Therapy Educational Course
AAPM 2011, Vancouver

Implanted Target Surrogates for Radiation Treatment Verification

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OBJECTIVES

- To discuss various types of markers and implantation techniques
- To discuss various marker detection techniques
- To discuss marker application on various treatment sites
- To discuss gating applications and real-time tracking with implanted markers
- To discuss quality assurance issues
- To discuss risk and patient safety issues

DISCLOSURES

None

OUTLINES

- Introduction
- Marker types
- Detection techniques
- Marker applications in different disease sites
- Gating and tracking
- Quality assurance issues

Dr. Kothary (marker implantation techniques, imaging guidance for implantation, tissue interaction and marker stability, risk management and patient safety)

INTRODUCTION

- Fiducial markers to achieve better localization.
- PTV margin reduction
- Intra-fractional and inter-fractional motion
- In-room imaging / IGRT
- Gating and real-time tracking
- Sites: prostate, lung, liver, pancreas, breast…
- AAPM TG 199:
  AAPM Recommendations on Implanted Target Surrogates for Radiation Treatment Verification
  Z. Wang(Chair), F. Yin(Co-Chair), J. Balter, T. Willoughby, H. Shirado, P. Kupelian, J. Kruse, S. Park, K. Shinohara, M. Wahidi, N. Kothary

MARKER TYPES

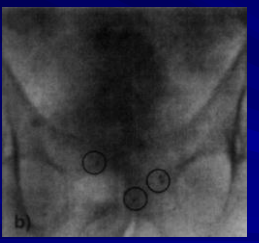
- Gold markers (seeds, coil, coupled)
- Surgical clips
- Brachytherapy seeds
- Electro-magnetic markers
- Implanted dosimeters
- Carbon marker
- Polymer marker

IMPLANTED MARKER DETECTION

- 2D MV imaging: EPID
- 3D MV imaging: MV CBCT
- 2D kV imaging: OBI, fluoroscopic imaging
- 3D kV: kV CBCT, DTS, in-room CT
- 4D kV: DTS, CBCT
- Electromagnetic system

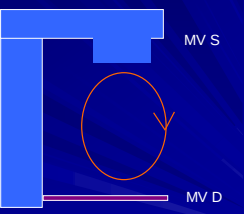
MARKER DETECTION

2D MV



Balter et al., IJROBP, 33(5), p1281-86, 1995

3D MV

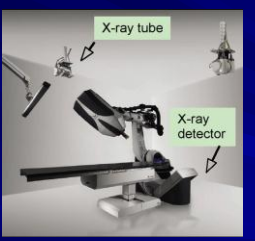


MV Cone-Beam CT

MARKER DETECTION: 2D KV

Harada et al., Cancer, 95(8), p1720-27, 2002

Room-Mounted X-Ray Systems



CyberKnife® imaging system

Novalis® imaging system

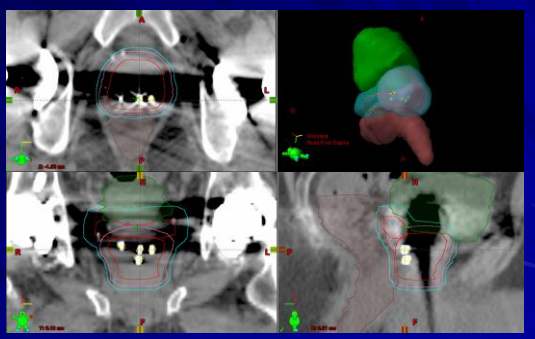
Gantry-Mounted X-Ray Systems

Elekta system

Varian system

Calypso System

PROSTATE: Simulation/Planning



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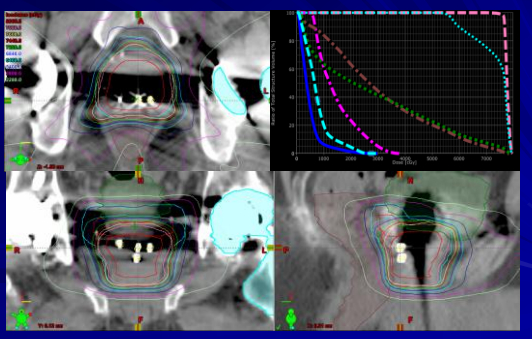


