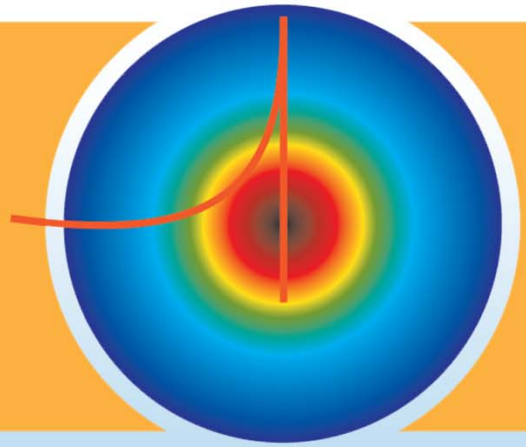
2015 AAPM SUMMER SCHOOL



Immobilization and Simulation

Jon J. Kruse
Mayo Clinic
Rochester, MN

MAYO CLINIC

Immobilization and Simulation

- External Immobilization
- Internal Immobilization
- Simulation

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Immobilization is Critical for PT

- Proton therapy demands repeatable, reliable simulation to successfully leverage the advantages of very selective dose distributions
- Robust treatment planning can help accommodate a small amount of variation
- Interaction between immobilization equipment and proton beam can be important as well

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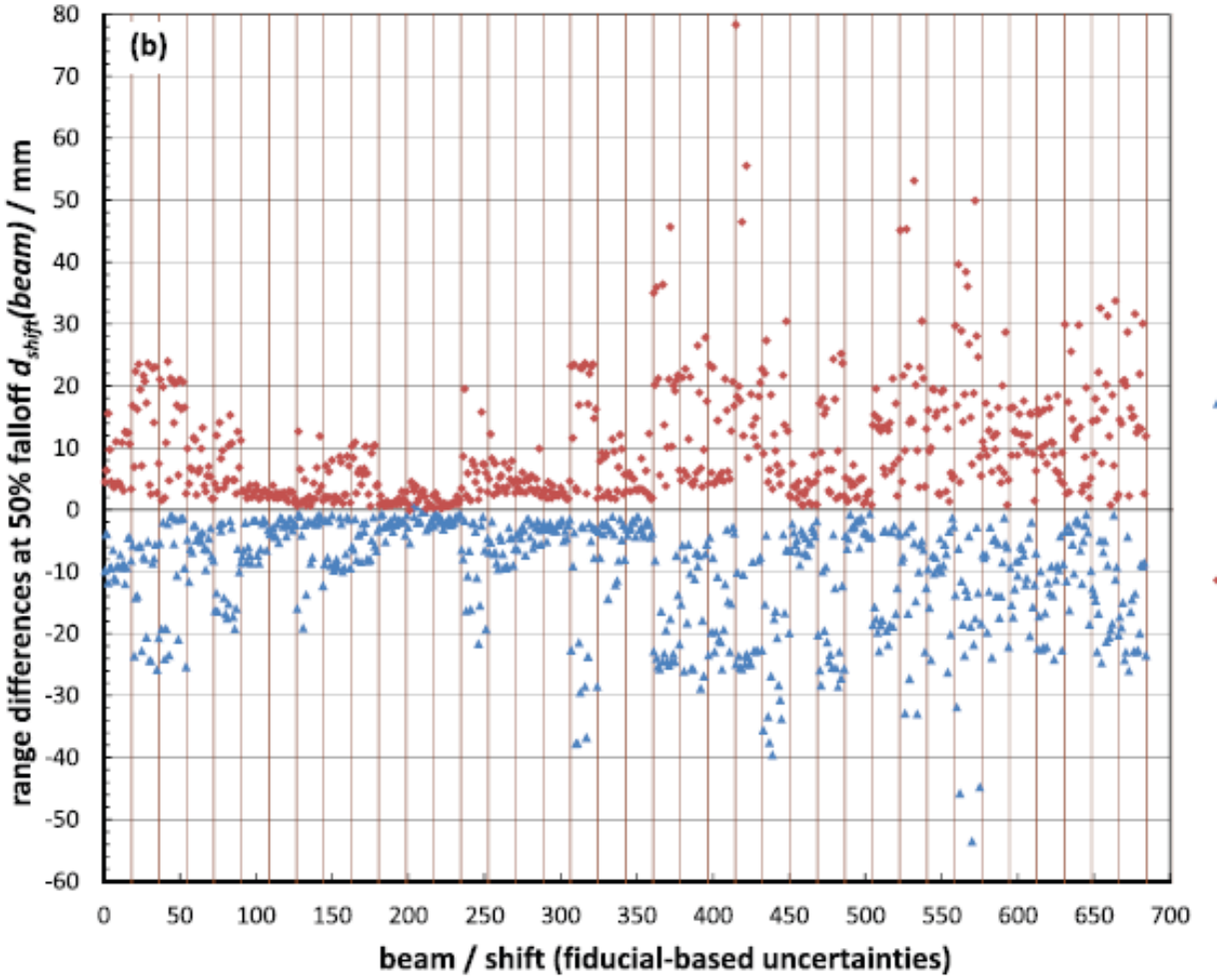
Impact of Setup Variation on Range



Liebl et al., MedPhys 2014

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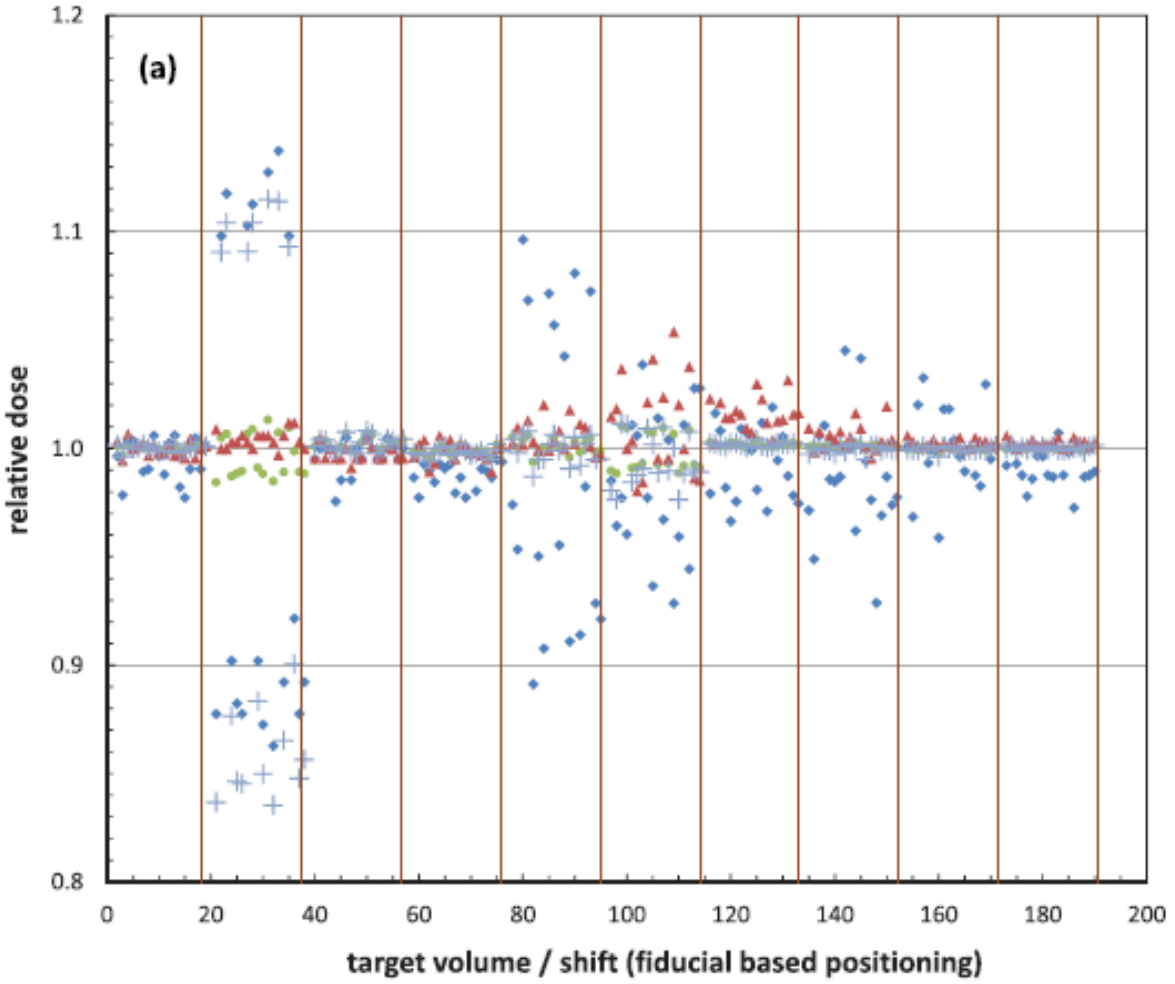
Impact of Setup Variation on Dose



Liebl et al., MedPhys 2014

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Dichotomy of Proton Immobilization

- Proton plans exhibit very steep dose gradients and transition from full dose to zero dose very quickly. Reliable immobilization is a must.
- Proton plans are extremely susceptible to deterioration due to interference between the proton beam and the immobilization equipment.

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Characterization of Treatment Couch

- **X-ray Treatments**
  - Treatment couches typically low *average* density
  - Often heterogeneous construction and hardware
  - Negligible attenuation of treatment beam
  - Dosimetric concern primarily limited to buildup effects
- **Proton Treatments**
  - Treatment couches typically uniform low density
  - Homogeneous construction is critical
  - Clinically meaningful shift in range of proton beam
  - Bolusing effects are not important

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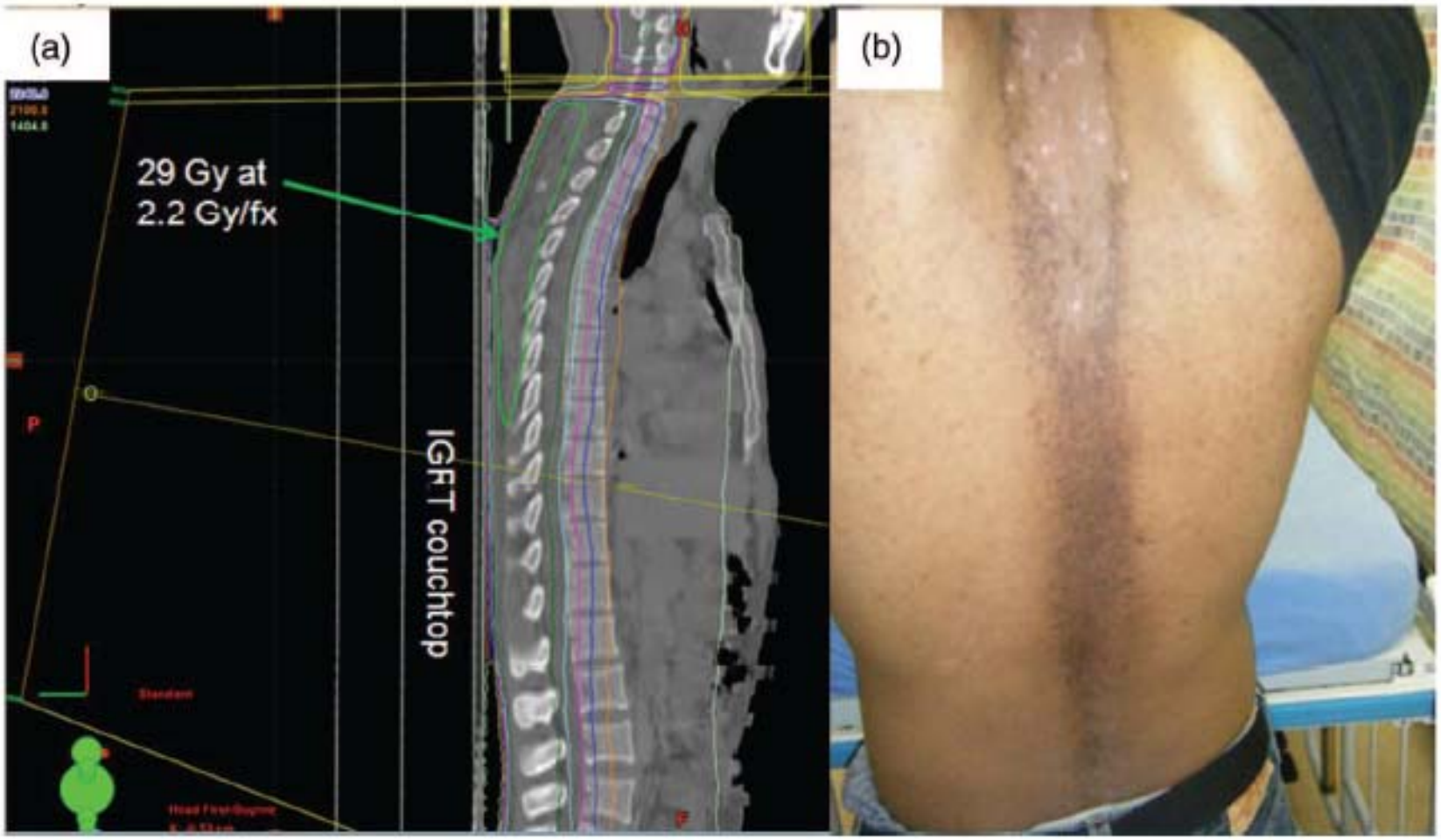
Characterization of Treatment Couch



