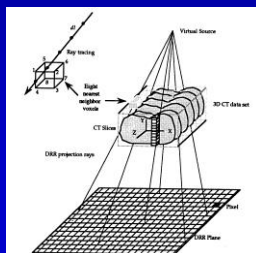
CT Simulation and Treatment Planning

CT + Positioning + 3D RTP Software

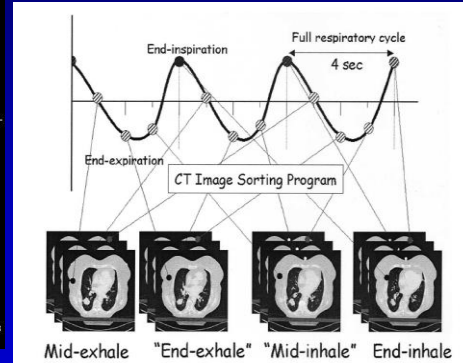
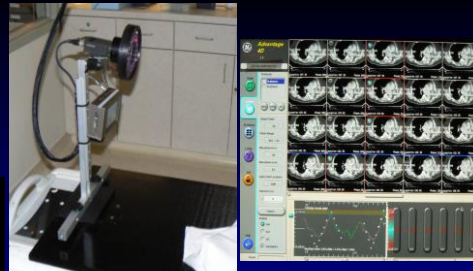
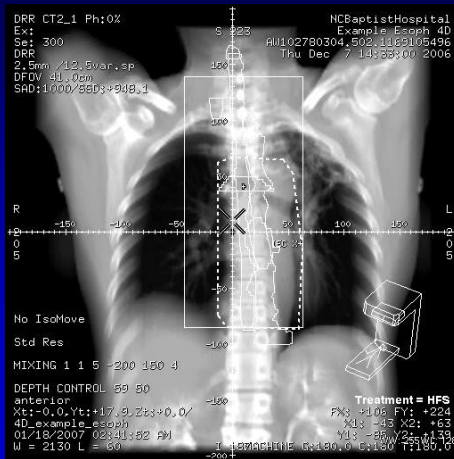


The Digitally Reconstructed Radiograph

- 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 University Underberg et al., IJROBP, 60, 2004

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

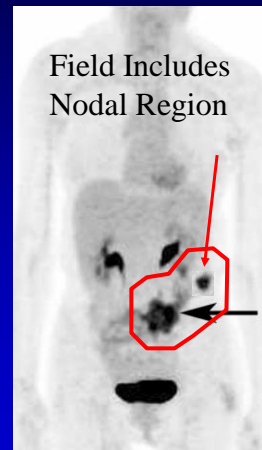
Node Negative

Simple Field



Node Positive

Field Includes Nodal Region



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

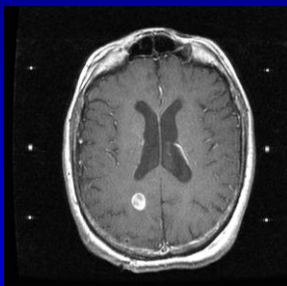
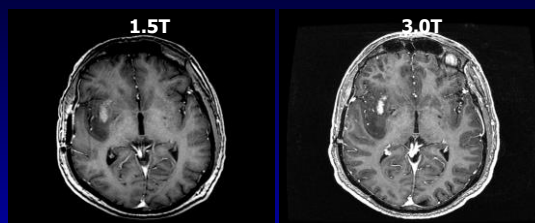
4D PET-CT: Liver



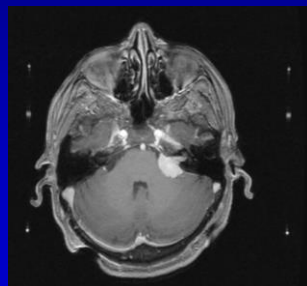
Courtesy of WT Kearns, Wake Forest Univ

Magnetic Resonance Imaging: Simulation and Treatment Planning

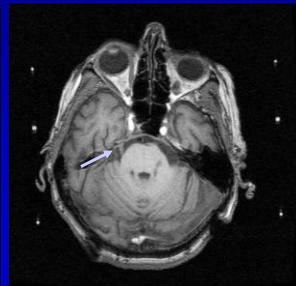
Courtesy of
EG Shaw,
Wake Forest
Univ



Brain Metastasis

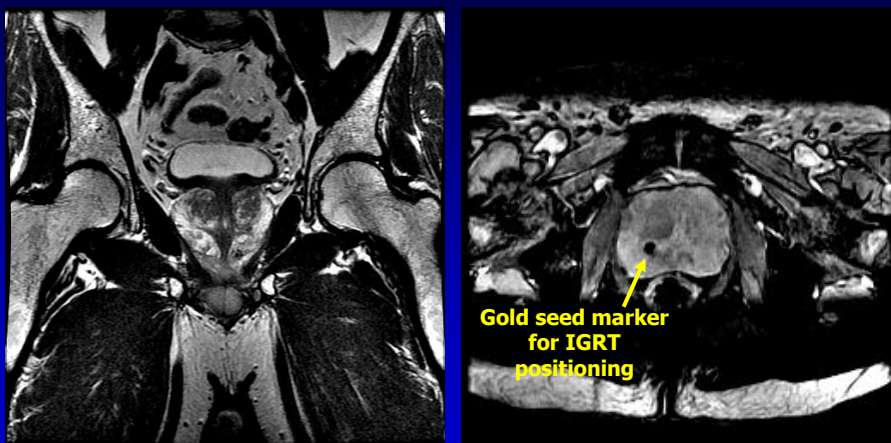


Acoustic Neuroma



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”

