TG-199: Implanted Markers for Radiation Treatment Verification

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DISCLOSURES

None

TG-199 Charges

- Review different types of applications of target surrogates in radiation therapy. Issues related patient complication, marker migration, dropping, and deformation will be addressed.
- Issues related to image guidance techniques with target surrogates will be discussed. PTV margin requirements for implanted marker guided setup and localization accuracy will be discussed for prostate, lung, liver/pancreas, and breast. Marker applications in verifying the accuracy of respiratory gated treatments will also be discussed.
- Issues related to patient safety during implantation and imaging acquisition will be addressed. QA programs and guidelines for end-to-end commissioning will be addressed

TG-199 Committee

- Medical Physicists:
  Zhiheng Wang, Ph.D. (Chair), Fang-Fang Yin, Ph.D. (Co-Chair), James Balter, Ph.D., Twyla Willoughby, Ph.D., SungYong Park, Ph.D., and Jon Kruse, Ph.D.
- Radiation Oncologists:
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- Pulmonologist:
  Momen Wahidi, M.D.
- Urologist:
  Katsuto Shinohara, M.D.

OUTLINE

MARKER TYPES

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

CLINICAL APPLICATIONS

- Prostate
- Lung
- Liver/Pancreas
- Breast

MARKER IMPLANTATION

- Prostate: Transrectal Ultrasound (TRUS) image guidance
- Lung: Bronchoscopy guidance or percutaneously with CT guidance
- Liver/Pancreas: Percutaneously with ultrasound, fluoroscopy, or CT guidance, or during laparotomy
- Breast: During lumpectomy or percutaneously

GENERAL CONSIDERATIONS

- Number of markers
- Size of markers
- Location
- Separation
- Imaging artifacts
- Marker Migrations
- Organ deformation
- Maker stability

Imaging Consideration

- CT metal artifacts
- MRI compatibility
- MRI image distortion
- Shadowing
- Pulse sequence selection
- Slice thickness
- Imaging dose

Prostate	Marker Type	Size	#	Locations	Days
Balter et al [2]	alloy (87% Au, 6% Pd, 4.5% Fe, In, Sn)	1.6 mm diameter spheres	3	The inferior, superior-lateral, and posterior borders of the prostate	
Crook et al [3]	Gold cylinders	0.08 cm in diameter and 3 cm in length	3	The base of the prostate near the seminal vesicles (marker l), the posterior aspect (marker 2), and the apex of the prostate (marker 3)	
Alasti et al [4]	Gold cylinders	diameter of 1 mm and a length of 5 mm	3	The base (marker 1), posterior aspect (marker 2), and apex (marker 3) of the prostate	
Litzenberg et al [6]	Gold cylinders	0.9 mm diameter gold wires cut to lengths of 0.9 - 1.2 mm	3	Two markers were placed near the superior lateral borders of the prostate and the third was placed near the apex	
Dehnad et al [7]	Porous gold	1.2 - 2.0 mm	4 - 5		1-9
Pouliot et al [9]		3 mm by 1.1 mm cylinders	3	Two markers were placed laterally on each side of the base and a third marker was placed at the apex, slightly off the midline to avoid urethral puncture	
Herman et al [10]	Gold cylinders	1.2 mm diameter by 3 mm length	3	The apex, mid-gland, and at the base	
Beaulieu et al [24]	Gold cylinders	2.6 mm in length and 1.6 mm in diameter	3	The base (posterior part), mid-gland and apex (posterior part)	
Chung et al [12]	Gold cylinders	1 - 5 mm	3	One each at the base, posterior mid portion and apex, beneath the prostatic capsule	>=3
Schallenkamp et al [14]	Gold cylinders	1 mm in diameter and 3 mm long	3 - 4	Prostate	
Kupelian et al [15]	Gold cylinders	0.7 to 0.8 mm in diameter and from 3 to 5 mm in length	3	Two markers were implanted toward the base of the prostate gland or at midgland, and 1 marker was implanted toward the apex.	
Fuller et al [25]	Gold cylinders	1.2 mm in diameter and 3 mm in length	4	Apex, mid-gland, and left and right base positions	>=3

