Università degli Studi
di Roma
Tor Vergata

La IGRT: aspetti radiobiologici e radioprotezionistici nella pratica clinica

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PTV

kV-CBCT

kV x-ray source and solid state flat panel detector.
Source/detector system mounted to the gantry arm for rotation around the patient.
Full-fan: the system is in its central position (small FOV).
Half-fan (offset): the detector is shifted off its central position such that only a part of the object is viewed at any one projection (large FOV).

Dosimeters - anthropomorphic phantom

placed inside the phantom to measure the the absorbed dose.

MV Portal image (PI)

Film or electronic portal imaging device (EPID).

Dosimeters - in vivo measurements

kV radiography

placed on the surface of the patient and inside (rectum, vagina, oral cavity) to measure the the absorbed dose.

kV x-ray source and solid state flat panel detector.
1. Dual sources and panel detector mounted to the floor and ceiling of treatment room.
2. Source/detector system mounted to the gantry arm for rotation around the patient.

Helical Tomotherapy

Similar to helical CT imaging in helical tomotherapy
there is a simultaneous motion of the couch and gantry (MV-Linac source)

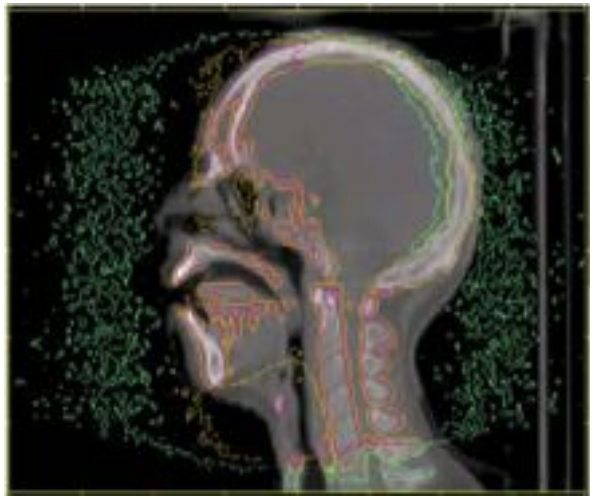
Monte Carlo simulation

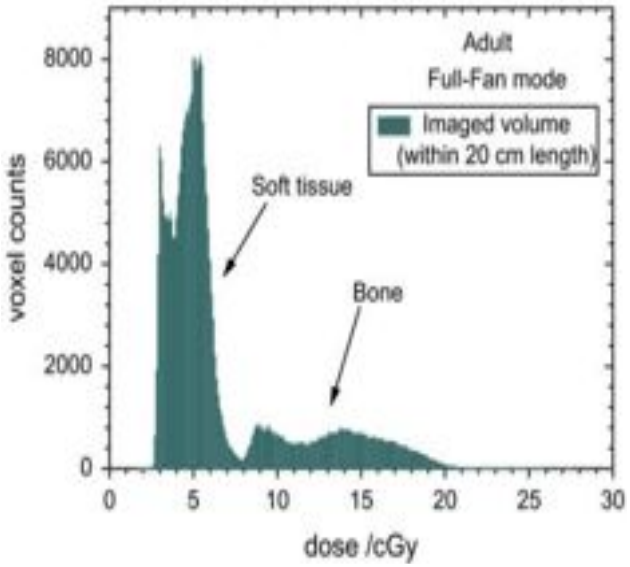
An x-ray source used in a specific image guidance procedure can be simulated accurately by using Monte Carlo techniques.

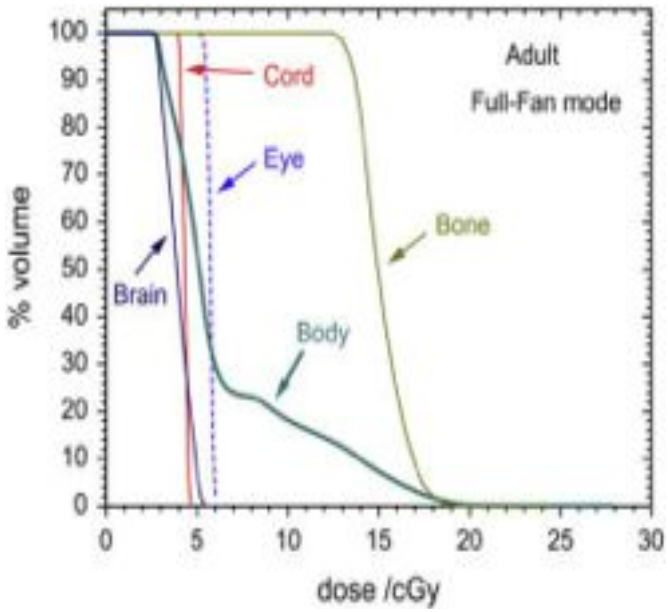
This method is capable of calculating patient dose resulting from an image guidance procedure.

MV-CBCT

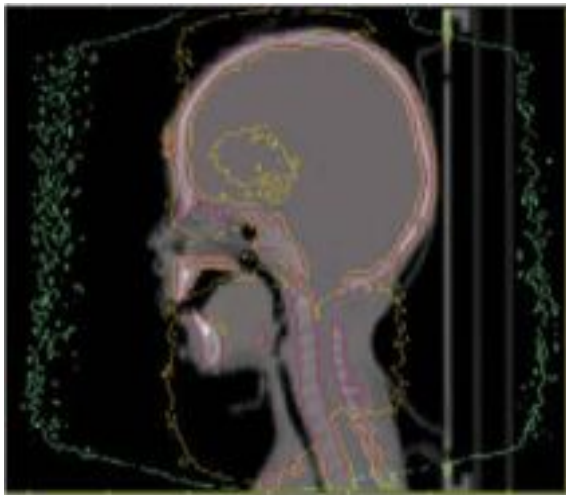
MV-Linac source and solid state flat panel detector.
Source/detector system rotate around the patient.

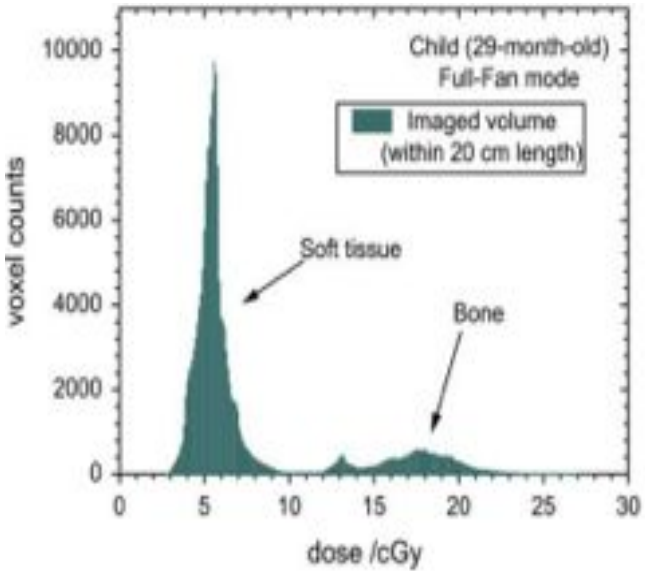


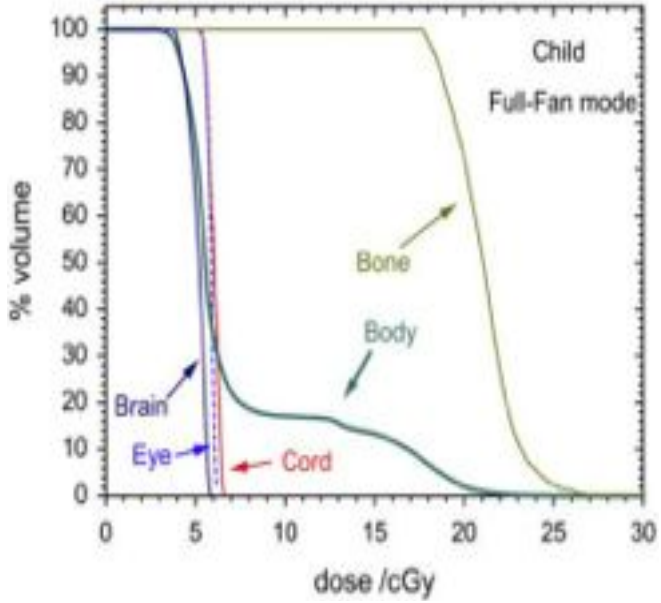




[125 kV, 80 mA, 25 ms]. Monte Carlo-calculated dose distributions from kV CBCT of an adult and a child