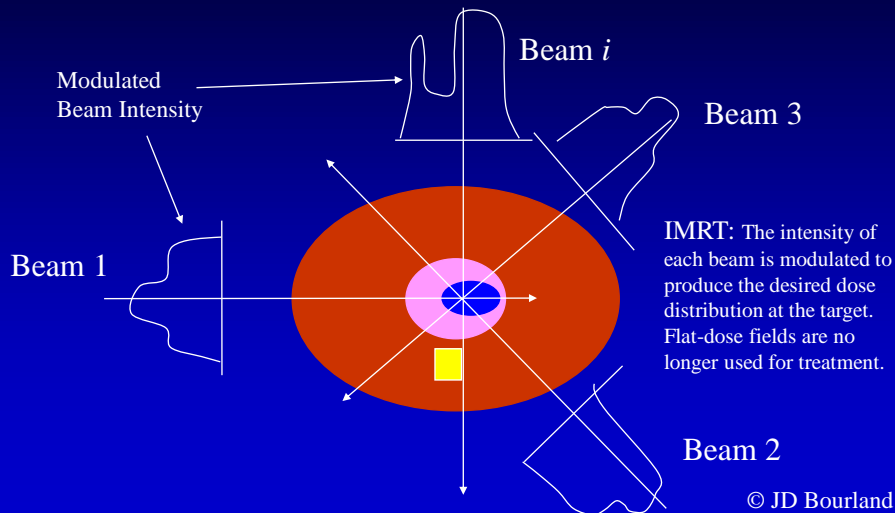


The Radiation Targeting Issue

See
then
Treat
then
See **adaptive**
then
Treat
(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?

Intensity Modulated Radiation Treatment



IMRT and Imaging

- 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

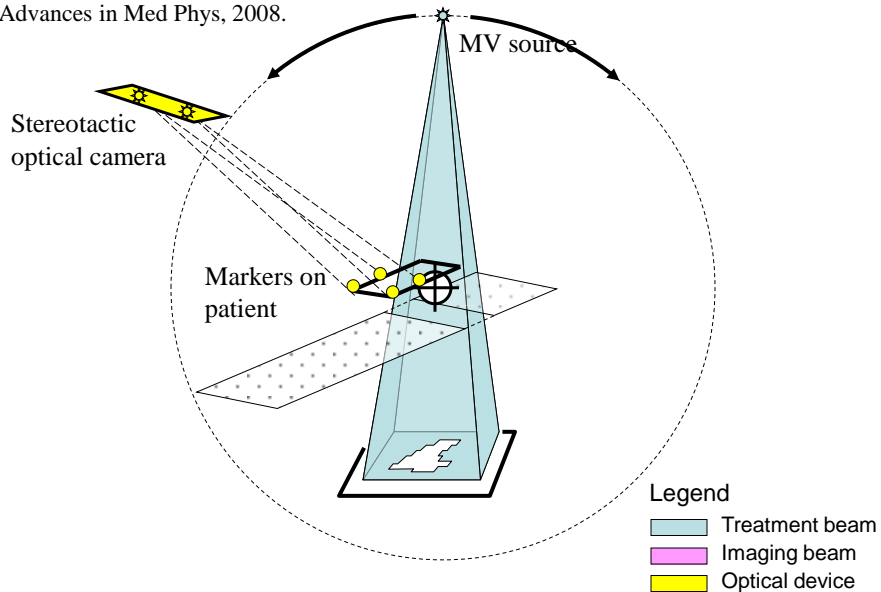
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Image-Based and -Guided RT