PROSTATE: Localization

2D kV with Markers vs CBCT with Markers vs CBCT Soft-tissue

Criteria	Comparison of image-guided modality		
	Orthogonal MV radiographs	Cone-beam CT	
		Fiducial markers	Soft-tissue
Dose	8 cGy	2.1–3.3 cGy	2.1–3.3 cGy
Correction scheme	Use DRRs to match marker locations	CofM shift based on auto-segmented 3D marker locations	Manual match of CTV contours and on-line image
Targeting accuracy	0.36 (mm)	0.12 (mm)	2.2 (mm)
Acquisition time	20 s	2 min	2 min
Largest source of uncertainty	Marker localization	Intrafraction motion	Interobserver variability

Moseley et al., IJROBP, 67(3), p942-53, 2007

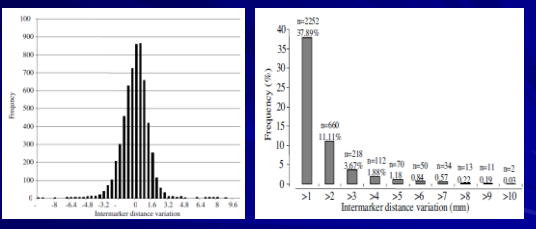
Marker Migration

Inter-marker distance standard deviation (mm)			Difference @ 1 month (mm)
A-B	B-C	C-A	
0.44	1.52	1.82	1.7
1.40	1.96	2.11	1.6
0.58	1.23	1.38	3.1
3.04	2.00	2.84	5.7
3.03	1.95	1.53	1.0
0.37	0.53	0.57	0.4
0.68	0.85	0.87	2.3
1.04	0.85	0.77	0.8
0.88	1.32	1.87	1.6
0.46	0.75	0.66	1.2
1.02	1.14	1.40	2.2

Pouliot et al., IJROBP, 56(3), p862-66, 2003

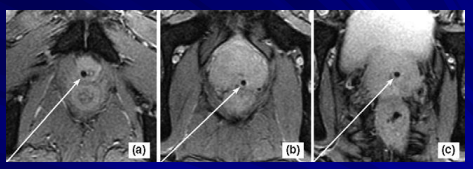
Marker Migration

Kupelian et al, 56 patients, 168 markers



Kupelian et al., IJROBP, 62(5), p1291-66, 2005

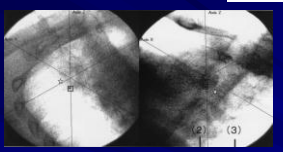
Tissue Deformation



Change in distance from CFM to CP	Mean	95% confidence interval
ΔLR(MRI #2-MRI #1)	0.0	−0.3 to 0.3
ΔAP(MRI #2-MRI #1)	−0.7	−1.3 to −0.2
ΔCC(MRI #2-MRI #1)	−0.4	−0.8 to 0.0
ABS(Δ3D[MRI #2-MRI #1])	1.8	1.4–2.2
ABS(Δ3DRecontour)	0.8	0.6–1.0

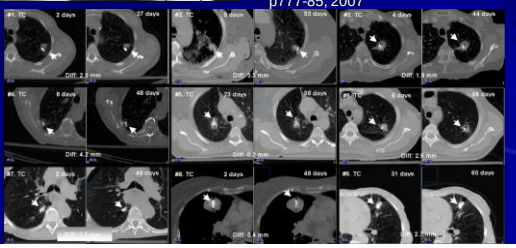
Nichol et al., IJROBP, 67(1), p48-56, 2007