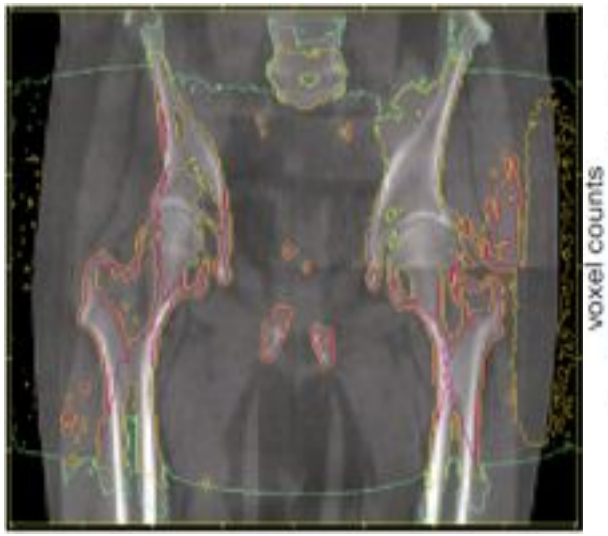


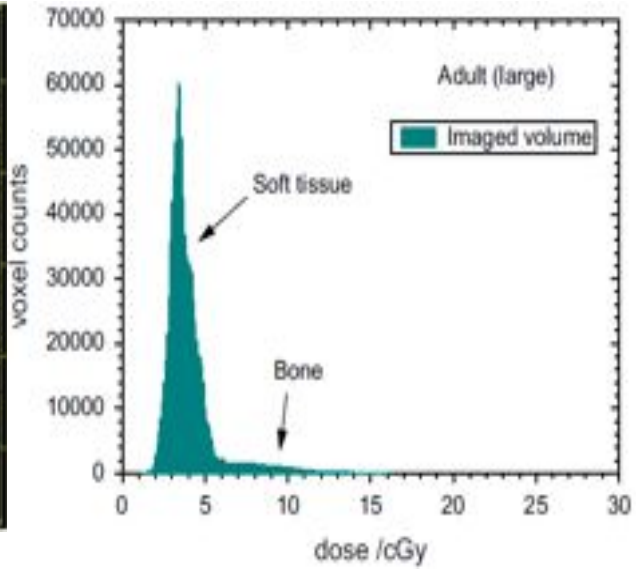


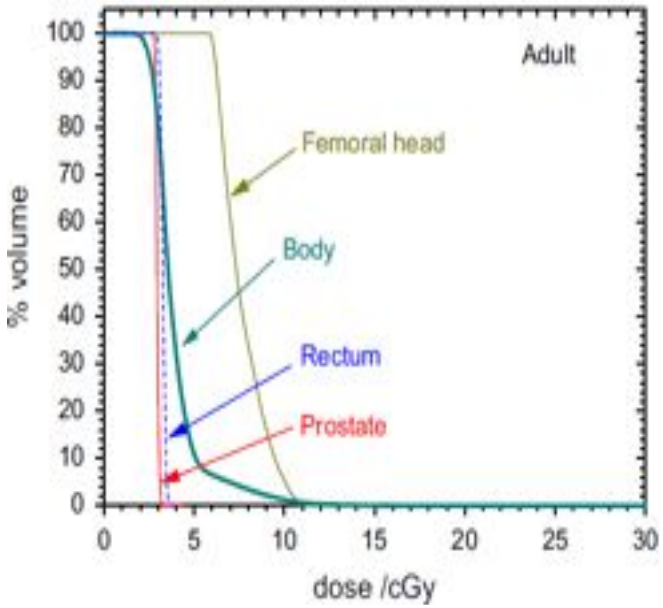


The smaller the patient size the larger the dose received

Ding, IJROBP 2009







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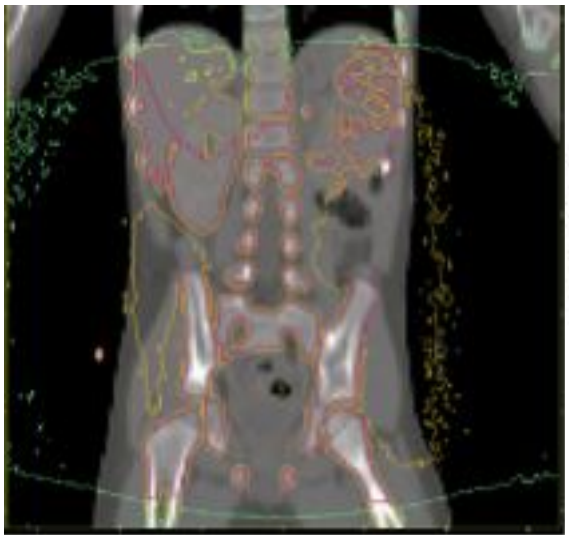
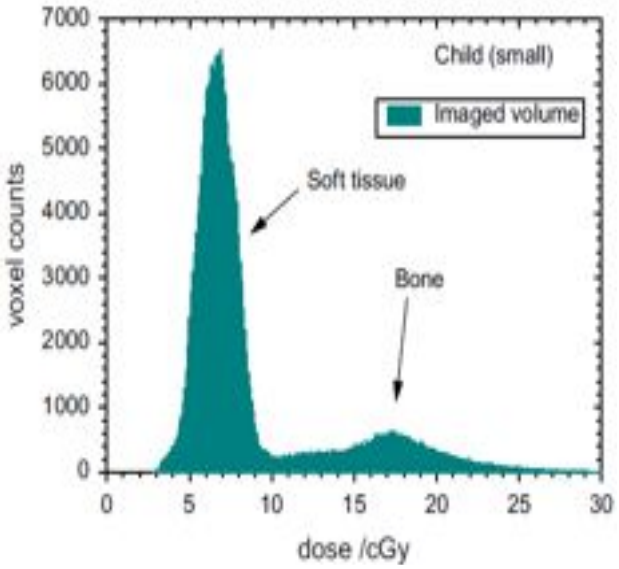
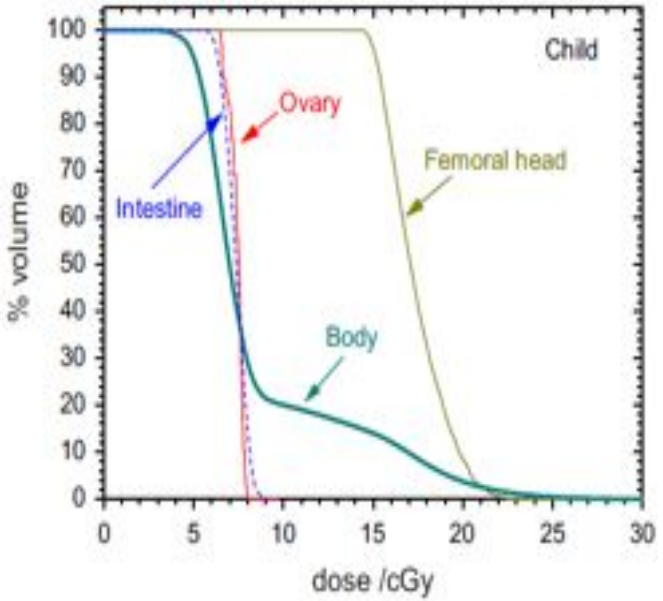






The smaller the patient size the larger the dose received

Ding, IJROBP 2009

Dose to organs (cGy)	Head and neck (adult)	Head and neck (pediatric)	Abdominal (large adult)	Abdominal (pediatric)	Chest (adult)
Eye	7–8 5–6 (full-fan)	7–8 5–6 (full-fan)			
Brain	3.5–5.5 2.4–5.4 (full-fan)	4.8–6.7 3.8–5.8 (full-fan)			
Cord	4.5–5.5 4–4.5 (full-fan)	6–7 5.5–6.5 (full-fan)			3–4.5
Thyroid	6–9 6–8 (full-fan)	7–10 7–9 (full-fan)			
Prostate			3	7–8	
Ovary			3–4	7–8	
Intestine			3–4	6–8	
Lung					3–6
Heart					3–6
Soft tissue (including skin)	3–9 3–7 (full-fan)	4–10 3–9 (full-fan)	1–5	3–9	2–9
Bone	11–28 8–21 (full-fan)	14–29 13–24 (full-fan)	6–11	9–29	9–24

Monte Carlo algorithm calculates radiation dose to each organ received by patients resulting from a kV CBCT scan based on individualized patient volumetric images

Daily CBCT for 30 fractions:

Eye ~ 180 cGy

Cord ~ 150 cGy

Thyroid ~ 240 cGy

Gonads ~ 120 cGy

Skin ~ 180 cGy

Rectum (adult) ~ 100 cGy

Bone ~ 720 cGy (pediatric)

Organ doses are 1-9 cGy to soft tissues and 6-29 cGy to bones depending on patient size and site of the scan

The dose received by pediatrics is almost doubled compared to adults

Ding, IJROBP 2009

Female Rando anthropomorphic phantom **At least 2 TLDs for each organ**

Site of scan	Scanning mode	Field of view	Reconstruction matrix	Slice thickness	Longitudinal extent
Head and neck	Full fan	24 cm	512 × 512	2.5 mm	15.5 cm
Chest	Half fan	40 cm	512 × 512	2.5 mm	13.7 cm
Pelvis	Half fan	40 cm	512 × 512	2.5 mm	13.7 cm

$$D_{eff} = \sum_T w_T \sum_R w_R D_{T,R}$$

W_T tissue weighting factor for tissue T
W_R radiation weighting factor for radiation R
$D_{T,R}$ mean adsorbed dose to an organ for radiation type R

Head (daily CBCT for 30 fr):

Lens: 180 cGy

Cord: 120 cGy

Skin (irradiated site): 180 cGy

Skin (whole body): 30 cGy

Thyroid: 330 cGy

Bone: 180 cGy

Effect. dose: 10 mSv x 1 CBCT

Chest (daily CBCT for 30 fr):

Lung: 150 cGy

Cord: 100 cGy

Skin (irradiated site): 180 cGy

Skin (whole body): 90 cGy

Breast: 150 cGy

Heart: 210 cGy

Liver: 120 cGy

Bone: 210 cGy

Effect. dose: 23 mSv x 1 CBCT

Pelvis (daily CBCT for 30 fr):

