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Imaging and Dosimetry System in Radiotherapy

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Outline

- Procedure in Radiotherapy
- Imaging in Radiotherapy
- Radiation Dosimetry in Radiotherapy
- Conclusion

Department of Physics FMNS UI

- Established in 1960s
- Has five concentration/division:
  - Nuclear and Particle Physics
  - Material Science
  - Instrumentation Physics
  - Condense Matter Physics
  - **Medical Physics and Biophysics**

Faculty Staffs : Medical Physics and Biophysics Division

Prof. Dr. Djarwani S. Soejoko
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Radiotherapy physics

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Radiotherapy physics

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Radiology physics

Dr. sc.hum. Deni Hardiansyah
Nuclear medicine physics

Akbar Azzi, M.Si**
Radiotherapy physics

Nurlely Kusuma, Ph.D
Biophysics

* PhD Students – Katolike Leuven Medical School
** PhD Student – Departemen Fisika FMIPA UI

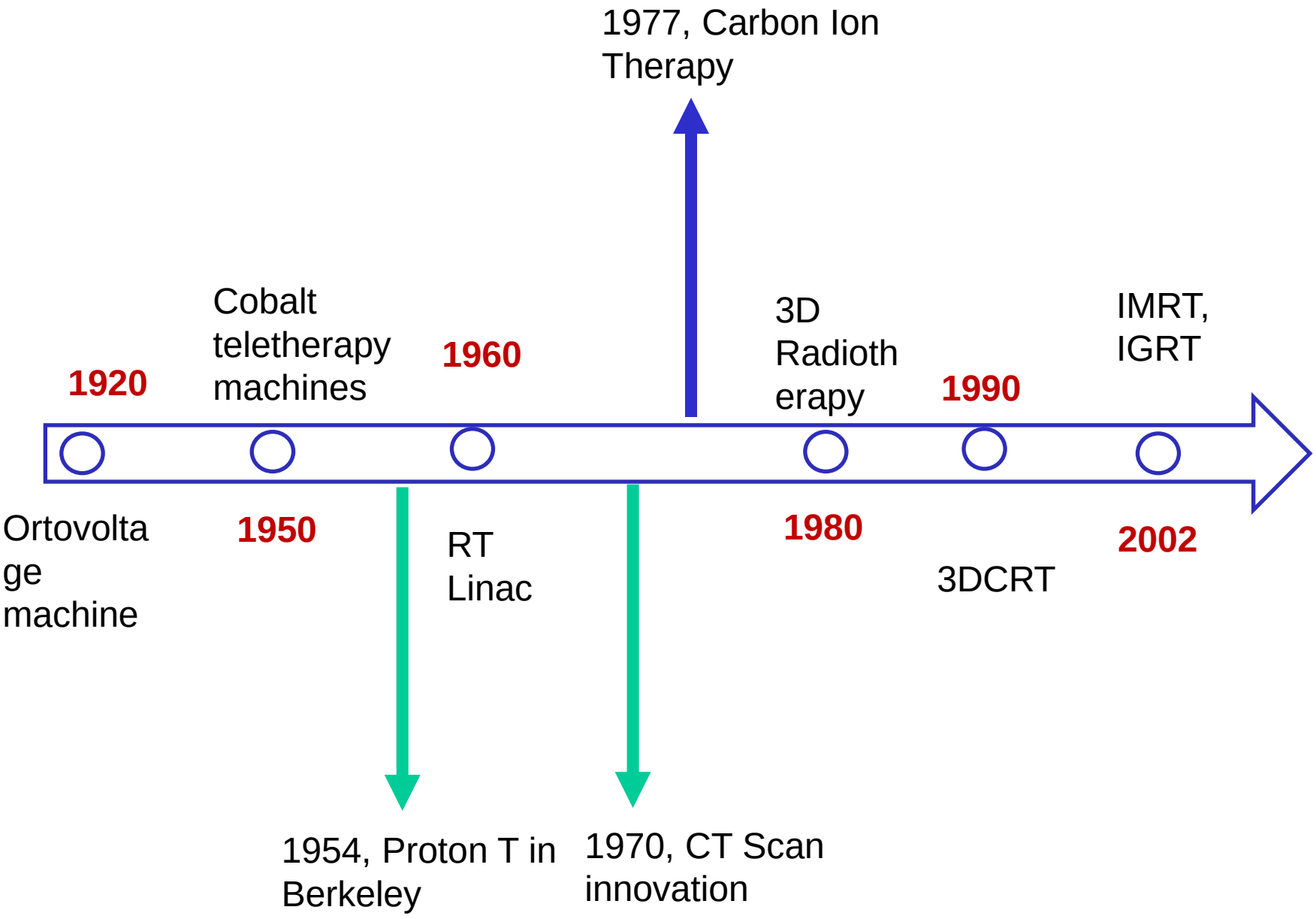
Medical Physics and Biophysics Students

- Around 20-30 undergraduate students in Physics with final project in medical physics and biophysics
- 15-20 Master Students in Medical Physics
- 1-2 PhD Students in Medical Physics

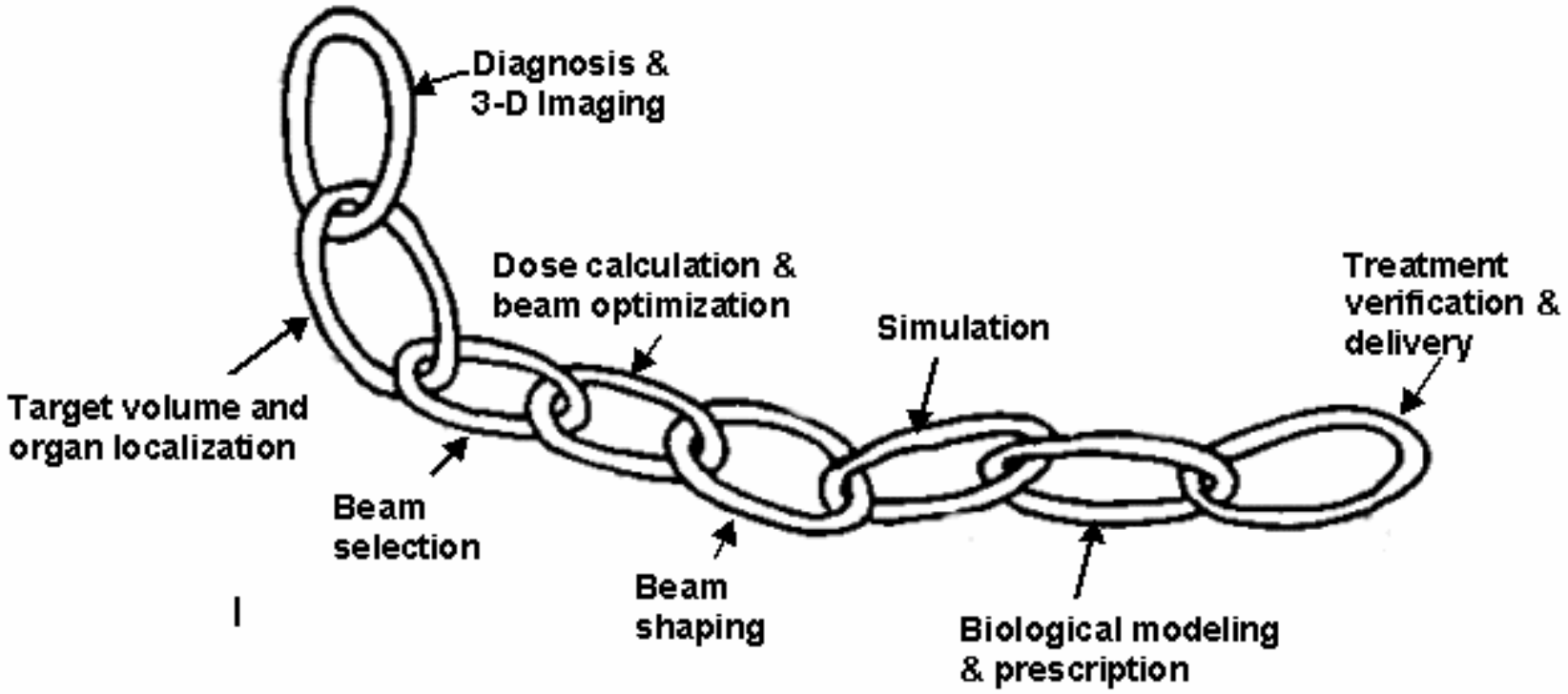
Acknowledgement

- Wahyu Edy Wibowo (Cipto Hospital)
- Andreas Nainggolan (MRCCC)
- Arief Sudarmaji (UI)
- Akbar Azzi (UI)
- Former Students
  - Aninda Fitriandini
  - Mukhlisin
  - Sasono Wijanarko
  - Hendya Prabangkara
  - Helga Silvia

Development of Radiotherapy Technology



Radiotherapy Procedure



H. Amol, ICTP (2007)

Physics in Medicine

- The first revolution in medical physics was announced thus

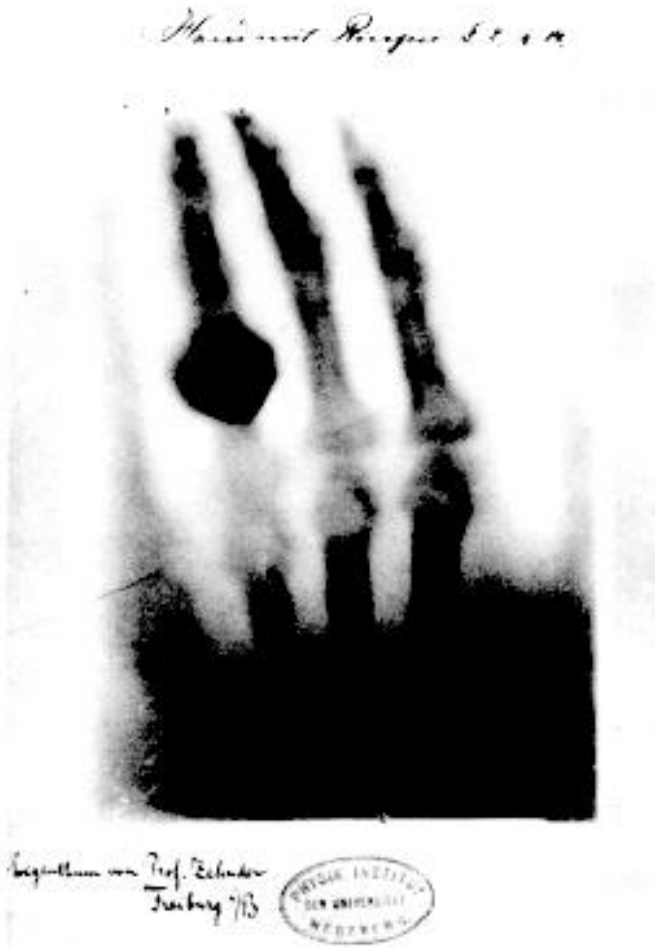
' The Newspaper reports of Prof. Rontgen's experiments have, during the past few days,excited considerable interest. The discovery does not appear to be entirely novel, as it was noted by Hertz that magnetic films are transparent to the kathode rays from a Crookes or Hittorf tube, and in Lenard's researches, published about two years ago, it is distinctly pointed out that such rays will produce photographic impressions...

Prof. Rontgen has extended the results obtained by Lenard in a manner that has impressed the popular imagination, while perhaps most important of all, he has discovered the exceedingly curious fact that bone is so much less transparent to these radiations than flesh and muscle.'

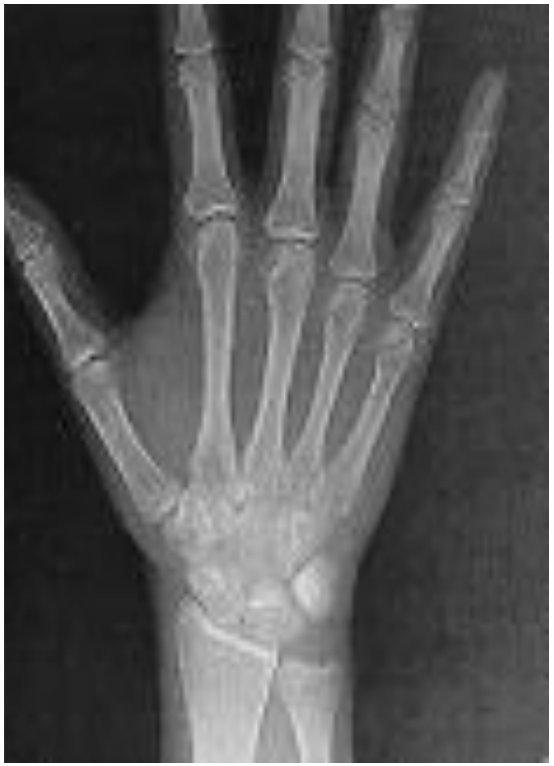
•Nature 23 January 1896

N.B. X-rays also played a big role in development of QM.
and of course heralded the beginning of medical physics

First and modern x-ray



Frau Roentgen's Left hand



Modern X-ray radiograph

Limitation of conventional x-rays

- Image is 2D projection
- Overlap object in the image will h
  occurred
- Small lesion or tricky position
  object will be difficult to be
  observed

Later Developments

More recently, physicists and engineers have initiated new developments in technology, rather than physicians.

1940's, 1950's

Background laid for ultrasound and nuclear medicine

1960's

Revolution in imaging – ultrasound and nuclear medicine

1970's

CT (Computerized Tomography)

- true 3D imaging

(instead of three dimensions crammed into two)

1980's

MRI (Magnetic Resonance Imaging)

PET (Positron Emission Tomography)

After 1973 ?