AAPM TG176 MedPhys 2014

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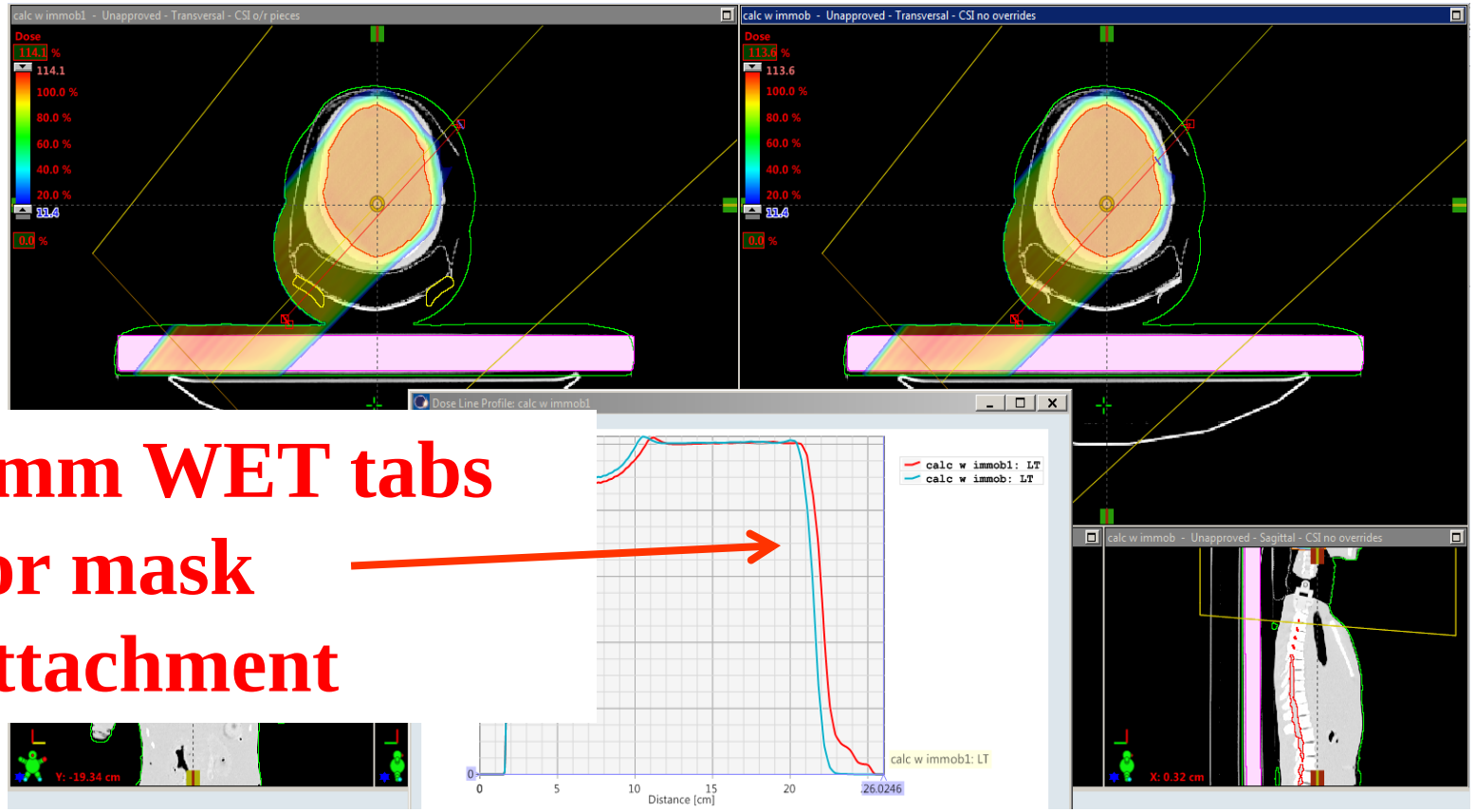
Characterization of Treatment Couch



4mm WET tabs for mask attachment

Calculate treatment beams with and without immobilization equipment in proton path

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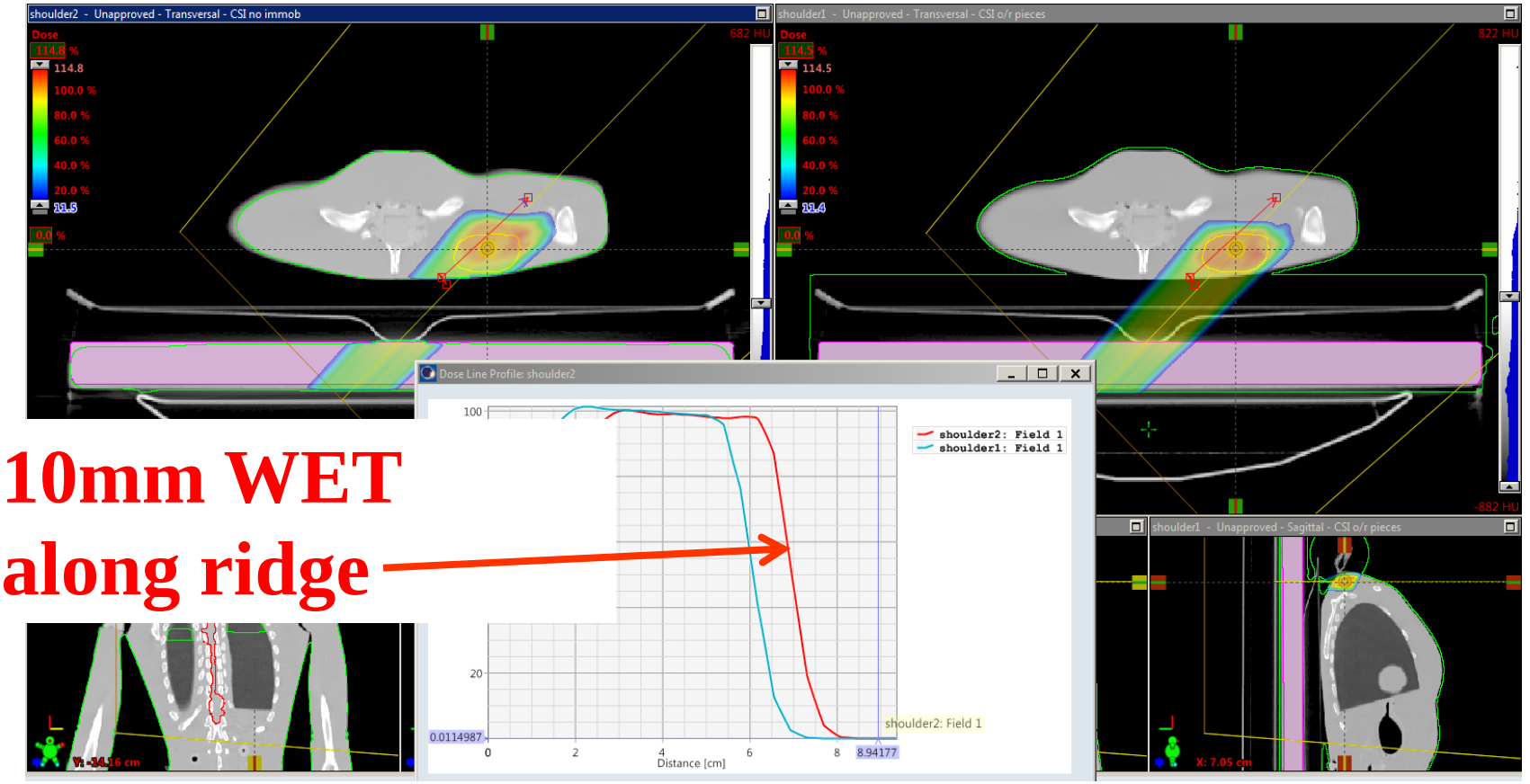
Characterization of Treatment Couch



10mm WET along ridge

Calculate treatment beams with and without immobilization equipment in proton path

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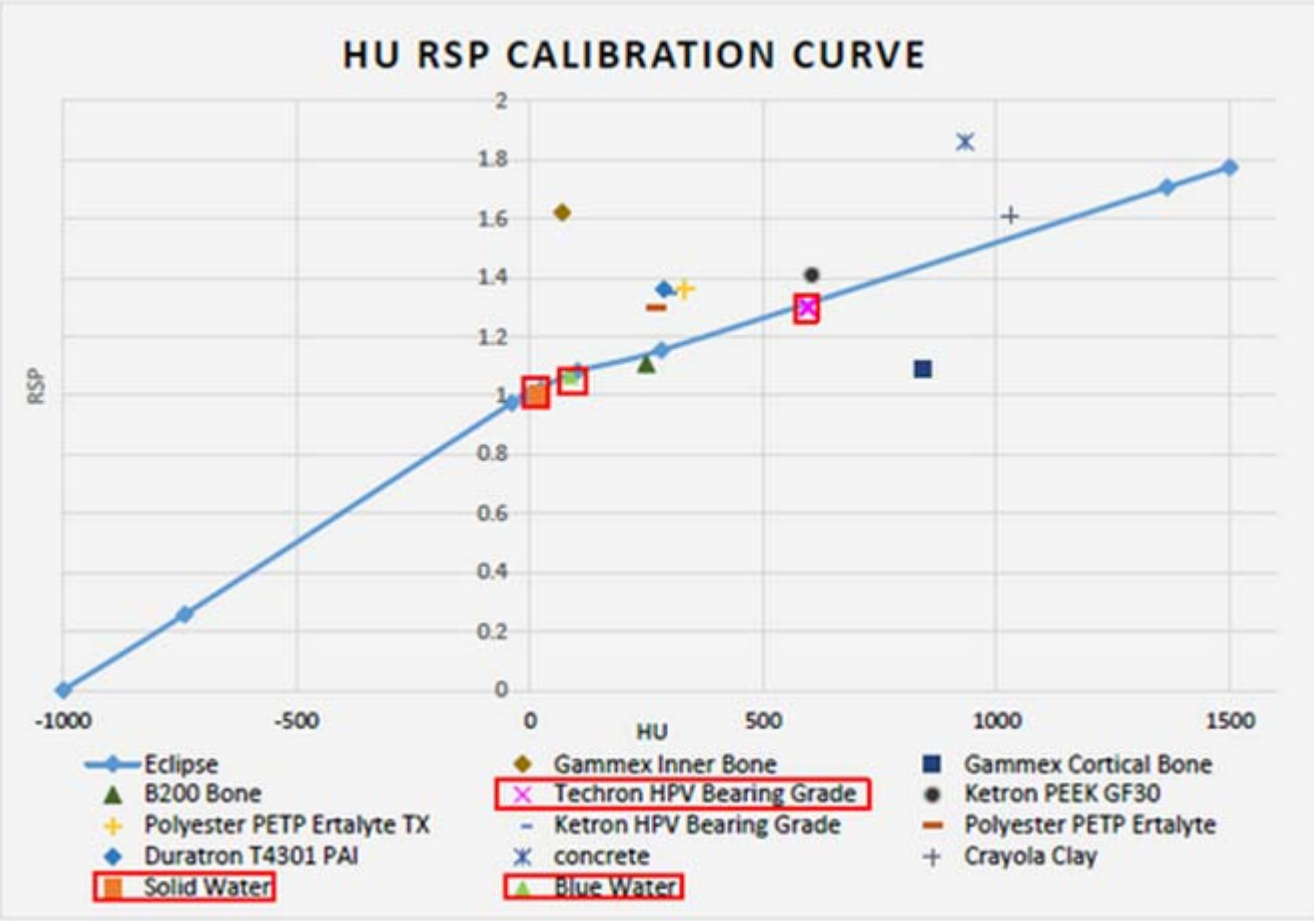
Characterization of Treatment Couch



Lewis et al., Intl Journal of Cancer Therapy and Oncology 2014

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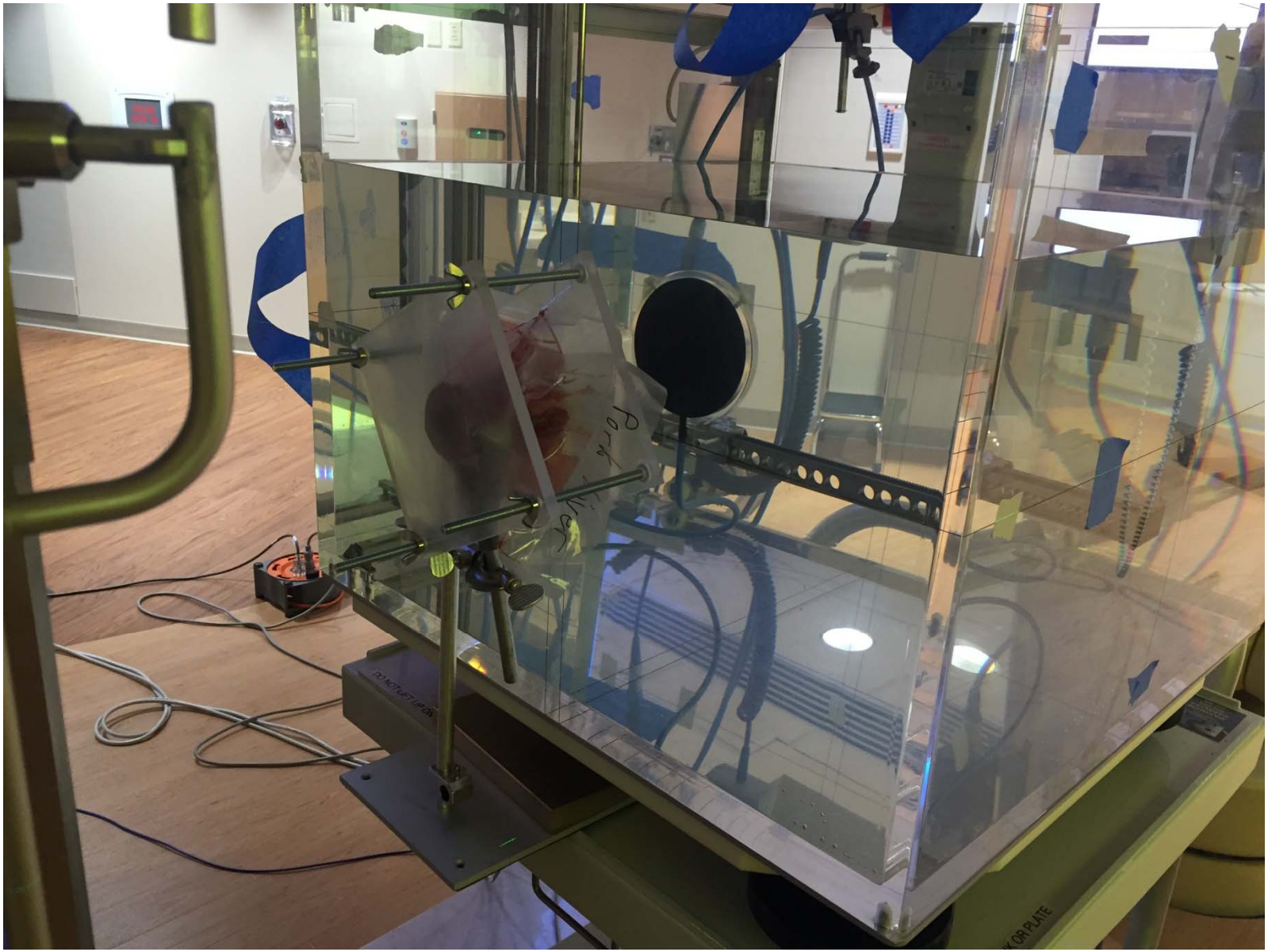
Experimental WET Determination