Rectum: 120 cGy

Small intestine: 180 cGy

Skin (irradiated site): 165 cGy

Skin (whole body): 90 cGy

Gonads: 120 cGy

Liver: 120 cGy

Kidney: 54 cGy

Bone: 120 cGy

Effect. dose: 23 mSv x 1 CBCT

Kan, IJROBP 2008

standard

Tissue/organ	Mean absorbed dose per scan (cGy)		
	Head scan	Chest scan	Pelvis scan
Gonads (ovary)	0.02 ± 0.008	0.06 ± 0.011	3.75 ± 0.309
Bone marrow (whole body)	0.80 ± 2.91	3.04 ± 3.23	2.03 ± 2.061
Bone marrow (irradiated site)	5.89 ± 0.78	6.89 ± 0.46	4.22 ± 0.330
Colon	0.05 ± 0.018	0.35 ± 0.067	5.43 ± 0.180
Lung	0.57 ± 0.31	5.34 ± 1.77	0.08 ± 0.024
Thyroid	11.08 ± 1.19	0.79 ± 0.07	0.04 ± 0.008
Skin (whole body)	0.92 ± 3.27	2.77 ± 3.10	2.59 ± 2.67
Skin (irradiated site)	6.66 ± 1.19	6.44 ± 0.95	5.43 ± 1.37
Bone surface	0.80 ± 2.91	3.04 ± 3.23	2.03 ± 2.061
Remainder organ			
Adrenals	0.05 ± 0.006	1.22 ± 0.078	1.05 ± 0.074
Brain	4.80 ± 0.687	0.08 ± 0.017	0.03 ± 0.011
Upper large intestine	0.05 ± 0.007	1.41 ± 0.012	1.17 ± 0.064
Small intestine	0.04 ± 0.009	0.31 ± 0.019	6.23 ± 0.287
Kidney	0.05 ± 0.011	0.81 ± 0.048	1.72 ± 0.133
Muscle	0.08 ± 2.91	3.04 ± 3.23	2.03 ± 2.061
Pancreas	0.04 ± 0.005	0.83 ± 0.014	1.90 ± 0.121
Spleen	0.06 ± 0.009	2.16 ± 0.175	0.67 ± 0.038
Thymus	11.05 ± 1.185	0.79 ± 0.07	0.04 ± 0.007
Uterus	0.02 ± 0.008	0.06 ± 0.008	3.80 ± 0.272
Other critical organ			
Rectum	0.02 ± 0.006	0.05 ± 0.008	3.99 ± 0.274
Lens	6.22 ± 0.49	0.13 ± 0.014	0.04 ± 0.018
Heart	0.20 ± 0.037	6.72 ± 0.55	0.17 ± 0.025
Spinal cord	4.08 ± 3.62	3.58 ± 3.23	0.11 ± 0.064
Effective dose (mSv)	10.26 ± 0.46	23.56 ± 0.35	22.72 ± 0.29

low-dose

Tissue/organ	Mean absorbed dose per scan (cGy)		
	Head scan	Chest scan	Pelvis scan
Gonads (ovary)	0.01 ± 0.005	0.02 ± 0.005	0.84 ± 0.075
Bone marrow (whole body)	0.17 ± 0.678	0.72 ± 0.899	0.47 ± 0.552
Bone marrow (irradiated site)	1.20 ± 0.023	1.65 ± 0.126	0.98 ± 0.077
Colon	0.02 ± 0.009	0.08 ± 0.017	1.18 ± 0.080
Lung	0.12 ± 0.064	1.17 ± 0.276	0.02 ± 0.006
Thyroid	2.10 ± 0.141	0.18 ± 0.006	0.01 ± 0.001
Skin (whole body)	0.15 ± 0.750	0.60 ± 0.773	0.59 ± 0.693
Skin (irradiated site)	1.34 ± 0.248	1.40 ± 0.292	1.23 ± 0.384
Bone surface	0.17 ± 0.678	0.72 ± 0.899	0.47 ± 0.552
Remainder organ			
Adrenals	0.02 ± 0.008	0.28 ± 0.021	0.25 ± 0.033
Brain	1.01 ± 0.138	0.02 ± 0.007	0.01 ± 0.004
Upper large intestine	0.01 ± 0.002	0.31 ± 0.004	0.28 ± 0.015
Small intestine	0.01 ± 0.009	0.08 ± 0.009	1.36 ± 0.052
Kidney	0.02 ± 0.007	0.18 ± 0.006	0.41 ± 0.032
Muscle	0.17 ± 0.678	0.72 ± 0.899	0.47 ± 0.552
Pancreas	0.01 ± 0.003	0.18 ± 0.010	0.45 ± 0.009
Spleen	0.02 ± 0.007	0.49 ± 0.025	0.15 ± 0.006
Thymus	2.10 ± 0.141	0.18 ± 0.006	0.01 ± 0.001
Uterus	0.01 ± 0.288	0.02 ± 0.003	0.85 ± 0.080
Other critical organ			
Rectum	0.01 ± 0.288	0.01 ± 0.006	0.88 ± 0.076
Lens	1.30 ± 0.309	0.03 ± 0.007	0.02 ± 0.005
Heart	0.04 ± 0.013	1.52 ± 0.104	0.04 ± 0.006
Spinal cord	0.875 ± 0.781	0.77 ± 0.826	0.02 ± 0.014
Effective dose (mSv)	2.10 ± 0.08	5.23 ± 0.122	4.89 ± 0.163

In-field organ dose reduction: 1/5 of those measured for the standard mode

Effective dose reduction: 1/5 of those calculated for the standard mode

Kan, IJROBP 2008

Female Rando anthropomorphic phantom

A total of 154 TLDs used for measurements

Organ/tissue	New (Version 1.4.13) Head Absorbed dose (mGy)	Old (Version 1.4.11) Head Absorbed dose (mGy)	New (Version 1.4.13) Pelvis Absorbed dose (mGy)	Old (Version 1.4.11) Pelvis Absorbed dose (mGy)	(Version 1.4.13) Pelvis	Old (Version 1.4.11) Pelvis
Gonad	0.04 ± 0.00	0.20 ± 0.02	11.66 ± 0.30	22.11 ± 0.47	125	125
Bone marrow	0.02 ± 0.00	0.08 ± 0.01	14.59 ± 0.17	28.68 ± 0.70	80	80
Colon	0.05 ± 0.00	0.22 ± 0.02	6.45 ± 0.11	12.50 ± 0.22	13	25
Lung	0.51 ± 0.00	2.56 ± 0.07	0.25 ± 0.01	0.50 ± 0.01	360	360
Stomach	0.07 ± 0.00	0.43 ± 0.02	1.35 ± 0.03	2.60 ± 0.06	655	655
Bladder	0.02 ± 0.00	0.13 ± 0.02	30.37 ± 0.54	59.35 ± 1.27	680	1,300
Breast	0.18 ± 0.01	1.35 ± 0.08	0.34 ± 0.01	0.70 ± 0.03	Half	Half
Liver	0.08 ± 0.00	0.43 ± 0.01	1.41 ± 0.02	2.70 ± 0.10	384×384	512×512
Esophagus	0.90 ± 0.02	3.82 ± 0.29	0.17 ± 0.01	0.36 ± 0.01		
Thyroid	13.85 ± 0.16	93.39 ± 3.90	0.11 ± 0.00	0.22 ± 0.00		
Skin	4.46 ± 0.04	16.84 ± 0.64	10.54 ± 0.29	20.56 ± 1.05		
Bone surface	0.02 ± 0.00	0.09 ± 0.01	20.83 ± 0.25	40.76 ± 1.01		
Brain	4.97 ± 0.09	20.32 ± 0.47	0.04 ± 0.00	0.08 ± 0.00		
Salivary gland	6.00 ± 0.12	13.00 ± 0.26	0.20 ± 0.01	0.25 ± 0.02		
Remainder organ						
Adrenals	0.07 ± 0.00	0.34 ± 0.02	2.03 ± 0.05	3.92 ± 0.06		
Small intestine	0.05 ± 0.00	0.28 ± 0.01	3.63 ± 0.07	6.93 ± 0.20		
Kidney	0.07 ± 0.00	0.29 ± 0.02	2.85 ± 0.06	5.46 ± 0.10		
Muscle	14.11 ± 0.13	27.01 ± 4.82	12.77 ± 0.29	25.31 ± 0.58		
Pancreas	0.07 ± 0.00	0.42 ± 0.02	1.45 ± 0.02	2.81 ± 0.05		
Spleen	0.09 ± 0.00	0.43 ± 0.03	1.39 ± 0.06	2.65 ± 0.15		
Thymus	2.68 ± 0.03	12.41 ± 0.66	0.11 ± 0.00	0.22 ± 0.00		
Lens	3.79 ± 0.07	59.38 ± 0.84	0.08 ± 0.00	0.15 ± 0.00		
Retina	9.01 ± 0.17	69.52 ± 0.99	0.06 ± 0.00	0.11 ± 0.00		
Optic nerve	10.48 ± 0.19	68.24 ± 0.85	0.05 ± 0.00	0.09 ± 0.00		
Optic chiasma	15.92 ± 0.21	59.46 ± 0.59	0.05 ± 0.00	0.09 ± 0.00		
Pituitary gland	13.41 ± 0.17	50.64 ± 0.51	0.05 ± 0.00	0.09 ± 0.00		
Brainstem	17.87 ± 0.29	57.17 ± 1.13	0.06 ± 0.00	0.10 ± 0.00		
Spinal cord	14.40 ± 0.12	39.94 ± 0.90	7.08 ± 0.21	13.82 ± 0.00		
Rectum	0.03 ± 0.00	0.11 ± 0.01	22.75 ± 0.55	46.48 ± 1.07		
Heart	0.26 ± 0.00	1.54 ± 0.05	0.33 ± 0.00	0.66 ± 0.02		
Total effective dose (mSv)	1.65 ± 0.01	9.39 ± 0.16	8.21 ± 0.04	16.00 ± 0.11		

New version.

