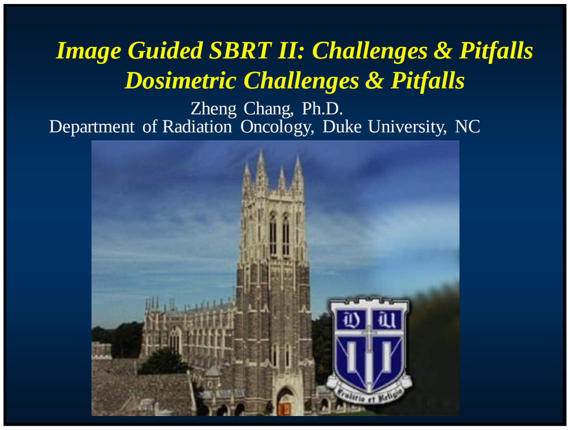
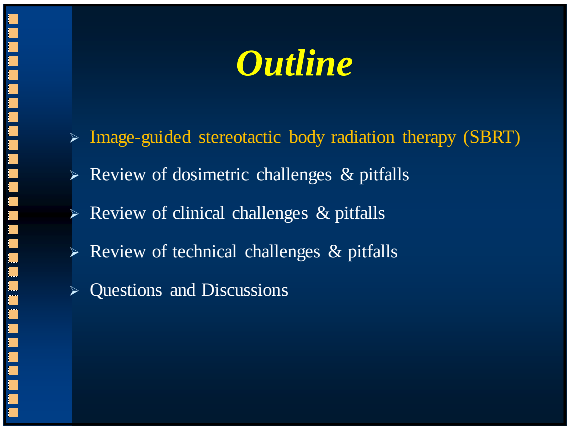


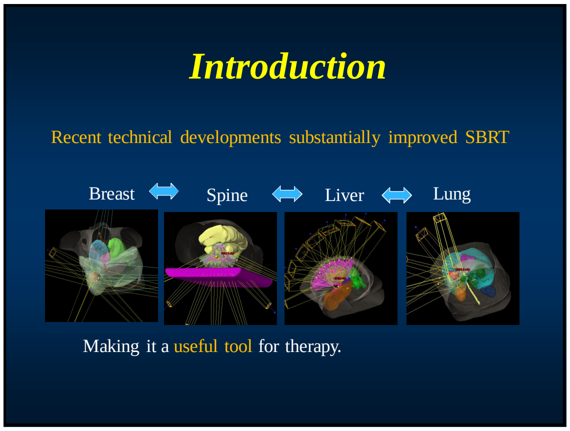
Image Guided SBRT II: Challenges & Pitfalls
Dosimetric Challenges & Pitfalls

Zheng Chang, Ph.D.
Department of Radiation Oncology, Duke University, NC



Outline

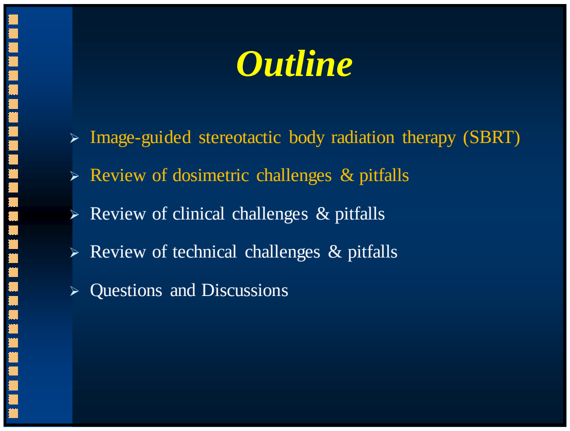
- Image-guided stereotactic body radiation therapy (SBRT)
- Review of dosimetric challenges & pitfalls
- Review of clinical challenges & pitfalls
- Review of technical challenges & pitfalls
- Questions and Discussions



Introduction

Recent technical developments substantially improved SBRT

Making it a useful tool for therapy.



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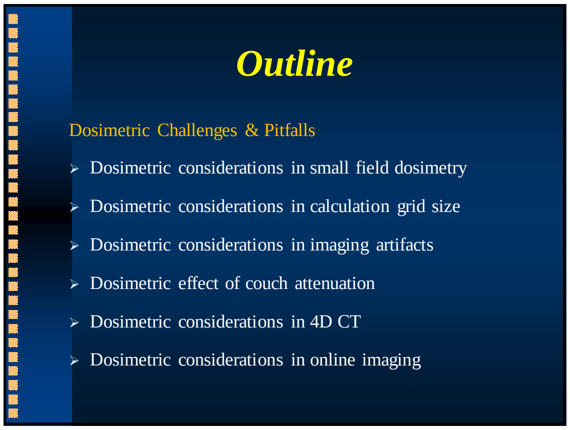
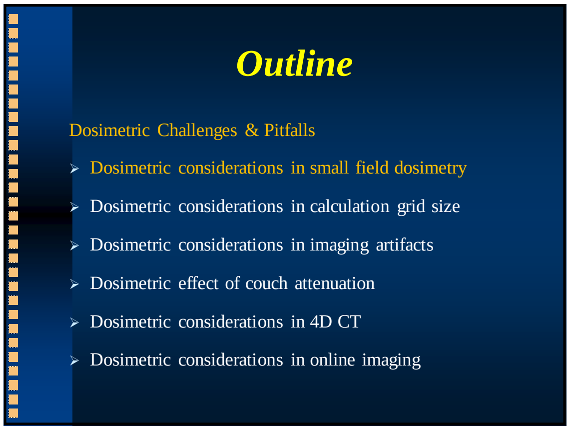


