Application of Implanted Markers in Proton Therapy

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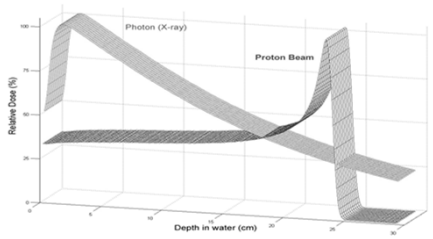
AAPM 2016, SAM Therapy Educational Course, 2016.08.04.

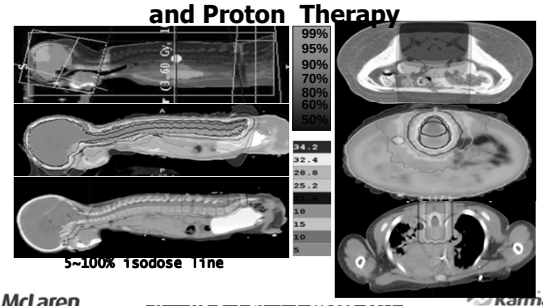
Course Outline

- **Brief review of protons characteristics that apply to fiducials**
- **Why different materials are needed for fiducial markers in proton therapy as compared to x-ray therapy**
- **What are the requirements for fiducial markers in proton therapy**
- **The impact of choice of fiducial material on dosimetry**
- **The impact of choice of fiducial material on radiopacity**
- **Fiducial marker options for proton therapy**

Accelerated proton beams are used for the treatment of cancer



CSI using 3D CRT, Tomotherapy, and Proton Therapy



5~100% isodose line

Yoon MG, Park SY, et al., IJROBP, 2011

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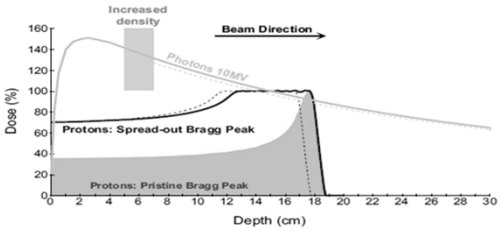
Range uncertainties in proton therapy are the biggest challenge and can be substantial.



M Engelsman, Semin. Radiat. Oncol., 2013

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Range Uncertainties in Proton Therapy

- Treatment Planning
  - CT noise, artifacts, resolution
  - HU – Stopping power conversion (CT calibration)
  - Dose calculation algorithm
- Treatment Delivery
  - Setup and positioning errors
  - Organ motion
  - Anatomical/Physiological change

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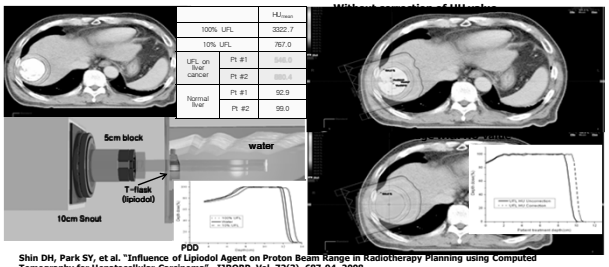
Influence of lipiodol on proton therapy for HCC

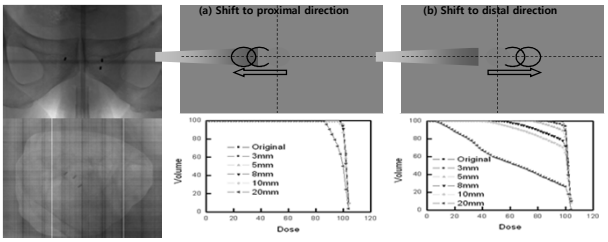


		HU_{mean}
100% UFL		3322.7
10% UFL		767.0
UFL on liver cancer	Pt #1	346.0
	Pt #2	666.4
Normal liver	Pt #1	92.9
	Pt #2	99.0

Shin DH, Park SY, et al. "Influence of Lipiodol Agent on Proton Beam Range in Radiotherapy Planning using Computed Tomography for Hepatocellular Carcinoma" , IJROBP, Vol. 72(3), 687-94, 2008

- Lipiodol is an iodine compound and it is used with an embolizing agent for HCC patients during TACE treatment
- HU values of partially lipiodolized lesions inside the PTV should be replaced by the average HU value of surrounding normal liver.

Internal motion induced reduction of dose in proton therapy

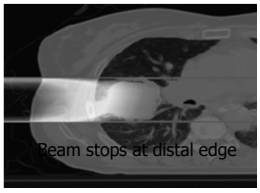


Yoon MG, Park SY, et al. "Interfractional and Intrafractional Movement Induced Dose Reduction of Prostate Target Volume in Proton Beam Treatment", IJROBP, Vol. 71(4), 1091-1102, 2008

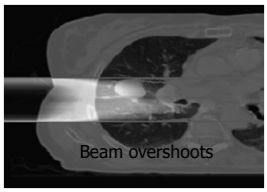
- Separate PTV with different margins transversely and along the direction of the beam
- Determine the beam parameters (field setup) using the CTV or GTV.
- Add appropriate margin for range modulation