Daily CBCT for 30 fr:

Lens: 12 cGy

Cord: 42 cGy

Thyroid: 40 cGy

Skin: 12 cGy (Head)/30 cGy (Pelvis)

Gonads: 30 cGy

Bone: 60 cGy

1.6 mSv x CBCT (Head)

8.2 mSv x CBCT (Pelvis)

Cheng, IJROBP 2011

Ding, IJROBP 2009. **OLD**

Daily kV-CBCT for 30 fr:

Lens: 180 cGy

Cord: 150 cGy

Thyroid: 240 cGy

Skin: 180 cGy

Gonads: 120 cGy

Bone: 330 cGy

Cheng, IJROBP 2011. **NEW**

Daily kV-CBCT for 30 fr:

Lens: 12 cGy

Cord: 42 cGy

Thyroid: 40 cGy

Skin: 30 cGy

Gonads: 30 cGy

Bone: 60 cGy

Kan, IJROBP 2008. **MULTISLICE CT**

30 fan beam CT (16-multislice):

Lens: 54 cGy

Cord: 50 cGy

Thyroid: 120 cGy

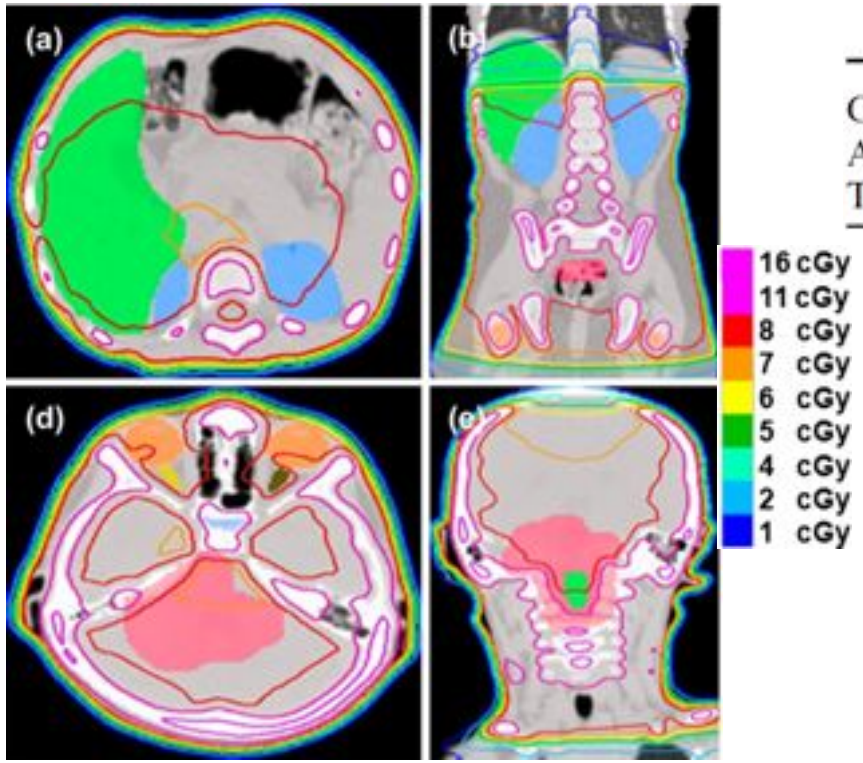
Skin: 120 cGy

Gonads: 60 cGy

Bone: 80 cGy

NEW GENERATION: in-field organ dose reduction

CBCT better than fan beam CT for in-field organ dose reduction



Characteristic	Patient 1	Patient 2	Patient 3	Patient 4
Gender	Male	Female	Male	Female
Age at treatment (y)	6	2.75	3.75	6
Treatment site	Abdomen	Abdomen	Brain	Brain

daily CBCT for 30 fr:

Lens: 69 cGy

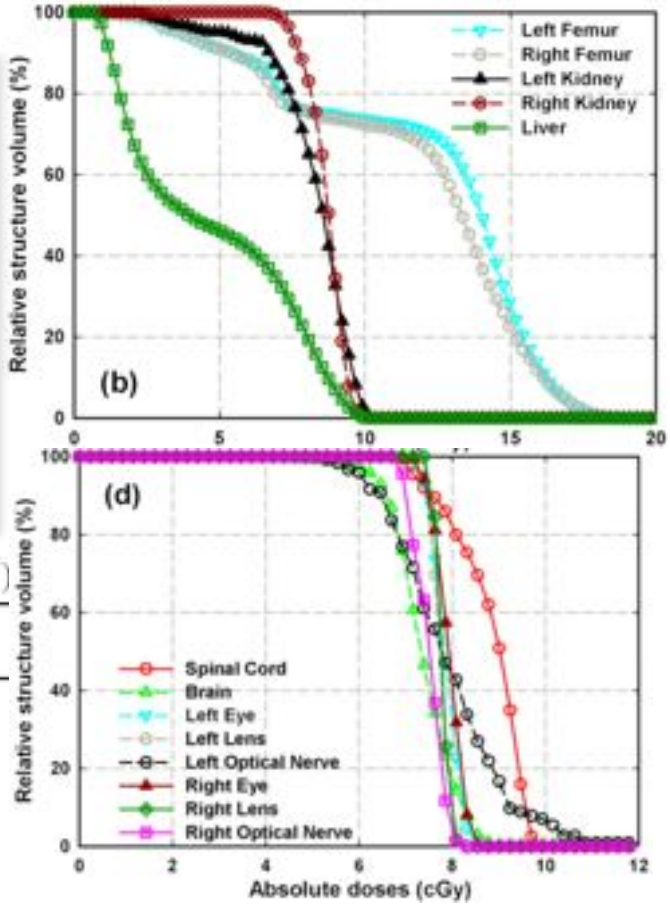
Cord: 198 cGy

Liver: 141 cGy

kidneys: 230 cGy

Testes: 87 cGy

Bone: 300 cGy



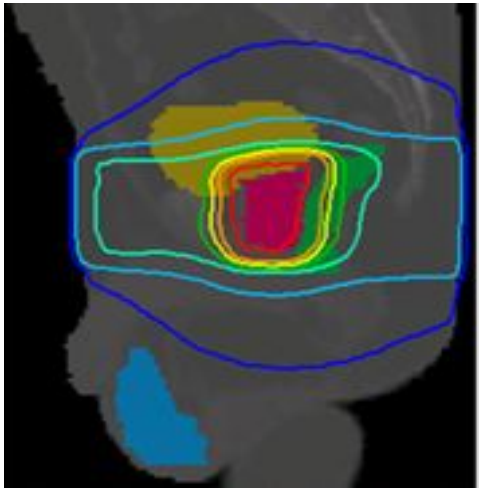
Mean dose (cGy)

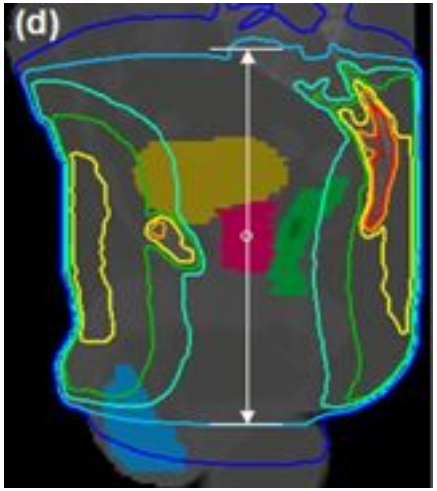
	kVCBCT half-fan (kV)				kVCBCT full-fan (kV)		
Organ at risk	60	80	100	125	60	80	100
Testes	1.2	1.6	2.0	2.9	0.4	0.8	1.2
Liver	1.6	2.4	3.2	4.7	1.7	2.5	3.4
Kidneys	2.4	3.9	5.2	7.7	3.3	4.8	6.4
Femoral heads	3.5	5.9	7.7	10.5	3.4	5.4	7.3
Spinal cord	1.9	3.7	5.5	8.8	2.5	4.4	6.6
Brain	1.6	3.2	4.8	7.6	1.8	3.3	5.1
Eyes	3.3	4.5	5.5	7.7	0.9	1.6	2.4
Lens	4.7	5.4	6.0	7.8	1.1	1.6	2.3
Optical nerves	1.6	3.1	4.6	7.2	0.8	1.7	2.7

With respect to 100% dose at the field border, organ dose decreased 20% every 1 cm outside the border

The dose received by pediatrics is almost doubled compared to adults

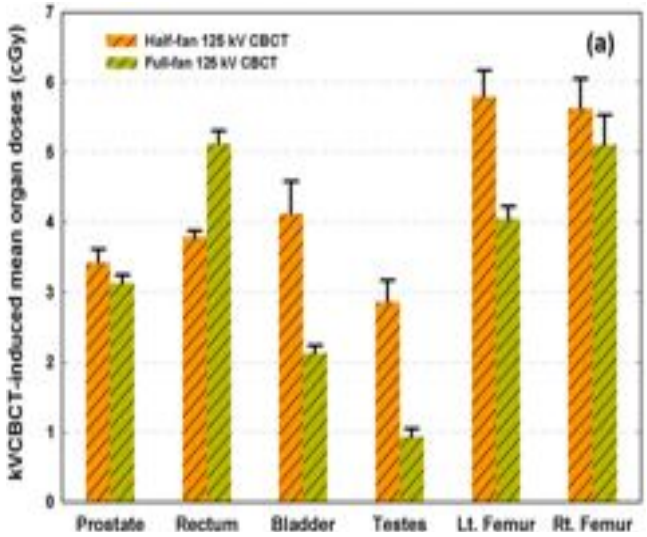
Deng, IJROBP 2012





IMRT and kVBCT

testicular adsorbed dose



For 30 fractions: 1 Gy to testes from daily kVCBCT
0.21 Gy from 30 PO-IMRT

Minimize CBCT field span
Maximize distance from OAR to field border
Choose the appropriate scanning mode to reduce exposure

Dose expressed in cGy

Organ	PO-IMRT (10 MV)	kVCBCT half-fan pelvis protocol				kVCBCT full-fan high-quality head protocol			
		60 kV	80 kV	100 kV	125 kV	60 kV	80 kV	100 kV	125 kV
Prostate	203.3	0.4	1.0	1.8	3.4	0.4	0.9	1.7	3.1
Rectum	117.3	0.5	1.2	2.1	3.8	0.9	1.8	3.1	5.1
Bladder	126.4	0.7	1.5	2.4	4.1	0.2	0.6	1.1	2.1
Testes	0.7	1.1	1.5	2.0	2.9	0.2	0.3	0.5	0.9
Left femoral head	69.1	0.8	2.0	3.3	5.8	0.5	1.2	2.3	4.0
Right femoral head	67.1	0.8	1.9	3.2	5.6	0.7	1.6	2.9	5.1

Deng, IJROBP 2012

kV-CBCT

kV x-ray source and solid state flat panel detector.
Source/detector system mounted to the gantry arm for rotation around the patient.
Full-fan: the system is in its central position (small FOV).
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MV Portal image (PI)

Film or electronic portal imaging device (EPID).

kV radiography

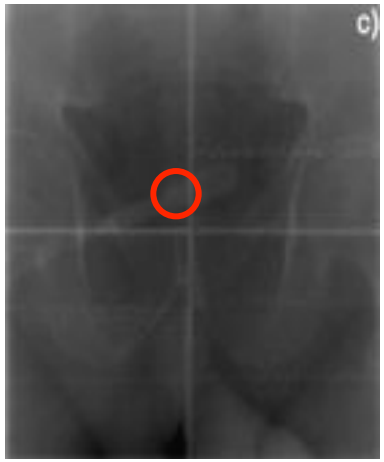
kV x-ray source and solid state flat panel detector.
1. Dual sources and panel detector mounted to the floor and ceiling of treatment room.
2. Source/detector system mounted to the gantry arm for rotation around the patient.