- 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

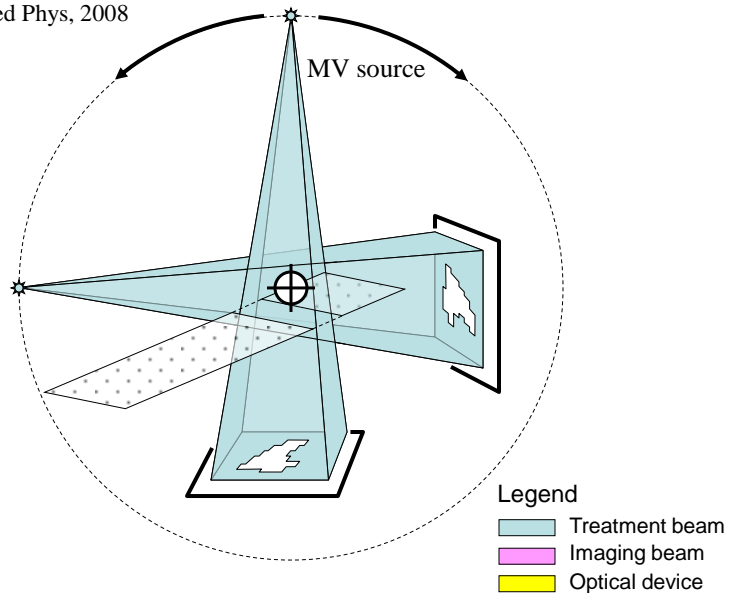
Optical Positioning and MV Treatment

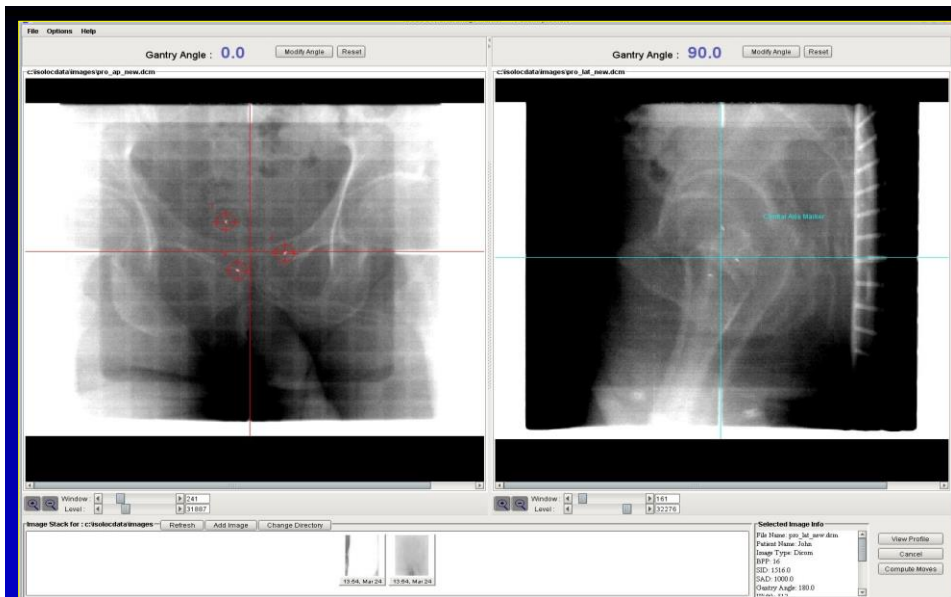
Bourland, Image-Guided Radiation Treatment
Advances in Med Phys, 2008.



Orthogonal MV Imaging (EPID) and MV Treatment

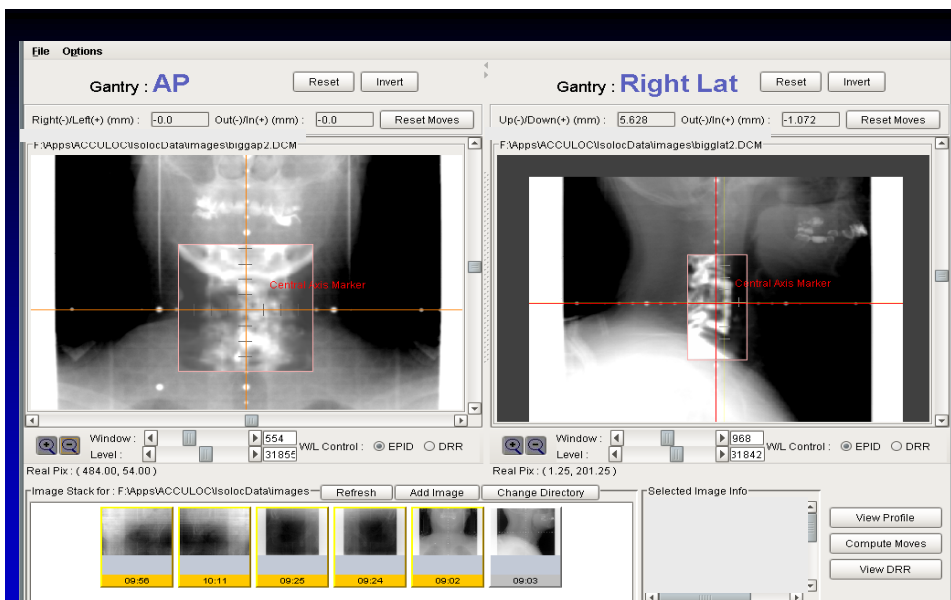
Bourland, Image-Guided Radiation Treatment
Advances in Med Phys, 2008