Outline

Dosimetric Challenges & Pitfalls

- Dosimetric considerations in small field dosimetry
- Dosimetric considerations in calculation grid size
- Dosimetric considerations in imaging artifacts
- Dosimetric effect of couch attenuation
- Dosimetric considerations in 4D CT
- Dosimetric considerations in online imaging



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Small Field Dosimetry

- Small field dosimetry (≤ 3cm × 3cm) may have challenges, including non-equilibrium condition and high dose gradients in a small region, especially for small field SBRT
- Small radiation field dosimetry in SBRT has been investigated intensively in the past:

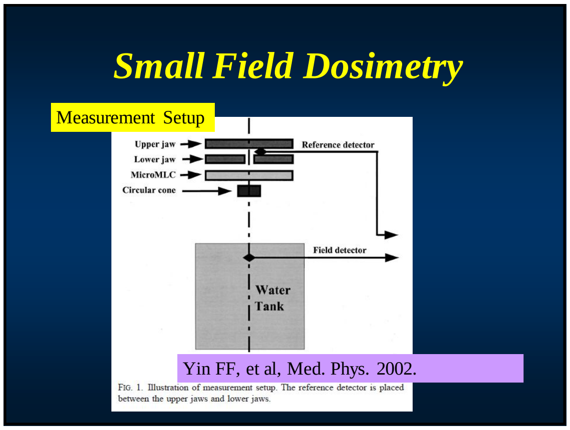
Benedict S, et al, TG101, Med. Phys. 2010.

Kim J, et al, JACMP, 2012

Hrbacek, et al., Int J Radiat Oncol Biol Phys, 2011.

Chang Z, et al, Med. Phys. 2008.

Yin FF, et al, Med. Phys. 2002.

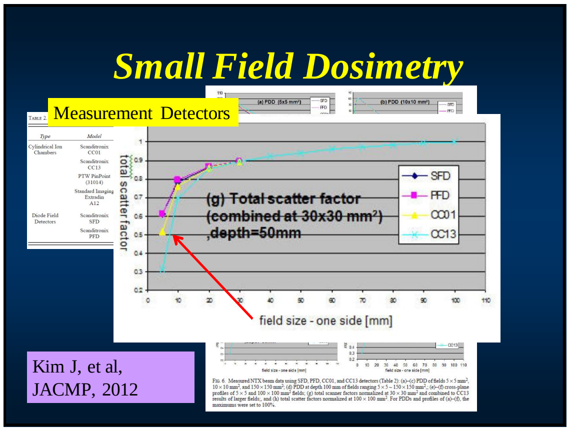


Small Field Dosimetry

Measurement Setup

Yin FF, et al, Med. Phys. 2002.

FIG. 1. Illustration of measurement setup. The reference detector is placed between the upper jaws and lower jaws.



Small Field Dosimetry

Measurement Detectors

TABLE 2.

Type	Model
Cylindrical Ion Chambers	Scanditronix CC01
	Scanditronix CC13
	PTW PinPoint (31014)
	Standard Imaging Extradin A12
Diode Field Detectors	Scanditronix SFD
	Scanditronix PFD

FIG. 6. Measured NTX beam data using SFD, PFD, CC01, and CC13 detectors (Table 2): (a)–(c) PDD of fields 5 × 5 mm², 10 × 10 mm², and 150 × 150 mm²; (d) PDD at depth 100 mm of fields ranging 5 × 5 ~ 150 × 150 mm²,; (e)–(f) cross-plane profiles of 5 × 5 and 100 × 100 mm² fields; (g) total scanner factors normalized at 30 × 30 mm² and combined to CC13 results of larger fields;, and (h) total scatter factors normalized at 100 × 100 mm². For PDDs and profiles of (a)–(f), the maximums were set to 100%.