LUNG

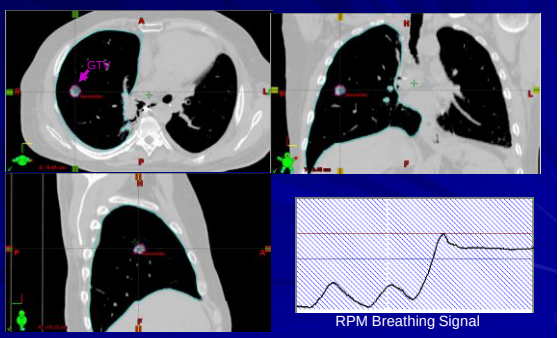


Shirado et al., IJROBP, 48(4), p1187-95, 2000

Kupelian et al., IJROBP, 69(3), p777-85, 2007

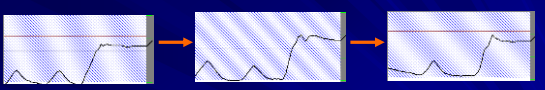


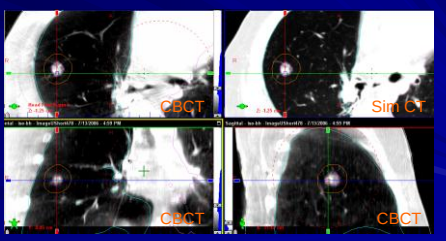
Breath-Hold Sim CT



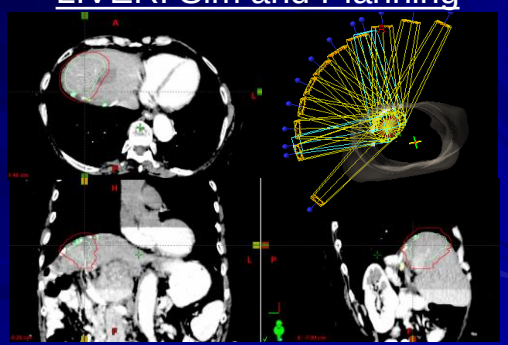
RPM Breathing Signal

Breath-Hold CBCT

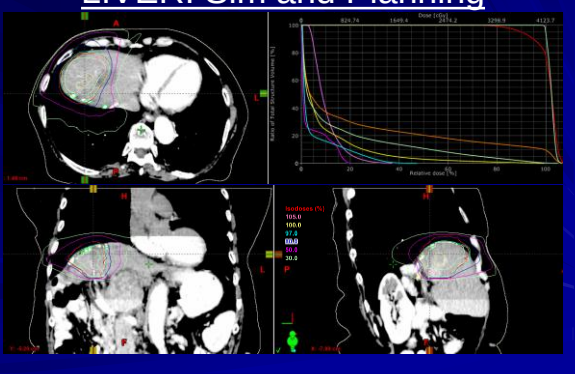




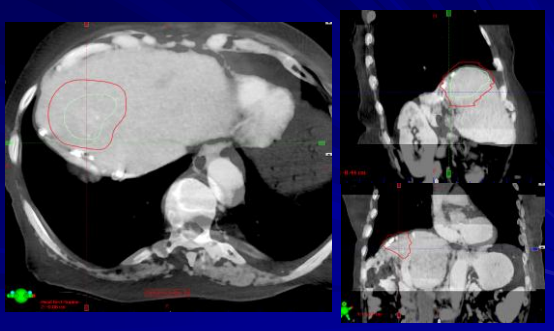
LIVER: Sim and Planning



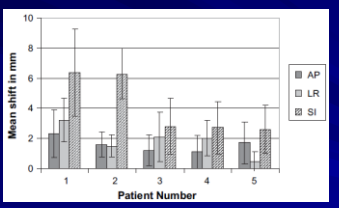
LIVER: Sim and Planning

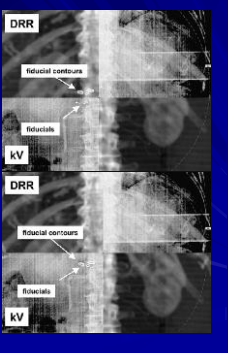


LIVER: Localization



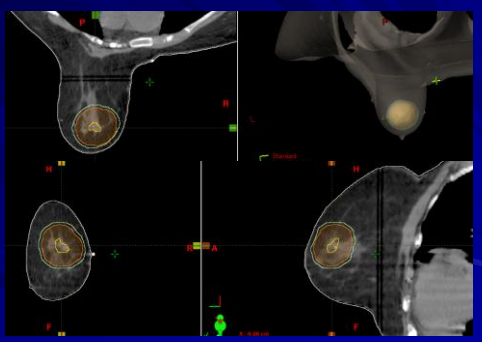
PANCREAS