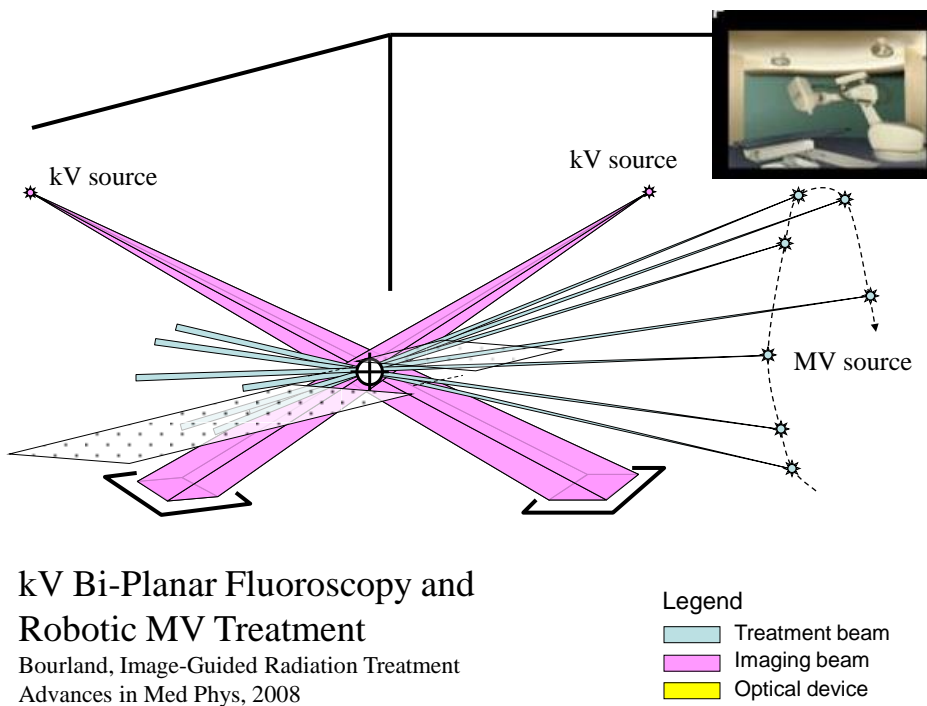
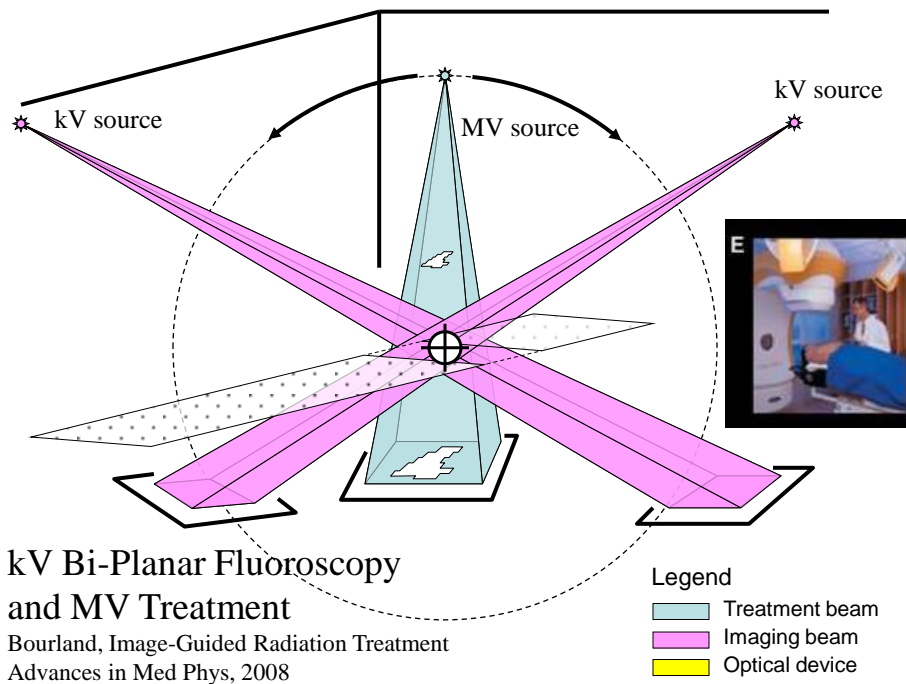
Implanted gold markers used to localize soft tissue targets like the prostate. Without markers, bony anatomy can be accurately aligned, but not the prostate itself.