Kim J, et al,
JACMP, 2012

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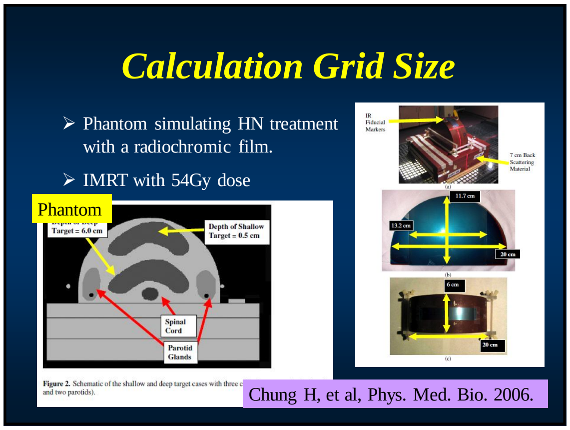
Calculation Grid Size

- Since TPS are used clinically, the uncertainty associated with calculation grid size has been an issue.
- Even today, with 3D and IMRT TPS, dose uncertainty due to grid size is still a concern.
- It is desirable to have an optimal grid size for specific clinical applications

Chung H, et al, Phys. Med. Bio. 2006.

Park J Y, et al, Radiation Oncology, 2014.



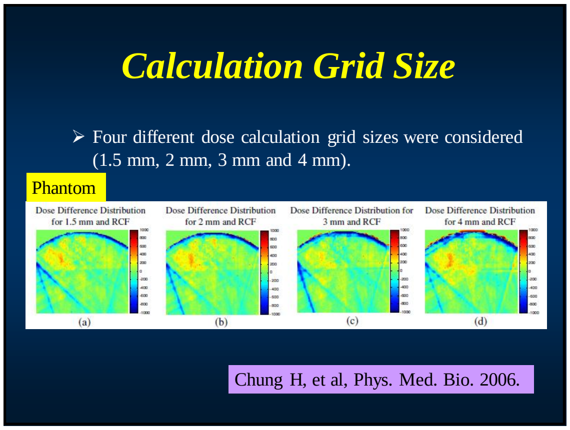
Calculation Grid Size

- Phantom simulating HN treatment with a radiochromic film.
- IMRT with 54Gy dose

Phantom

Figure 2. Schematic of the shallow and deep target cases with three c and two parotids).

Chung H, et al, Phys. Med. Bio. 2006.

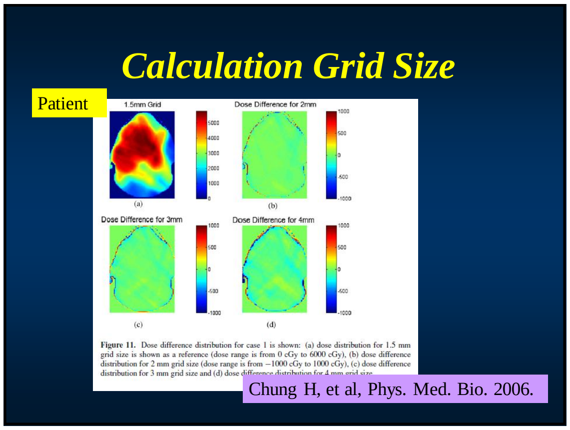


Calculation Grid Size

- Four different dose calculation grid sizes were considered (1.5 mm, 2 mm, 3 mm and 4 mm).

Phantom

Chung H, et al, Phys. Med. Bio. 2006.

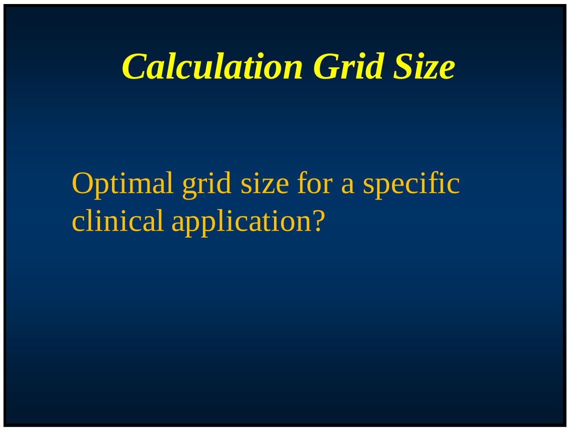


Calculation Grid Size

Patient

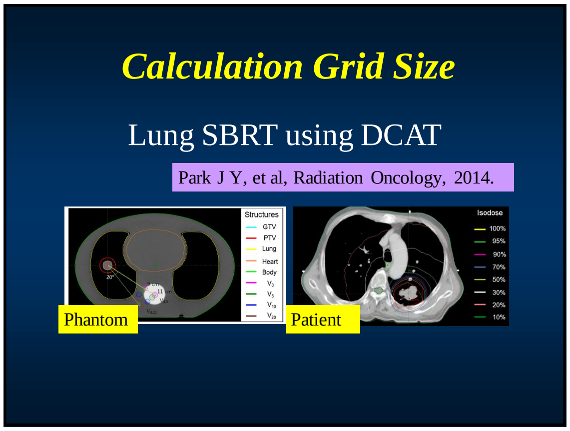
Figure 11. Dose difference distribution for case 1 is shown: (a) dose distribution for 1.5 mm grid size is shown as a reference (dose range is from 0 cGy to 6000 cGy), (b) dose difference distribution for 2 mm grid size (dose range is from −1000 cGy to 1000 cGy), (c) dose difference distribution for 3 mm grid size and (d) dose difference distribution for 4 mm grid size.