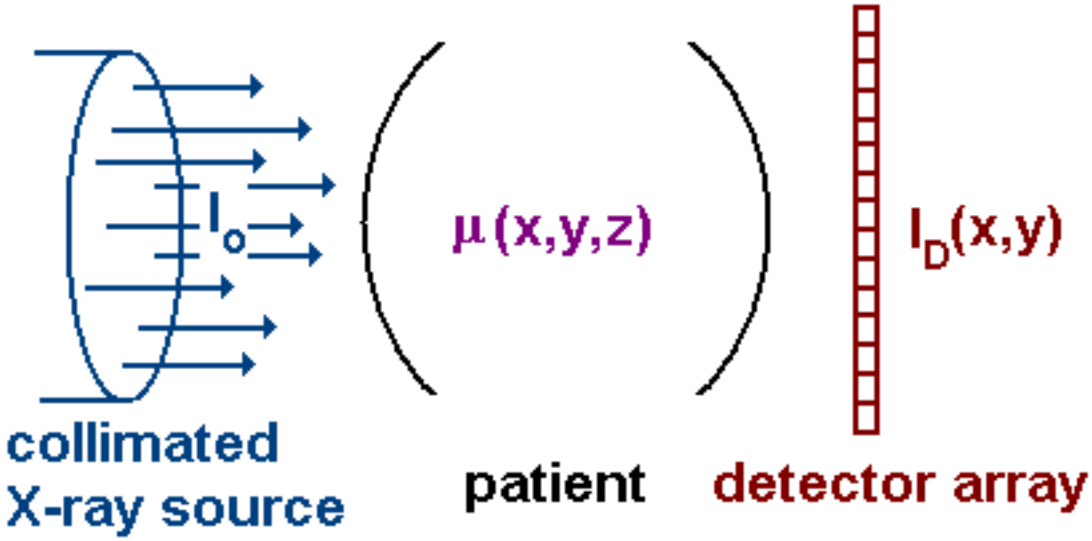
Your Majesties, Your Royal Highnesses, Ladies and Gentlemen,

Neither of this year's laureates in physiology or medicine is a medical doctor. Nevertheless, they have achieved a revolution in the field of medicine. It is sometimes said that this new X-ray method that they have developed –computerised tomography – has ushered medicine into the space age. Few medical achievements have received such immediate acceptance and met with such unreserved enthusiasm as computerised tomography. It literally swept the world".

Speech by Professor Torgny Greitz at the Nobel prize ceremony in 1979 at which A. M Cormack and G.N. Hounsfield received the prize for Physiology or Medicine

The Hounsfield's real legacy is the introduction of Tomography into medical imaging

Computerized Tomography (CT)



Result: $I_D(x,y) \propto \mu(x,y)$

1972 Hounsfield announces findings at British Institute of Radiology

1979 Hounsfield, Cormack receive Nobel Prize in Medicine

(CT images computed to actually display attenuation coefficient μ(x,y))

Important Precursors:

1917 Radon: Characterized an image by its projections

1961 Oldendorf: Rotated patient instead of gantry

First Generation CT Scanner

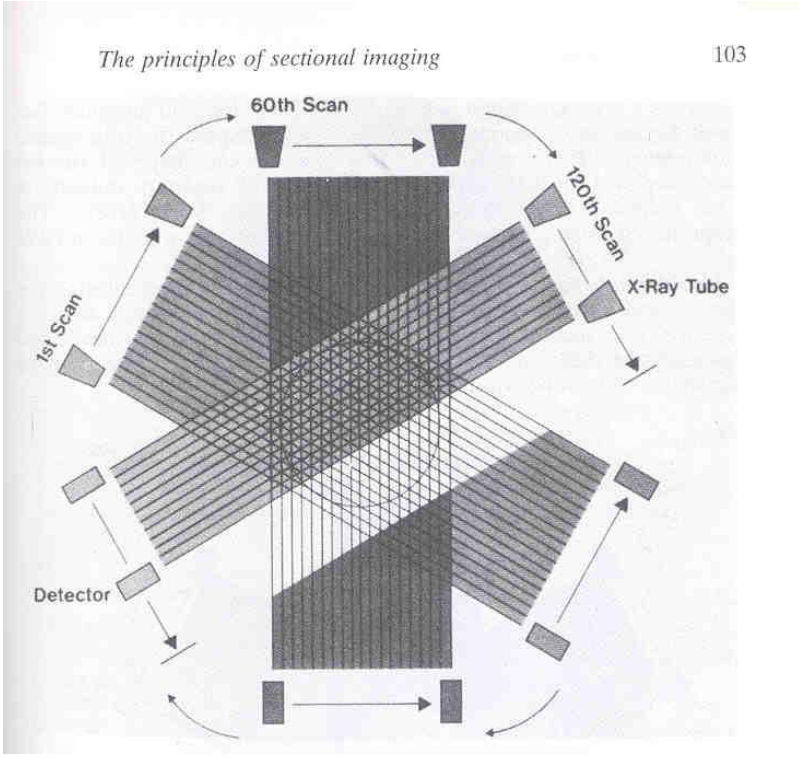
Acquire a projection (X-ray)

- Translate x-ray pencil beam and detector across body and record output

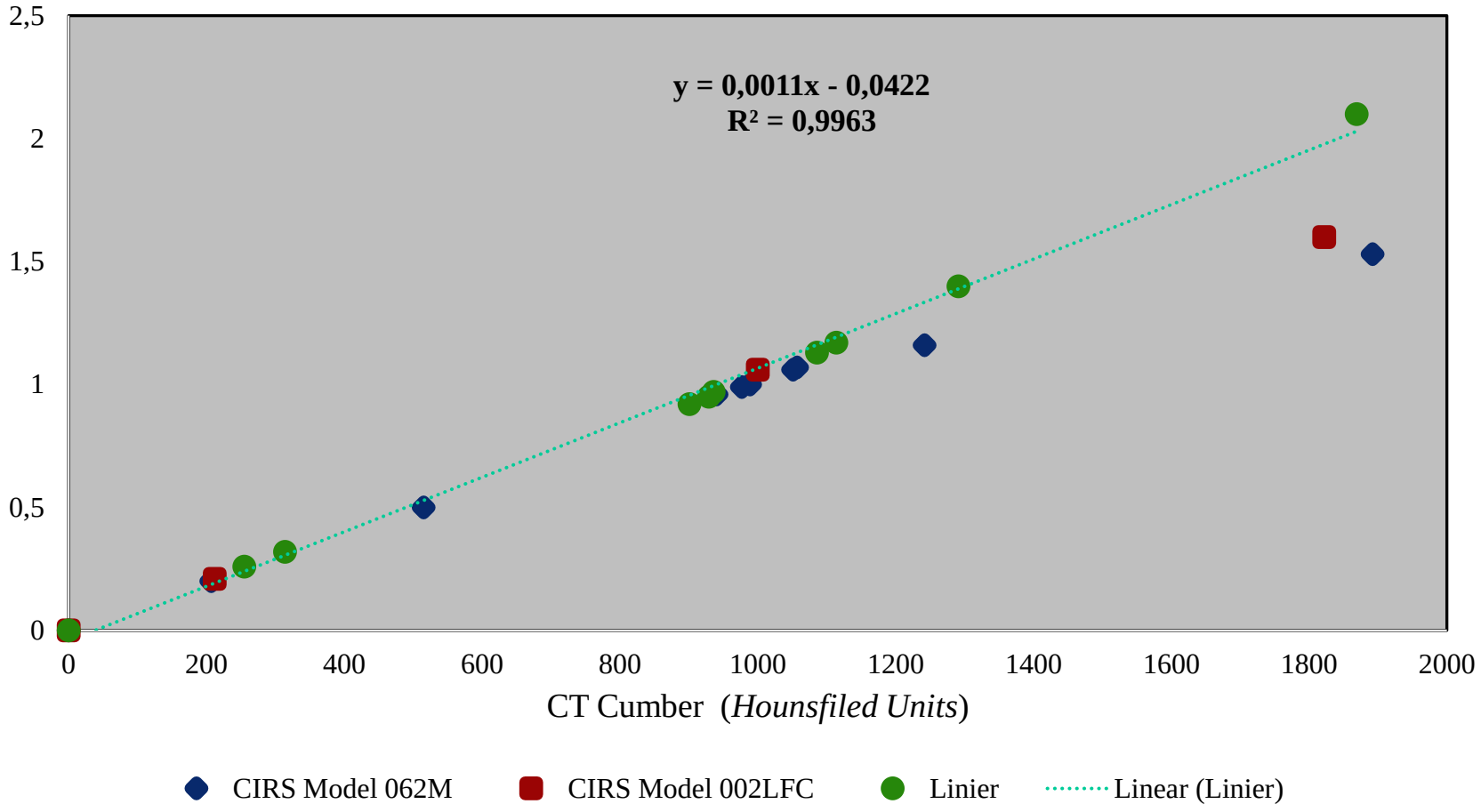
Rotate to next angle

- Repeat translation

Assemble all the projections.



Do we need CT number Calibration in RT?

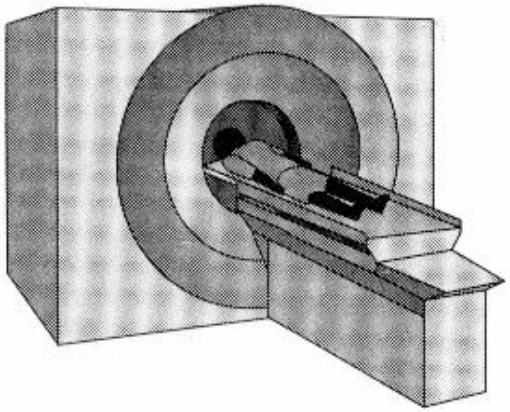


CT number and electron density calibration will be used for dose distribution calculation in the treatment planning system in radiotherapy

Imaging modalities in RT

H. Amol, ICTP (2007)

CT—Standard of Care



- CT used for vast majority of RT simulations
- 3–5 mm slices common practice

Imaging Options

Each with Distinct Merit

CT: Highly effective tool for depicting anatomical references; unable to image metastasis

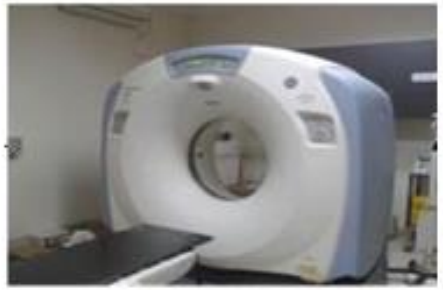
PET: Assesses metabolic activity rather than anatomic structure

MR: Ability to finely differentiate tissues

- CT is gold standard imaging in CT
- Fusion of CT with PET or MR is beneficial for target volume definition