Tumor shrinkage in proton therapy

Planning CT



CT after 5 weeks



S Mori, G Chen, MGH

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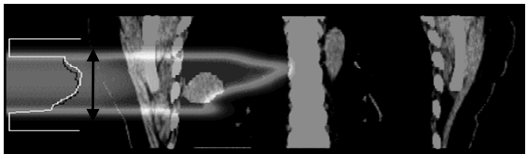
Organ motion in proton therapy

Free breathing Treatment



Tsunashima/Dong
Courtesy of Lei Dong

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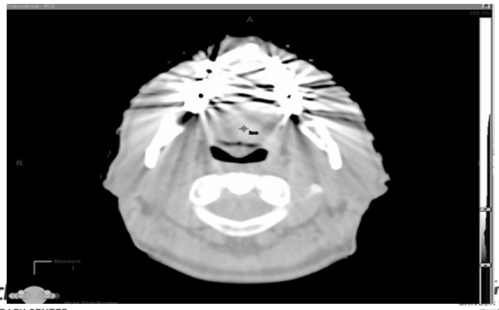
CT Artifacts



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Fiducial Markers

- Originally developed in the pre-conformal radiotherapy era to verify the position of tissue
- Ensure target localization of tumors and organs
- Often made of high density materials such as gold to increase visibility in X-ray imaging
- Used for a variety of sites (prostate, liver, lung, breast, eye, etc)
- Will impact dose delivery, this effect is more pronounced in proton therapy

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Ideal characteristics of fiducial markers in Proton Therapy

- Good radiographic visibility in diagnostic X-rays
- No distortion of the delivered dose
- Minimal artifact in the CT images used for treatment planning
- No migration during treatment

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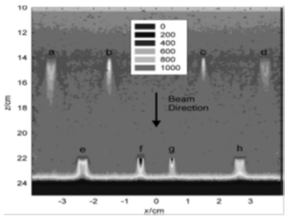
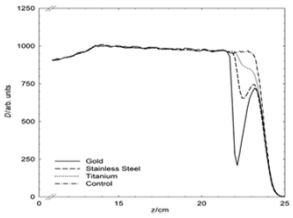
Dose Perturbations in Proton Therapy: MC Simulations





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W Newhauser, PMB, Vol. 52, 2007

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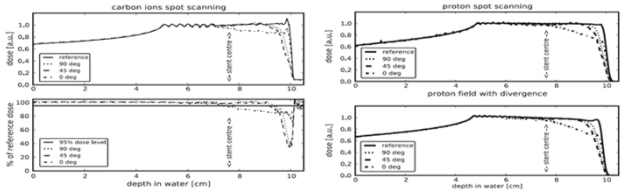
Dose Perturbations for Ni-Ti markers in Carbon Ion and Proton Therapy



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R HerrMann, Acta Oncologica, Vol. 49, 2010

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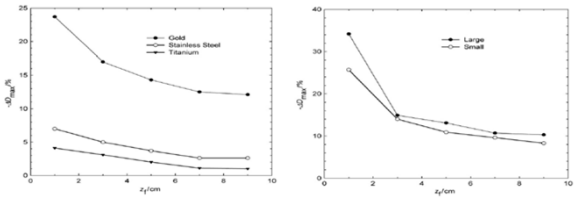
Impact of distance from the distal end of the beam on dosimetric impact



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W Newhauser, PMB, Vol. 52, 2007

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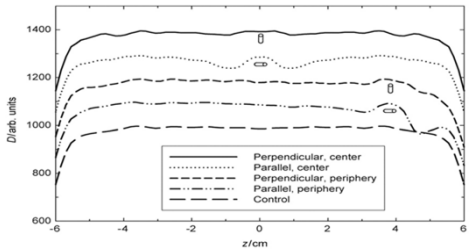
An opposed pair of proton beams



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W Newhauser, PMB, Vol. 52, 2007

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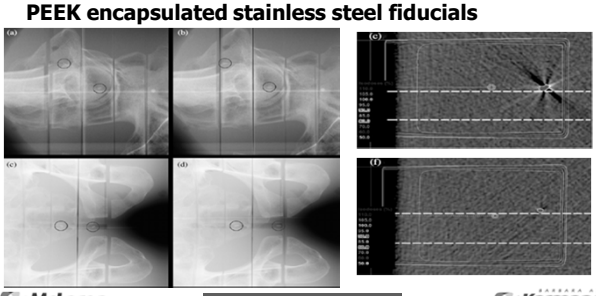
Radiographic images of the carbon coated ZrO_2 and PEEK encapsulated stainless steel fiducials



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J Cheung, PMB, Vol. 55, 2010

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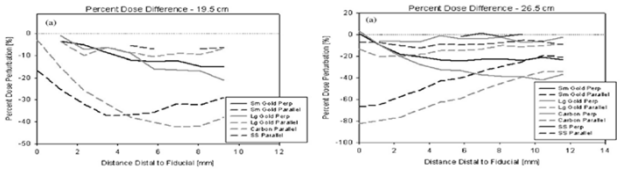
Dose Perturbations for the carbon coated ZrO_2 and PEEK encapsulated stainless steel fiducials