Chung H, et al, Phys. Med. Bio. 2006.



Calculation Grid Size

Optimal grid size for a specific clinical application?



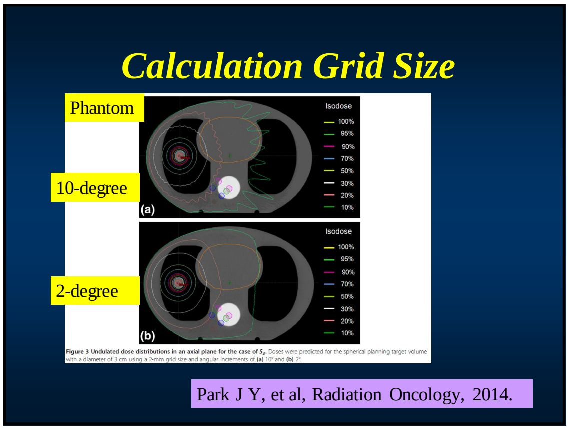
Calculation Grid Size

Lung SBRT using DCAT

Park J Y, et al, Radiation Oncology, 2014.

Phantom

Patient



Calculation Grid Size

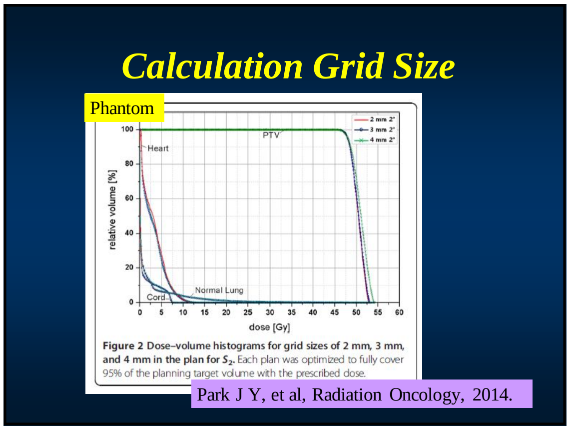
Phantom

10-degree

2-degree

Figure 3 Undulated dose distributions in an axial plane for the case of S_3. Doses were predicted for the spherical planning target volume with a diameter of 3 cm using a 2-mm grid size and angular increments of **(a)** 10° and **(b)** 2°.

Park J Y, et al, Radiation Oncology, 2014.



Calculation Grid Size

Phantom

Figure 2 Dose–volume histograms for grid sizes of 2 mm, 3 mm, and 4 mm in the plan for S_2. Each plan was optimized to fully cover 95% of the planning target volume with the prescribed dose.

Park J Y, et al, Radiation Oncology, 2014.

Calculation Grid Size

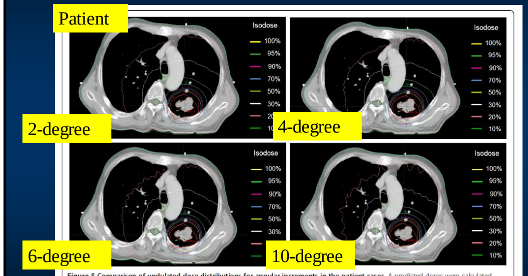


Figure 5 Comparison of undulated dose distributions for angular increments in the patient cases. A predicted doses were calculated using a 2-mm grid size and angular incre

Park J Y, et al, Radiation Oncology, 2014.

Calculation Grid Size

Lung SBRT using DCAT

A parameter set with a 3-mm grid size and a 4° angular increment is found to be appropriate for predicting patient dose distributions with a dose difference below 1% while reducing the computation time by more than half for lung SBRT using DCAT

Park J Y, et al, Radiation Oncology, 2014.

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Imaging Artifacts

- CT simulation plays an important role in RT by providing 3D anatomical image data for treatment planning.
- CT images provide excellent anatomical information to enable organ contour and accurate localization of tumors and organs at risk for treatment planning
- CT images provide CT numbers (Hounsfield unit) to account for attenuation for heterogeneity correction in dose calculation

Wu V, et al, Med. Phys. 2011.

Spadea M, et al, JACMP, 2013.

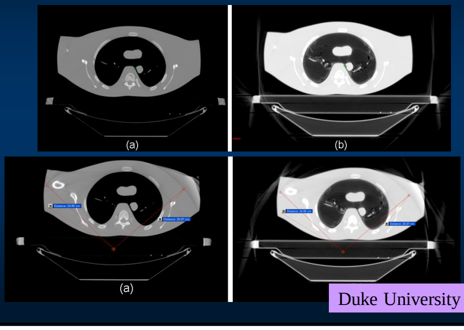
CT-Simulators

Imaging Artifacts

- Conventional CT simulators (~70 cm diameter) will often not fit immobilizers or extra large patient.
- CT simulators with wide-bore of 80–90 cm diameter were designed to address these issues.
- To maintain image quality, some of the wide-bore CT scanners still maintain conventional maximum scan FOV of 50 cm. The reconstructed FOV may be larger than the sFOV, but with truncated projection data and compromised image quality for large objects.