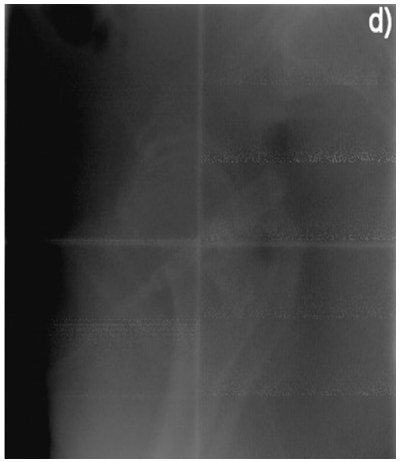
Helical Tomotherapy

Similar to helical CT imaging in helical tomotherapy
there is a simultaneous motion of the couch and gantry (MV-Linac source)

MV-CBCT

MV-Linac source and solid state flat panel detector.
Source/detector system rotate around the patient.



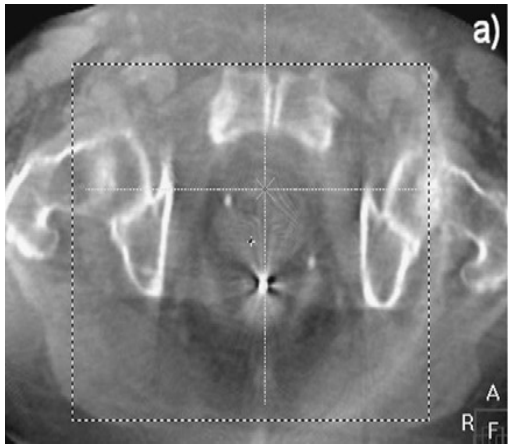


6 MV images:
for 30 fr.

Skin dose: 382 cGy
Rectum dose: 196 cGy

Results of in-vivo dose measurements (mGy)

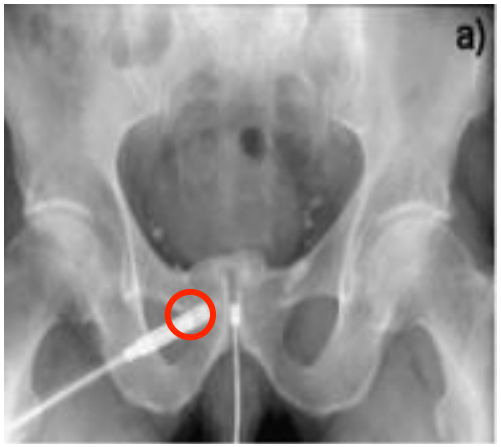
Dose (mGy)	MV		kV		CBCT
	AP	Lateral	AP	Lateral	
Surface					
av	57.78	69.42	0.75	1.12	
SD	1.17	1.41	0.13	0.24	
Rectum					
av	33.90	31.69	0.19	0.13	17.23
SD	1.81	1.75	0.08	0.04	2.76



kV-CBCT image:
for 30 fr.

Skin dose: 60 cGy
Rectum: 52 cGy

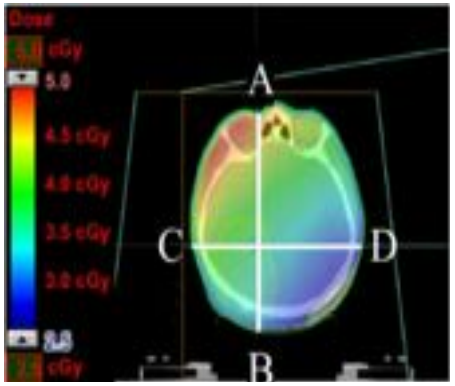
CTDI-phantom dose measurements
at 1 cm depth (skin): 2 cGy



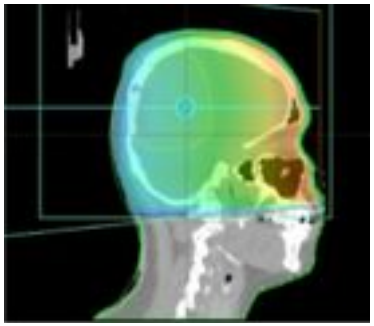
kV-radiogr.:
for 30 fr.

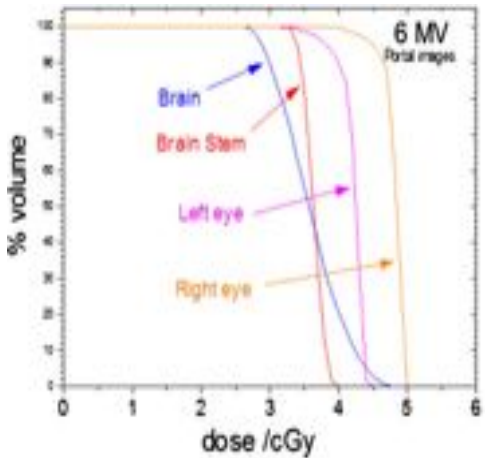
Skin dose: 5.6 cGy
Rectum dose: 1 cGy

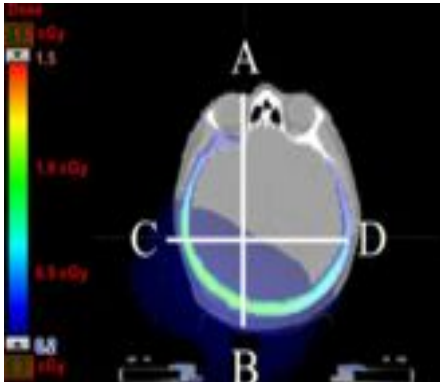
Walter, Radiother Oncol 2007



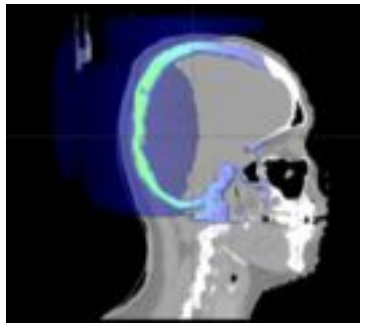
6 MV (30 fr.):
eyes: 120 cGy
br. stem: 111 cGy

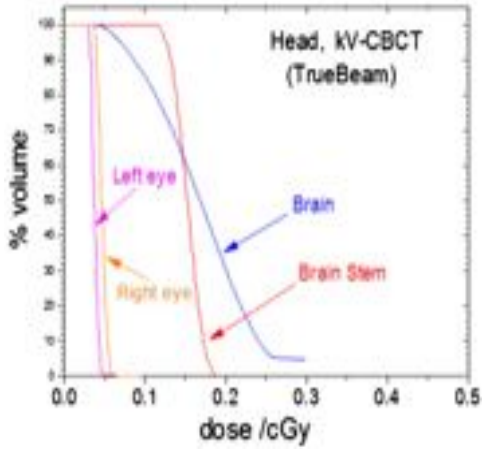


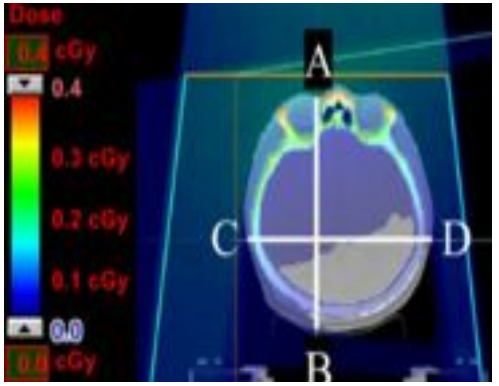




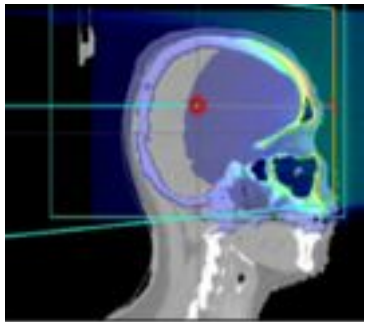
kV-CBCT (30 fr.):
eyes: 1.2 cGy
br. stem: 4.8 cGy

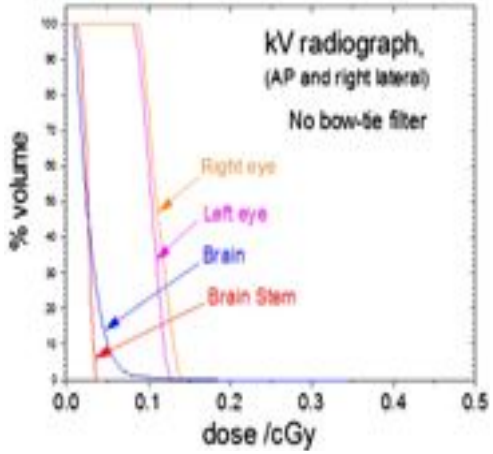




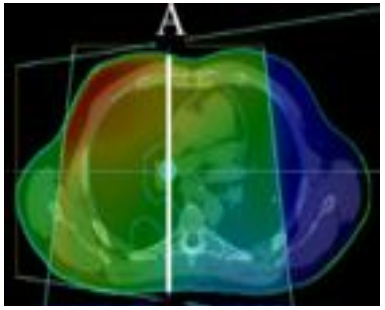


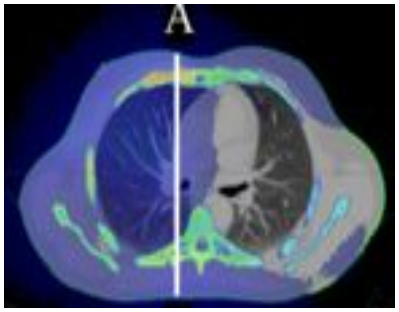
kV radiogr. (30 fr.):
eyes: 3.6 cGy
br. stem: 0.9 cGy