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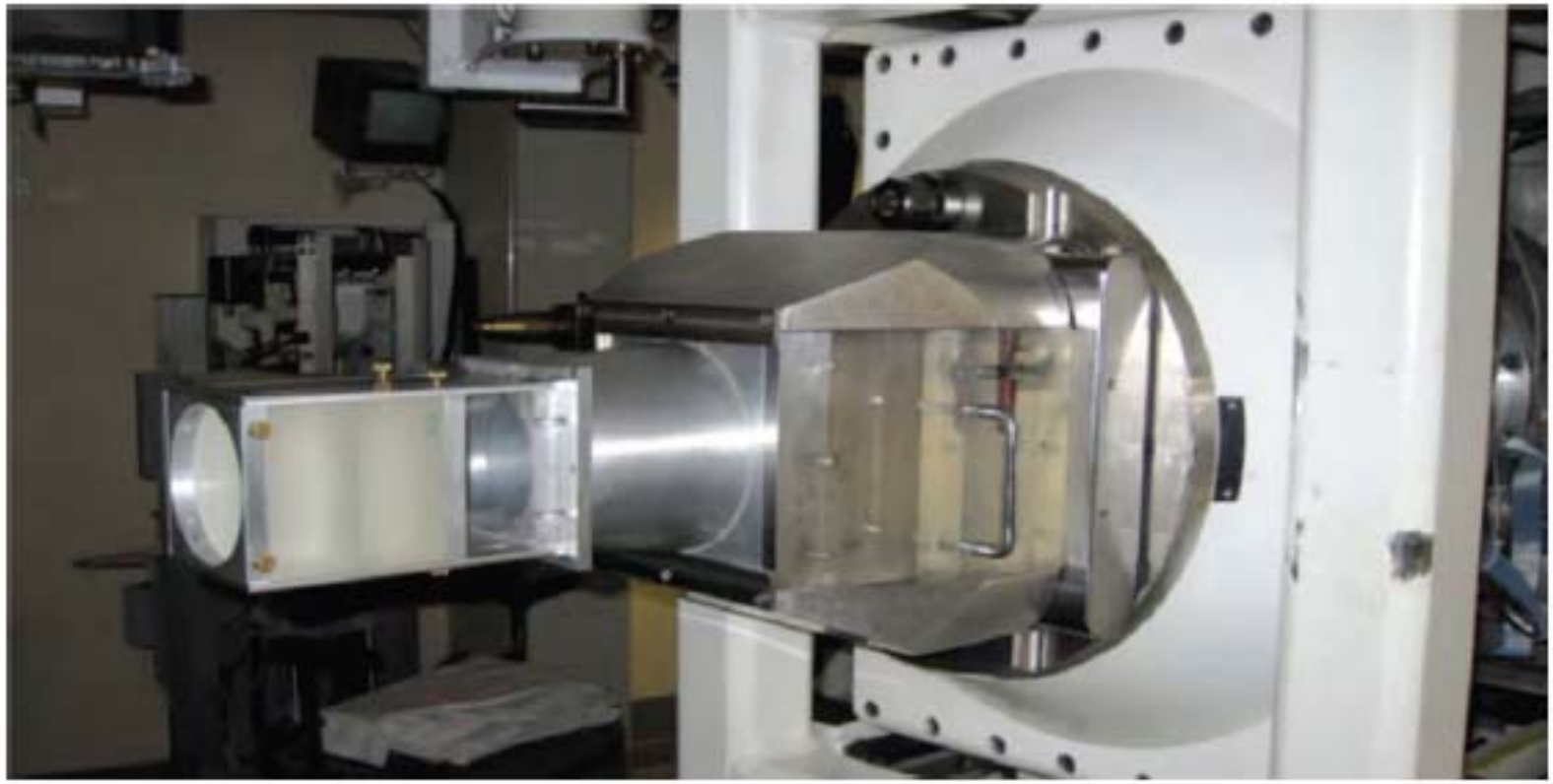
Experimental WET Determination



Wroe et al., TCRT 2014

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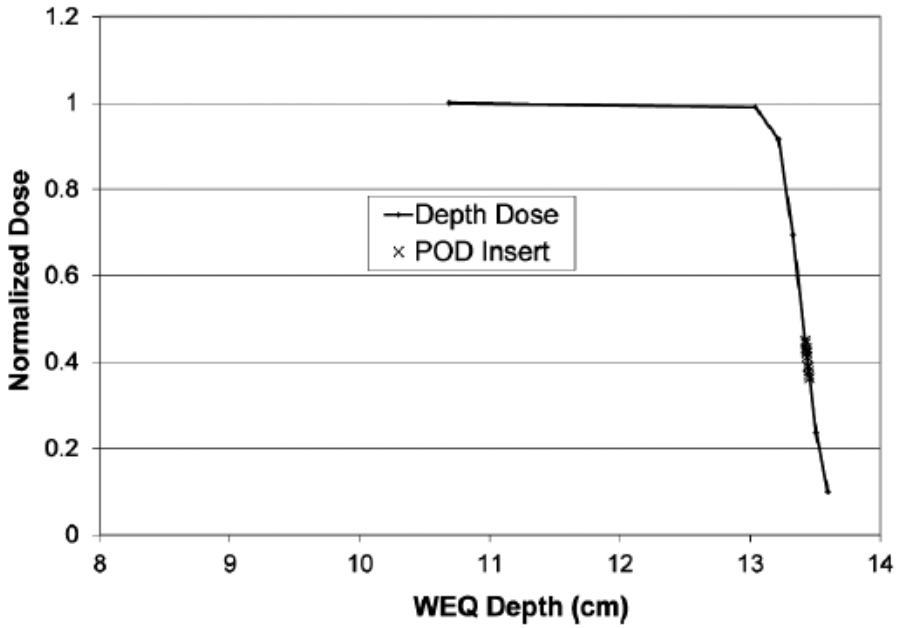
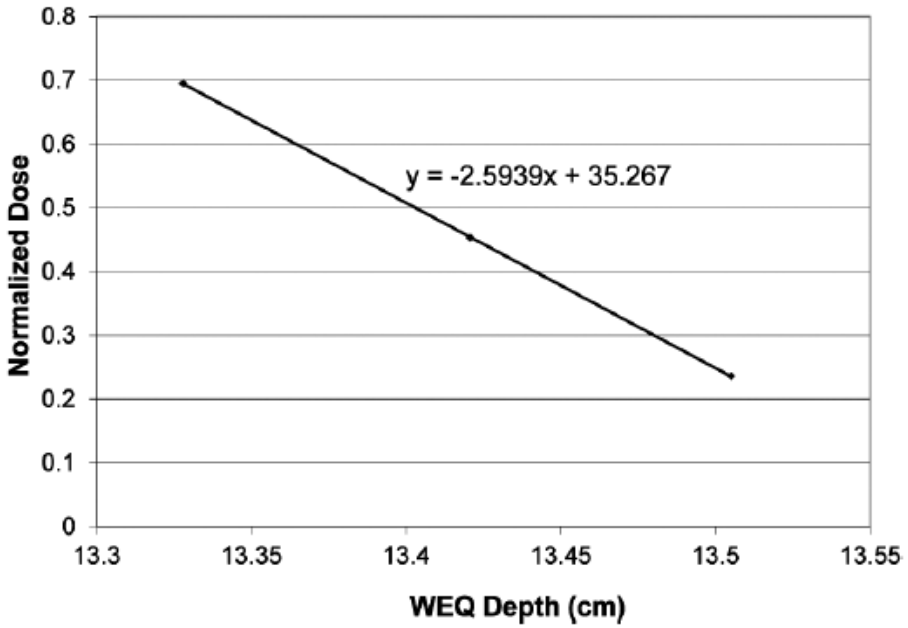
Experimental WET Determination





Wroe et al., TCRT 2014

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Experimental WET Determination

- **Need to measure multiple points in each device**
  - Ensure homogeneity within a given device
  - Check consistency between devices within a clinic
- **Does measured WET match calculated WET?**
  - Yes: include full couch top in CT simulation scan, incorporate couch into calculation
  - No: Contour couch top in treatment plan and override CT numbers to achieve correct WET

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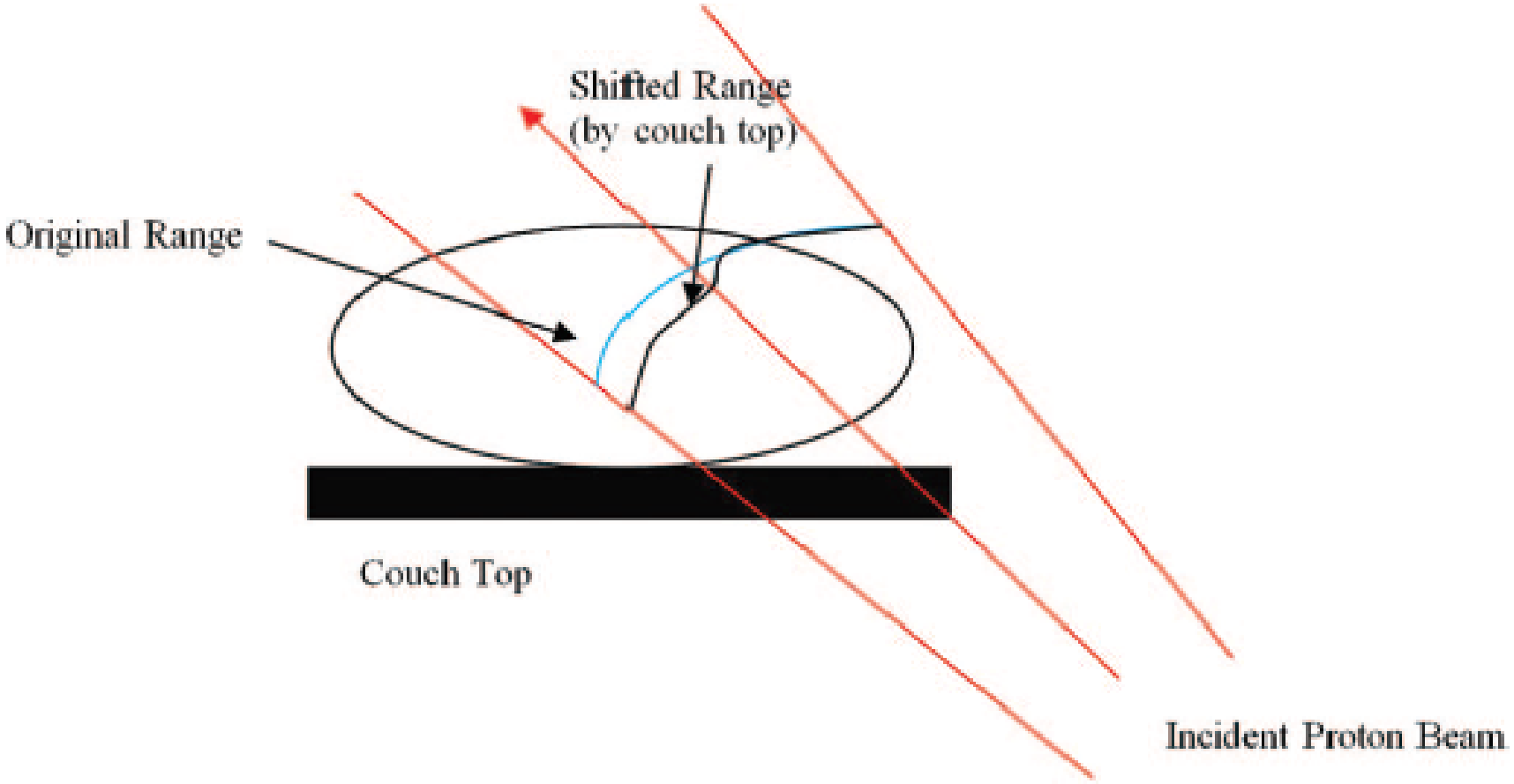
Edge Effects



AAPM TG176 MedPhys 2014

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Edge Effects

- Index all immobilization equipment to treatment couch
  - Indexing hardware can introduce its own problems
  - MDA showed that even with indexing, patient position on couch varied by ~1 cm
- Avoid treatment beams that traverse couch edges
- Move patient relative to couch edge

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MDA CSI Technique

- Patient is lifted 10 cm off couch top by rigid foam board
- Posterior oblique cranial fields avoid couch edges

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Treatment Couch Design

- Must be free of heterogeneities
- Fixation points for thermoplastic masks, bite blocks, and other immobilization devices
- One size does not fit all
- Modular design allows for specialized couch tops for various treatment sites
  - Head and Neck/Brain
  - Pelvis
  - Pediatrics
  - "Active" couch tops

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Modular Couch Design

Qfix Kvue Couch

- Base end mounted on robotic positioners, pedestals, linacs, and CT simulators
  - Linac compatibility for mixed modalities, contingency
  - CT imaging for inclusion within Tx plan

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Modular Couch Design

- **Should follow contour of patient's head and neck**
  - **Bringing aperture close to patient for scattered beam therapy**
  - **Bringing range shifter close to patient for scanning beam therapy**

Qfix BOS extension

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Modular Couch Design

Qfix Kvue Prone Breast Insert

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Contoured Couch Surfaces

- Excessive adipose tissue may exhibit widely varying shapes from day to day
  - Posterior neck in H&N Treatments
  - Pelvis contour in prostate, GYN treatments
- Variable external contour leads to changes in target depth
- A customized, contoured couch surface can help present a consistent external contour to the proton beam