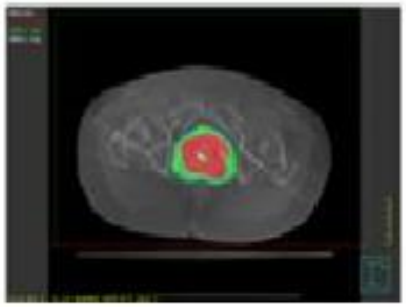
Images or patient data

patient



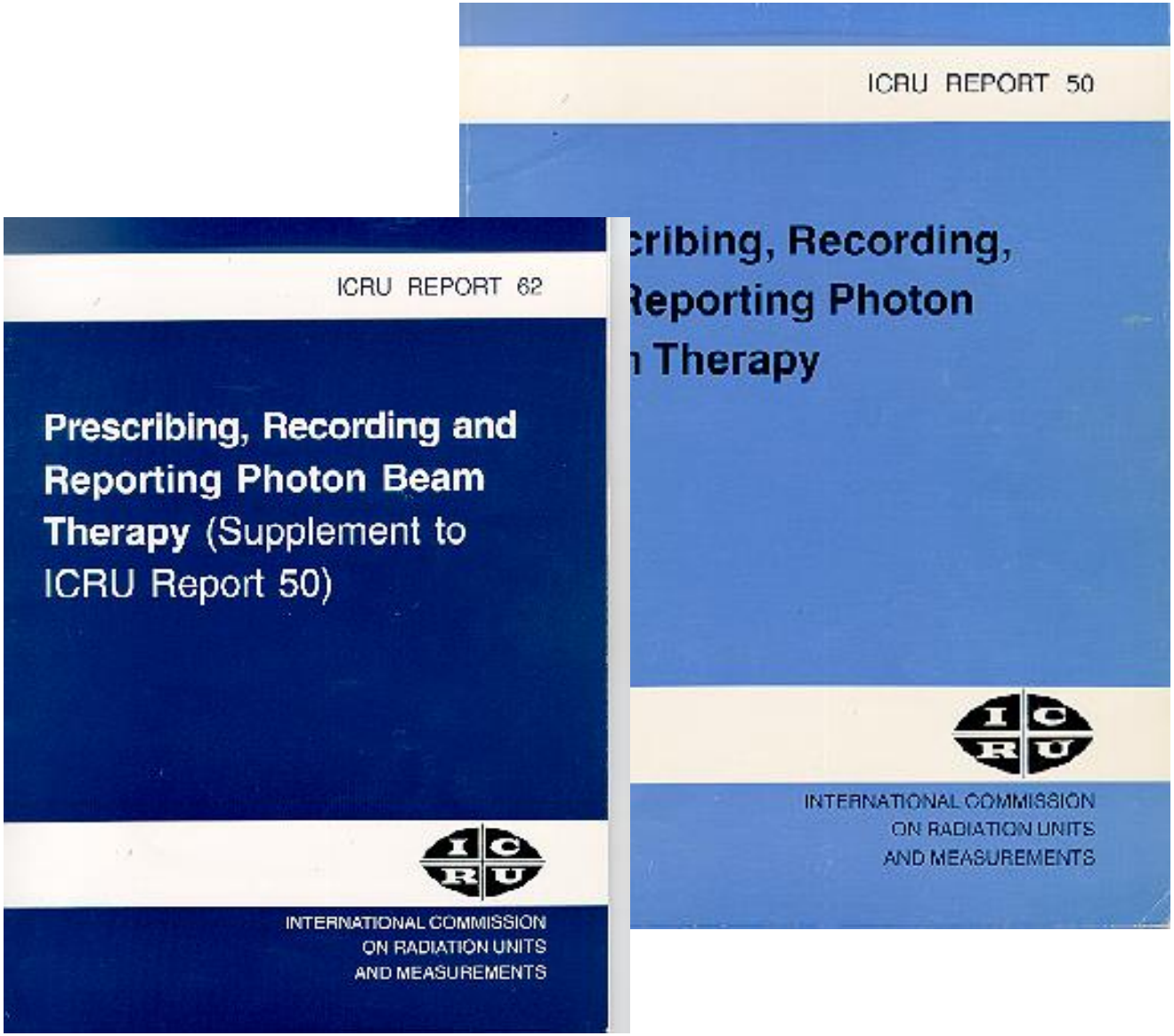
Imaging modalities

Image or patient data

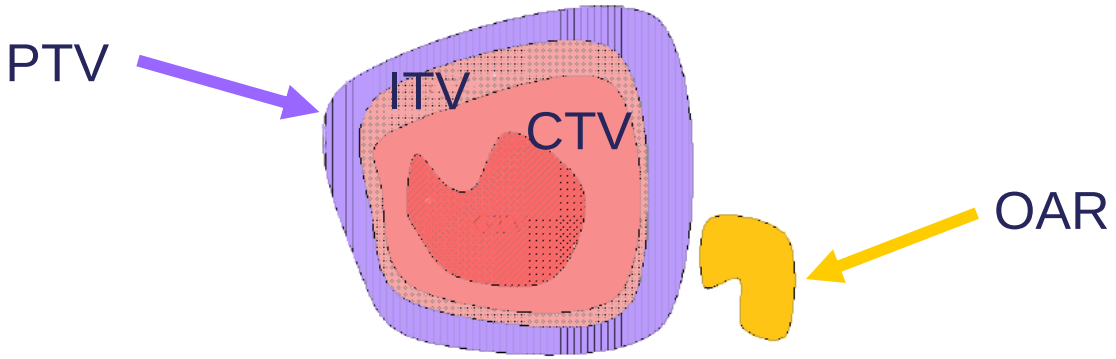


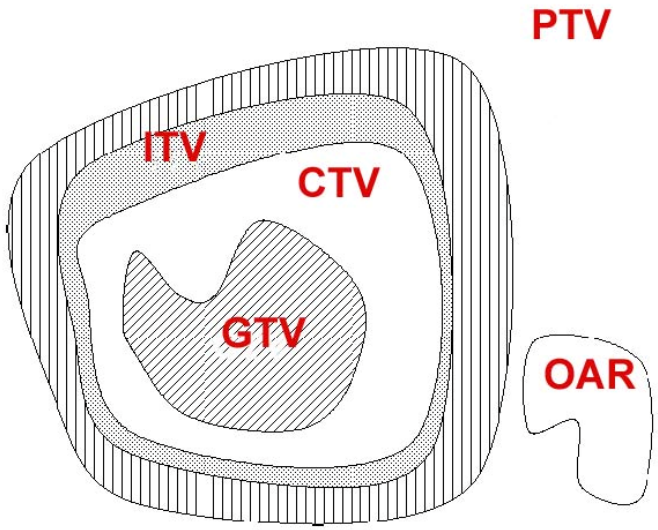
Treatment Planning System

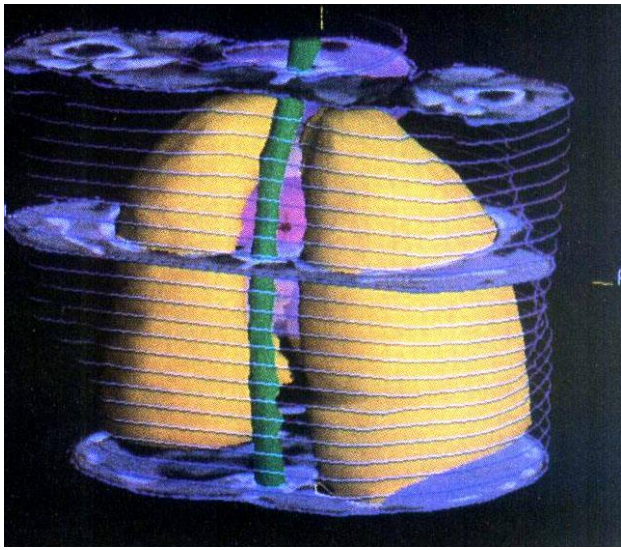
Target volume definition



Target volume and organ at risk

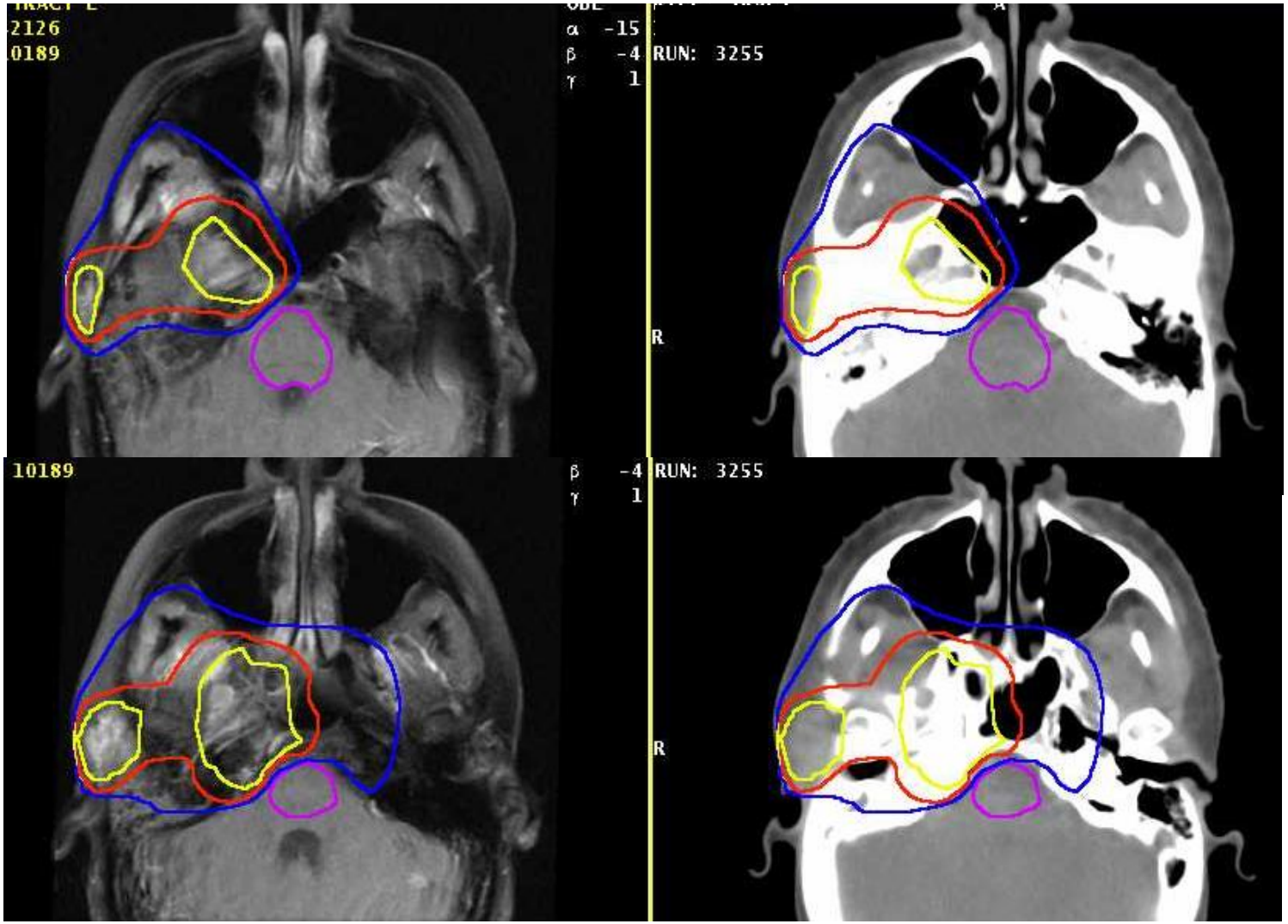






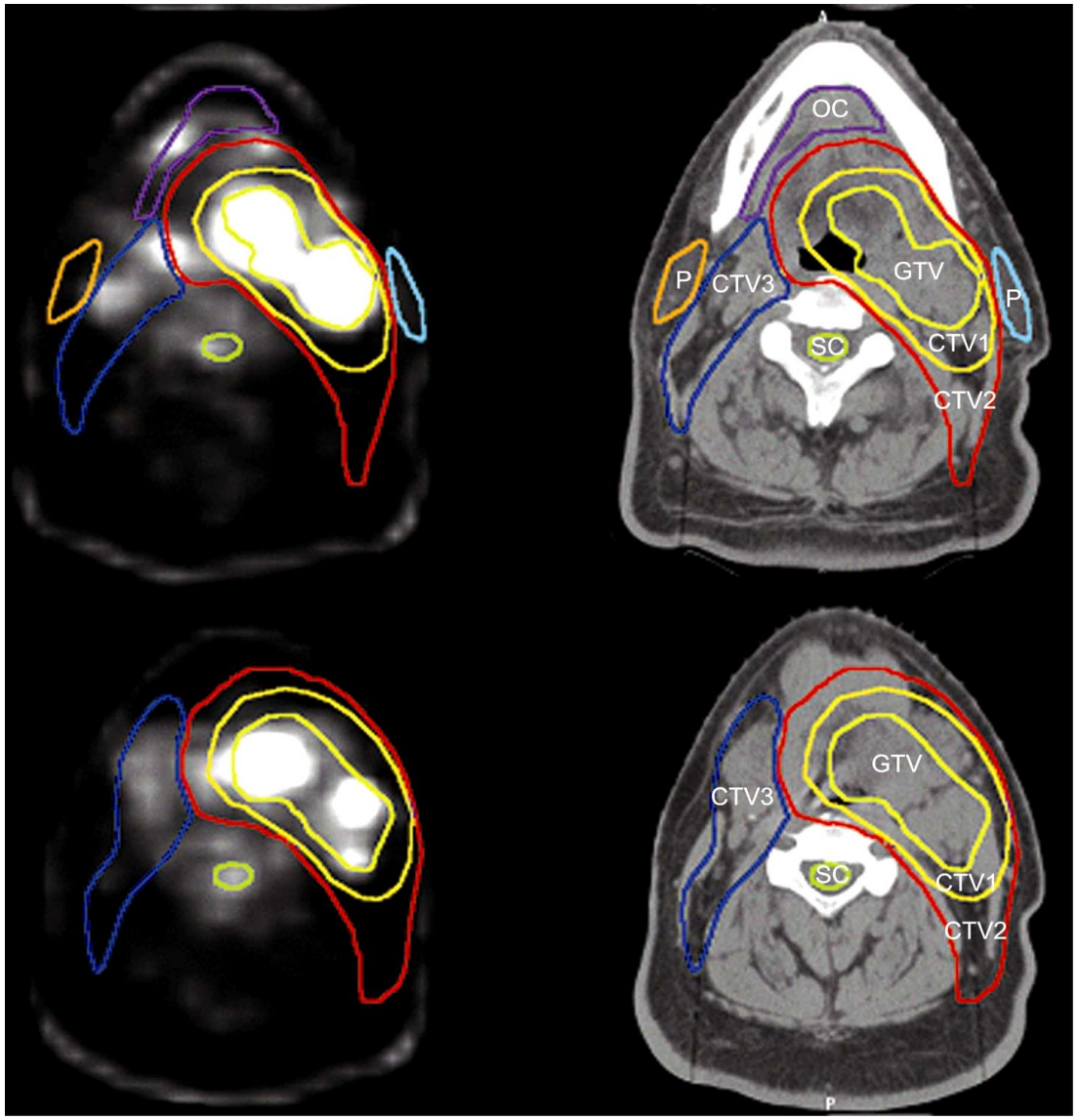
Radiation Oncology Physics : IAEA

MR-CT based treatment planning



H. Amol, ICTP (2007)

PET-CT based treatment planning

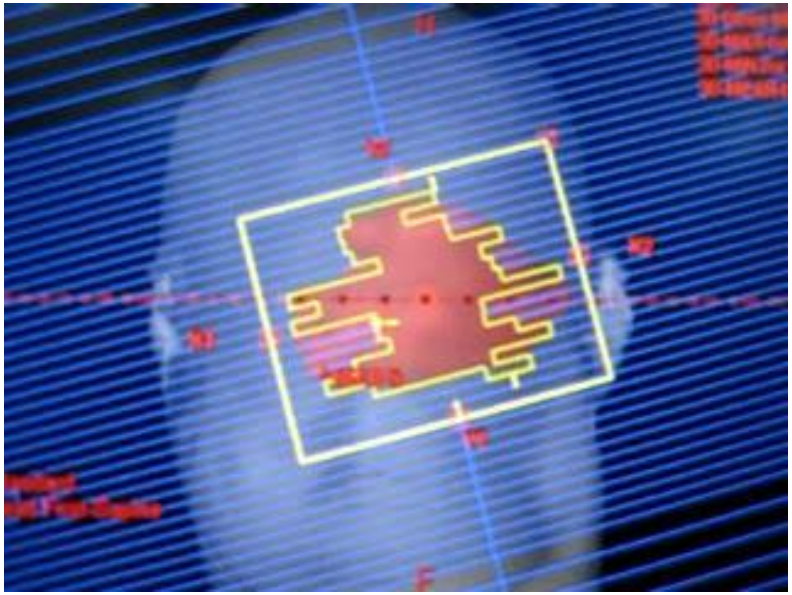


H. Amol, ICTP (2007)

Advances radiotherapy techniques

IMRT

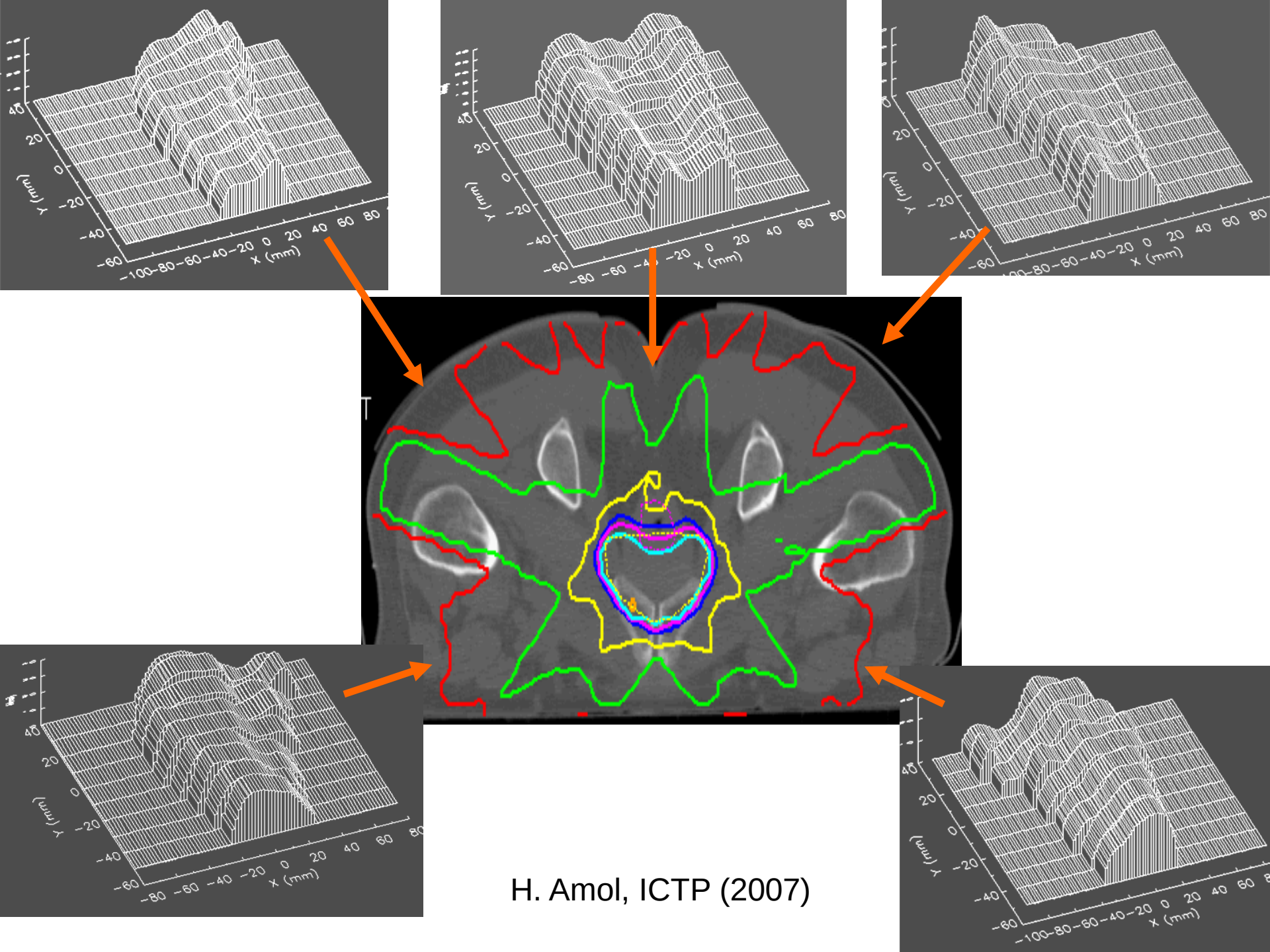
- **Intensity modulated**
- **MLC movement**