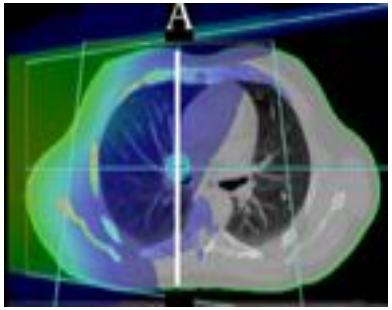




Ding, Radiother Oncol 2013



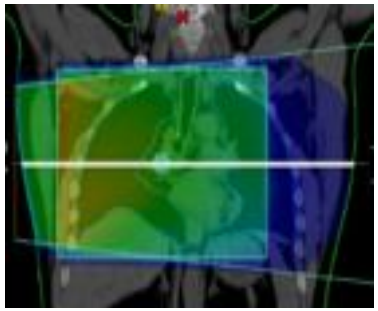


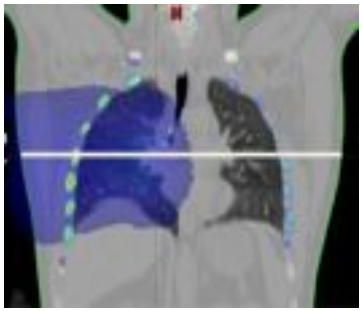


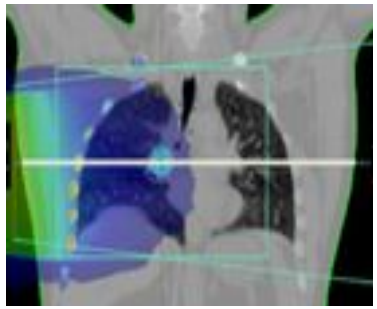
6 MV (30 fr.):
right lung: 114 cGy
heart: 105 cGy

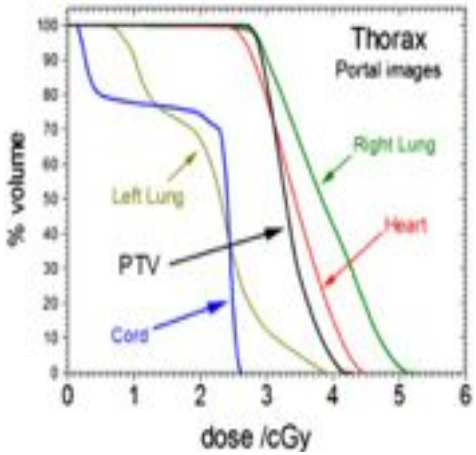
kV-CBCT (30 fr.):
right lung: 8.1 cGy
heart: 6 cGy

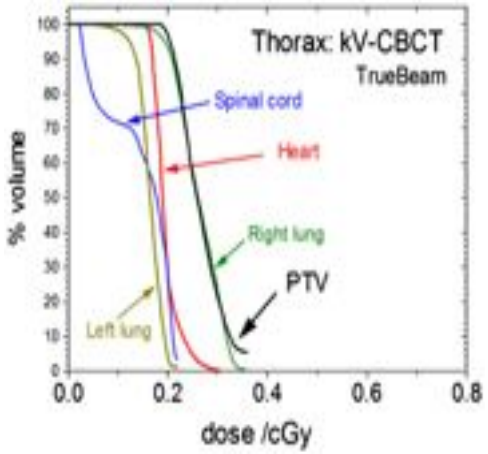
kV radiogr. (30 fr.):
right lung: 3.6 cGy
heart: 2.1 cGy

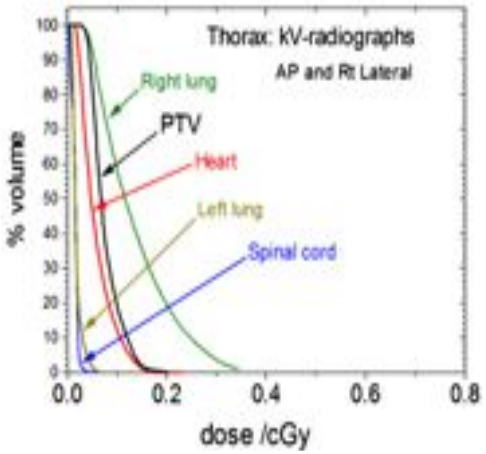




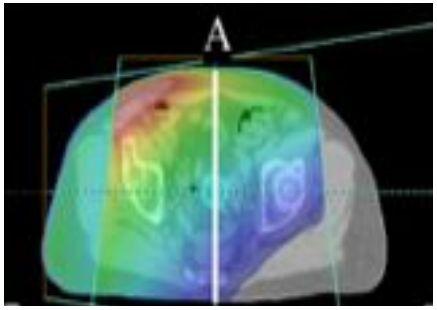




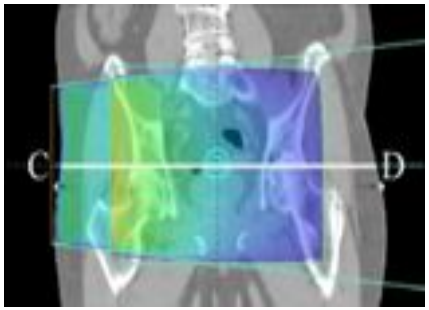


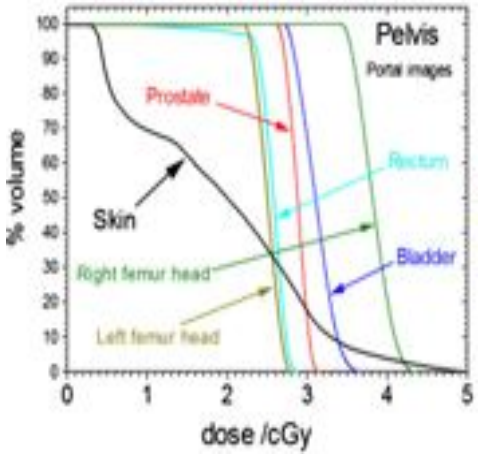


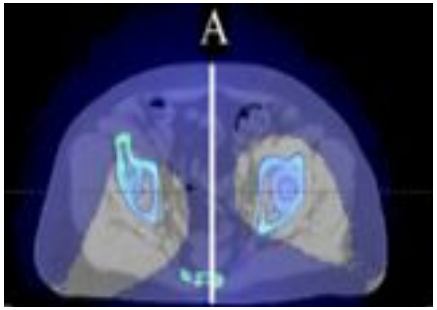
Ding, Radiother Oncol 2013



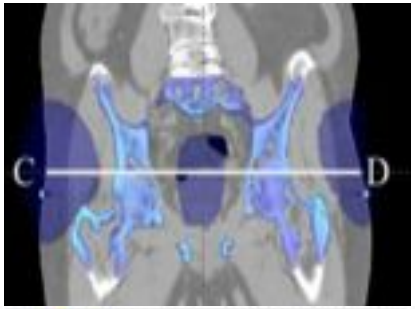
6 MV (30 fr.):
pros.: 90 cGy
rect.: 84 cGy
blad.: 100 cGy
skin: 65 cGy
bone: 90 cGy

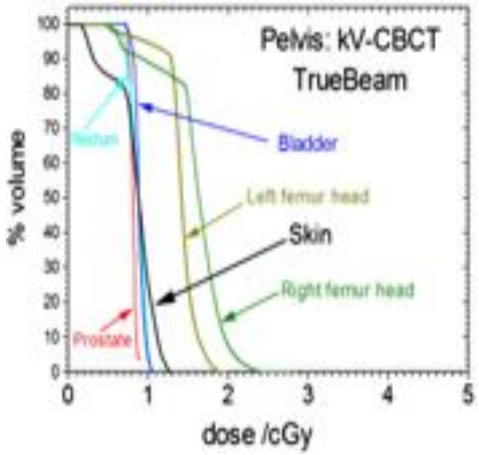


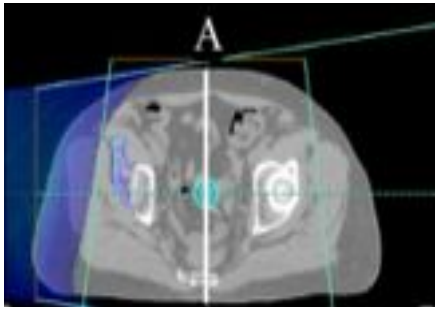




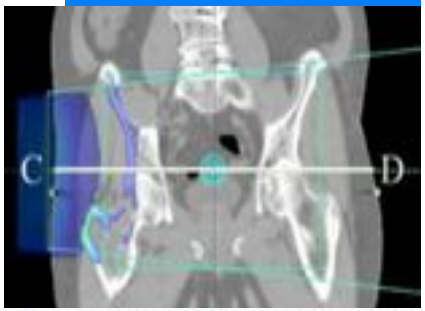
kV-CBCT (30 fr.):
pros.: 30 cGy
rect.: 30 cGy
blad.: 30 cGy
skin: 30 cGy
bone: 54 cGy

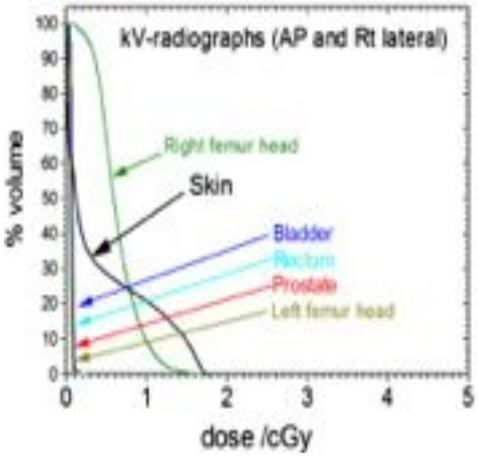






kV radiog. (30 fr.):
pros.: 3 cGy
rect.: 3 cGy
blad.: 3 cGy
skin: 9 cGy
bone: 24 cGy





Ding, Radiother Oncol 2013

kV-CBCT

kV x-ray source and solid state flat panel detector.
Source/detector system mounted to the gantry arm for rotation around the patient.
Full-fan: the system is in its central position (small FOV).
Half-fan (offset): the detector is shifted off its central position such that only a part of the object is viewed at any one projection (large FOV).