Prostate	Marker Type	Size	#	Locations	Days
Nichol et al [18]	Gold cylinders	3 mm in length with diameters of 0.8, 1.0, or 1.2 mm	3 - 6	Two at the base of the prostate on the right and left sides; two at the apex of the prostate on the right and left sides; and one marker at the prostate midline.	
van der Heide et al [19]	Gold cylinders	diameter 1 mm, length 5 mm	3	Prostate	7
Haverkort et al [146]	Gold cylinders		4	Two markers were placed at the base in each lobe and two at the apical area of each lobe	>=4
Mutanga et al [36]	Gold cylinders	a diameter of 1mm and a height of 5 mm	3-4	Prostate	>=7
Schiffner et al [20]	Gold cylinders	1.1 mm in diameter and 3 mm in length	2-3	Prostate bed: into the vesicourethral anastomosis, retrovesicular tissues, and, when present, recurrent tumor nodules	>=14
Willoughby et al [103]	RF transponders	1.85 mm in diameter and 8 mm in length	3	The apical, left mid/base, and right mid/base regions of the prostate	14
Kupelian et al [104]	RF transponders		3	One each in the left and right base and one in the apex. Every effort was made to ensure the transponders were within the prostate boundary and off midline to avoid loss through the urethra	4
Tanyi et al [30]	RF transponders		3	Prostate	7
de Kruijf et al [117]	Ir-192 Tracer Gold cylinder		1 4	Prostate	
Carl et al [110]	NiTi stent	diameter of the stent is 7 mm and for the collar 14 mm	1	Prostate	14-21

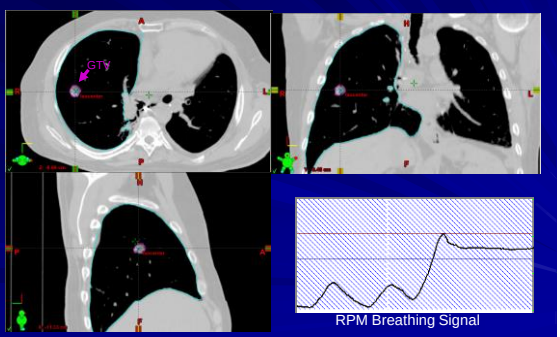
Liver	Marker type	Size	#	Locations	Days
Kitamura et al [38]	Gold sphere	2 mm diameter spheres	1	In tumor	
Wurm et al. [41]	Gold marker	0.75 mm in diameter and ~ 30 mm in length	1	In tumor	
Berbeco et al. [147]	Gold marker		3 or more	On the periphery of the tumor	
Wunderink et al. [50]	Gold cylinders	diameter 1 mm, length 5 mm	3	Outside the tumor to avoid tumor cell spread	7
Goyal et al. [51]	Gold marker	3 – 5mm	Ave 5	In or around tumor	7
Seppenwoolde et al. [55]	Gold cylinders	5mm long and 1mm diameter	3	In liver	7
Yue et al. [120]	Lipiodol			Transarterial chemoembolization was performed by infusion of 5–10 mL iodized oil contrast medium	

Pancreas	Marker type	Size	#	Locations	Days
Jayachandran et al. [45]	Gold cylinders		5 - 6	Either into the pancreatic tumor or into the resected tumor bed	>= 5
Mahadevan et al. [47]	Gold cylinders	0.8 mm in diameter and ~ 5 mm in length	3 - 5	In and around the tumor	7
Murphy et al. [49]	Gold cylinders		3 - 5	In tumor	>=5
Wunderink et al. [50]	Gold cylinders			Around lesions	>7
Goyal et al. [56]	Gold cylinders	3 to 5 mm	3 - 6	Within or around the tumor tissue and at a minimum distance of 2 cm between adjacent markers	7

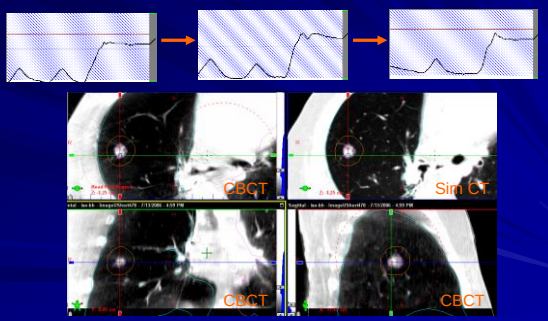
Breast	Marker type	Size	#	Locations	Days
Vicini et al. [98], Weed et al. [99]	Surgical clips		Mean: 6	Around lumpectomy cavity	
Kim et al. [80]	Gold rings	3 mm in diameter, with a 1-mm central hole and 1-mm thickness.	4-6 (6 intended)	Around lumpectomy cavity	
Leonard et al. [75]	Gold cylinders	1.2 mm in diameter and ~ 3 mm in length	3	Around lumpectomy cavity	~7
Shaikh et al. [76], Yue et al. [77]	Gold rings	2 mm in diameter	6	Sutured to the superior, inferior, medial, lateral, and posterior walls of the surgical cavity.	
Kirova et al. [100]	Surgical clips		2-5	Around lumpectomy cavity	
Topolnjak et al. [101]	Surgical clips		Median: 5	Around lumpectomy cavity	
Jozsef et al. [78]	Gold cylinders		3	On the patient's back and sides and a fourth on the lateral aspect of the breast (patient prone)	
Park et al. [79]	Gold coils or cylinders	2.6 mm in length and 1.6 mm in diameter	3-4	2 cm deep to the lumpectomy cavity	