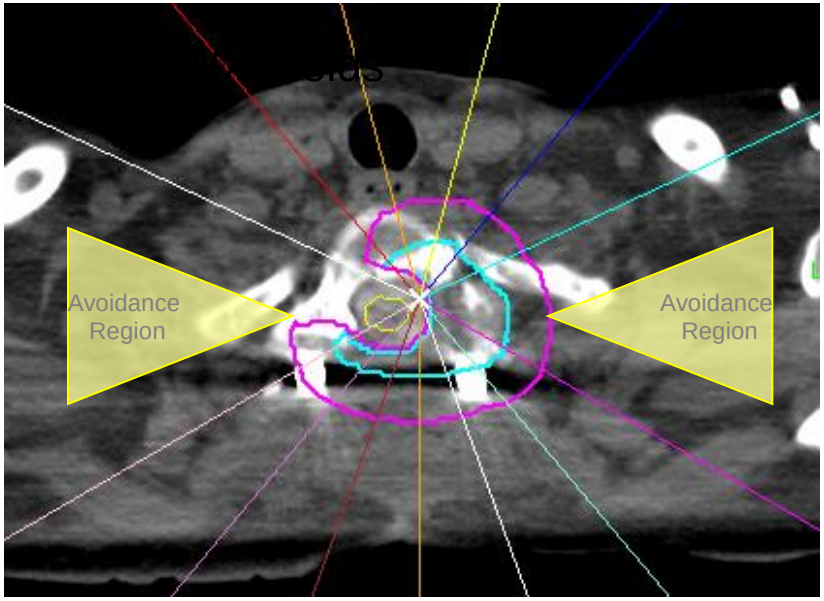
RapidArc (VMAT)

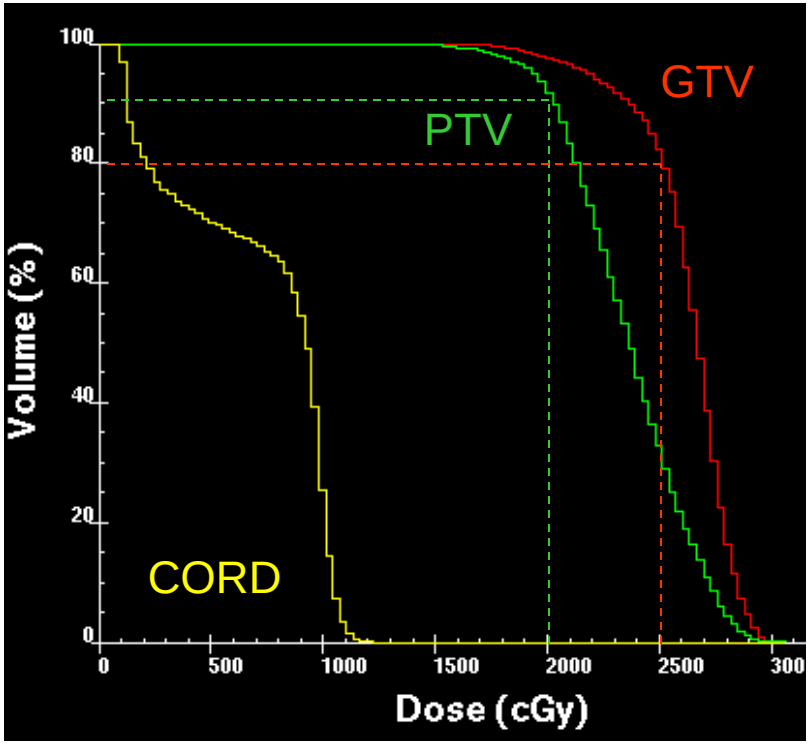
- **Gantry rotation**
- **MLC Movement**
- **Vary the dose rate**

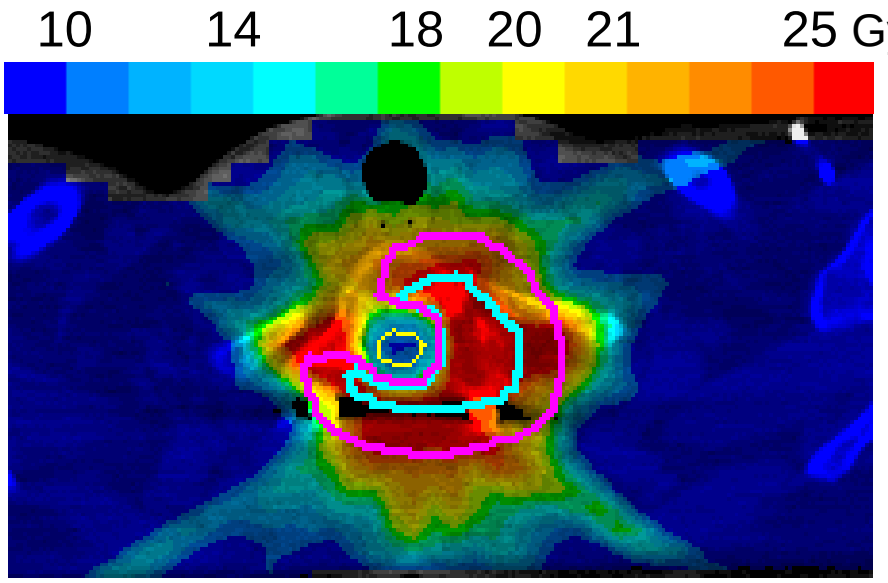
Video from Varian


H. Amol, ICTP (2007)

Treatment Plan



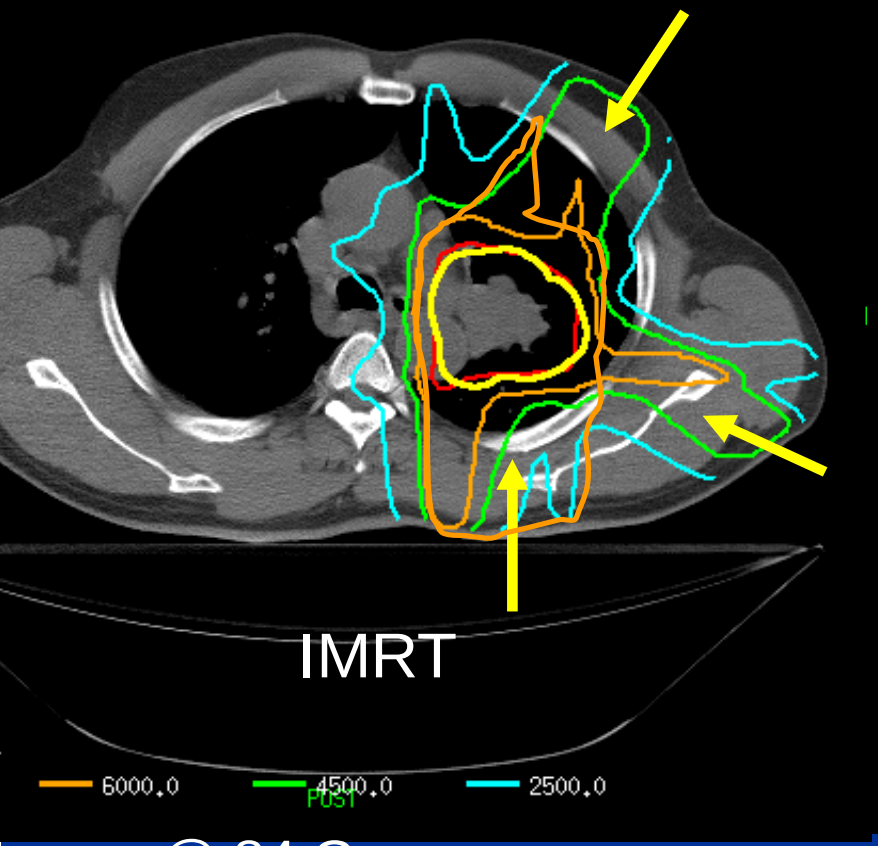


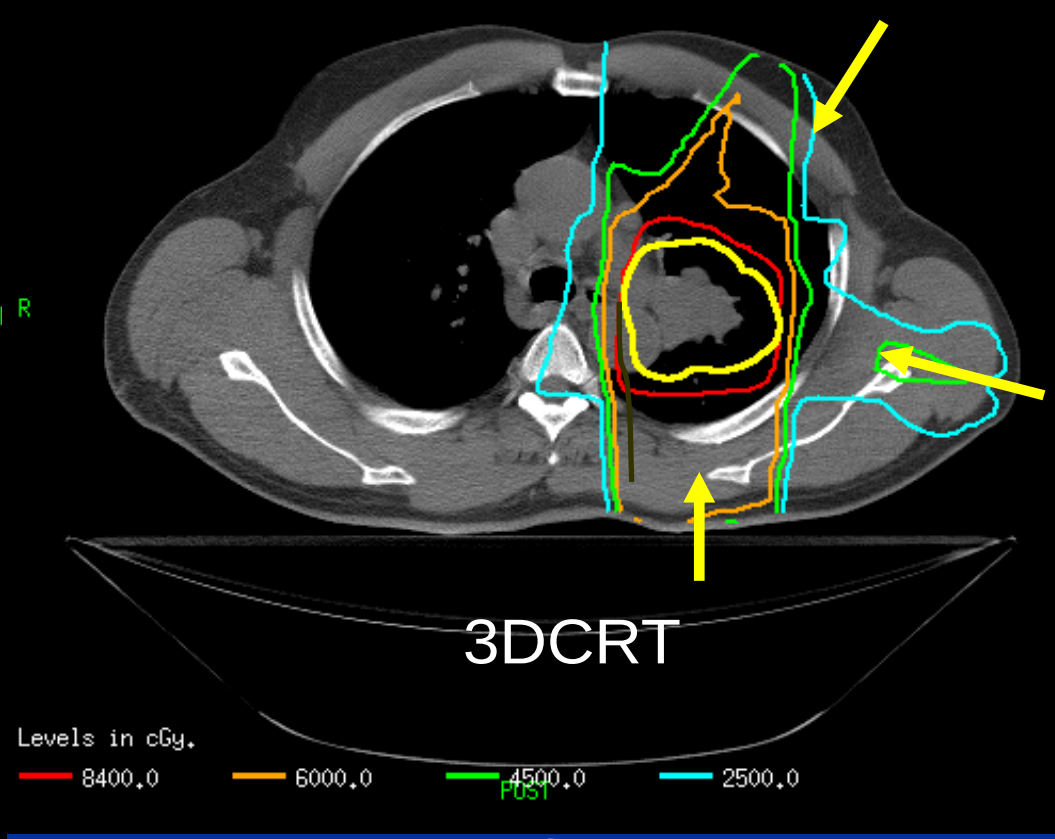


Beam arrangement:
Typically 7 fields depending on location, dose,
amount of cord “enclosure”