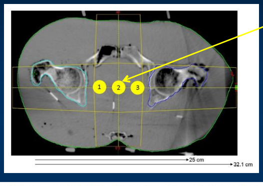
Wu V, et al, Med. Phys. 2011.

Imaging Artifacts



Duke University

Imaging Artifacts



Tumor at 2

Wu V, et al, Med. Phys. 2011.

TABLE VII. Treatment planning results for VMAT technique in pelvis phantom. The percent differences in dose calculation of the target dose (TD) at the iso-center point and the 3D mean target dose relative to the bore center image (position 1 in Fig. 1) are presented. 6 MV data for the off-center image (positions 3) and with and without heterogeneity correction are included.

	Image position 3			
	Heterogeneity off		Heterogeneity on	
Tumor position	Isocenter TD (%)	3D mean TD (%)	Isocenter TD (%)	3D mean TD (%)
2	−0.4	−0.2	0.8	0.9

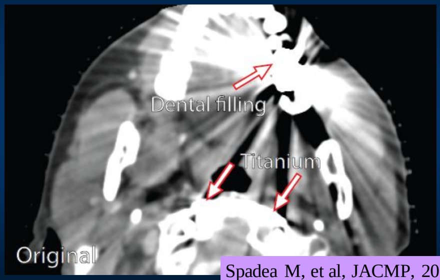
Imaging Artifacts

- Metal artifacts in computed tomography (CT) appear as dark and bright streaks arising from implants.
- Metal artifacts obscure important information regarding OAR and tumor.
- Errors in CT numbers is a concern in RT treatment planning.

Spadea M, et al, JACMP, 2013.

Verburg J, et al, Phys. Med. Bio. 2012

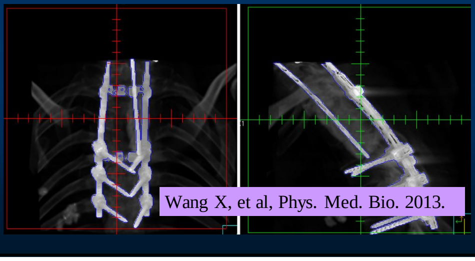
Imaging Artifacts



Spadea M, et al, JACMP, 2013.

Imaging Artifacts

- Spine SBRT is frequently delivered to patients with spinal hardware such as titanium rods.

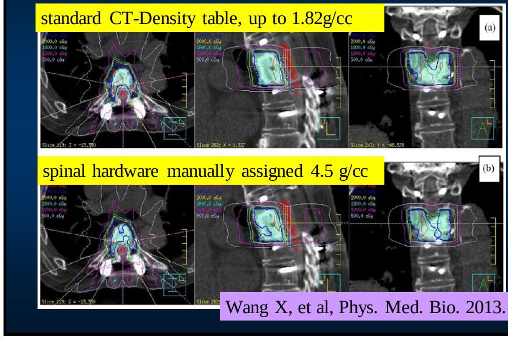


Wang X, et al, Phys. Med. Bio. 2013.

Imaging Artifacts

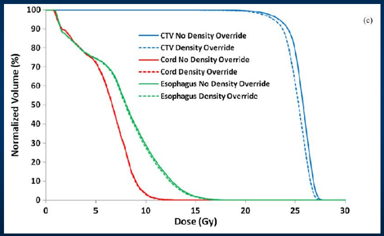
standard CT-Density table, up to 1.82g/cc

spinal hardware manually assigned 4.5 g/cc



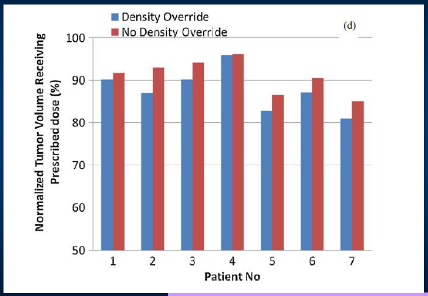
Wang X, et al, Phys. Med. Bio. 2013.

Imaging Artifacts



Wang X, et al, Phys. Med. Bio. 2013.

Imaging Artifacts



Wang X, et al, Phys. Med. Bio. 2013.

Imaging Artifacts

- Metal artifacts can introduce dosimetric errors in spinal SBRT treatment planning.
- Using a CT–density table with a maximum density of 1.82 g/cc is a practical way to reduce the dosimetric error from the artifacts, but could underestimate the dose perturbation.
- When a significant amount of hardware in the beam path, to manually override the density of titanium hardware to 4.5 g/cc in dose calculation is recommended.

Wang X, et al, Phys. Med. Bio. 2013.

Outline

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Couch Attenuation

- In RT, treatment planning is to be dosimetrically and geometrically accurate.
- To achieve the best possible treatment accuracy, the couch should be stiff in order to avoid any sagging effects of the table.
- Couch should not create any imaging artifacts that might decrease the setup accuracy of the treatment.
- However, existence of couch does attenuate radiation beam.