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Loma Linda Pod

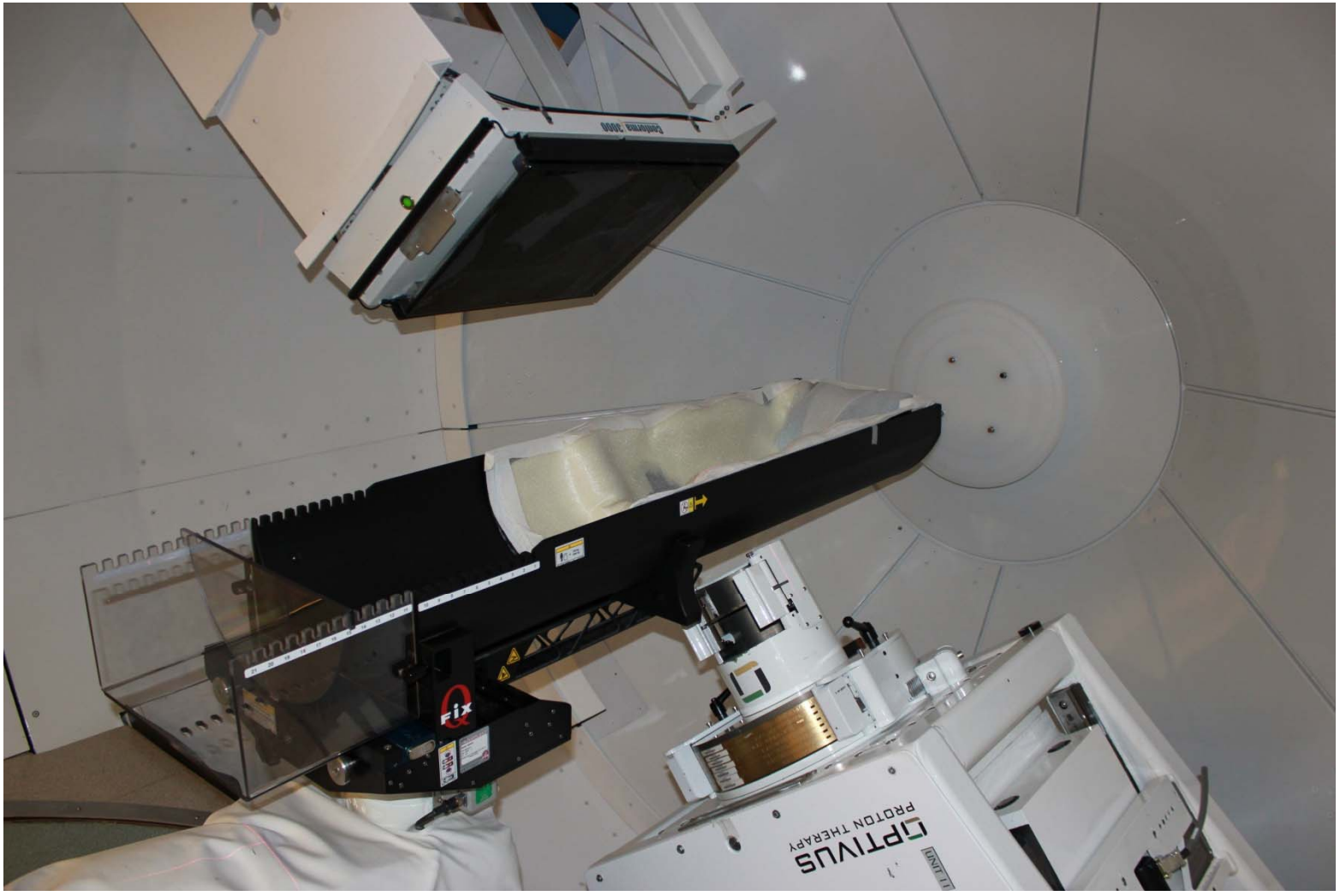

Image courtesy of A. Wroe

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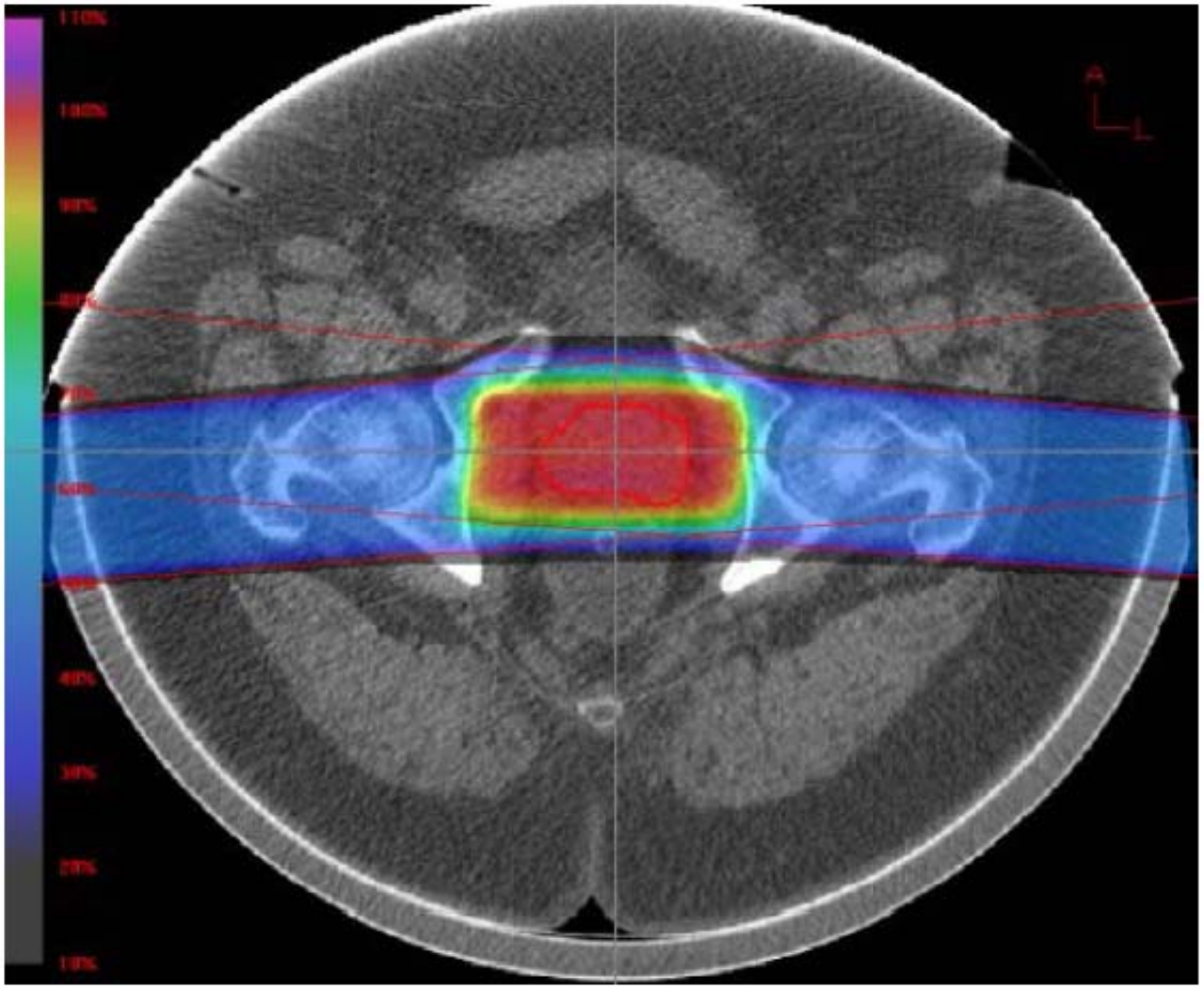
Loma Linda Pod



Wroe et al., TCRT 2014

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MRI Compatibility

- MRI is an increasingly important imaging modality for radiotherapy treatment planning and assessment
- Carbon fiber couch tops are generally great for proton therapy treatments
- Carbon fiber, unfortunately, is not compatible with MRI procedures
  - Deformable registration between MRI and CT
  - MRI compatible versions of treatment couches

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MRI Compatibility

- **Image on flat MRI couch and use deformable registration**

Table 6. Results for the magnetic resonance imaging/computed tomography liver data (mm)

Study no.	Institution	Investigator	ABS AVG LR AP SI	ABS SD LR AP SI	MAX LR AP SI	AVG mag
2	CMS	Han	2.6 5.0 2.2	2.3 1.4 1.6	6.8 6.6 5.4	6.5
10	Philips Medical Systems	Kaus, Vik	1.1 3.2 2.5	0.9 1.8 0.6	2.5 5.9 3.3	4.5
11	Princess Margaret Hospital	Brock, Nguyen	1.5 2.0 2.6	1.3 1.2 1.6	3.5 3.3 5.6	3.9

Abbreviations: ABS AVG = absolute average; ABS SD = absolute standard deviation, MAX = maximum; Vector mag = vector magnitude; AVG mag = average magnitude. LR = left–right; AP = anterior–posterior; SI = superior–inferior; CMS = CMS Software.

Brock et al., IJROBP 2010

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MRI Compatibility

- Kevlar wrapped foam core couches are similarly low density; MRI compatible
- One device for both imaging and treatment

Civco Body Pro-Lok

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MRI Compatibility

- ABS version for MRI imaging only
- Some commercially available
- Could be manufactured in-house
  - Incorporate MRI coils

Qfix MRI BoS

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Active Immobilization Devices

- Minimum range for most proton therapy systems is approximately 4 cm
- Treatment of superficial lesions requires a range shifter – typically mounted in the head of the machine
- Range shifters have non-zero scattering power, and so any air gap between range shifter and patient can lead to dramatic increase in spot size
- Place range shifter on or in the couch

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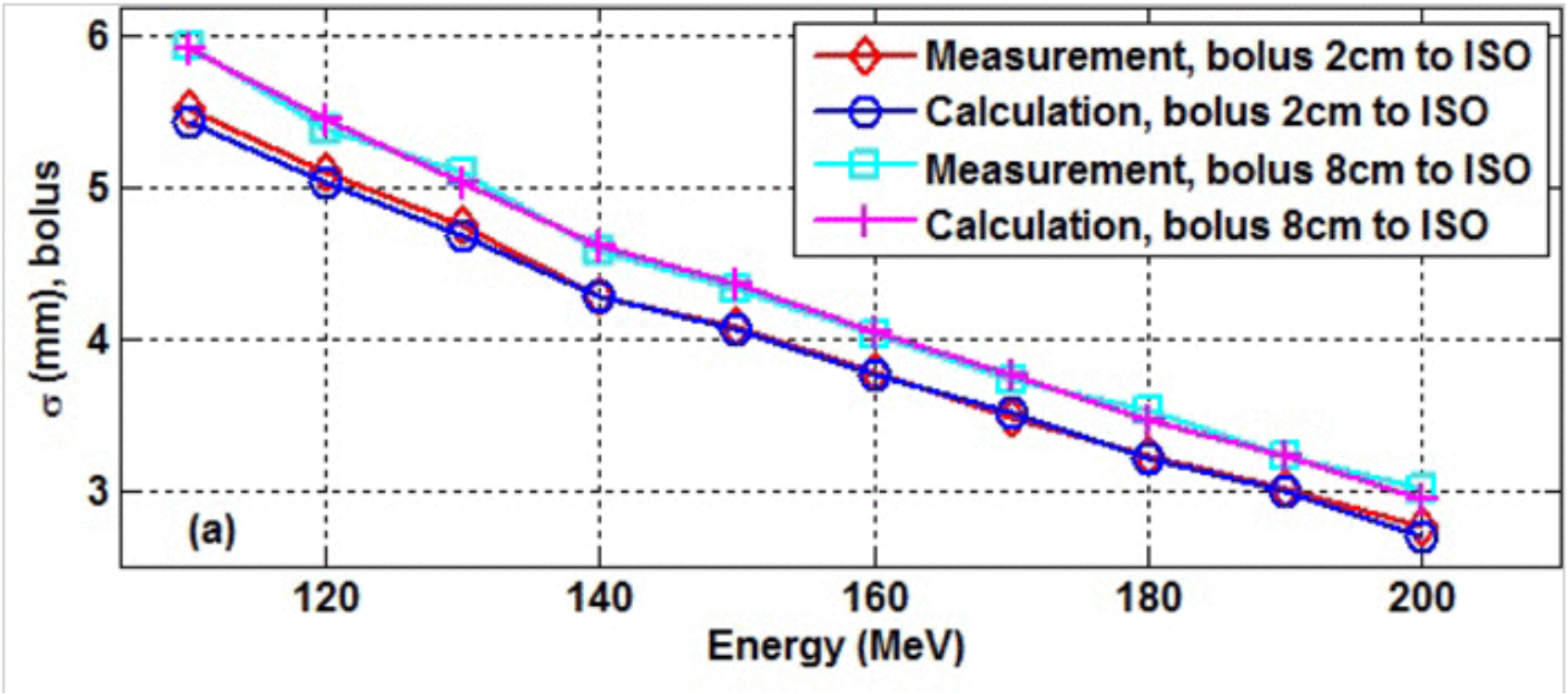
Range Shifter to Pt Air Gap



Shen et al., MedPhys 2015

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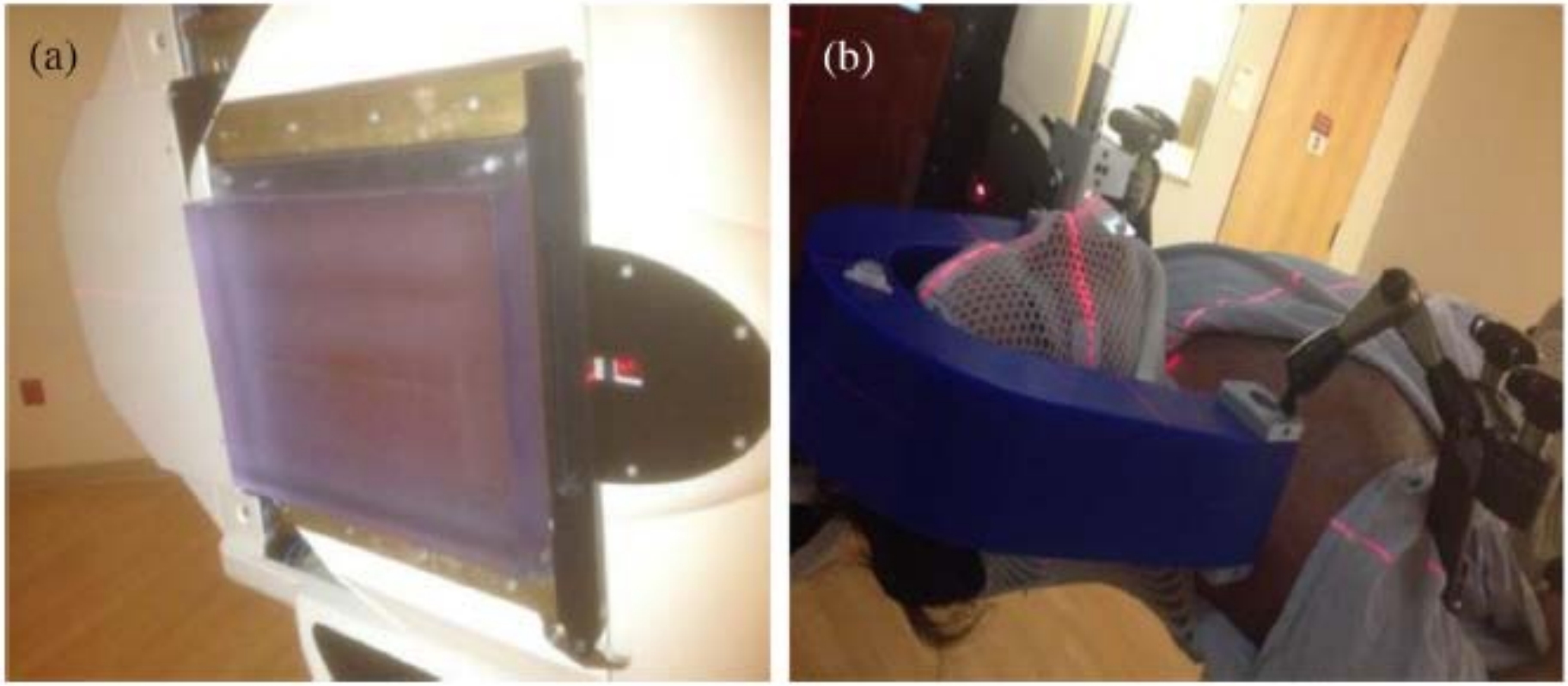
Universal Bolus