Courtesy of Wake Forest University



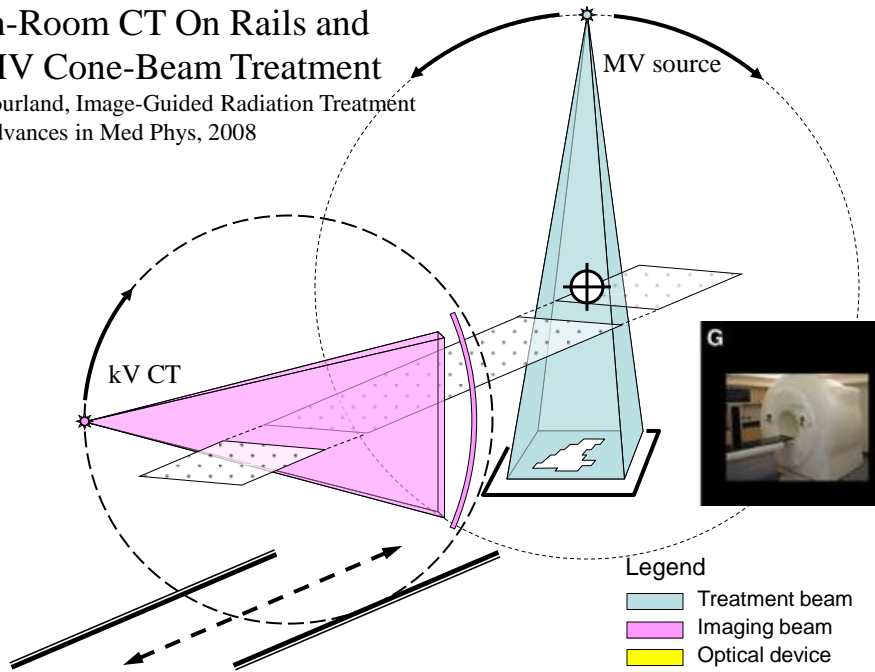
At WFUBMC, this software has been used to improve localization for prostate, head and neck, and paraspinal cancers.

Courtesy of Wake Forest University



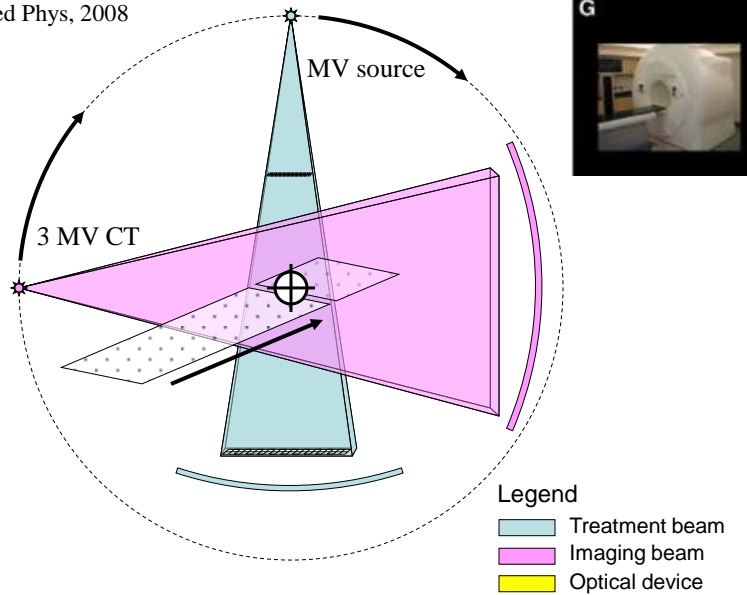
In-Room CT On Rails and MV Cone-Beam Treatment

Bourland, Image-Guided Radiation Treatment
Advances in Med Phys, 2008



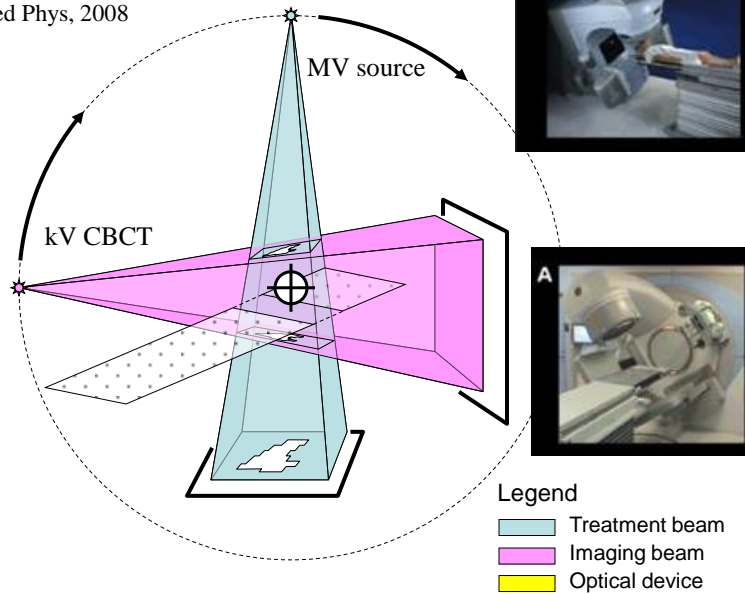
MV Fan-Beam CT and MV Fan-Beam Treatment