H. Amol, ICTP (2007)

Comparison of IMRT and 3DCRT Planning



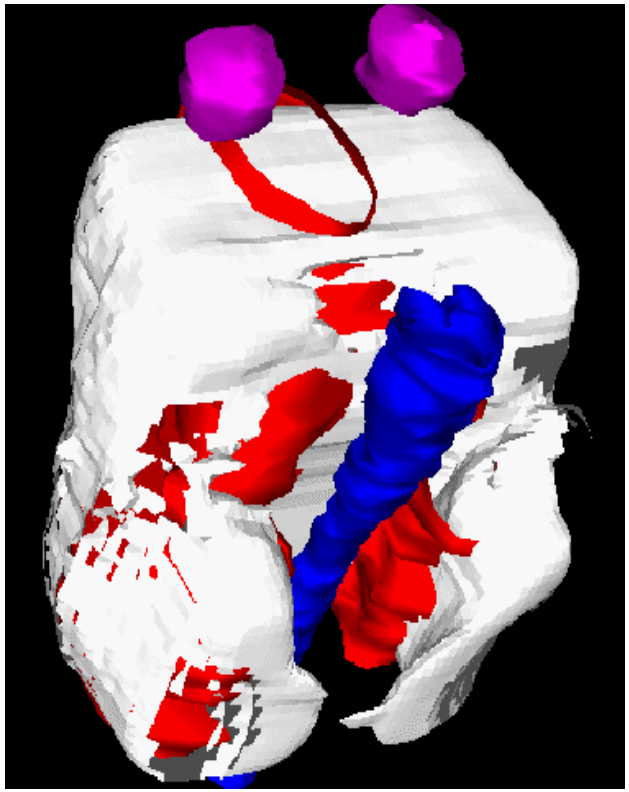


@ 84 Gy,
NTCP = 0.42

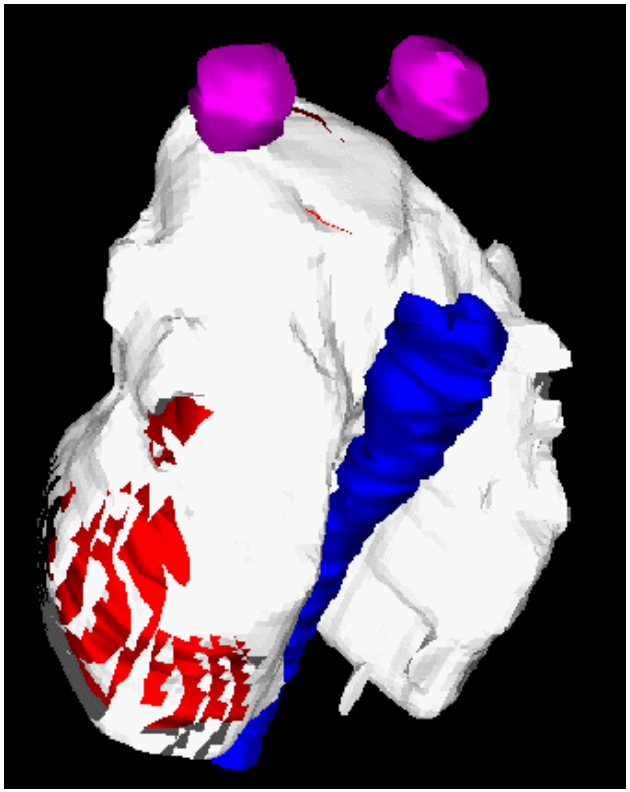
@ 84 Gy
NTCP = 0.77

H. Amol, ICTP (2007)

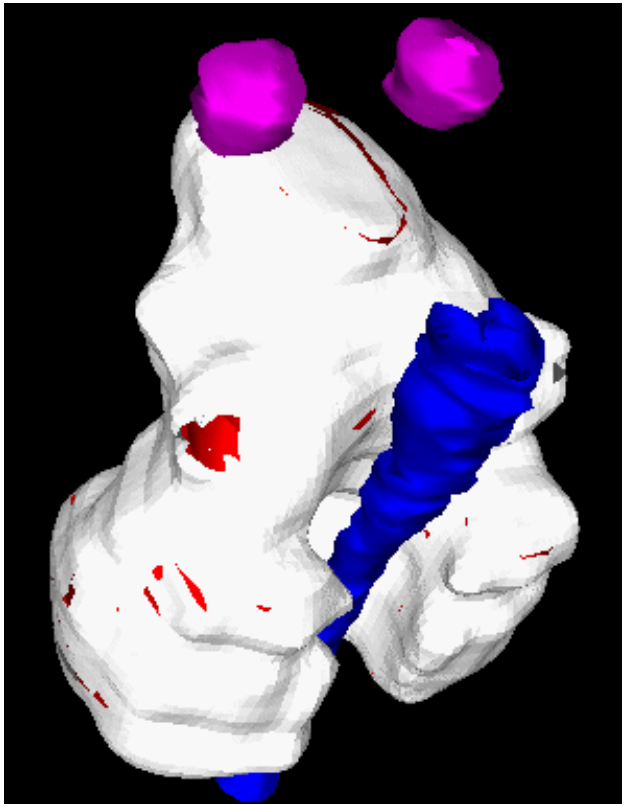
Comparison dose planning simulation (2)



Konvensional



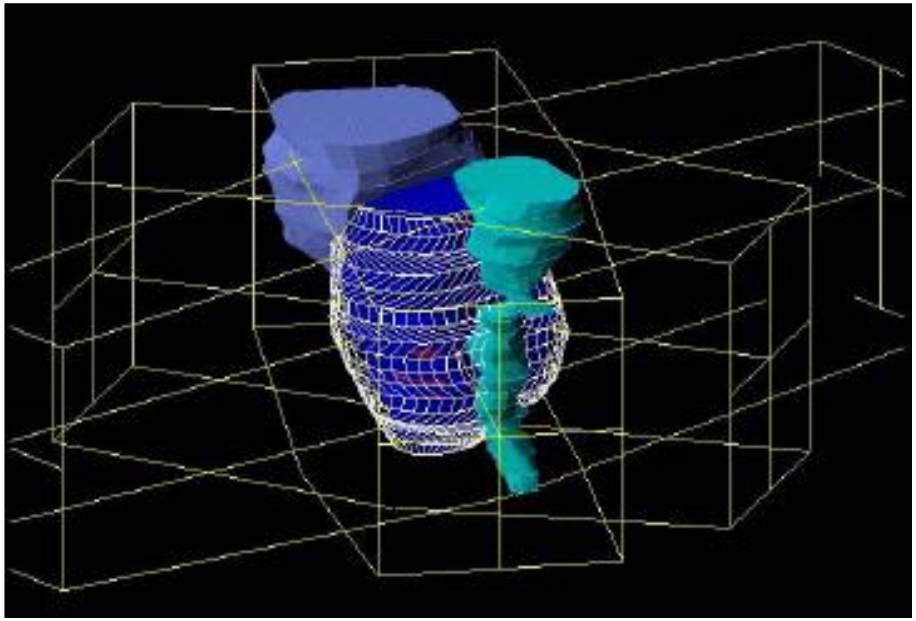
3DCRT

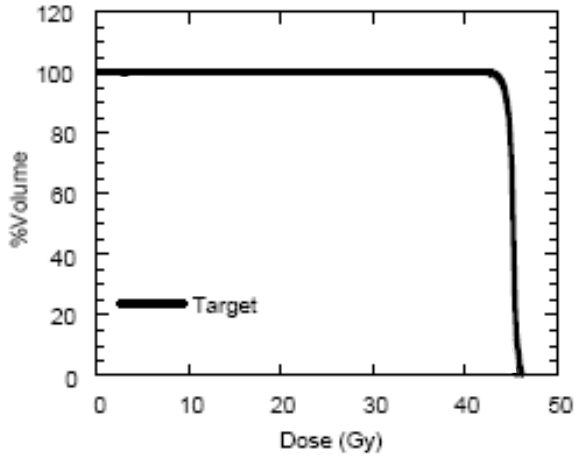


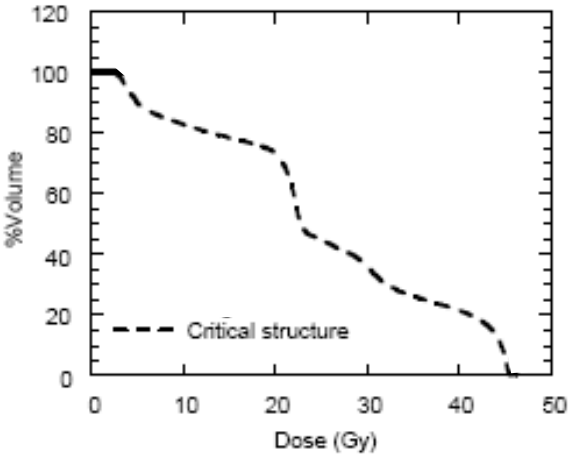
IMRT

H. Amol, ICTP (2007)

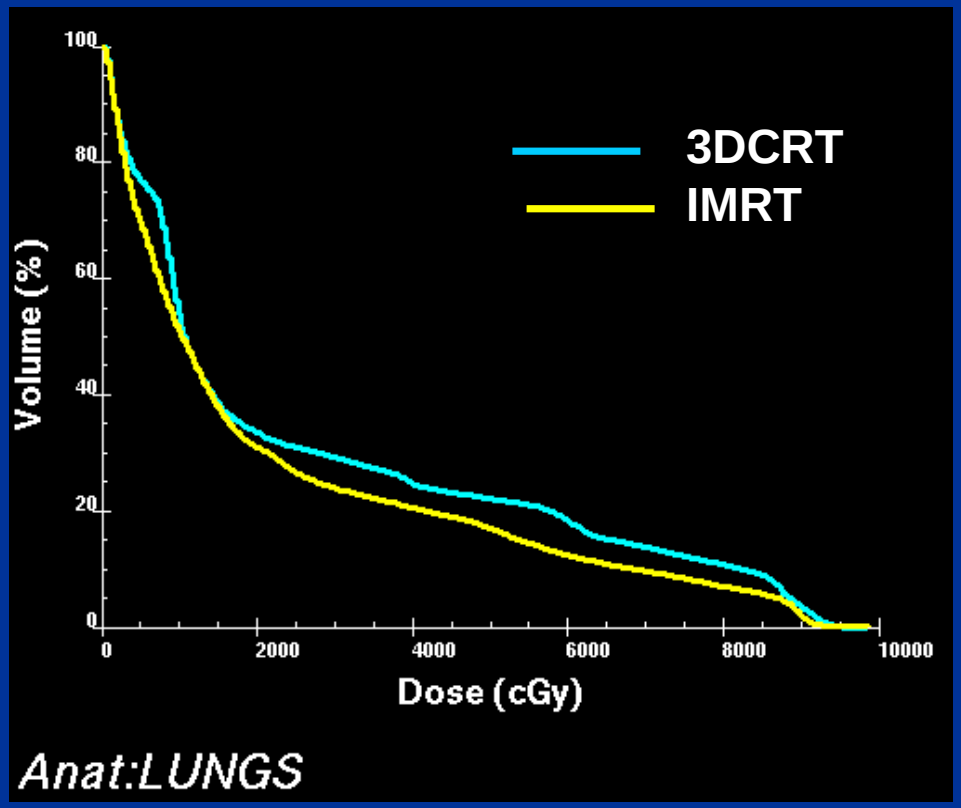
Dose distribution evaluation

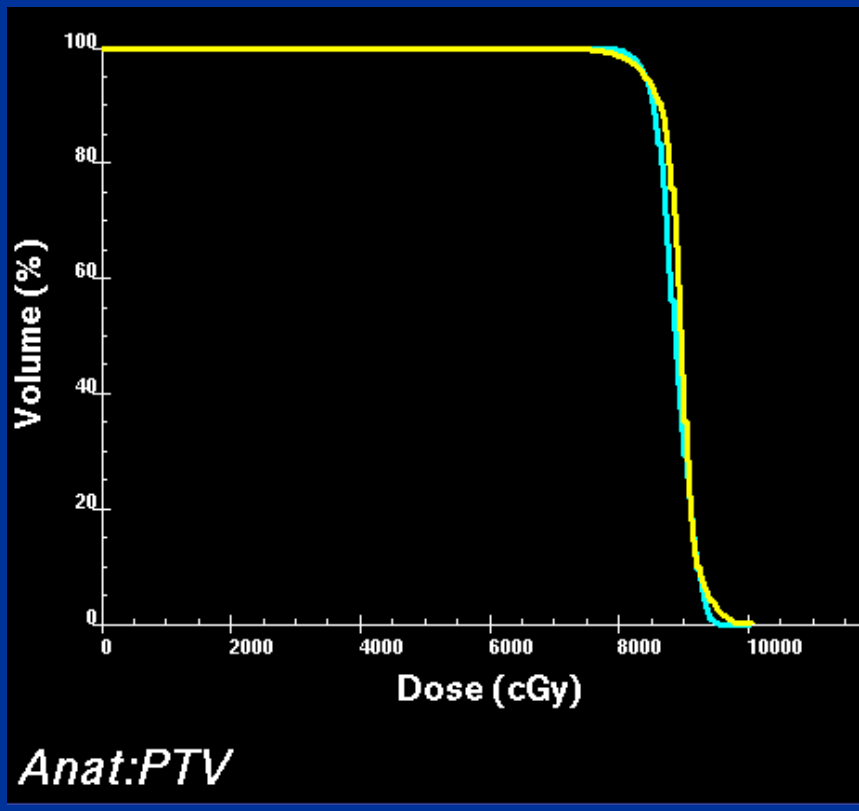






Radiation Oncology Physics : IAEA

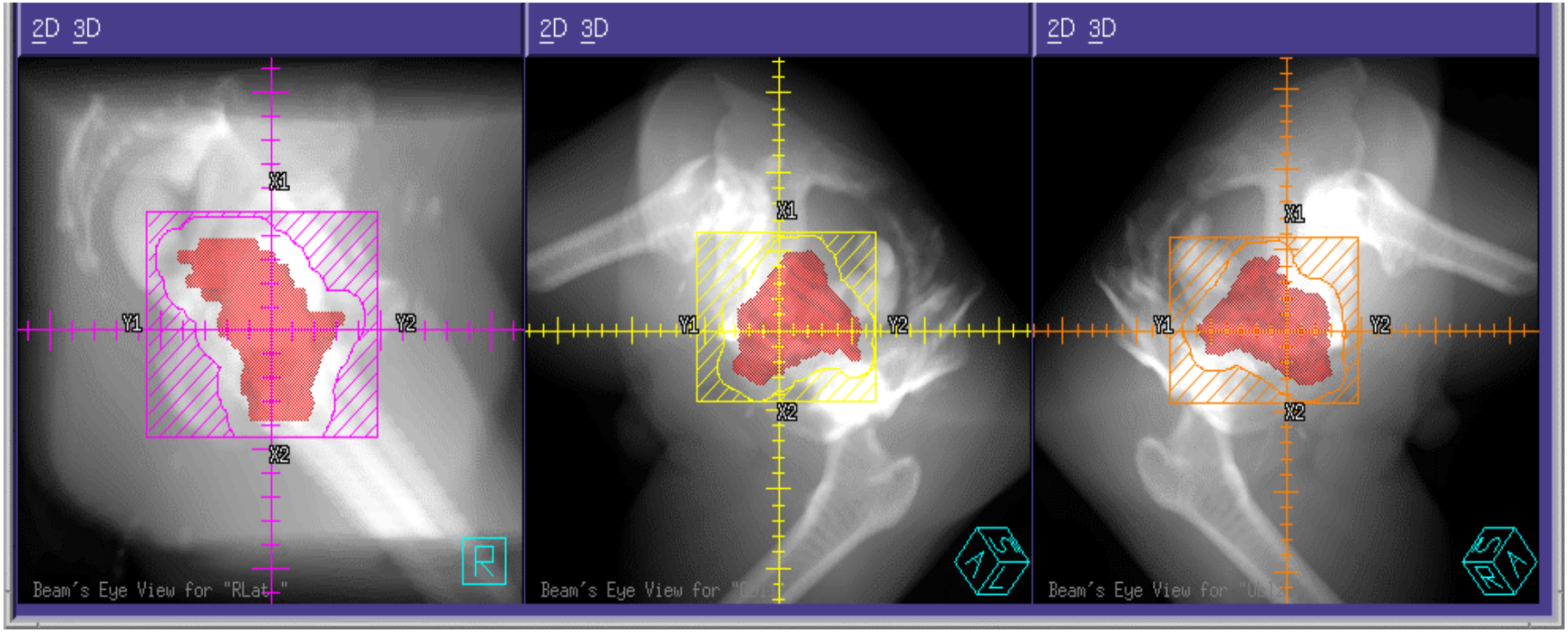




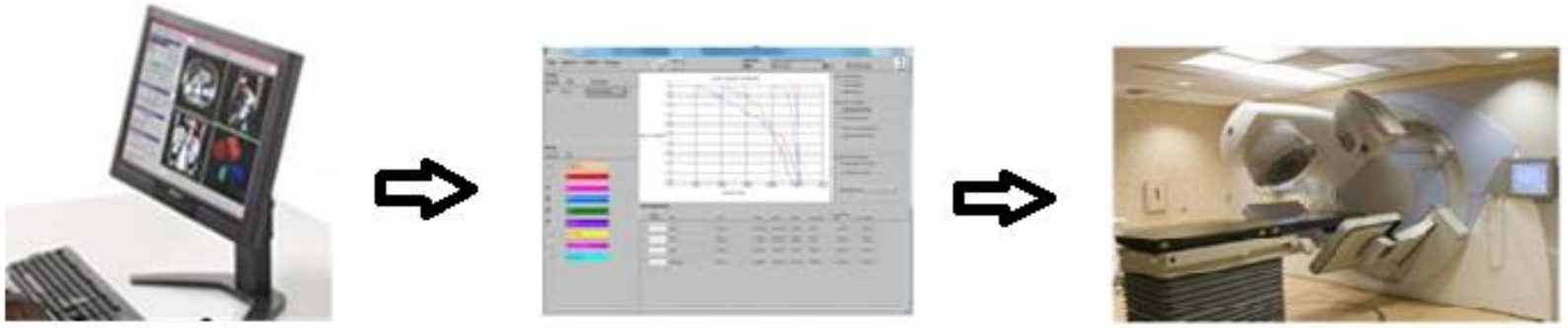
IMRT vs. 3DCRT: DVH for lungs and PTV

H. Amol, ICTP (2007)

Virtual Simulation – Digitally reconstructed radiographs



Transfer Data simulation to Treatment Room



- Data TPS is transferred to treatment room through PACS system
- Data monitor unit and patient positioning of patient will be used by radiation therapist to treat patient
- Before patient treatment, the verification will be performed to check the patient positioning accuracy.
- Image guided system (Electronic portal imaging devices (EPID) or Cone beam CT (CBCT) are employed for this proposes