Both et al., IJROBP 2014

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Universal Bolus

Image courtesy of Stefan Both

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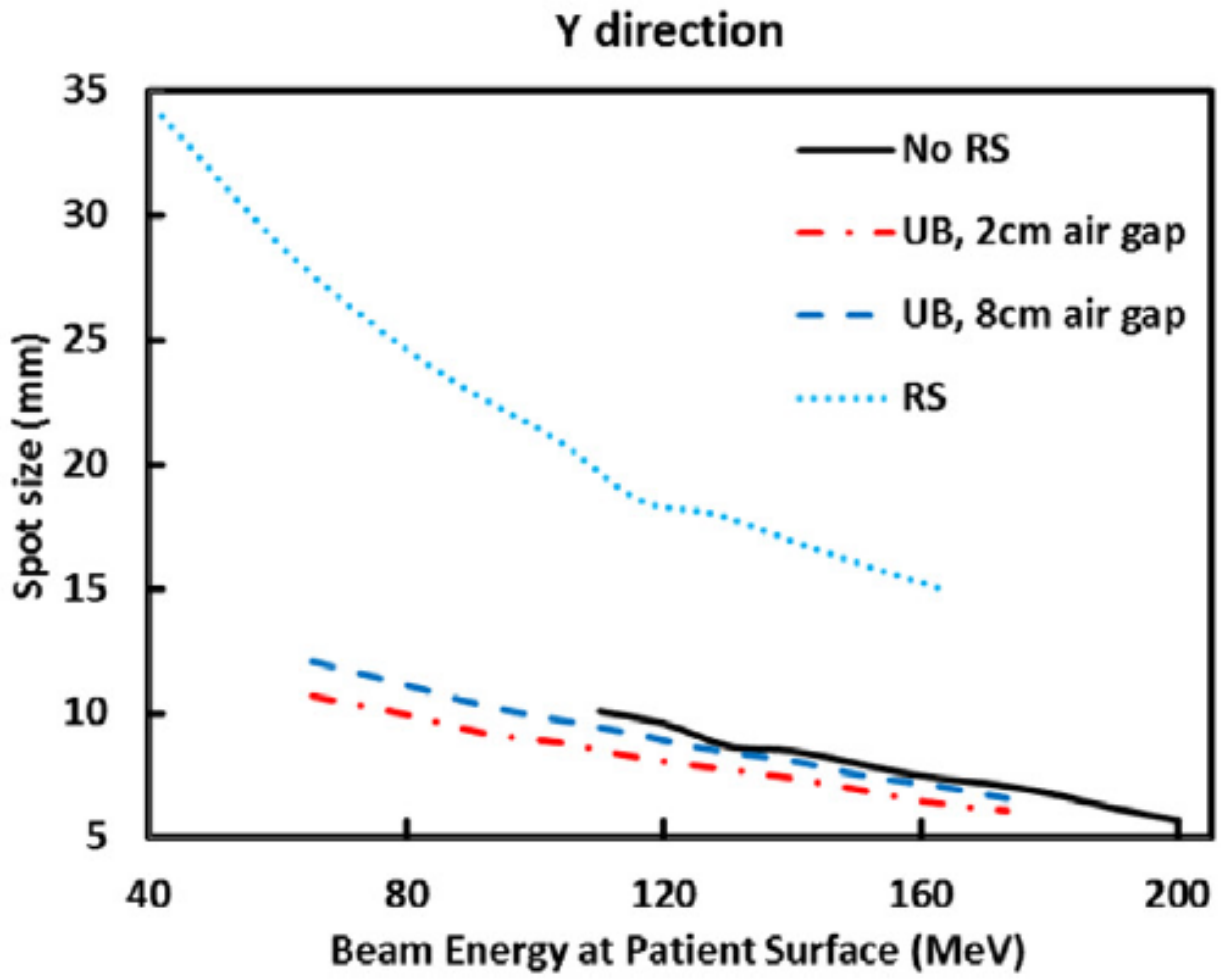
Spot Size at Patient with UB



Both et al., IJROBP 2014

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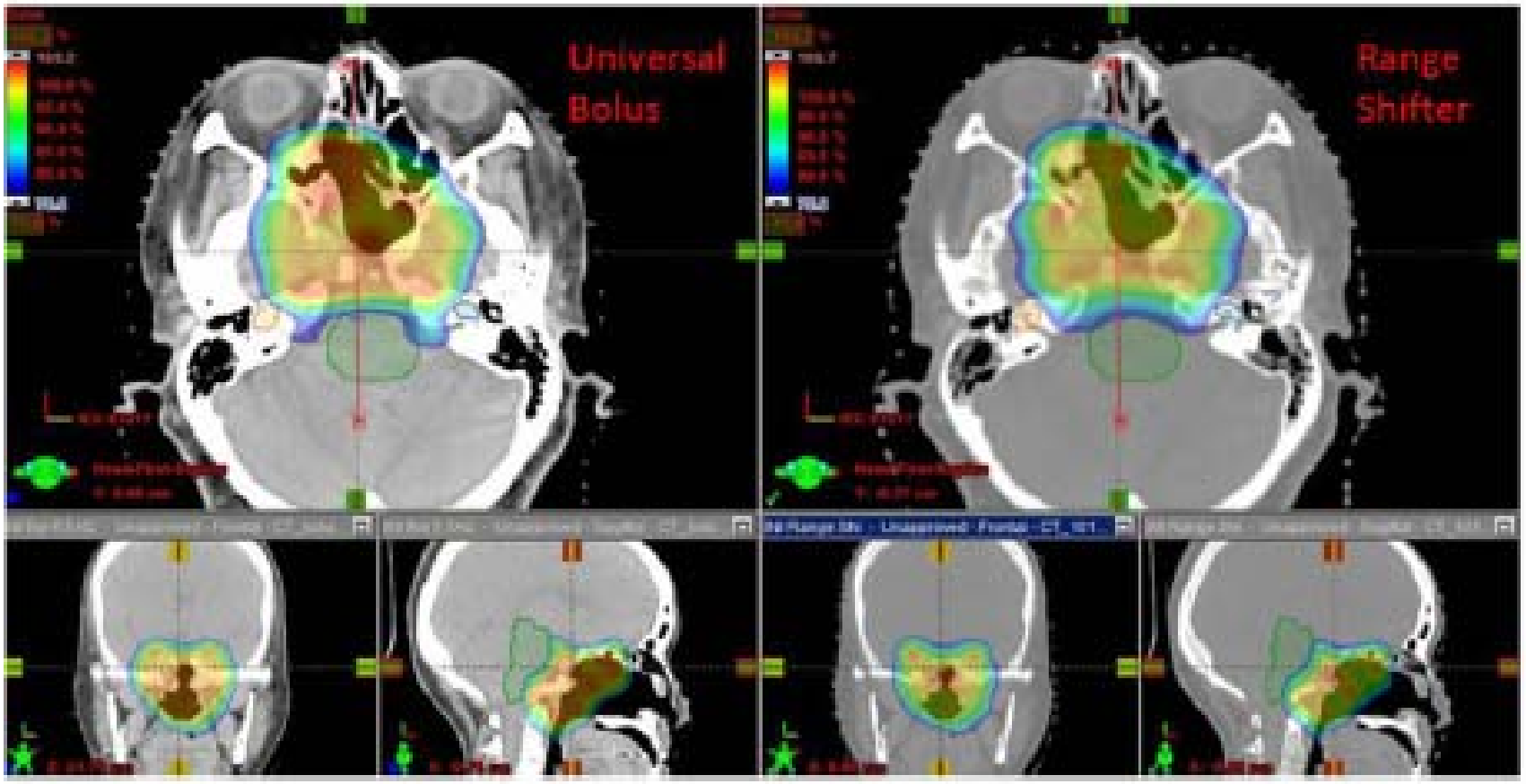
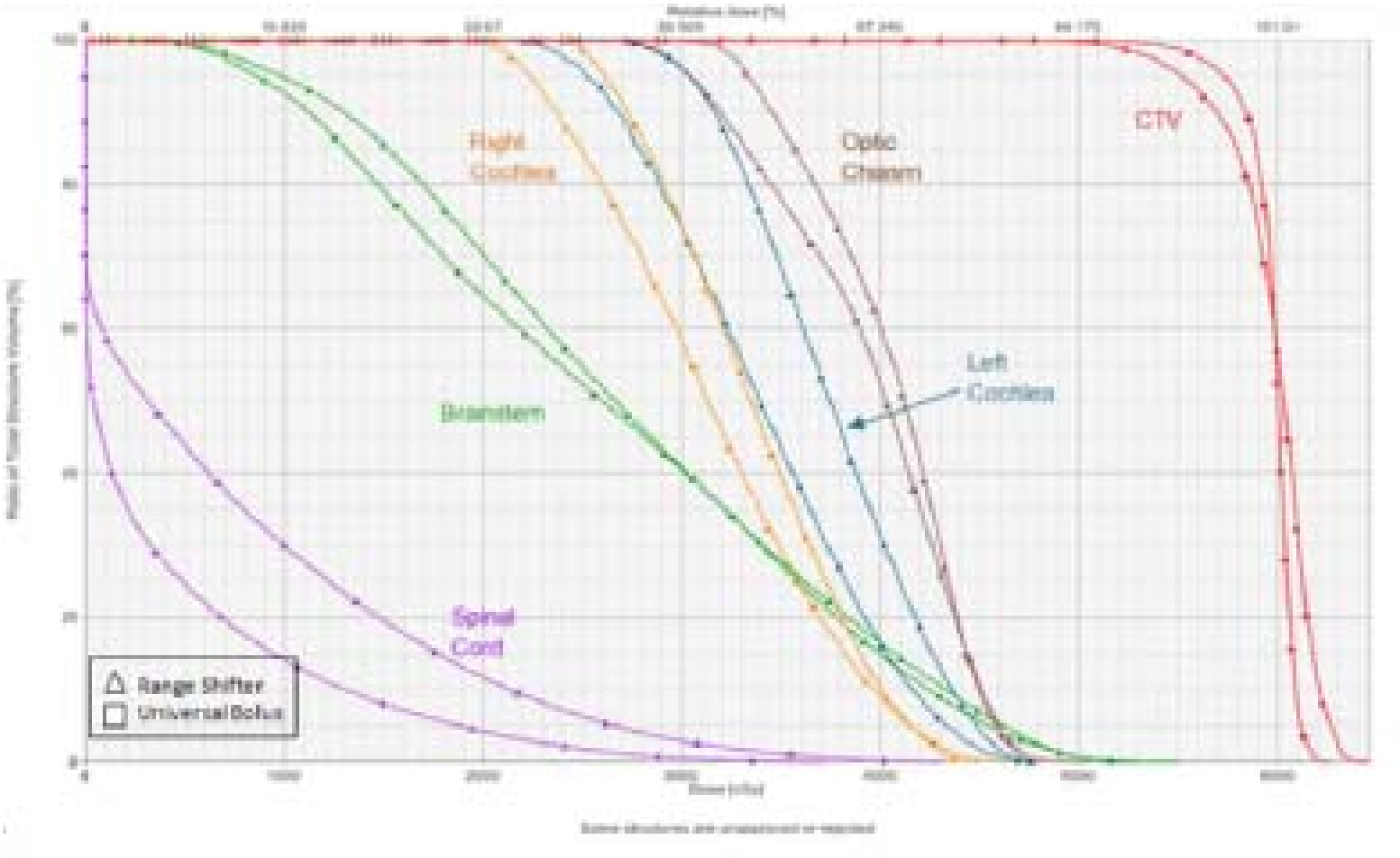
Treatment Plan with UB



Both et al., IJROBP 2014

MAYO CLINIC

Treatment Plan with UB



Both et al., IJROBP 2014

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Range Shifting Couch Top

- CSI requires large, superficial treatment fields
- Large area range shifter may be difficult to position close to patient's head
- Posterior and posterior oblique treatment fields were found to be optimal
- Spot scanning treatment technique with long gradient match regions allows for robust supine treatment

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CSI with Range Shifter

- Mayo Clinic range shifters are mounted in the treatment head approx. 35 cm and 28 cm from isocenter
- Static nozzle, but robotic positioner can move patient closer to range shifters
- Too much motion away from isocentric setups may move patient out of imaging field of view
- Development of range shifting couch top

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Range Shifting Couch Top

- Fits into couch base as a standard extension
- 4.2 cm WET plastic with carbon fiber top and bottom layers
- Indexing points on edges for immobilization overlay

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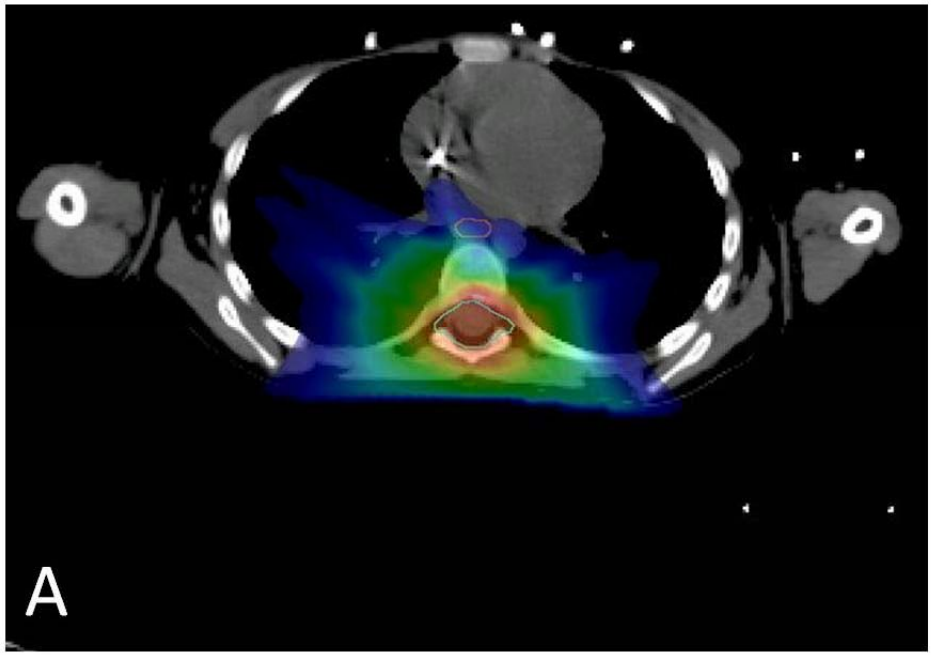
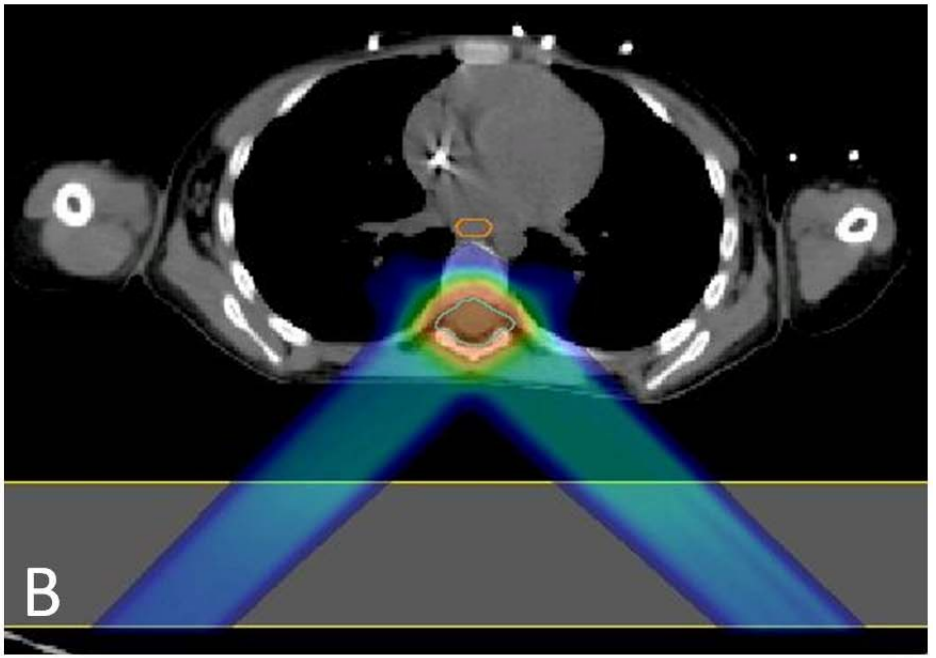
Range Shifting Couch Top