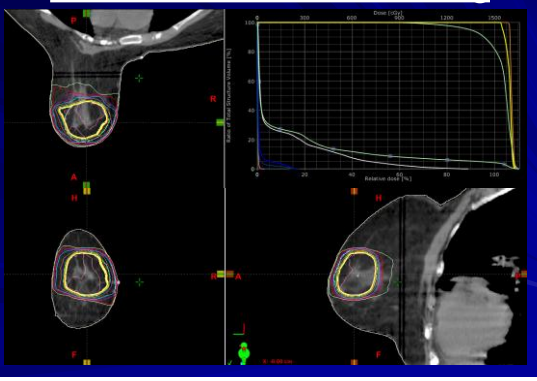


Jayachandran et al., IJROBP, 76(2), p603-7, 2010

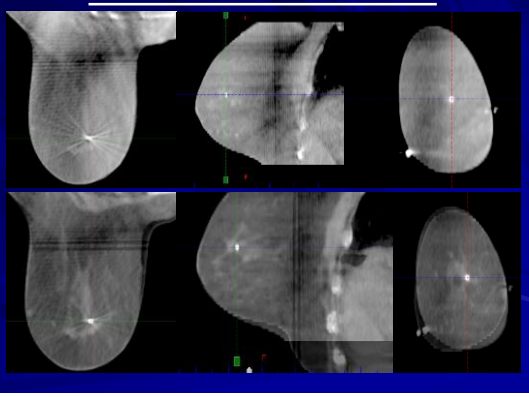
BREAST: Sim and Planning



BREAST: Sim and Planning

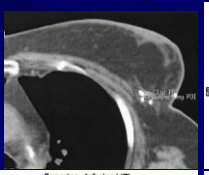


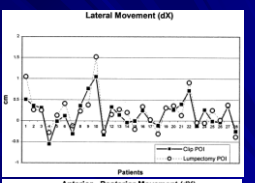
BREAST: Localization

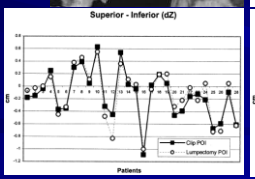


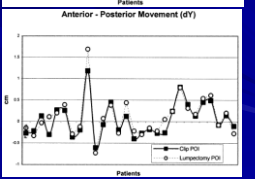
Surgical Clips for PBI

N=28







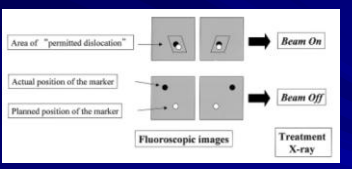


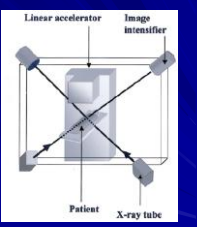
Weed et al., IJROBP, 60(2), p484-92, 2004

GATING AND TRACKING

- Implanted marker for real-time tracking
- Implanted marker for external gating treatment verification