Seppälä J, et al, JACMP, 2011.

Vanetti M, et al, Phys. Med. Bio. 2009

Pulliam K, et al, Phys. Med. Bio. 2011

Couch Attenuation

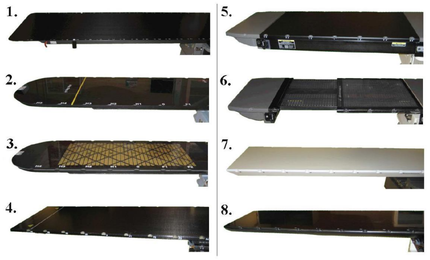
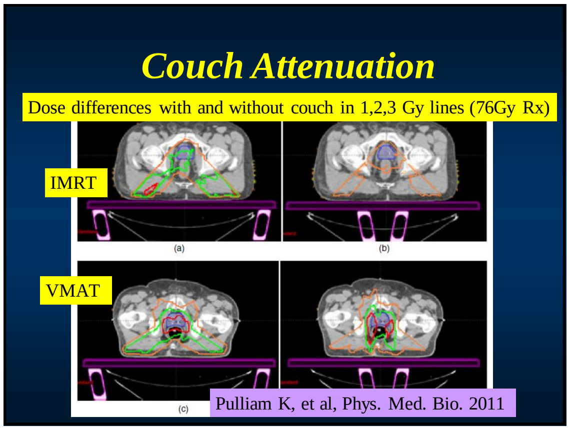


Fig. 1. Couch inserts studied: 1) BrainLAB imaging couch top, 2) Qfix kVue Standard, 3) Qfix kVue DoseMax, 4) MEDTEC model MT-IL 3303, 5) universal sandwich panel, 6) Varian grid insert, 7) DIGNITY AirPlate, 8) Varian Exact IGRT couchtop.

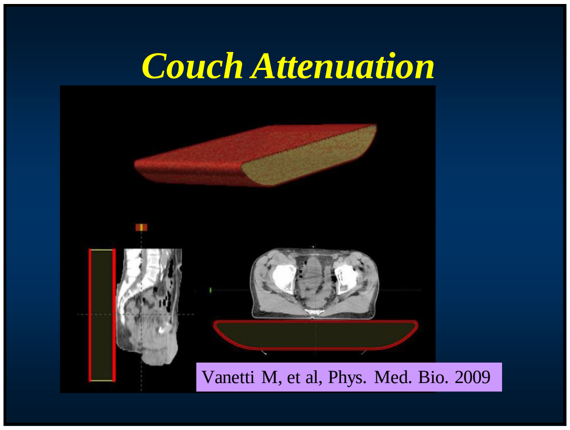
Seppälä J, et al, JACMP, 2011.



Couch Attenuation

Dose differences with and without couch in 1,2,3 Gy lines (76Gy Rx)

Pulliam K, et al, Phys. Med. Bio. 2011



Couch Attenuation

Vanetti M, et al, Phys. Med. Bio. 2009

Couch Attenuation

Six prostate patients selected for the study, with RA. Each patient, two targets were defined, PTVI (70 Gy) including prostate gland and PTVII (50 Gy)including seminal vesicles and areas at risk.

Table 2. Difference between plans calculated for the thick couch model and for the no couch model.

Organ	6 MV Mean (Gy)	15 MV Mean (Gy)
PTVI	1.3 ± 0.3	0.9 ± 0.2
PTVII–PTVI	0.7 ± 0.2	0.5 ± 0.1
Rectum	0.6 ± 0.2	0.4 ± 0.1
Bladder	0.6 ± 0.2	0.4 ± 0.1
Femurs	0.04 ± 0.01	0.03 ± 0.01
Healthy tissue	0.2 ± 0.1	0.1 ± 0.1

Vanetti M, et al, Phys. Med. Bio. 2009

Couch Attenuation

- There are significant and potential clinical impact discrepancies at the level of the target volumes if calculations are performed without couch and delivery is with couch .
- The effect is particularly relevant at low energy (6 MV in this case).

Vanetti M, et al, Phys. Med. Bio. 2009

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Dose Calculation with 4D CT

- 4DCT allows physicians to take into account the tumor motion when delineating target volumes.
- Remains controversial how to accurately calculate and verify the planned dose compared to the delivered dose for a continuously moving target with surrounding critical organs.
- Recently, dose is calculated based on spatial and temporal information of tumor and normal tissue derived from 4DCT.

Benedict S, et al, TG101, Med. Phys. 2010.

Tian Y, et al, Phys. Med. Bio. 2012.