Tx Head RS

RS Couch Top

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Immobilization QA

- Periodic CT scans of all couches and immobilization devices
  - Verify consistency, heterogeneity
- Visual inspection for cracks
- Inspection or retirement of any cushioned devices
- Steady rotation of cushioned devices between Tx rooms and simulation suite

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Internal Immobilization

- **We may also use devices inside the patient to localize or regulate internal anatomy position**
  - **Radiographic fiducial markers**
  - **Active fiducial markers**
  - **Endo-rectal balloons**
  - **Rectal Spacers**

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Radiographic Fiducials

- Fiducial markers for x-ray therapy appear in the literature in early 1990's
- Widespread availability of in-room aSi imagers made daily on-line fiducial based localization feasible
- Recognized as standard of care for many years for prostate, liver SBRT, etc.
- May be more problematic for protons

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Fiducial Markers in Protons

- High density markers may pose unique challenges in proton therapy
  - CT artifact
  - Dose shadow
- Lower density carbon based markers may be a better fit for proton therapy
- Dosimetric impact should be verified carefully

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Dosimetric Impact of Markers

- Dose shadow may be more relevant in proton therapy because of small number of treatment fields
  - Density of marker influences the effect
  - Orientation of marker relative to field direction also important

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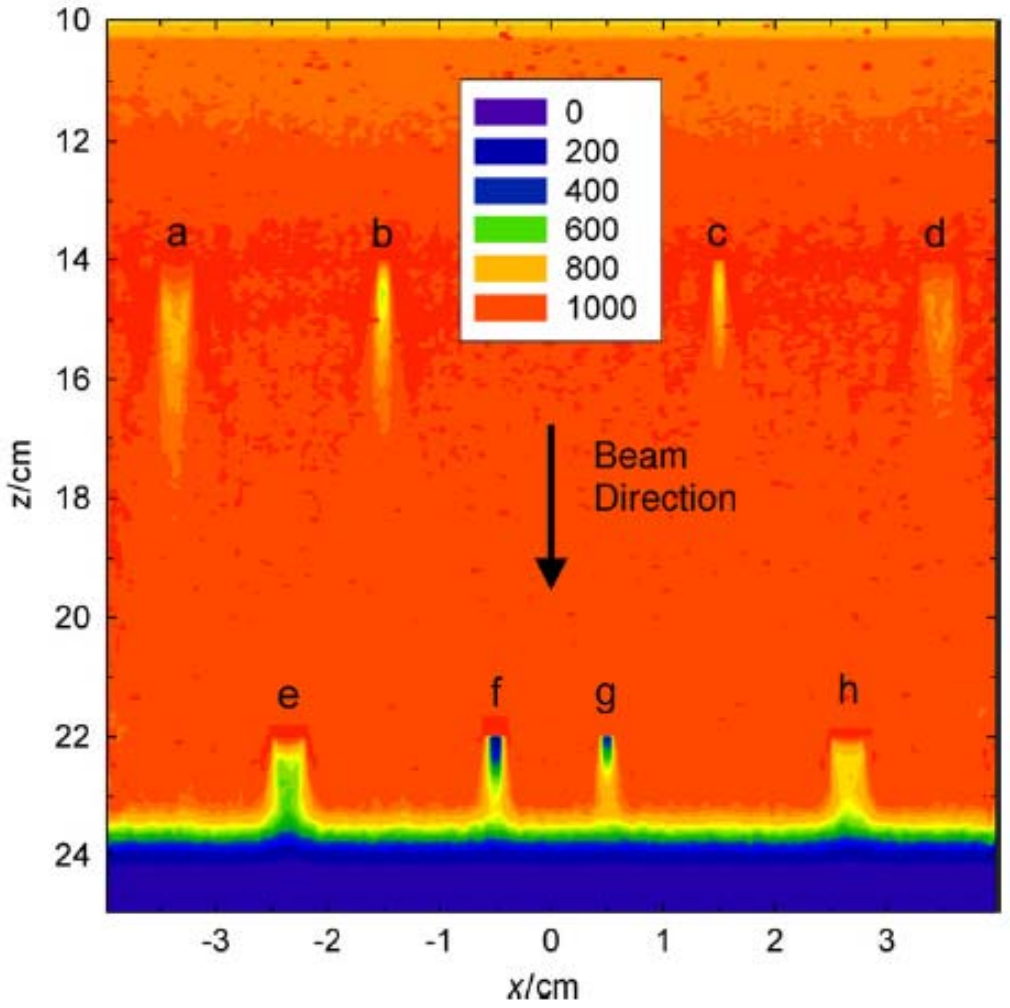
Dosimetric Impact of Markers



Newhauser et al., PMB 2007

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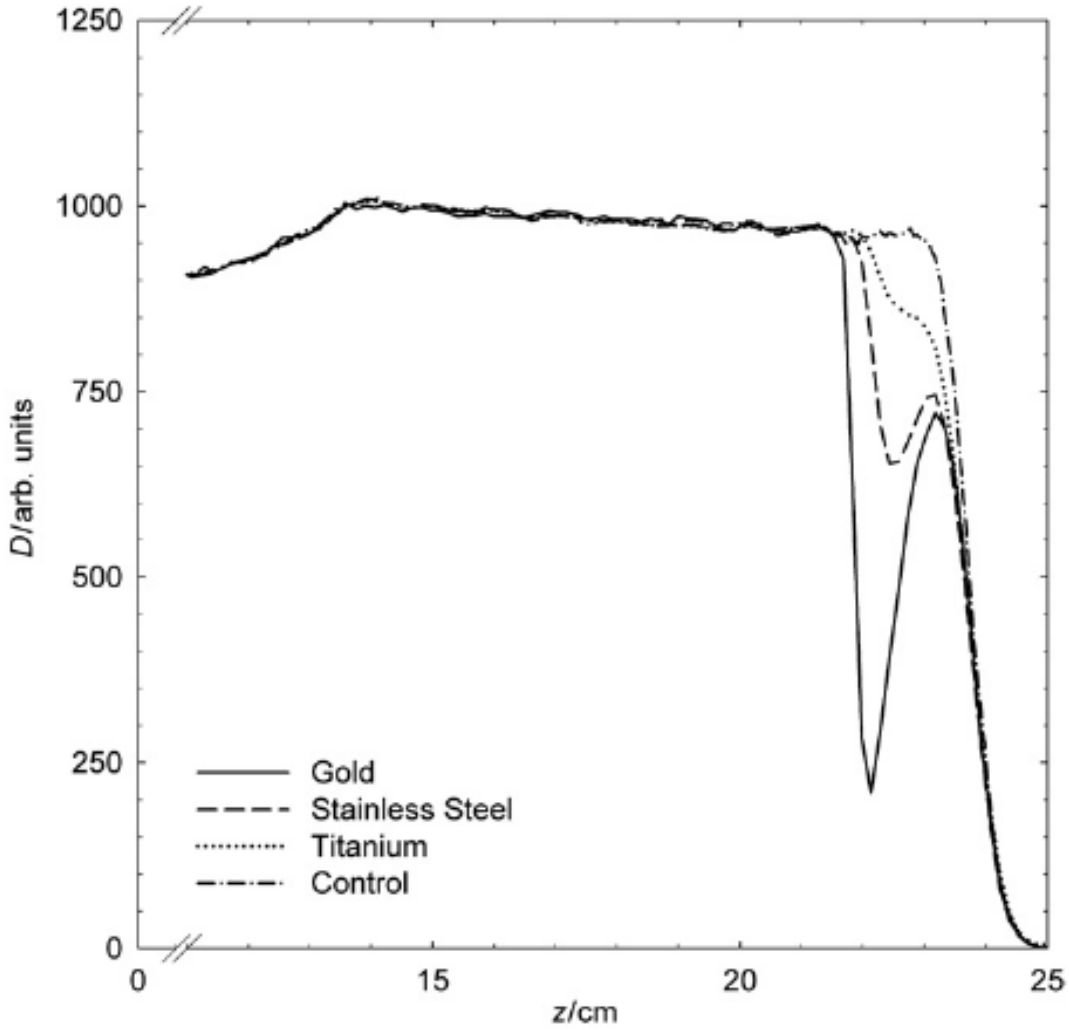
Dosimetric Impact of Markers



Newhauser et al., PMB 2007

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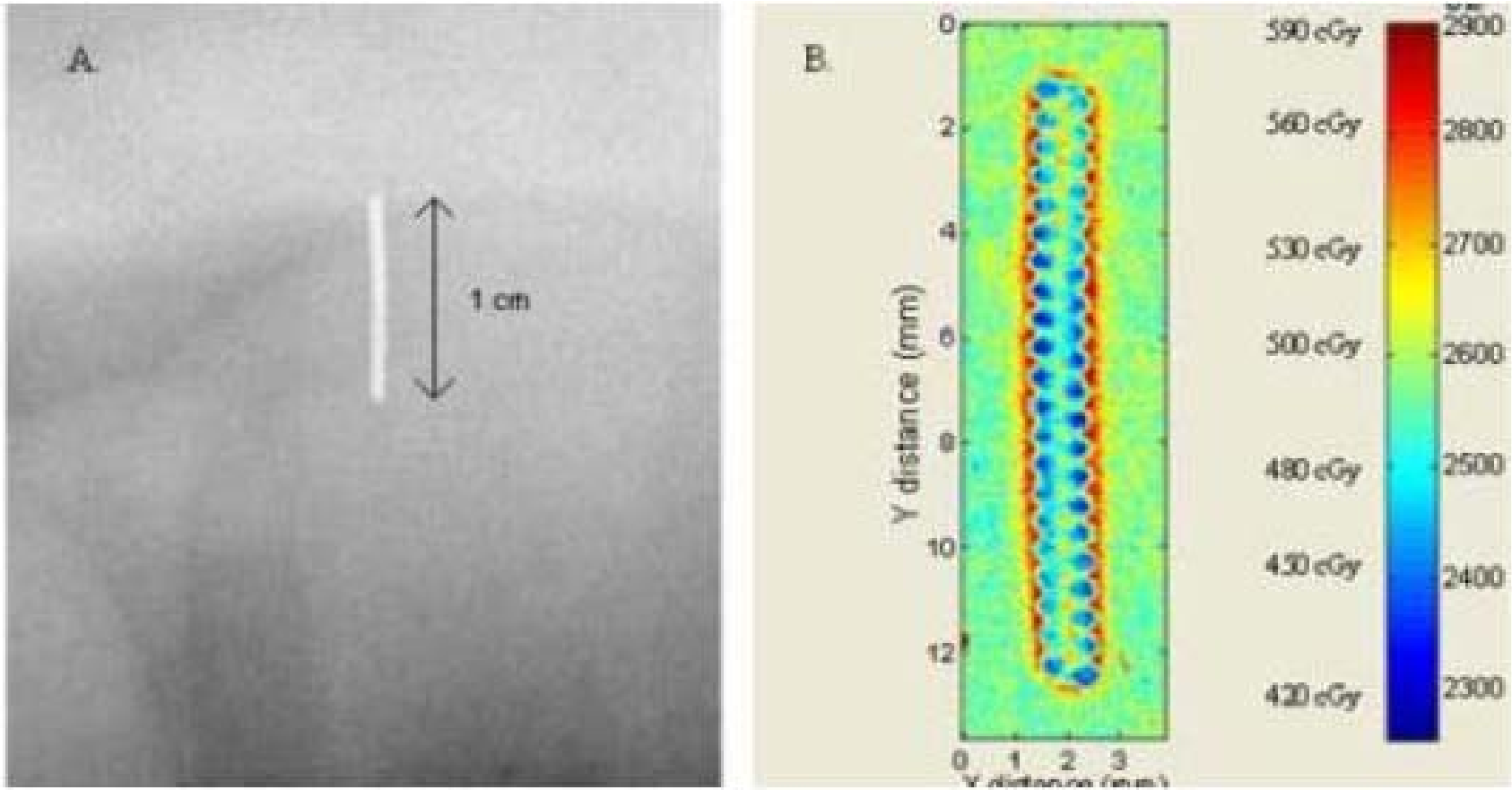
Dosimetric Impact of Gold Coils



Giebeler et al., JACMP 2009

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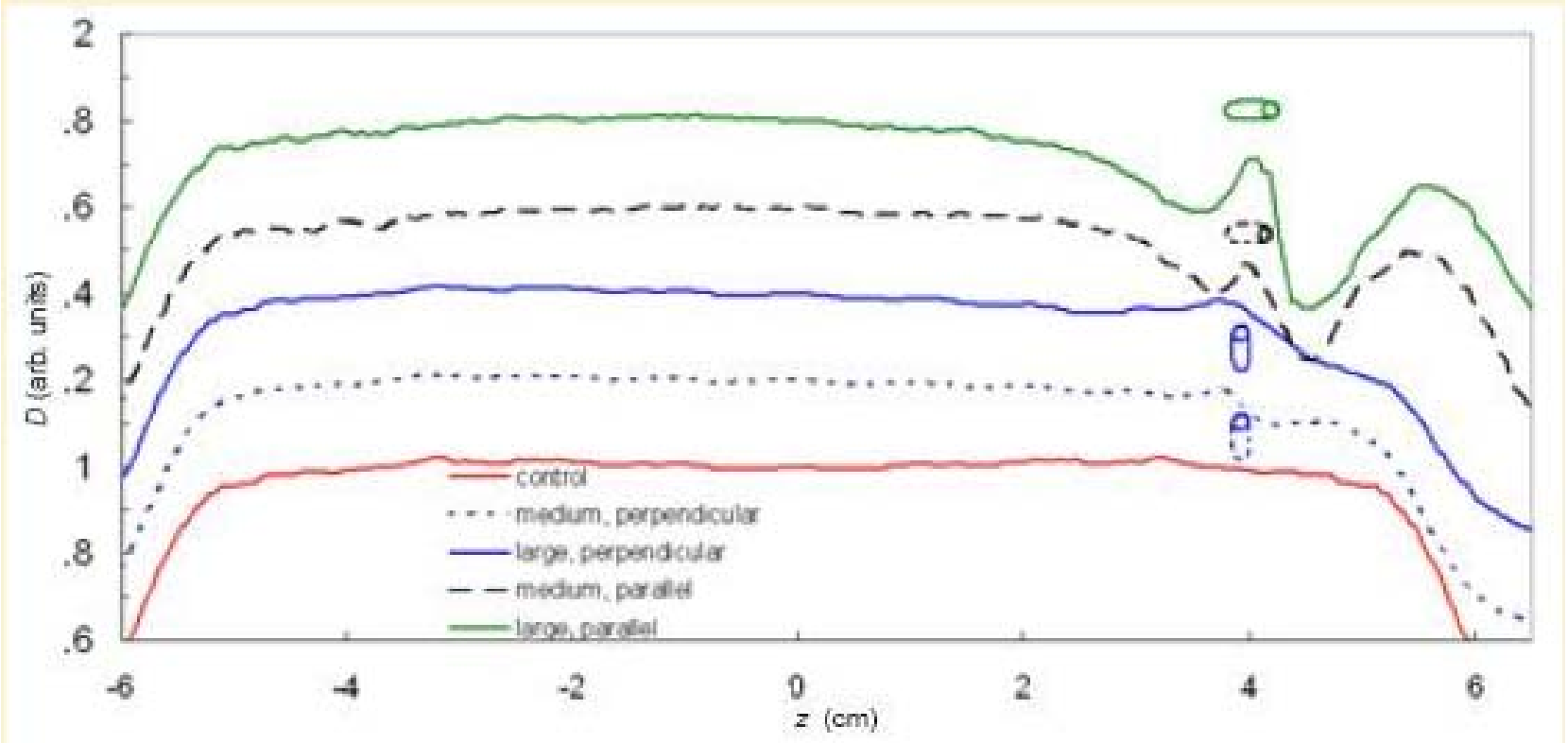
Dosimetric Impact of Gold Coils