MV Portal image (PI)

Film or electronic portal imaging device (EPID).

kV radiography

kV x-ray source and solid state flat panel detector.
1. Dual sources and panel detector mounted to the floor and ceiling of treatment room.
2. Source/detector system mounted to the gantry arm for rotation around the patient.

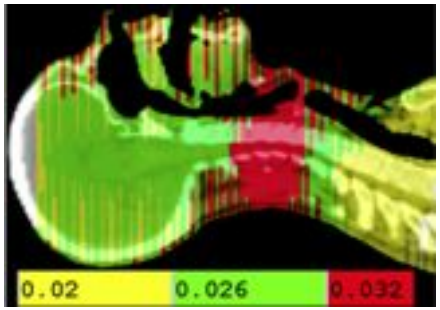
Helical Tomotherapy

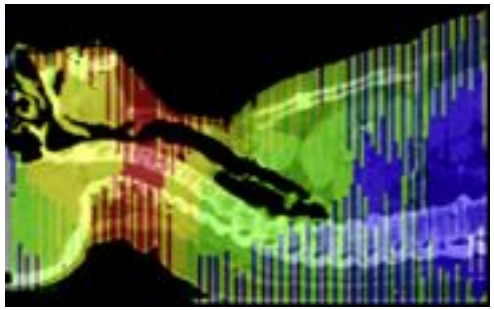
Similar to helical CT imaging in helical tomotherapy
there is a simultaneous motion of the couch and gantry (MV-Linac source)

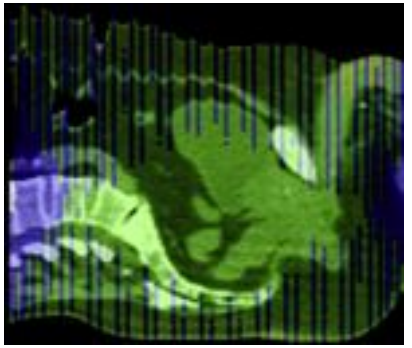
MV-CBCT

MV-Linac source and solid state flat panel detector.
Source/detector system rotate around the patient.

Tomotherapy

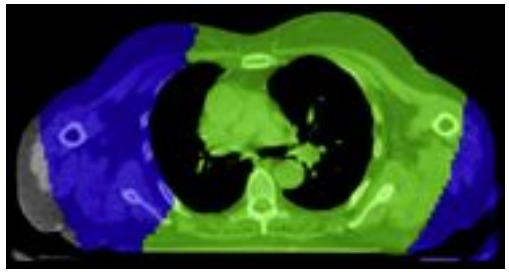


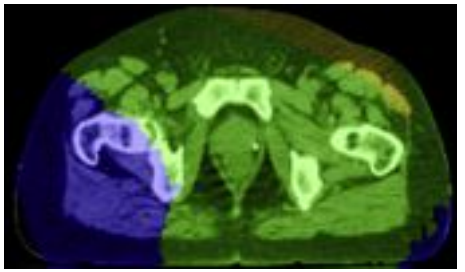




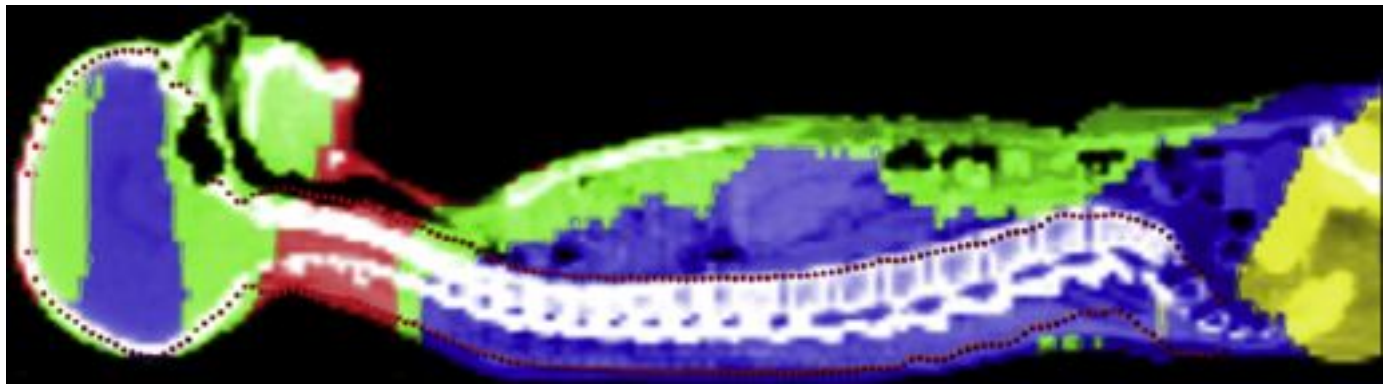
pitch: table transl. (mm)/collimator width (mm)

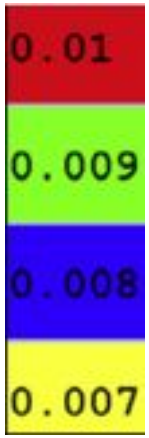
Fine pitch: 1
Normal: 2
Coarse: 3





Mean dose: [normal pitch]	eyes 1.48 cGy	cord 1.51 cGy	lungs 1.14 cGy	heart 1.12 cGy
	gonads 1 cGy	skin 0.9 cGy	bone 1 cGy	





Gy

Shah, IJROBP 2008

Patient	Mean (cGy)	Maximum (cGy)
Head and neck		
Lacrimal glands	1.48	1.66
Optic nerves	1.42	1.58
Optic chiasm	1.38	1.47
Brain stem	1.36	1.50
Mandible	1.37	1.76
Parotids	1.45	1.75
Cord superior	1.51	1.69
Brain	1.07	1.64
Breast/sternum		
Contralateral breast	1.07	1.61
Lungs	1.14	1.59
Sternum	1.14	1.64
Spinal cord	1.18	1.42
Heart	1.12	1.53
Prostate		
Prostate	1.03	1.15
Hips	1.02	1.22
Penile bulb	1.01	1.08
Seminal vesicles	1.06	1.11
Bladder	1.05	1.31
Rectum	1.04	1.20
Lung/esophagus		
Esophagus	1.14	1.61
Lungs	1.04	1.41
Heart	1.05	1.30
Spinal cord	1.07	1.70
Mandible	1.32	1.76
Parotids	1.46	1.77
Craniospinal axis		
Spinal canal	1.33	1.69
Trachea	1.56	1.80
Lens	1.47	1.50
Arms	0.80	1.38
Stomach	1.28	1.51
Heart	1.35	1.47
Liver	1.26	1.46
Kidney	1.26	1.35
Lungs	1.30	1.50
Parotids	1.54	1.62

Tomotherapy

Range of mean adsorbed dose for a single MV-CT: 1 - 1.6 cGy

3.5 MV (30 fr.):
eyes: 44 cGy
cord: 45 cGy
lungs: 34 cGy
heart: 33 cGy
gonads: 30 cGy
skin: 30 cGy
bone: 30 cGy

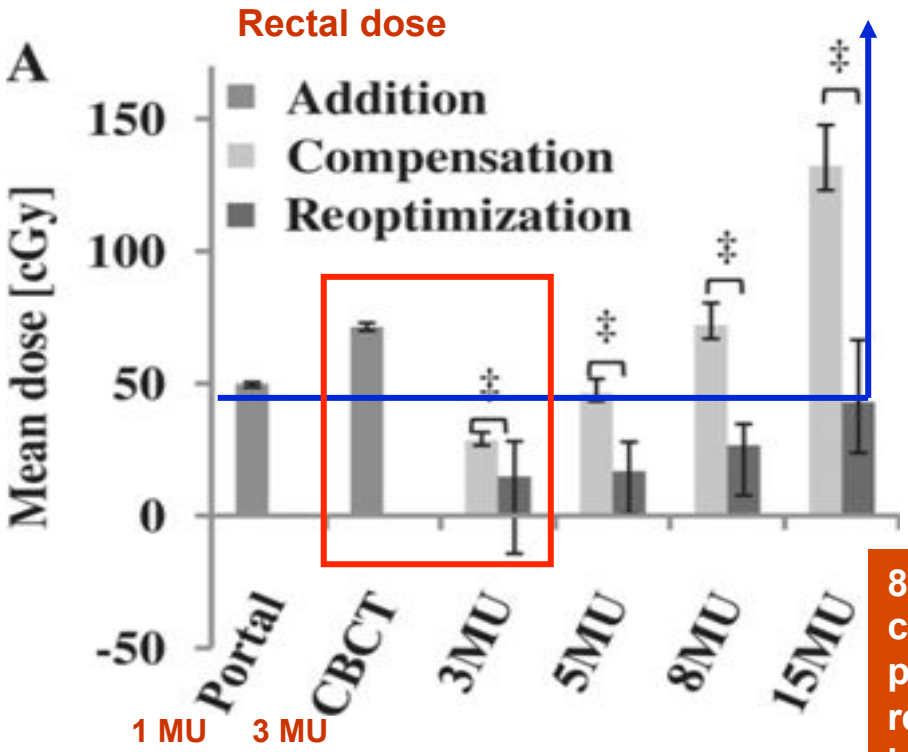
Shah, IJROBP 2008

MV-CBCT: 200° rotation. 3 MU for recognizing skeletal structures; 8 MU for soft tissue

IMRT plan (prostate): the dose covering 95% of the PTV (D95) normalized to the prescribed dose (74 Gy)