Bourland, Image-Guided Radiation Treatment
Advances in Med Phys, 2008



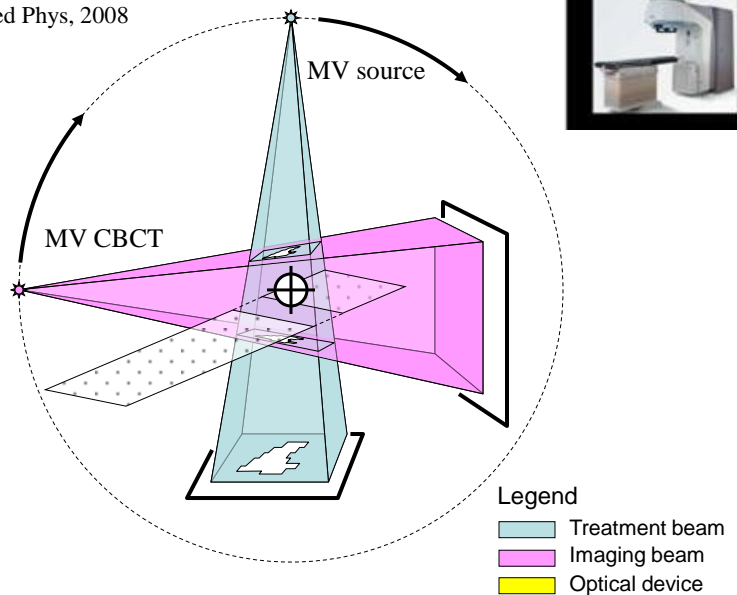
kV Cone-Beam CT and MV Treatment

Bourland, Image-Guided Radiation Treatment
Advances in Med Phys, 2008

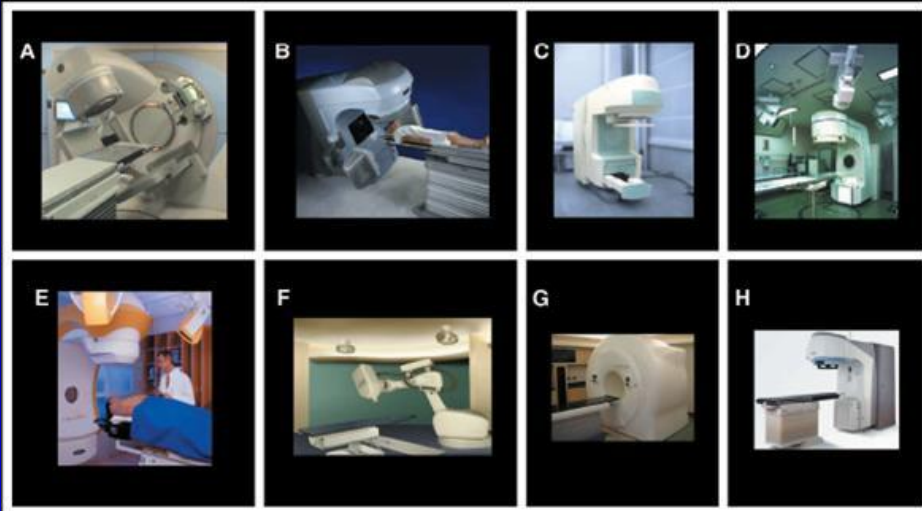


MV Cone-Beam CT and MV Treatment

Bourland, Image-Guided Radiation Treatment
Advances in Med Phys, 2008

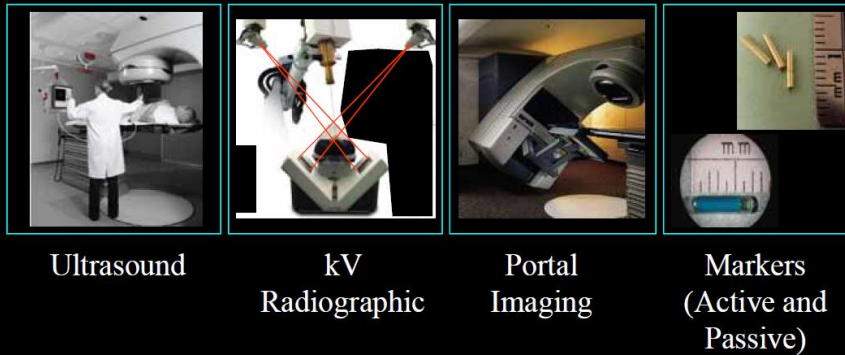


Vendor IGRT Implementations



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

IG Technologies - Generation I



Courtesy DA Jaffray, PhD

IG Technologies - Generation II



Siemens
PRIMATOM™

kV CT
Approach



TomoTherapy
Hi-Art™

MV CT
Approach



Elekta Synergy™



Varian OBI™



Siemens MVision™



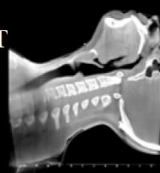
Siemens Artiste™

kV and MV Cone-beam CT
Approach

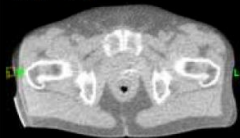
Courtesy DA Jaffray, PhD

Sample IGRT Images

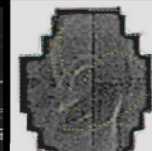
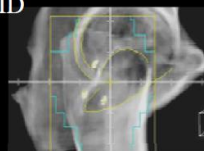
kV
CBCT