Giebeler et al., JACMP 2009

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Endo-rectal Balloons

- Reduce inter- and intra-fractional variation of prostate position within the body
- Reduce rectal toxicity by limiting volume of rectal wall within high dose treatment volume
- Generally more widely adapted in proton centers because localization of soft tissue target alone does not guarantee adequate target coverage

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Intra-Fx Motion

- Wang et al., used Calypso beacons to measure intra-fractional motion during prostate EBRT with and without ERB
- ~1000 treatment fractions monitored with and without ERB
- Tracked fraction of time with various magnitude 3D and single direction prostate deviations

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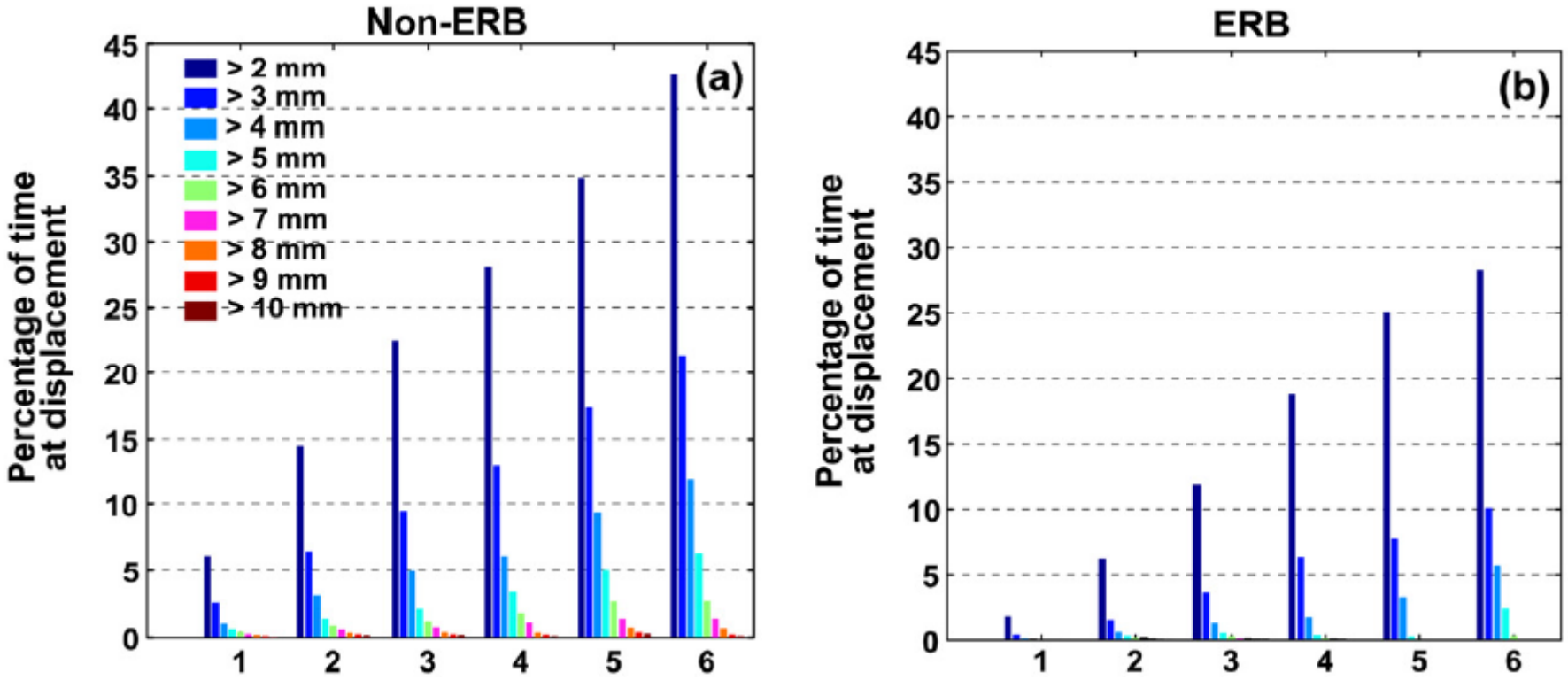
Intra-Fx Motion



Use of ERB can reduce IM from 5 mm to 3 mm

Wang et al., IJROBP 2011

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Elimination of Heterogeneities

- ERBs in proton clinics are typically filled with water to avoid gas pockets and heterogeneities along the path of lateral beams, at the border of the target
- Vargas et al., studied dosimetric benefit of water filled ERB vs water injected directly in the rectum
- Water alone may be tolerated better than ERB

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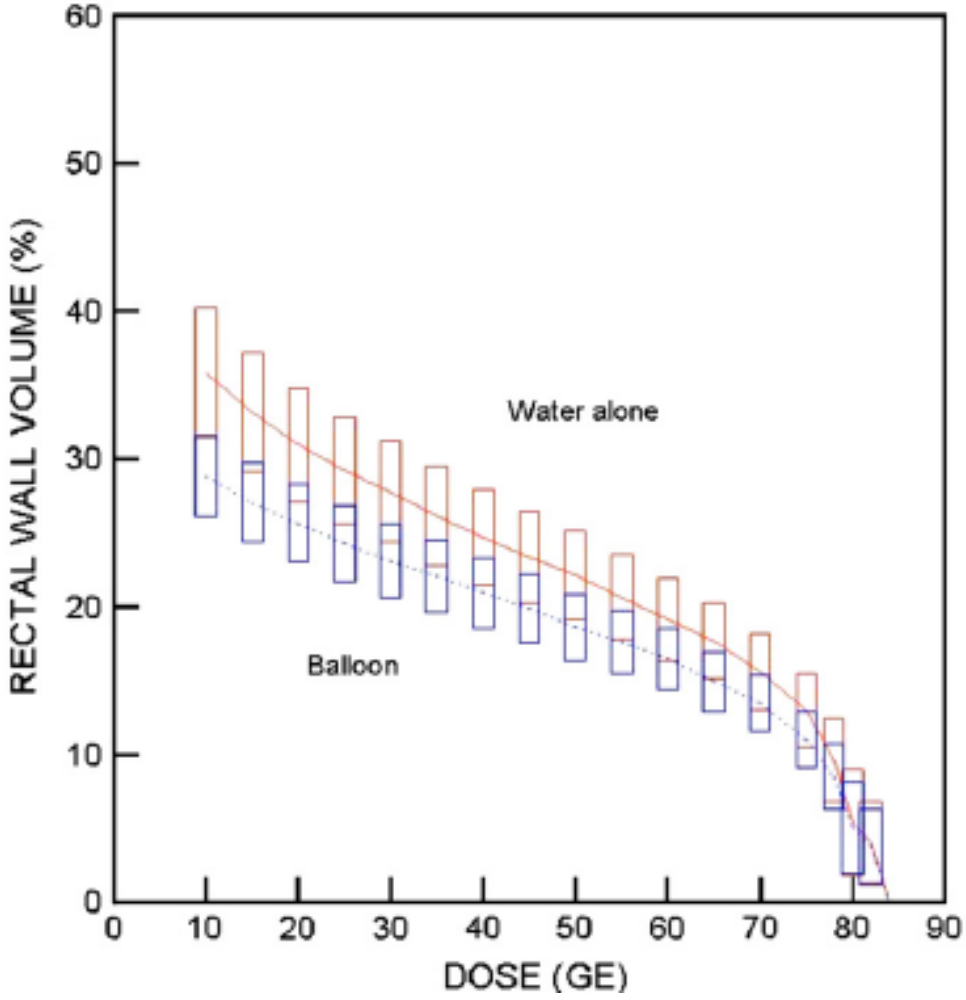
ERB vs. Water



Vargas et al., IJROBP 2007

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ERB Placement Technique

- Variability in ERB placement may reduce the benefit in the use of these devices
- Buildup of gas superior or anterior to the balloon may introduce unwanted changes in the internal anatomy
- Newer design ERBs may help reduce this variability

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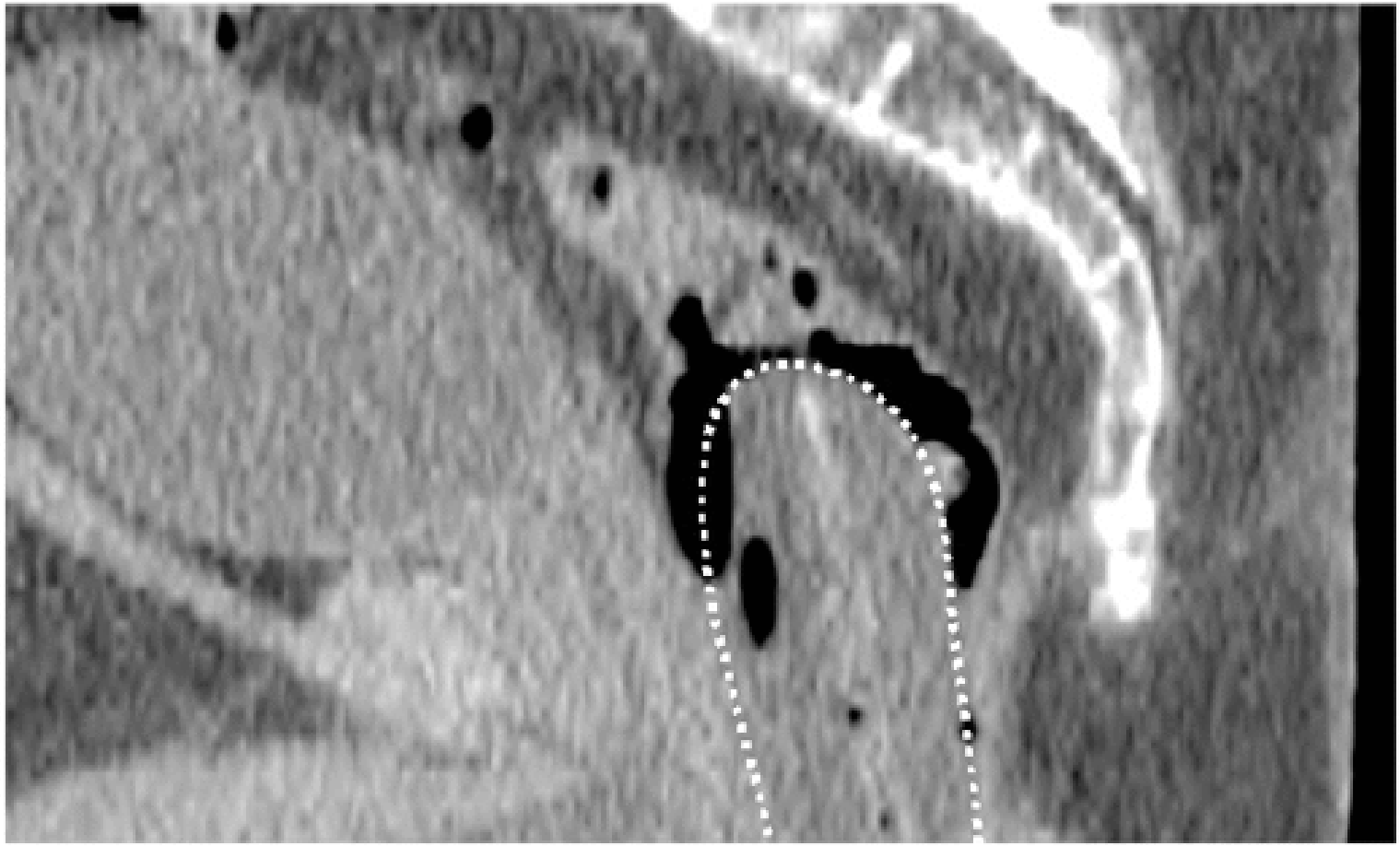
Vented ERB



Wootton et al., JACMP 2012

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Vented ERB

Wootton et al., JACMP 2012

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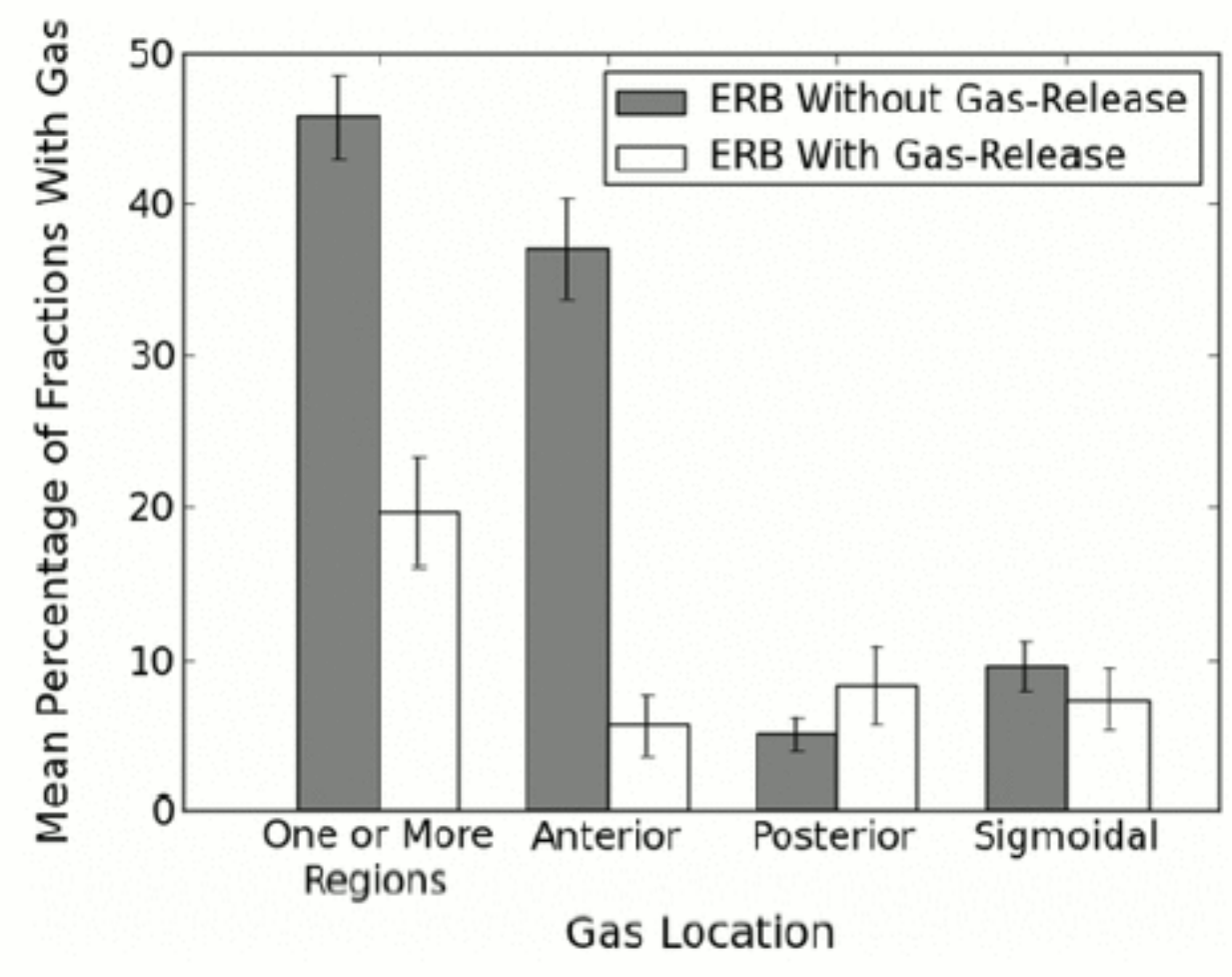
Vented ERB