J Cheung, PMB, Vol. 55, 2010

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Key Elements to consider the Markers for Proton Therapy

- Material composition
- Size
- Orientation
- Location

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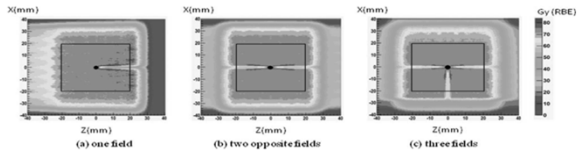
Biological effect of dose distortion by fiducial markers in spot-scanning proton therapy



- 1.5 and 2 mm spherical gold markers were recognized by fluoroscopy
- 1.5 mm gold marker does not affect TCPs
- For 2 mm gold marker, it is safe to use two or more fields

T Matsuura, Med Phys, Vol. 39, 2012

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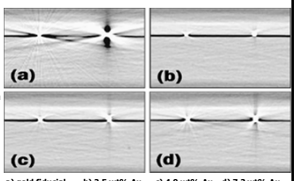
Microscopic gold particle-based fiducials in proton therapy

a) gold fiducial b) silicone c) 2.5 wt% Au d) 4.9 wt% Au e) 7.2 wt% Au



a) gold fiducial b) 2.5 wt% Au c) 4.9 wt% Au d) 7.2 wt% Au

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Lim YK, Lee SB, Park SY, et al., IJROBP, Vol. 47(5), 2009

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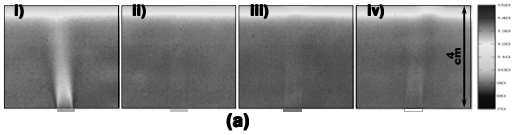
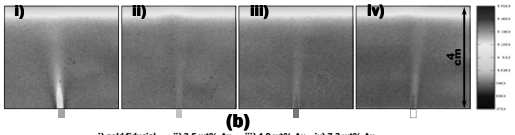
Film Dosimetry: Gafchromic EBT film



(a)



(b)

i) gold fiducial ii) 2.5 wt% Au iii) 4.9 wt% Au iv) 7.2 wt% Au

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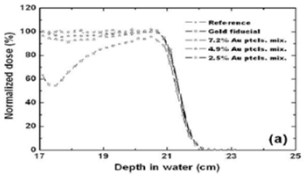
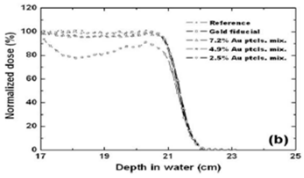
Depth dose profiles for a) parallel b) perpendicularly aligned markers





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Lim YK, Lee SB, Park SY, et al., IJROBP, Vol. 47(5), 2009

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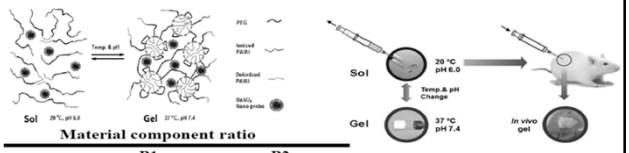
Injectable fiducial markers with $BaSO_4$ and polymer for proton therapy

$BaSO_4$ + Polymer (PAUU)+PBS



Material component ratio

	B1	B2
Polymer	10wt%	10wt%
PBS	90wt%	90wt%
$BaSO_4$	Polymer wt% ×10wt%	Polymer wt% ×20wt%

Courtesy of Youngyhi Han

Ahn SH, Gil MS, Han YY, et al., Med. Phys., Vol. 42, 2015

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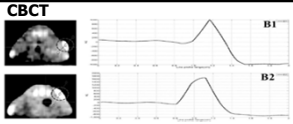
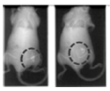
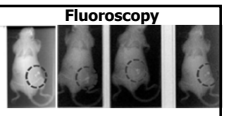
CBCT



OBI



Fluoroscopy



Material	Orientation Parallel	Perpendicular
GOLD	-15.05%	-9.77%
STAINLESS STEEL[304]	-7.92%	-4.43%
TITANIUM	-6.92%	-0.78%
$BaSO_4$ (20wt%)	-3.79%	-0.53%

$BaSO_4$(B2)

Gold Marker

Courtesy of Youngyhi Han

Ahn SH, Gil MS, Han YY, et al., Med. Phys., Vol. 42, 2015

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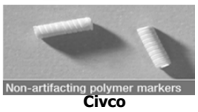
Commercially available fiducial markers

Viscoil (IBA)



Civco

Carbon Markers (Civco)

FlexiCoil (Civco)

BiomarC(Carbon Med)

Beammarks (Beampoint)

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Summary

- The physical characteristics of proton beams show a very favorable dose distribution in depth by spread out Bragg peak
- However, PT is more sensitive to uncertainties in treatment planning and beam delivery compared to x-ray therapy
- Implanted markers for proton therapy should have

  1) No or minimal dose distortion

  2) Good radiographic visibility in diagnostic X-rays

  3) Minimal artifacts in the CT images

  4) No migration during treatment
- Key factors for fiducial markers in proton therapy:

  Material, Size, Orientation, and Location

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