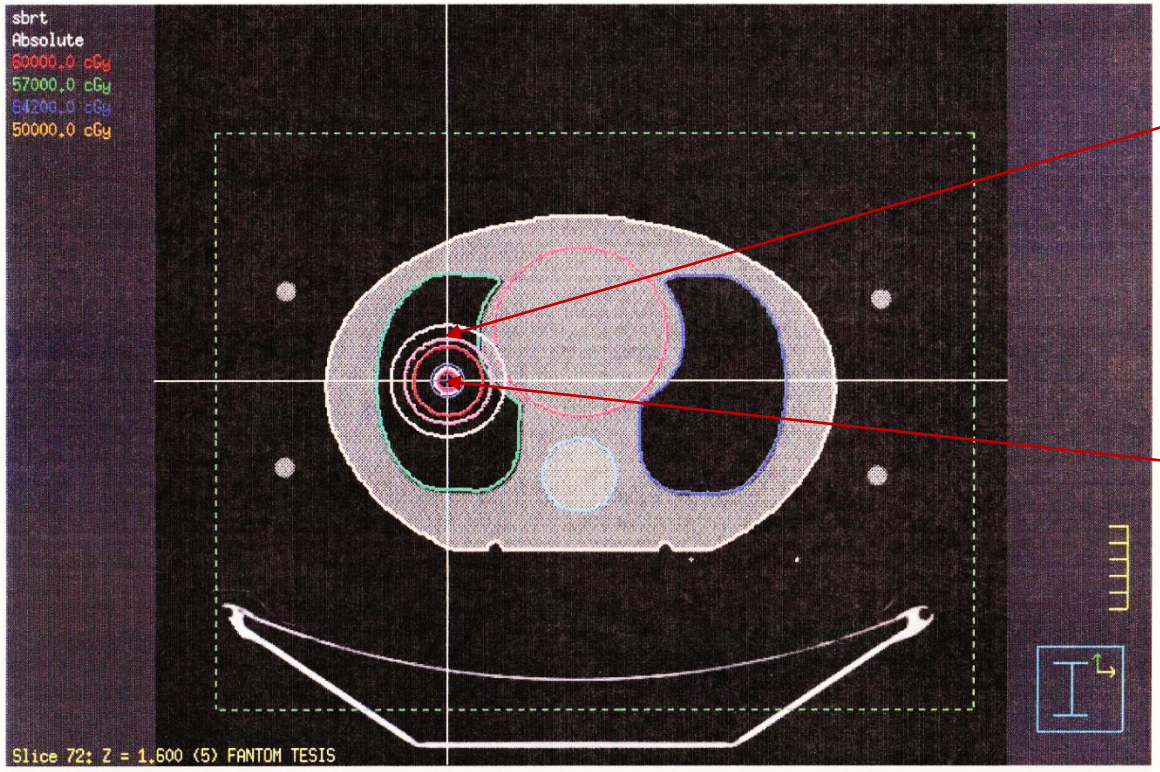
Dose Verification or Patient Specific QA ?

- This is aimed to ensure that the dose delivered to patient is accurate as simulated in treatment planning
- The best way is direct measurement for all patient, however it will consume the time
- It will be performed after patient treatment finished

Patient Specific QA

- The PSQA is procedure to ensure the dose delivering to patient
- Some methods :
  - Point dose Measurement (Ionization chamber, film, TLD)
  - Planar Dose Measurement(MatriXX, EPID)
  - 3D dose verification (Gel Dosimetry)
  - Log File Dose Verification

Dose Simulation In TPS



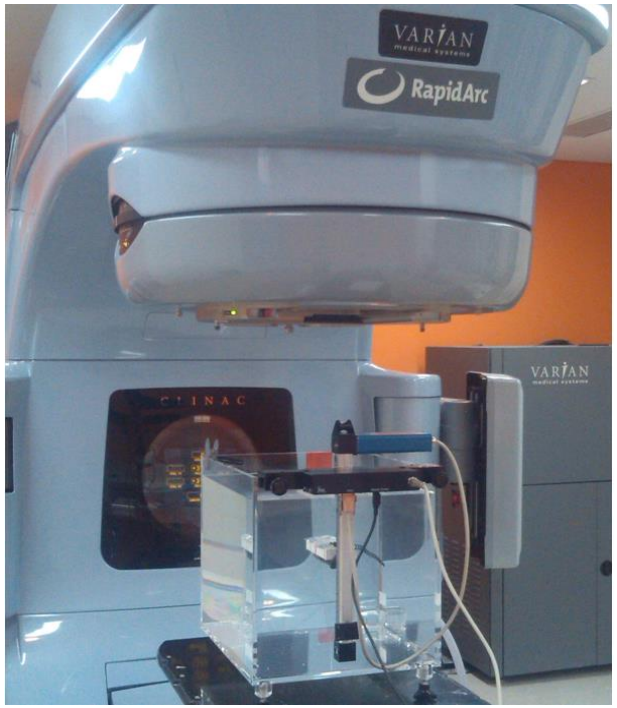
3D-CRT & IMRT

GTV = 2.5 cm (24.2 cc)
CTV = GTV + 0.5 cm (35 cc)
PTV = CTV + 0.5 cm (56.3 cc)

SBRT

GTV = 1 cm (3.8 cc)
CTV = GTV + 0.1 cm (4.5 cc)
PTV = CTV + 0.1 cm (5.4 cc)

Linac Output Calibration



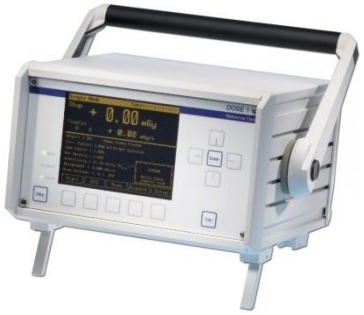
Water phantom IBA WP1D
(10 cm depth, SAD 100 cm, FS 10 x 10)

Chamber Farmer FC65-G

- RapidArc Clinac® iX Linac for **x-ray photon beam 6 MV**
- Ionization chamber type Farmer FC65-G and Wellhofer Dose1 electrometer (calibrated by PTKMR BATAN)
- Determination of photon beam output at z_{ref} and z_{max} is calculated according to Equations:

$$D_{w,Q}(z_{ref}) = M_Q . N_{D,w,Q0} . k_{Q,Q_o}$$

$$D_{w,Q}(z_{max}) = \frac{100 . D_{w,Q}(z_{ref})}{TMR(z_{ref})}$$



Electrometer Dose1 (Wellhofer)

Classification and Calibration of TLD-100

Water phantom IBA WP1D

TLD reader Harshaw 3500

- TLD classification was performed to reduce response variation of TLD dosimeter reading during experiment.
- **The TLDs had sensitivity in the range of ±3% each group.**
- TLDs were placed at depth *(z)* of 10 cm and irradiated using x-ray photon beam 6 MV with **single dose at about 200 cGy**, field size of 10 x 10 cm^2, and SAD of 100 cm.
- After 48 hr → reading

Calibration of Gafchromic EBT Film

Solid water phantom Adapterplate RW3-FC65

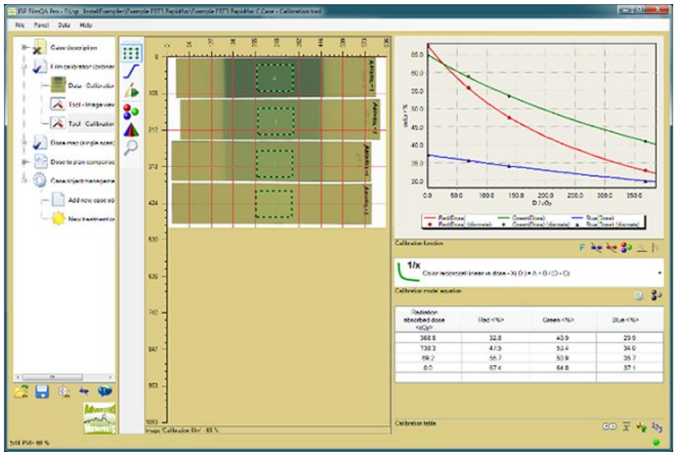
- SAD 100 cm, FS 10 x 10 cm

- Film inserted at depth of 10 cm and irradiated using X-ray photon beam 6 MV

Serial Dose Calibration

No	MU	Dose(cGy)
1	20	15.727
2	40	31.455
3	80	62.909
4	120	94.364
5	160	125.818
6	200	157.273
7	240	188.727
8	280	220.182
9	320	251.636
10	360	283.091
11	400	314.546

Epson V700 Scanner (Res. 72 DPI, TIFF)



FilmQA Pro & ImageJ Software

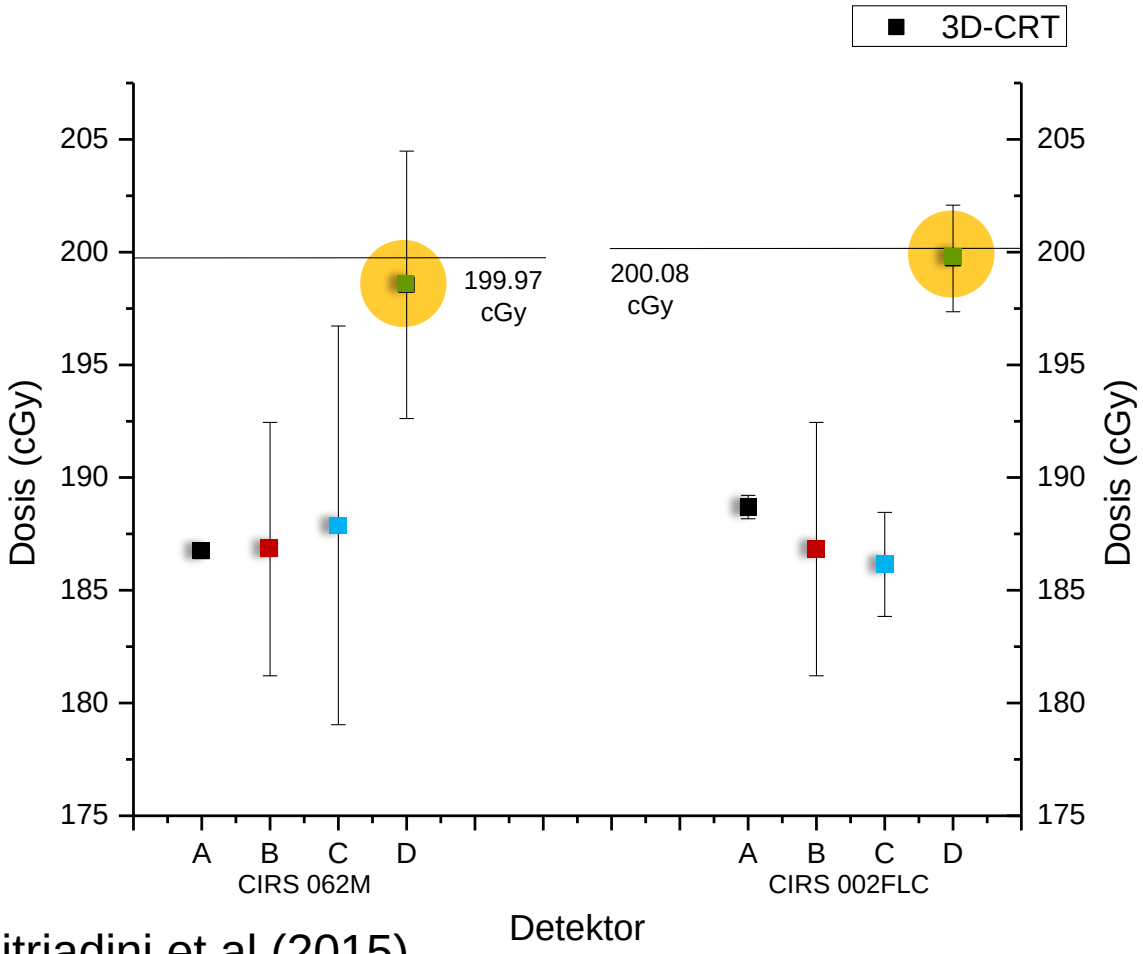
Dosimetry Analysis

The dose difference (Δ%) of measured dose and planned dose were evaluated according to AAPM TG 119 recommendation:

$$(\Delta\ \%) = 100x\left(\frac{D_{meas} - D_{plan}}{D_{prescription}}\right)$$

Dose comparison in Simulated Target

3D-CRT



- A) PTW N30013
- B) Exradin A16
- C) TLD
- D) Film EBT2

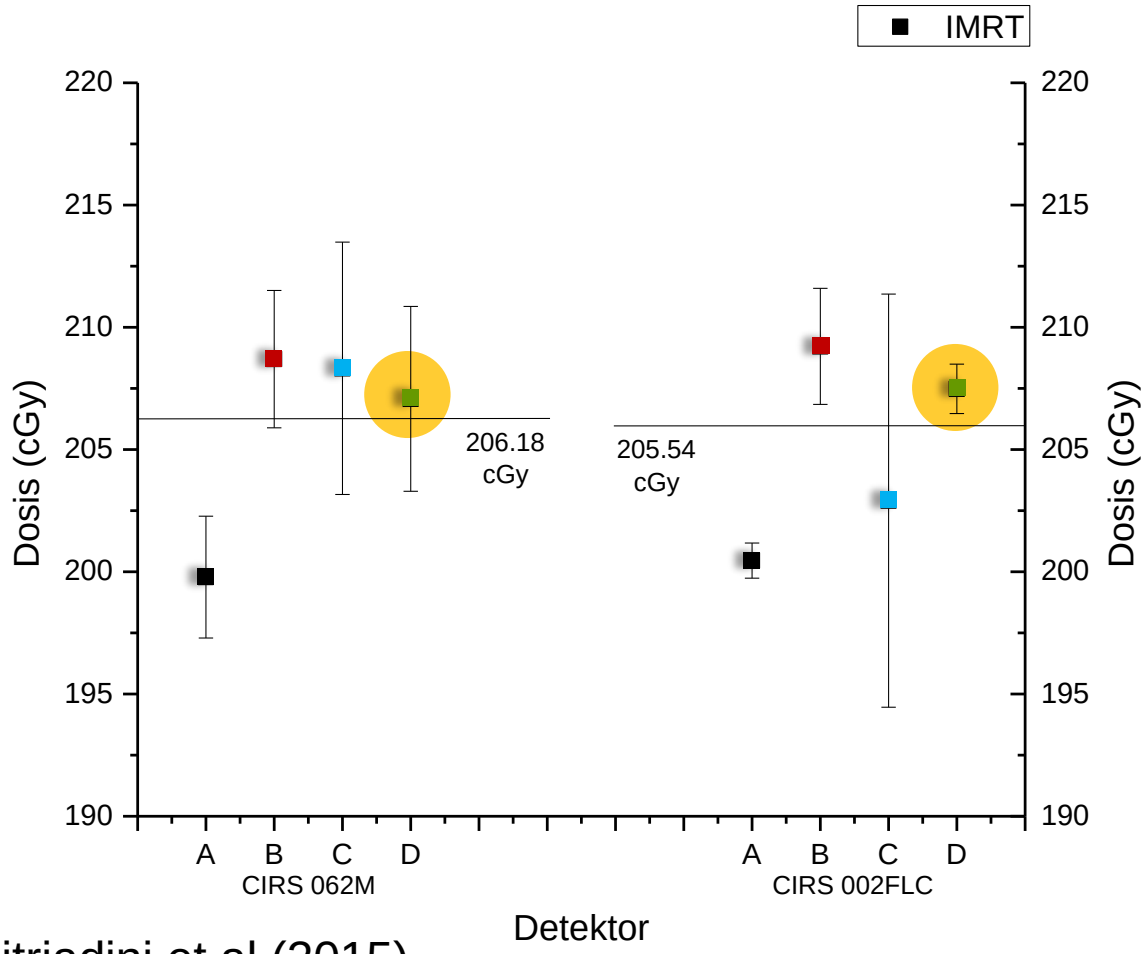
***Discrepancy**

Dosemeter	0062M	002FLC
PTW N30013	-6.62%	-5.69%
Exradin A16	-6.57%	-6.62%
TLD	-6.44%	-6.96%
Film EBT2	-0.71%	-0.18%

Fitriadini et al (2015)

Dose Comparison in Simulated Target

IMRT



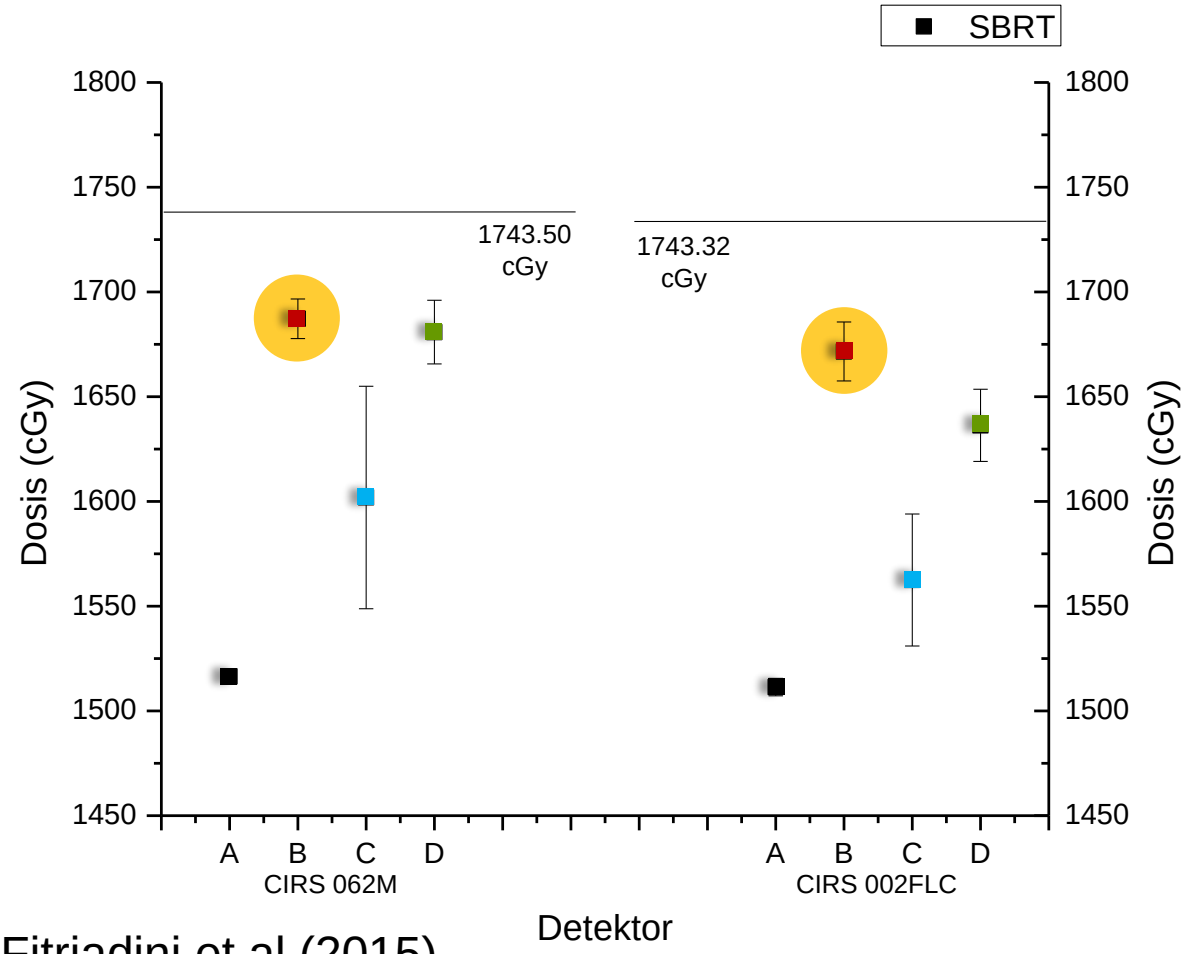
Fitriadini et al (2015)

***Discrepancy**

Dosemeter	0062M	002FLC
PTW N30013	-3.10%	-2.47%
Exradin A16	1.22%	1.79%
TLD	1.04%	-1.28%
Film EBT2	0.43%	0.94%

Dose Comparison in simulated target

SBRT



Fitriadini et al (2015)

Discrepancy

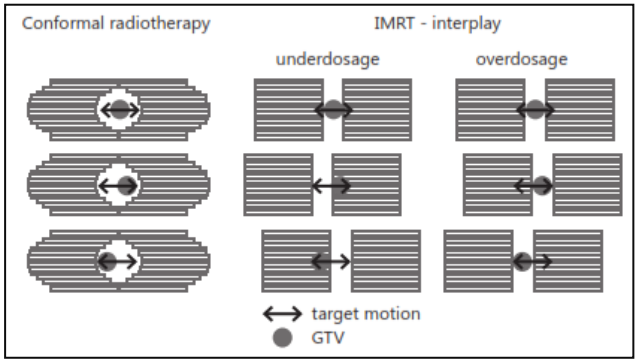
Dosemeter	0062M	002FLC
PTW N30013	-13.02%	-13.30%
Exradin A16	-3.23%	-4.12%
TLD	-8.12%	-10.37%
Film EBT2	-3.59%	-6.14%

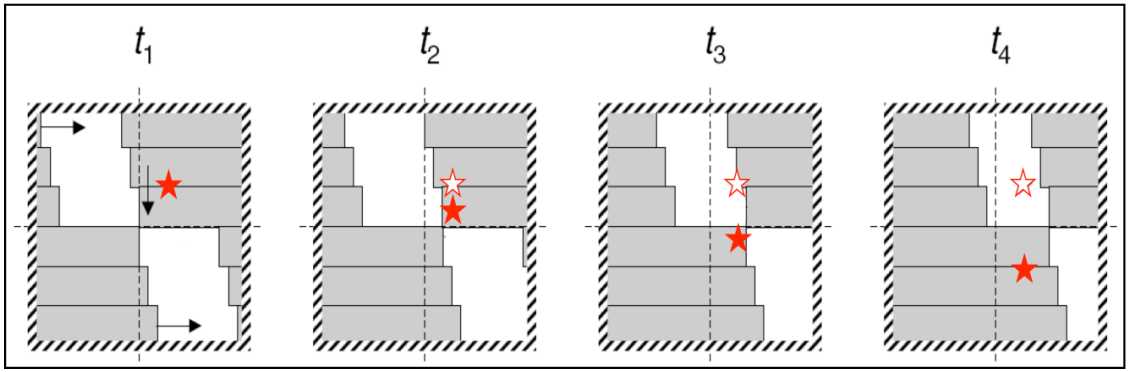
Conclusion

- EBT film has highest precision with uncertainty less than 2% → Inline with Devic (2007) and Yarahmadi (2013)
- TLD has highest uncertainty → Inline with Viera (2012)
- The dosimetry in small field dosimetry (example SBRT) has to follow the new protocol dosimetry and also aware with volume averaging correction factor

Dose verification in target motion ?

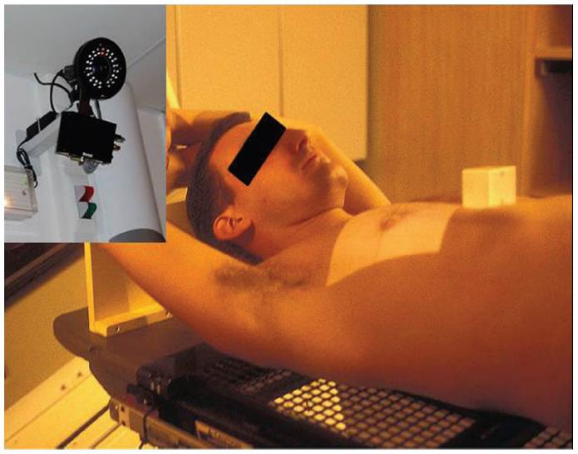
- IMRT and VMAT in lung cancer treatment in Indonesia → Not implemented the respiratory management technique (i.e IGRT and tumor tracking)
- The presence of **tumour motion** during dose delivery can generate unwanted dose discrepancies inside the TV → **Interplay effect.**
  - is caused by the combination of the intra-fraction target motion and the beam motion (MLC) which generates variations of the dose each voxel.
  - Limited to intensity modulated treatments, where only a fraction of the PTV is irradiated at any given time.

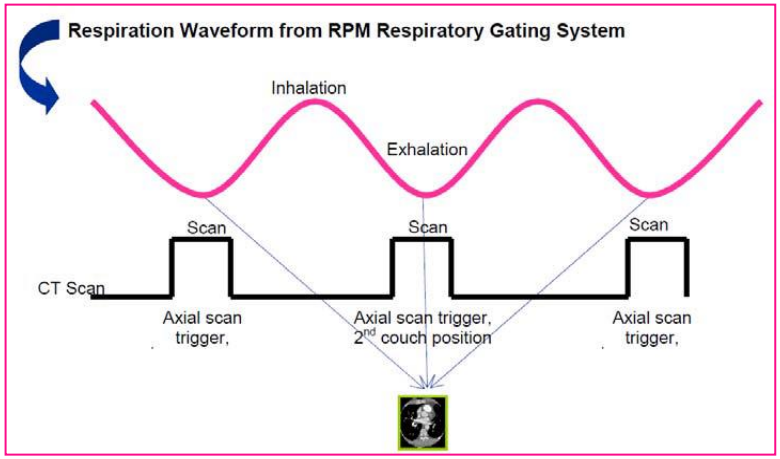




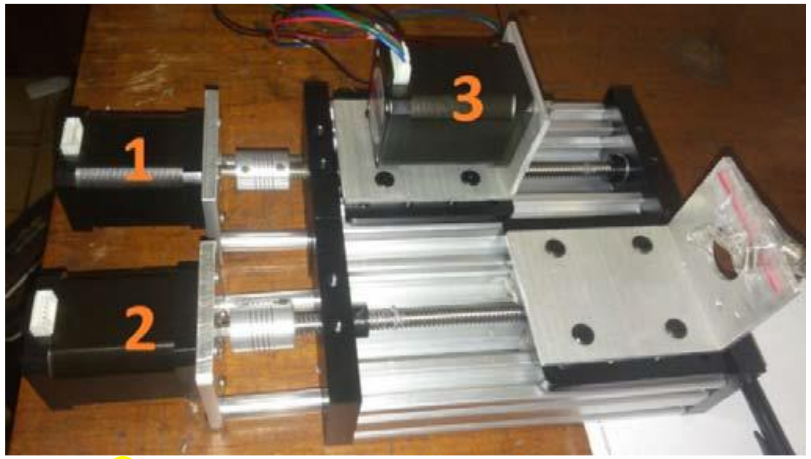
Movement organ problem in radiotherapy

RPM (*Real-Time Position Management*) (Merk: Varian)