Dose Calculation with 4D CT

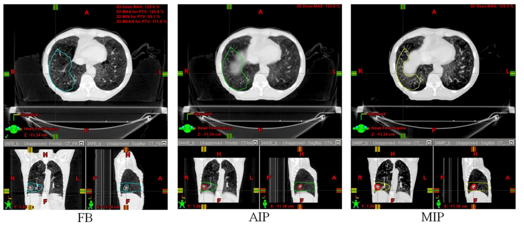

Fig. 1. Axial, coronal, and sagittal FB (left), AIP (middle), and MIP (right) images for a patient whose PTV (inner contours in coronal and sagittal images) was near the diaphragm. Absolute volume of lung minus PTV receiving greater than 5 Gy (Abs. V5) in both AIP plans (outer contours) and MIP plans (outer contour) were also showed.

Tian Y, et al, Phys. Med. Bio. 2012.

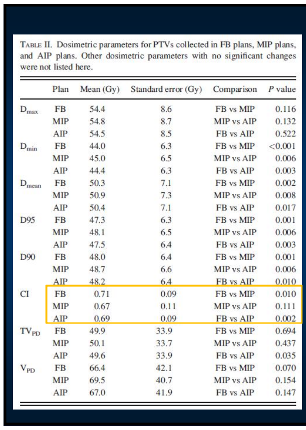

Table II. Dosimetric parameters for PTVs collected in FB plans, MIP plans, and AIP plans. Other dosimetric parameters with no significant changes were not listed here.

	Plan	Mean (Gy)	Standard error (Gy)	Comparison	*P* value
D_{max}	FB	54.4	8.6	FB vs MIP	0.116
	MIP	54.8	8.7	MIP vs AIP	0.132
	AIP	54.5	8.5	FB vs AIP	0.522
D_{min}	FB	44.0	6.3	FB vs MIP	<0.001
	MIP	45.0	6.5	MIP vs AIP	0.006
	AIP	44.4	6.3	FB vs AIP	0.003
D_{mean}	FB	50.3	7.1	FB vs MIP	0.002
	MIP	50.9	7.3	MIP vs AIP	0.008
	AIP	50.4	7.1	FB vs AIP	0.017
D95	FB	47.3	6.3	FB vs MIP	0.001
	MIP	48.1	6.5	MIP vs AIP	0.006
	AIP	47.5	6.4	FB vs AIP	0.003
D90	FB	48.0	6.4	FB vs MIP	0.001
	MIP	48.7	6.6	MIP vs AIP	0.006
	AIP	48.2	6.4	FB vs AIP	0.010
CI	FB	0.71	0.09	FB vs MIP	0.010
	MIP	0.67	0.11	MIP vs AIP	0.111
	AIP	0.69	0.09	FB vs AIP	0.002
TV_{PD}	FB	49.9	33.9	FB vs MIP	0.694
	MIP	50.1	33.7	MIP vs AIP	0.437
	AIP	49.6	33.9	FB vs AIP	0.035
V_{PD}	FB	66.4	42.1	FB vs MIP	0.070
	MIP	69.5	40.7	MIP vs AIP	0.154
	AIP	67.0	41.9	FB vs AIP	0.147

20 patients with lung lesions were evaluated for this study.

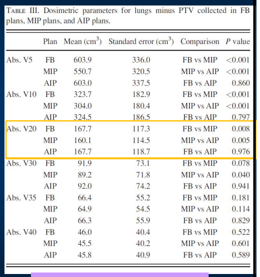

Table III. Dosimetric parameters for lungs minus PTV collected in FB plans, MIP plans, and AIP plans.

	Plan	Mean (cm^3)	Standard error (cm^3)	Comparison	*P* value
Abs. V5	FB	603.9	336.0	FB vs MIP	<0.001
	MIP	550.7	320.5	MIP vs AIP	<0.001
	AIP	603.0	337.5	FB vs AIP	0.860
Abs. V10	FB	323.7	182.9	FB vs MIP	<0.001
	MIP	304.0	180.4	MIP vs AIP	<0.001
	AIP	324.5	186.5	FB vs AIP	0.797
Abs. V20	FB	167.7	117.3	FB vs MIP	0.008
	MIP	160.1	114.5	MIP vs AIP	0.005
	AIP	167.7	118.7	FB vs AIP	0.976
Abs. V30	FB	91.9	73.1	FB vs MIP	0.078
	MIP	89.2	71.8	MIP vs AIP	0.040
	AIP	92.0	74.2	FB vs AIP	0.941
Abs. V35	FB	66.4	55.2	FB vs MIP	0.181
	MIP	64.9	54.5	MIP vs AIP	0.114
	AIP	66.3	55.9	FB vs AIP	0.829
Abs. V40	FB	46.0	40.4	FB vs MIP	0.522
	MIP	45.5	40.2	MIP vs AIP	0.601
	AIP	45.8	40.9	FB vs AIP	0.589

Tian Y, et al, Phys. Med. Bio. 2012.

Dose Calculation with 4D CT

- No significant differences in dosimetric parameters for both PTVs and lung between FB plans and AIP plans. AIP datasets are more suitable because AIP datasets were less prone to artifacts.
- MIP plans tend to provide significantly smaller low-dose region in lung compared to AIP plans. However, decrease was mainly caused by change of lung volume. So, MIP plans tend to be underestimated or overestimated when lesions are close to denser tissues.
- AIP seems favorable for planning and dose calculation for lung SBRT

Tian Y, et al, Phys. Med. Bio. 2012.