Tracking with Fluoroscopic Imaging

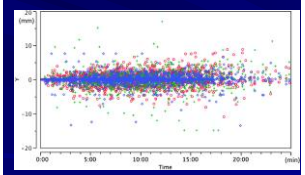


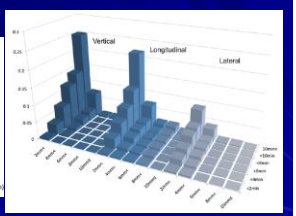


Harada et al., Cancer, 95(8), p1720-27, 2002

Tracking with Fluoroscopic Imaging

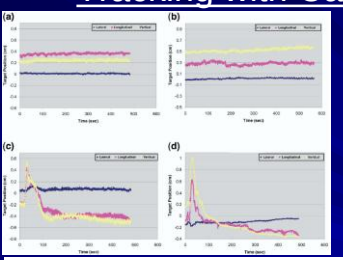
20 Prostate Cases





Shimizu et al., IJROPB, in printing, 2011

Tracking with Calypso

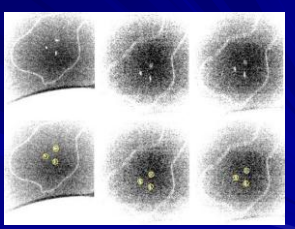


Willoughby et al., IJROPB, 65(2), p528-34, 2006

Kupelian et al., IJROPB, 67(4), p1088-98, 2007

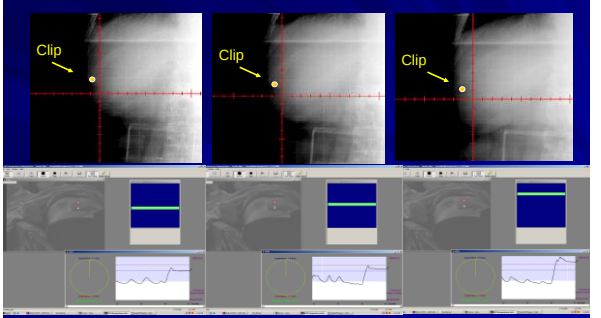
Patient	No. fractions analyzed	Fractions with >3-mm excursion for >30 s cumulative #	%	Fractions with >5-mm excursion for >30 s cumulative #	%
All (n = 35)	1157	473	41	179	15

Tracking with EPID Phantom Study



Keall et al., Med. Phys., 31(12), p3492-9, 2004

GATING VERIFICATION



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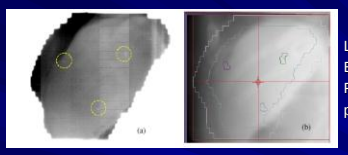
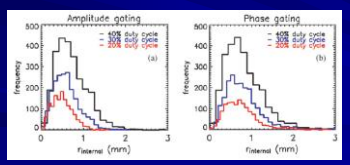
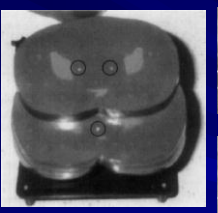


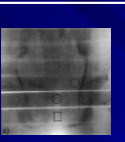
Liver case study
Berbeco et al.,
Phys. Med. Biol., 50,
p3669-79, 2005

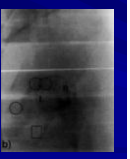


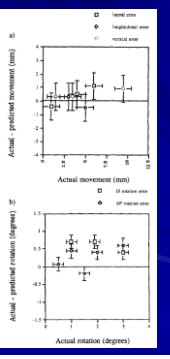
8 lung cases
Berbeco et al.,
Phys. Med. Biol., 50,
p3655-67, 2005

END-TO-END TEST WITH PHANTOM









Balter et al., IJROBP, 33(5), p1281-86, 1995

QUALITY ASSURANCE ISSUES

- End-to-end test
  - Marker visibility
  - Imaging accuracy
  - Tracking accuracy
  - Tracking system latency
- Marker migration
- Tissue deformation
- Min number of markers
- Dose perturbations (especially with proton beams)

SUMMARY

- Implanted markers as target surrogates have been used in various treatment sites, including prostate, lung, liver, pancreas, breast, etc.
- Various imaging and marker detection techniques have been used for treatment guidance.
- Implanted markers have been used for real-time tracking and gating verification.

Dr. Kothary: Marker Implantation

Thank You