MV CT



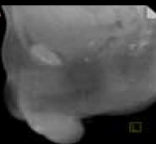
EPID



kV
CBCT



MV
CBCT



Courtesy DA Jaffray, PhD

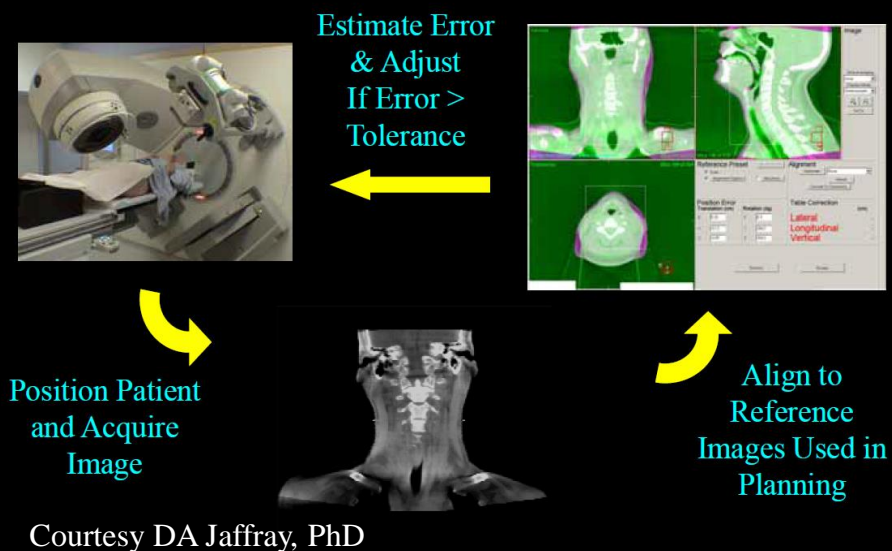
The Radiation Targeting Issue

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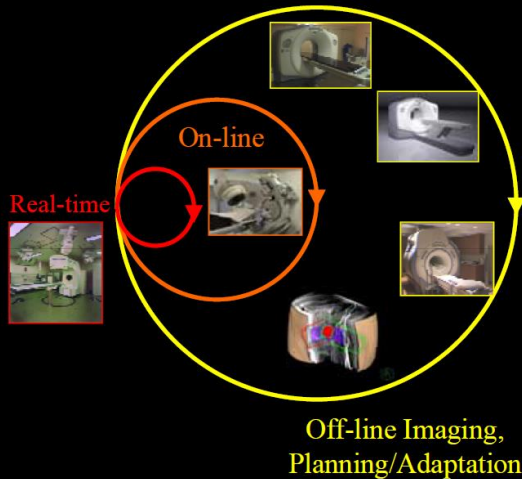
adaptive

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Typical On-line Image-Guidance Process



IGRT and Timelines of Intervention



Courtesy DA Jaffray, PhD

- Definitely not exclusive processes
- Efficiency, technology, and degree of mobility will drive the relative use of these scales.
- Need sufficient information in the on-line imaging to indicate the need for off-line re-planning.
- Off-line planning may require additional and/or different information.

IGRT Intervention Options

- Real Time – constant adjustment/revision, requires real-time imaging/tracking/gating
- On-Line – most common approach – one-time (daily) imaging performed, position adjusted as needed, treatment proceeds without further intervention
- Off-Line – imaging, followed by off-line evaluation, re-planning, adaptation

Next Generation IGRT

- Ultrasound – revisited and revived
- Large-scale kV-CBCT + MV RT – it is here
- MR-gRT – MR-guided RT – it is here

MR-Gamma MR-Linac

VERO - Very Large Bore MV + CBCT



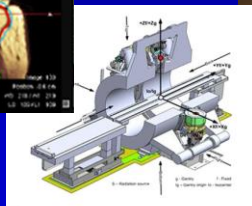
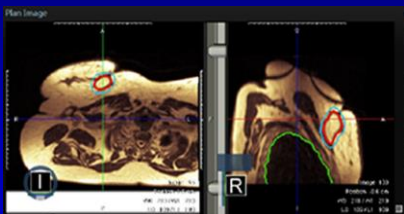
The Future is MR-gRT

Pollard JM, Wen Z, Sadagopan R, Wang J, Ibbott GS.
The future of image-guided radiotherapy will be MR guided.
Br J Radiol 2017; 90: 20160667

- Superior soft tissue imaging
- 6 MR + gamma units
- 1 In-room mobile MR + Linac
- 7 MR + Linac
 - 2 or 3 basic MR + Linac designs
- Site-specific MR pulse sequences
- Multiple challenges for integration

Gamma + MRI

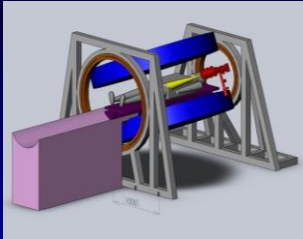
- Robotic 3-head Co-60, 550 cGy/min, “strobed”
- 0.35 T MRI, vertical gap
- In clinical use



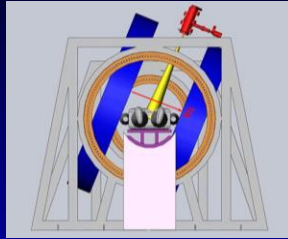
Mutic S, Dempsey JF. Sem Radiat
Oncol, Jul 24(3): 196-9, 2014.