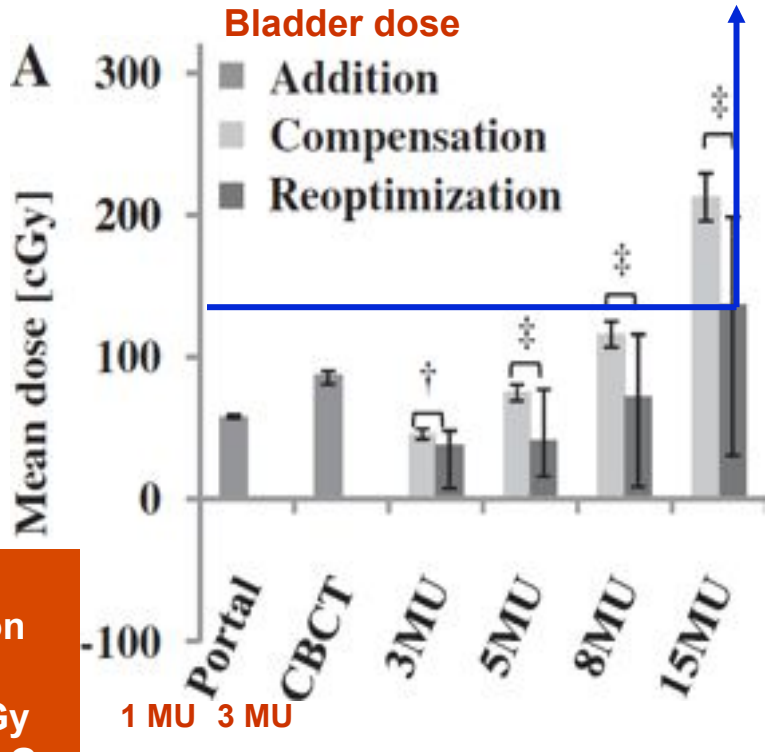
1. **Addition plan**: CBCT arc beam added to clinically approved treatment plan.
2. **Compensation plan**: simple rescaling of IMRT beam weights, keeping imaging dose constant.
3. **Reoptimization plan**: new IMRT plan optimization after adding MV-CBCT.

Mean rectal dose with reoptimiz. (37 fr): 50 cGy



8 MU CBCT compensation plan (37 fr): rectum 75 cGy bladder 110 cGy

Mean bladder dose with reoptimiz. (37 fr): 130 cGy

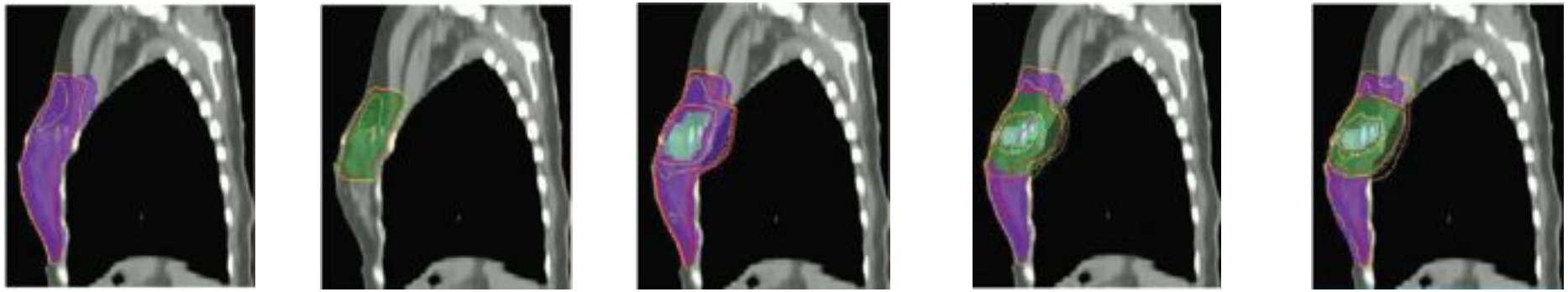


Akino, IJROBP 2012

1 fraction	6 MV PI (0°-90°)	kV radiogr. (0°-90°)	kV-CBCT	3.5 MV-CT
eyes	4.5 cGy	0.15 cGy	0.04 cGy*	1.48 cGy
cord	2.5 cGy	0.05 cGy	0.2 cGy	1.5 cGy
bone	4 cGy	1 cGy	1.8 cGy	1 cGy
gonads	3 cGy	0.1 cGy	0.9 cGy	1 cGy
skin	2.5 cGy	0.3 cGy	1 cGy	0.9 cGy

30 fractions	6 MV PI (0°-90°)	kV radiogr. (0°-90°)	kV-CBCT	3.5 MV-CT
eyes	135 cGy	4.5 cGy	1.2 cGy*	44.4 cGy
cord	75 cGy	1.5 cGy	6 cGy	45 cGy
bone	120 cGy	30 cGy	54 cGy	30 cGy
gonads	90 cGy	3 cGy	27 cGy	30 cGy
skin	75 cGy	9 cGy	30 cGy	27 cGy

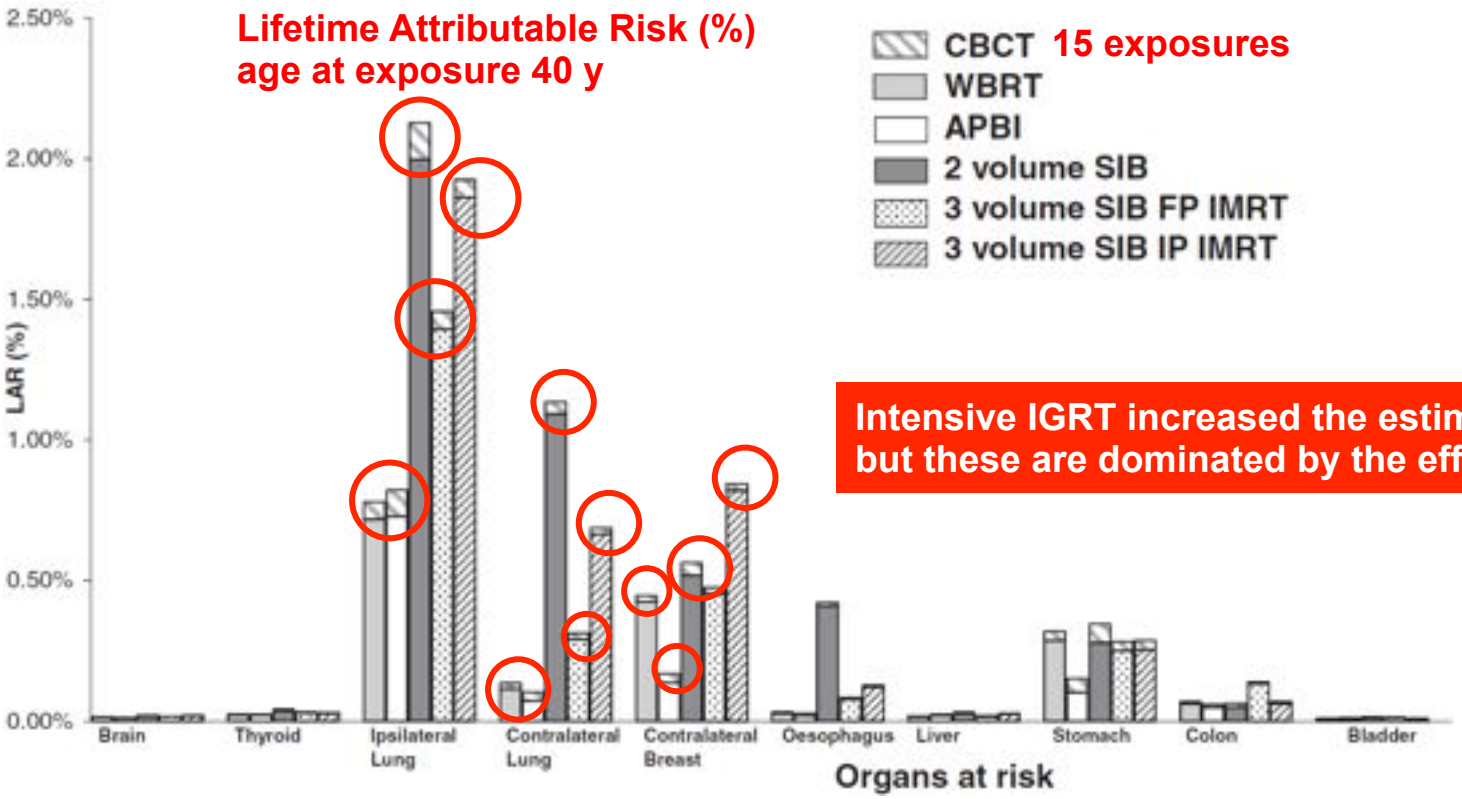
* partial rotation



WBRT	APBI	2 vol. SIB	3 vol. FPSIB	3 volume IPSIB
40 Gy	38.5 Gy	51.5/74 Gy	36/40/53 Gy	36/40/53 Gy
15 fr	10 fr	31 fr	15 fr	15 fr

Plans transferred to a CT scan of a Rando anthrop. phantom. TLDs placed within the phantom

Second cancer lifetime attributable risk using Biological Effects of Ionizing Radiation (BEIR) VII



Intensive IGRT increased the estimated values of LAR but these are dominated by the effect of dose from RT

Donovan, Med Phys 2012

IGRT has improved the accuracy of radiation delivery and has emerged as the new paradigm for patient positioning and target localization.

Information for image guidance dose to radiosensitive organs is important as we are in the IGRT era.

The probabilistic risk associated with the additional image-guided procedures is difficult to assess.

The low additional dose of the new IGRT techniques represents a low risk to the patient, especially compared against the beneftis provided by image guidance.

Recommendations **As Low As Reasonably Achievable**

1. Consider the type of imaging necessary for the image guidance task.

2. Efficient use of imaging procedures.

2.a. Reduce the frequency of acqusitions.

2.b. Reduce the field size as much as possible.

2.c. For CBCT adjust x-ray settings acquisition when necessary.

2.d. Select beam directions that minimize imaging dose to specific organ when acquiring kV and CBCT images.