Lung	Marker Type	Size	#	Locations	Days
Shirato et al. [83], Shimizu et al. [58]	Gold sphere	2 mm in diameter	1	in tumor	
Harada et al. [59]	Gold sphere	1.0, 1.5, or 2.0 mm in diameter	1	in or near tumor	
Seppenwoolde et al. [60]	Gold sphere	2.0 mm in diameter	1	in or near tumor	
Imura et al. [61]	Gold sphere	1.5 mm in diameter	1-9	in or near tumor	0-5
Willoughby et al. [64]	Visicoil	0.7-mm diameter _ 2.0-cm long	1	in tumor	
Kupelian et al. [67]	Visicoil	1.0-2.0-cm long, 0.7-cm diameter	1	in or near tumor	
Shah et al. [166]	RF transponder		1 or more	in or near tumor	

Breath-Hold Sim CT



Breath-Hold CBCT



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

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

PTV MARGINS

Prostate	Configuration	Margin LR (mm)	Margin AP (mm)	Margin SI (mm)
Dehnad et al. [7]	Gold markers with EPID localization	6	6	6
Schallenkamp et al. [14]	Gold markers with EPID localization	2.8	2.9	2.7
van der Heide [148]	Gold markers with EPID localization	1.8	4.0	2.5
Cheung et al. [149]	Gold markers with EPID localization	3	4	3
Beltran et al. [150]	Gold markers with EPID localization	4.3	4.8	4.9
Skarsgard et al. [151]	Gold markers with EPID localization	3.6	3.7	3.7
Tanyi et al. [30]	CBCT-based marker alignment without intrafraction motion	2.46	2.28	2.56
Tanyi et al. [30]	CBCT-based marker alignment with intrafraction motion	2.81	3.23	3.68
Tanyi et al. [30]	RF tracking	1.36	2.28	2.64

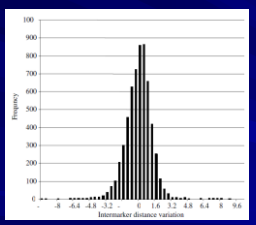
Marker Migration

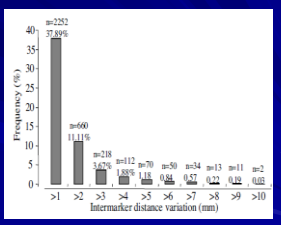
Inter-marker distance standard deviation (mm)			Difference @ 1 month (mm)
A-B	B-C	C-A	
0.44	1.52	1.82	1.7
1.40	1.96	2.11	1.6
0.58	1.23	1.38	3.1
3.04	2.00	2.84	5.7
3.03	1.95	1.53	1.0
0.37	0.53	0.57	0.4
0.68	0.85	0.87	2.3
1.04	0.85	0.77	0.8
0.88	1.32	1.87	1.6
0.46	0.75	0.66	1.2
1.02	1.14	1.40	2.2

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

Marker Migration

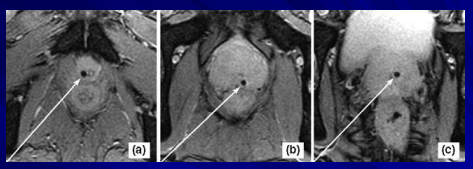
Kupelian et al, 56 patients, 168 markers





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

Tissue Deformation

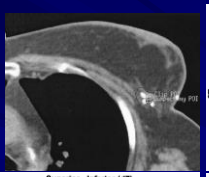


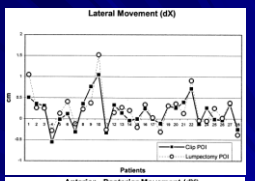
Change in distance from CFM to CP	Mean	95% confidence interval
ΔLR(MRI #2-MRI #1)	0.0	−0.3 to 0.3
ΔAP(MRI #2-MRI #1)	−0.7	−1.3 to −0.2
ΔCC(MRI #2-MRI #1)	−0.4	−0.8 to 0.0
ABS(Δ3D[MRI #2-MRI #1])	1.8	1.4–2.2
ABS(Δ3DRecontour)	0.8	0.6–1.0

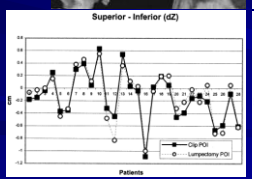
Nichol et al., IJROBP, 67(1), p48-56, 2007