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Imaging Dose

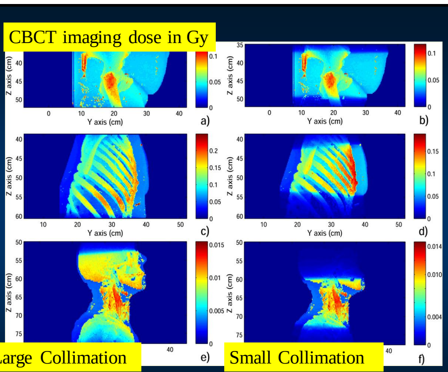
- Image guidance has emerged for patient positioning and target localization in radiotherapy.
- Imaging dose received as part of treatment has long been regarded as negligible.
- Introduction of more intensive imaging procedures for IGRT now urges clinician to evaluate therapeutic and imaging doses in a more balanced manner.

Murphy M, et al, TG75, Med. Phys. 2007.

Ding G, et al., Int J Radiat Oncol Biol Phys, 2009.

Spezi E, et al., Int J Radiat Oncol Biol Phys, 2011.

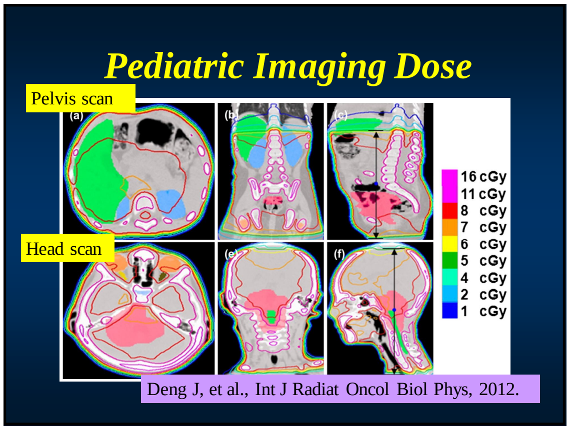
CBCT imaging dose in Gy



Large Collimation

Small Collimation

Spezi E, et al., Int J Radiat Oncol Biol Phys, 2011.

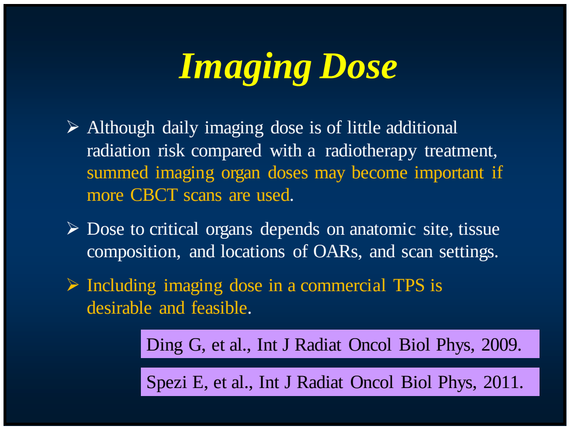


Pediatric Imaging Dose

Pelvis scan

Head scan

Deng J, et al., Int J Radiat Oncol Biol Phys, 2012.

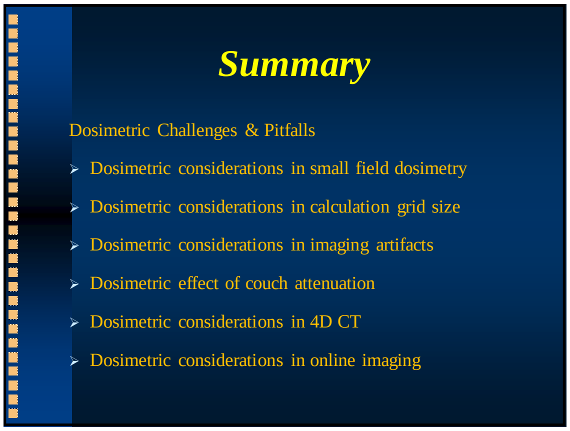


Imaging Dose

- Although daily imaging dose is of little additional radiation risk compared with a radiotherapy treatment, summed imaging organ doses may become important if more CBCT scans are used.
- Dose to critical organs depends on anatomic site, tissue composition, and locations of OARs, and scan settings.
- Including imaging dose in a commercial TPS is desirable and feasible.

Ding G, et al., Int J Radiat Oncol Biol Phys, 2009.

Spezi E, et al., Int J Radiat Oncol Biol Phys, 2011.



Summary

Dosimetric Challenges & Pitfalls

- Dosimetric considerations in small field dosimetry
- Dosimetric considerations in calculation grid size
- Dosimetric considerations in imaging artifacts
- Dosimetric effect of couch attenuation
- Dosimetric considerations in 4D CT
- Dosimetric considerations in online imaging