Courtesy Viewray, Inc

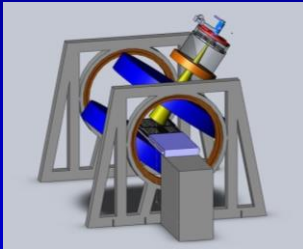
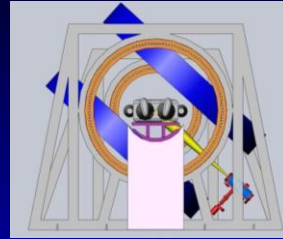
MR + Linear Accelerator: Gimbal



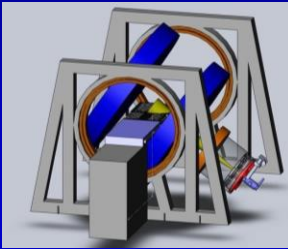
Longitudinal Orientation



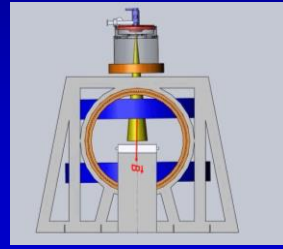
Courtesy of University of Alberta, Canada



Transverse Orientation

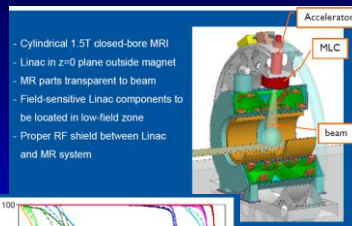


Courtesy of University of Alberta, Canada

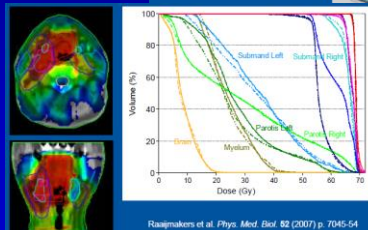


UMC Utrecht Design

- Elekta Linac, Philips MR




- Cylindrical 1.5T closed-bore MRI
- Linac in $z=0$ plane outside magnet
- MR parts transparent to beam
- Field-sensitive Linac components to be located in low-field zone
- Proper RF shield between Linac and MR system



Lagendijk JJW, Raaijmakers BW et al.
PMB 59(2014) R349-R369.

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			

IGRT Processes

- Quality Assurance Procedures
 - Devices, software, observer interpretation, information technology
- Patient Alignment Correction Strategies
- Patient Dose Assessment

Technologies and Imaging

Radiation Therapy, Management and Dosimetry Workplace Survey 2010

A Nationwide Survey Conducted by the American Society of Radiologic Technologists
With Support from Varian Medical Systems

November 2010



American Society of Radiologic Technologists

Which of the following services does your facility provide?

	N	Percent	Percent of Respondents
Intensity-modulated radiation therapy (IMRT)	2870	11.9	96.0
CT/simulation	2798	11.6	93.7
Conformal radiation therapy delivery	2708	11.2	90.7
Image-guided radiation therapy (IGRT)	2321	9.6	77.7
BiD/TID vs. single treatment delivery	2094	8.7	70.1
High-dose rate brachytherapy	1903	7.9	63.7
Single-dose stereotactic radiation therapy	1477	6.1	49.5
Low-dose rate brachytherapy	1191	4.9	39.9
PET-CT	1127	4.7	37.7
Ultrasound localization	917	3.8	30.7
Gated delivery	903	3.7	30.2
Pediatric radiation therapy	793	3.3	26.6
Total skin/electron	722	3.0	24.2
Total body irradiation	687	2.8	23.0
PET	663	2.7	22.2
Volumetric modulated arc therapy (VMAT)	386	1.6	12.9
Intraoperative	302	1.2	10.1
Dynamic adaptive radiation therapy (DART)	128	0.5	4.3
Hyperthermia	124	0.5	4.2
Proton therapy	68	0.3	2.3

Imaging Approaches

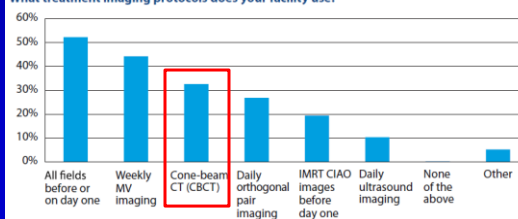
What treatment imaging protocols does your facility use?

	Frequency	Percent of Respondents
All fields before or on day one	1755	52.3
Weekly MV imaging	1487	44.3
Cone-beam CT (CBCT)	1093	32.6
Daily orthogonal pair imaging	900	26.8
IMRT CIAO images before day one	651	19.4
Daily ultrasound imaging	346	10.3
None of the above	7	0.2
Other	176	5.2
Total	6415	191.2



American Society of Radiologic Technologists

What treatment imaging protocols does your facility use?



Summary: 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: 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 Ctr