Wootton et al., JACMP 2012

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Hyaluronic Acid

- Naturally occurring fluid harvested from rooster combs
- Used medically as a lubricant in degenerative joint disorders
- Replacement for eye fluid
- Injected between prostate and rectal wall to push rectum posterior of the high dose region of a treatment plan

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Rectal Spacers in HDR

- Prada et al. used rectal spacers during HDR prostate boost after EBRT
- First HDR treatment delivered without HA
- Second Tx delivered with HA
- ~2cm separation between prostate and rectum achieved
- Rectal doses calculated and measured

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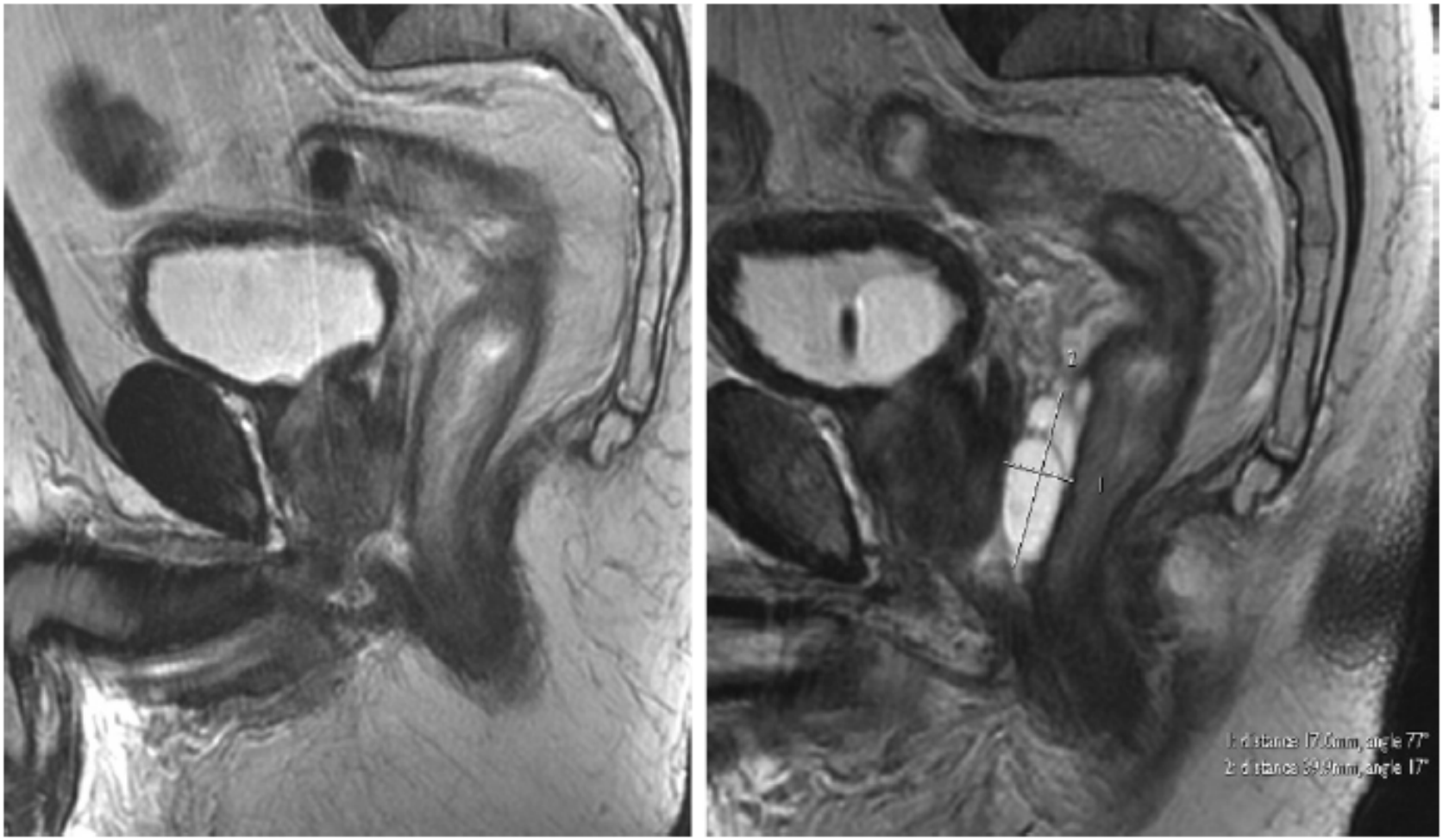
Rectal Spacers in HDR



Prada et al., IJROBP 2007

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Rectal Spacers in HDR

Table 2. Difference in the mean rectal dose with and without hyaluronic acid injection

	Without hyaluronic acid	With hyaluronic acid	*p* values
Patients	27	27	
Mean	47.1%	39.2%	< 0.001
Standard deviation	9.7%	6.2%	
Rectum mean Dmax	708.1cGy (± 135.2 SD)	507.4 cGy (± 113.5 SD)	< 0.001
Rectum mean Dmean	608.3 cGy (± 114.6 SD)	441.8 cGy (± 1.3.2 SD)	< 0.001

Prada et al., IJROBP 2007

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Rectal Spacers in EBRT

- Subsequent studies have shown a clinically important separation between prostate and rectum can be achieved without substantial procedure morbidity
- Larger clinical studies have shown significant improvement in acute QOL for patients with spacers
- Cadaver study showed that anterior proton beams could be used in prostate treatments without fear of ranging out in rectum

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Treatment Simulation

- **Build customized immobilization devices**
  - Carefully consider immobilization pose, considering expected treatment beams
  - Construct masks, molds, etc.
- **Acquire CT scan**
  - Substrate and stopping power data for dose calculation
  - Source of reference images for daily setup assessment
- **Where possible, separate these processes**

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Separate Immobilization Appointment

PHYSICS CONTRIBUTION

A PROTOCOL FOR THE REDUCTION OF SYSTEMATIC PATIENT SETUP ERRORS WITH MINIMAL PORTAL IMAGING WORKLOAD

HANS C. J. DE BOER, M.SC. AND BEN J. M. HEIJMEN, PH.D.

Department of Radiation Oncology, Division of Clinical Physics, Daniel den Hoed Cancer Center/University Hospital, Rotterdam, The Netherlands

- It is well known that patients setup early in a course of radiotherapy is much different from their typical setup
- Leaving time between immob construction and CT scan allows devices to shrink, harden, etc.
- Inspect the immobilization devices for wrinkles, folds, etc. that may introduce problematic heterogeneities
- Consider beam angles before building immobilization devices

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CT Scan

- Use only calibrated protocols
- Match reconstruction protocols to patient size
- Include couch top and all immobilization equipment in image, if possible
- Normalize (where possible) position of patient within scanner

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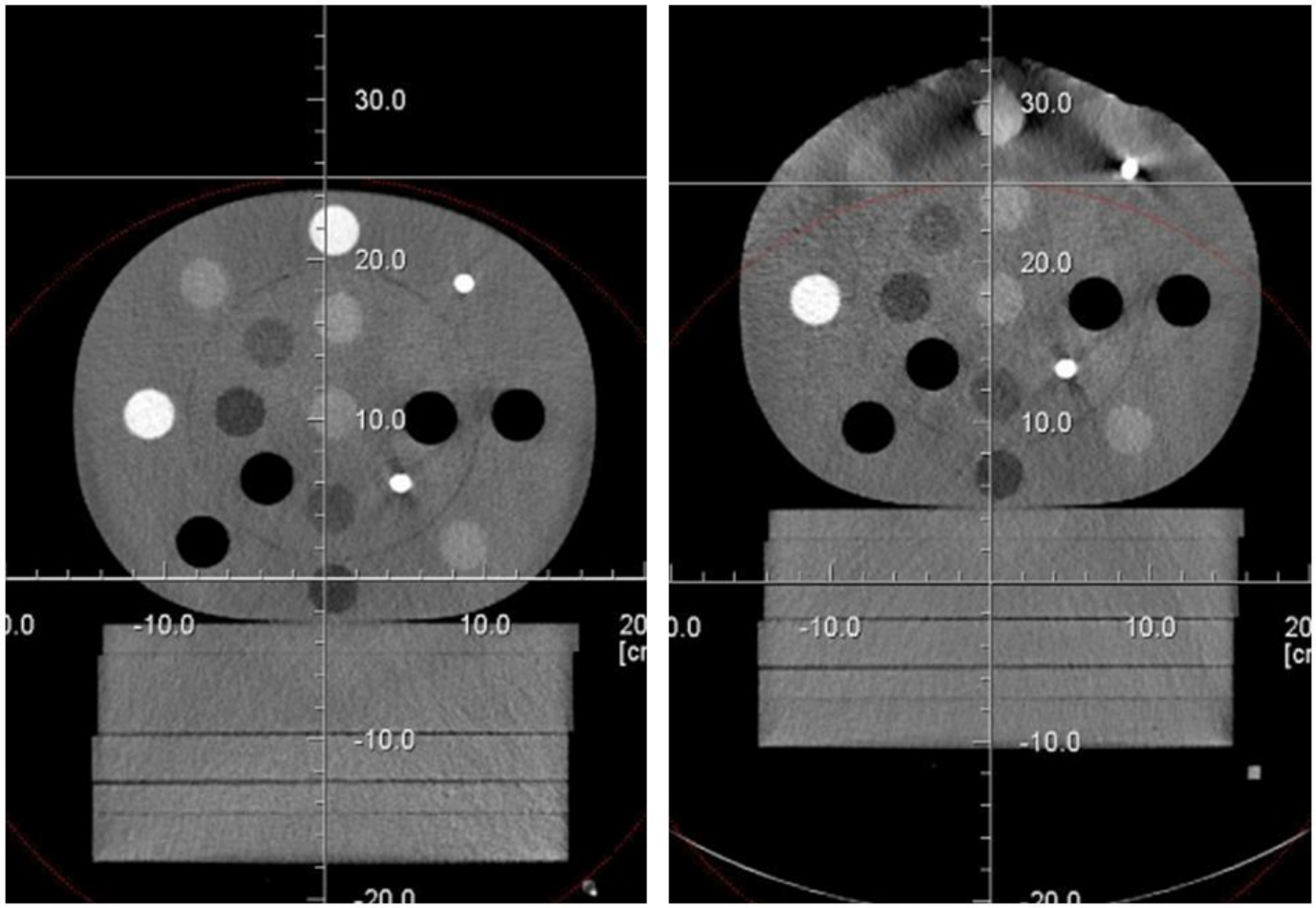
Position of Heterogeneities in Image



Courtesy of D. Brinkmann, Mayo Clinic

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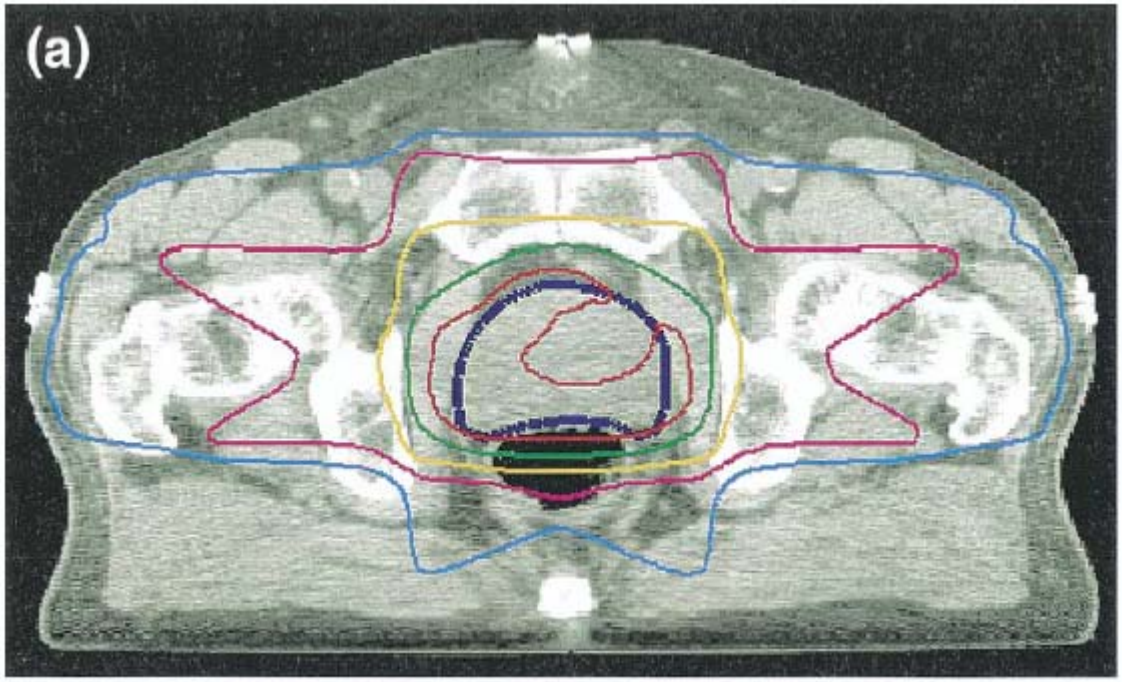
Anatomical Anomolies

- Examine the scan for transient anatomical problems before sending patient away



De Crevoisier et al., IJROBP 2005

MAYO CLINIC

Thanks for your attention