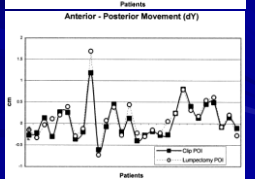
Surgical Clips for PBI

N=28







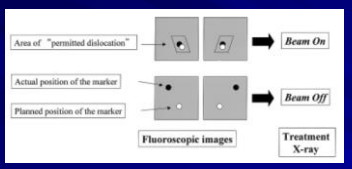


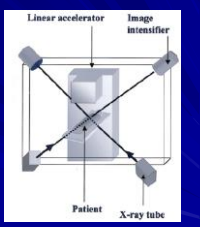
Weed et al., IJROBP, 60(2), p484-92, 2004

GATING AND TRACKING

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

Tracking with Fluoroscopic Imaging

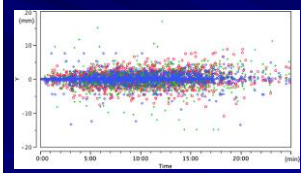


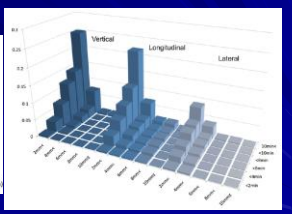


Harada et al., Cancer, 95(8), p1720-27, 2002

Tracking with Fluoroscopic Imaging

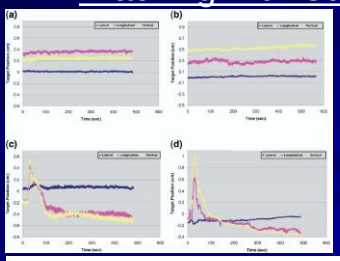
20 Prostate Cases





Shimizu et al., IJROPB, in printing, 2011

Tracking with Calypso

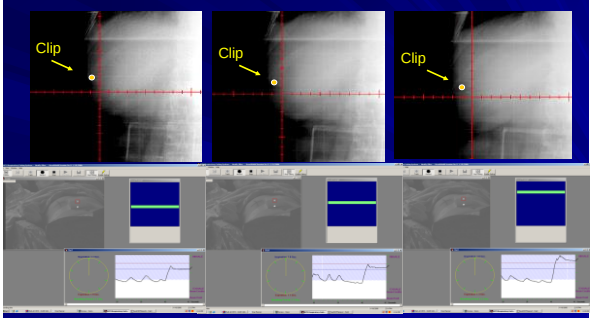


Willoughby et al., IJROPB, 65(2), p528-34, 2006

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

GATING VERIFICATION



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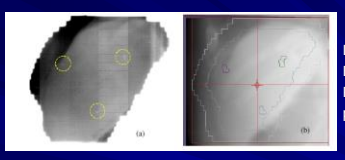
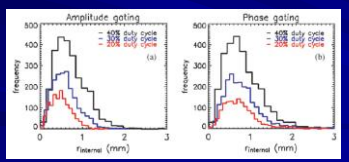
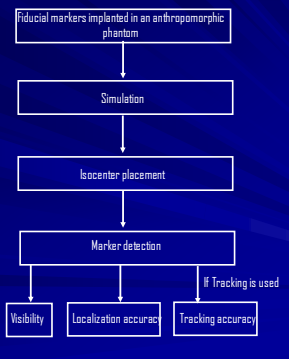


Liver case study
Berbeco et al., Phys. Med. Biol., 50, p3669-79, 2005

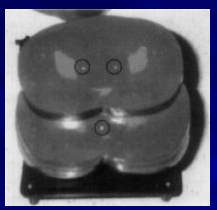


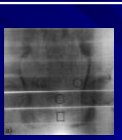
8 lung cases
Berbeco et al., Phys. Med. Biol., 50, p3655-67, 2005

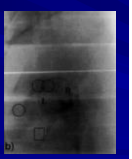
END-TO-END TEST

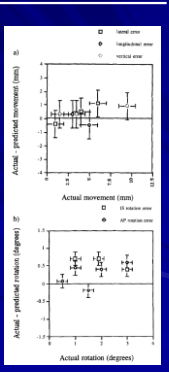


END-TO-END TEST WITH PHANTOM









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

QUALITY ASSURANCE

System QA

- End-to-end commissioning performed.
- Accuracy of the marker imaging system should be checked periodically. This includes daily, monthly and annual checks.
- Pre-treatment QA of the fiducial detection and localization system should be performed, and recalibrated if necessary.

Patient Specific QA

- Intended number of markers and marker locations should be discussed among the team members.
- The patient should be informed of potential risks and complication associated with marker implantation.
- Markers should be checked for their integrity and properly sterilized before implantation.
- Final positions of the implanted markers should be checked once the implantation is done to ensure they are appropriate for RT guidance. If the requirements are not met, discuss with team for any possible correction solutions.
- Timing between implantation and simulation should be discussed.
- In the course of the treatment delivery, relative positions between implanted markers and the target volume should be checked regularly.

Thank You