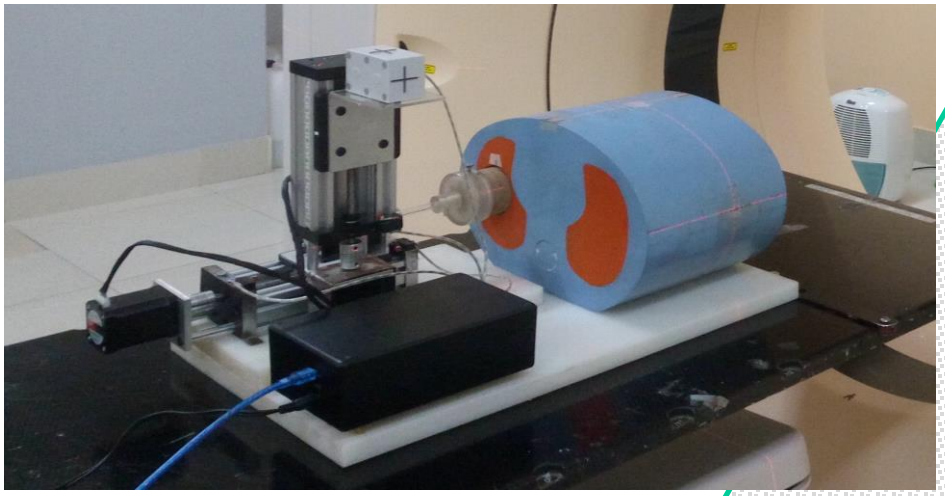


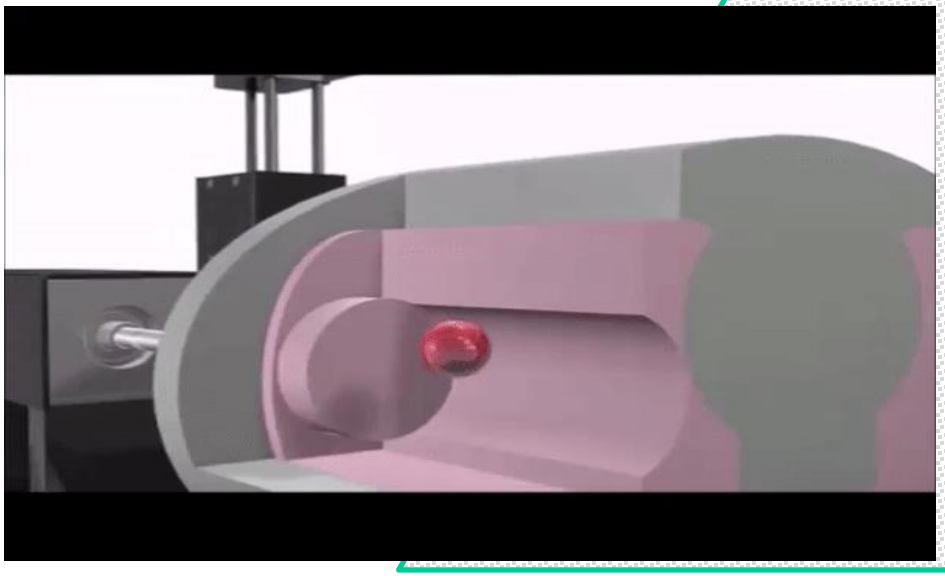


Phantom Design



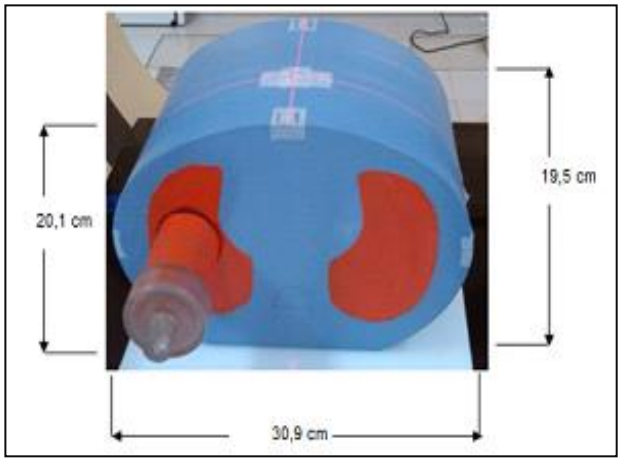
3 Motor Stepper for motion simulation



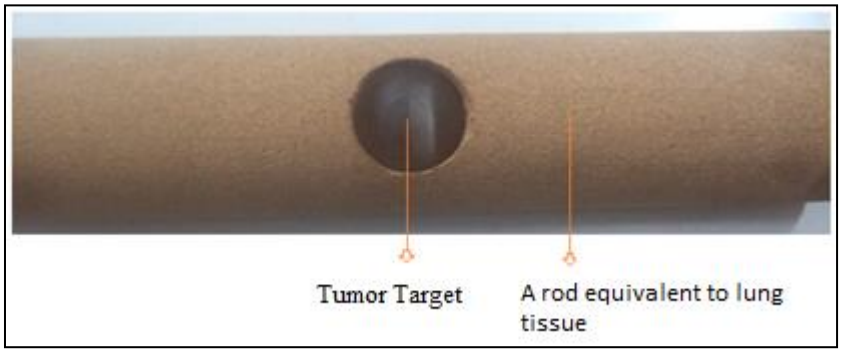


Wijanarko et al (2020)

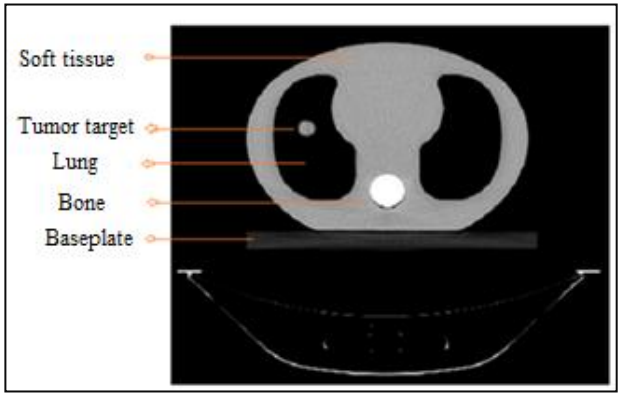
In-House Dynamic Thorax Phantom Development



Oval shaped thorax phantom

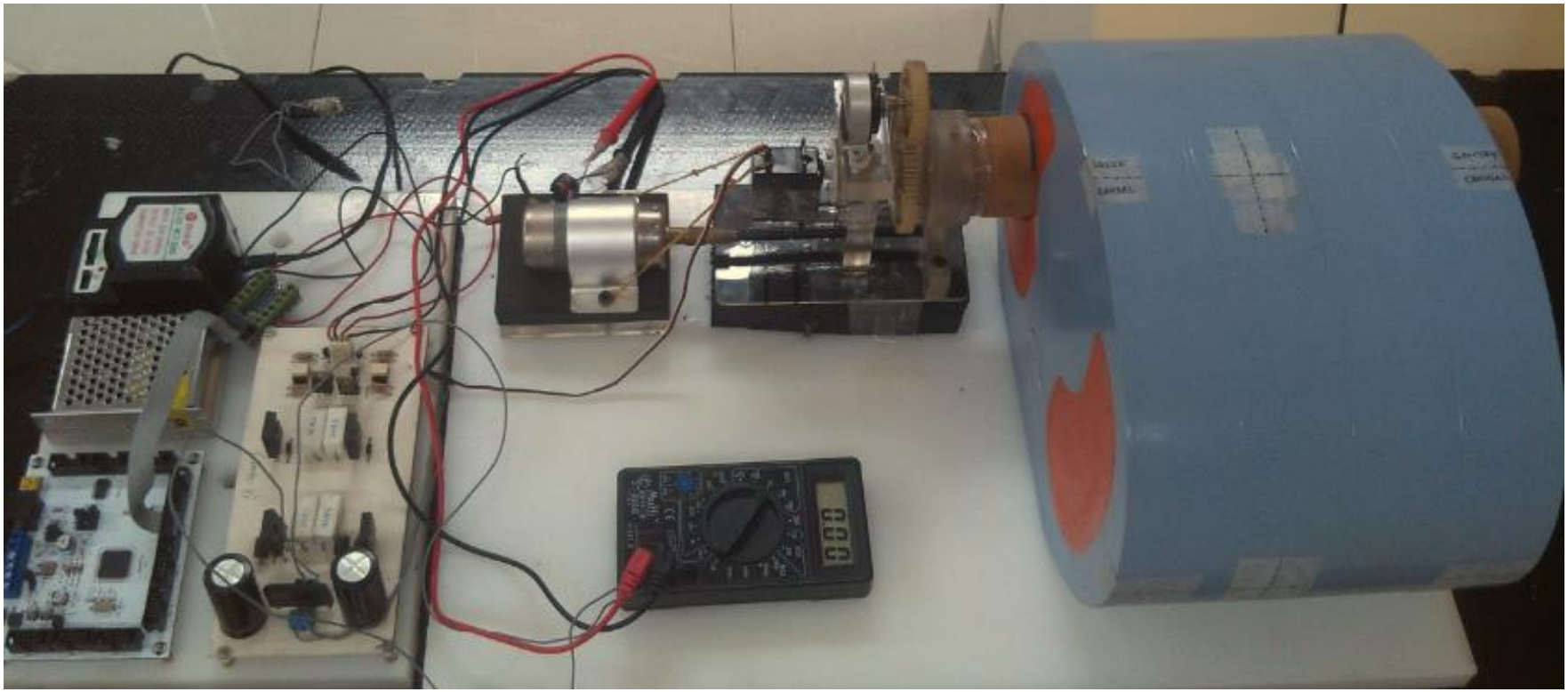


A rod equivalent to lung tissue contain spherical shaped target is represented tumor target with diameter of 33.5 mm (volume of 19.7 cc)



Radiograph of Thorax Phantom

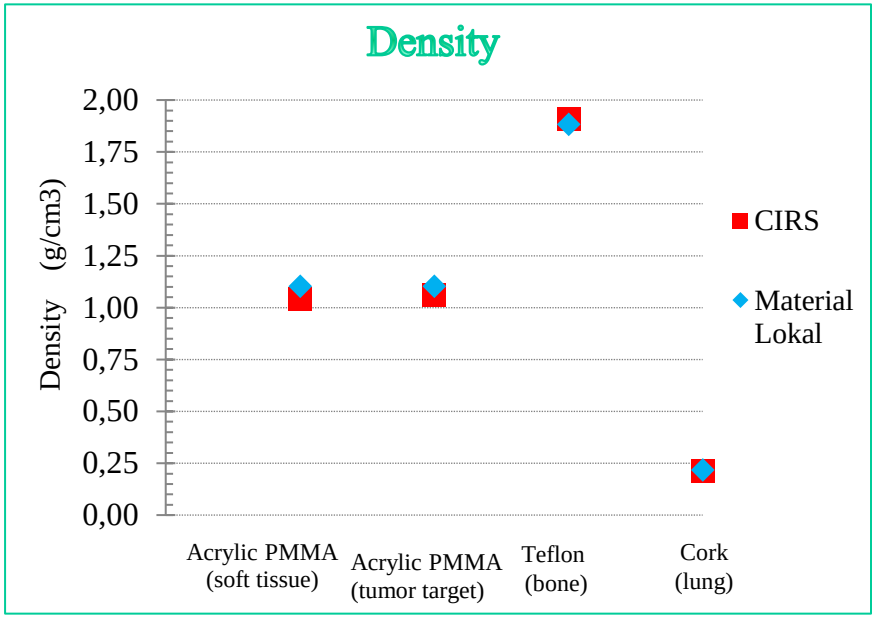
Parameter	Spesification
Dimension	51.5 cm x 30.5 cm x 22.1 cm
Weight	17.1 Kg
Material	• Acrylic PMMA (Soft tissue & tumor target) • Cork (Lung) • Teflon (Bone) • PE (Baseplate)

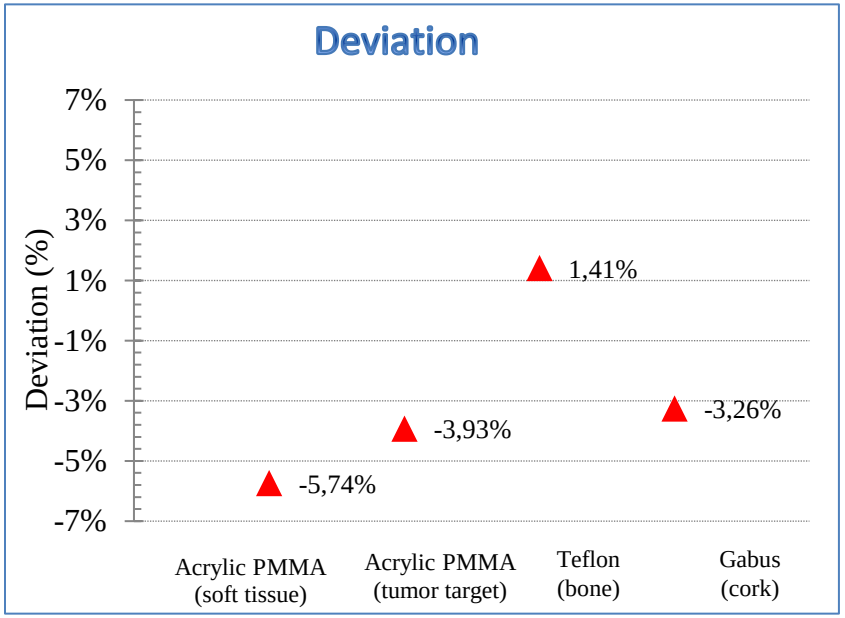


Motion Amplitude	Motion Period
9.3 mm	2.3 s
20 mm	3.44 s
30 mm	4.22 s

The average breathing cycle of lung tumor motion:
amplitude ±20 mm and frequency of 12 – 17 cycle/minute (period of 3.5 – 5 s)

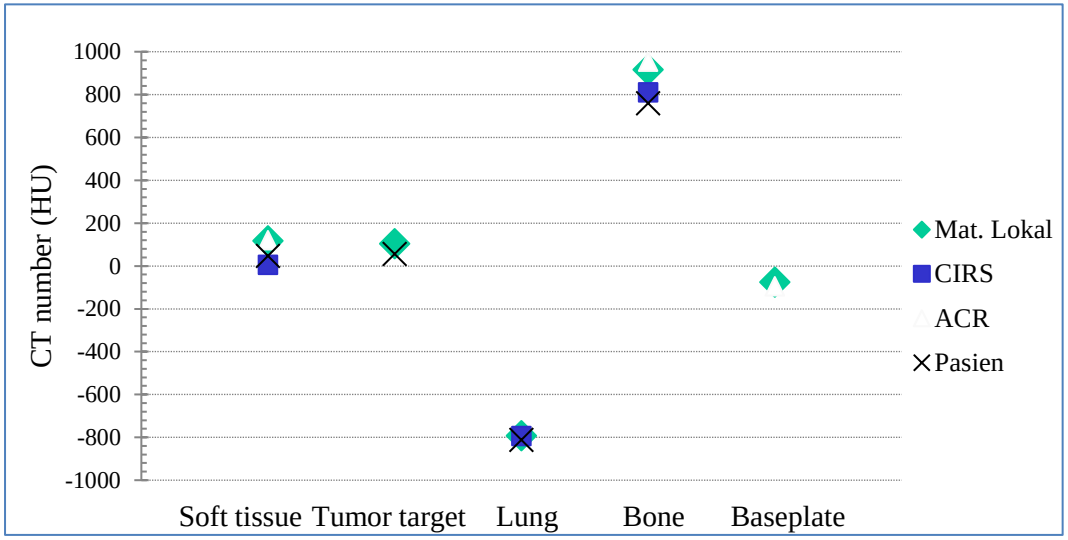
Density and deviation values of local material and CIRS





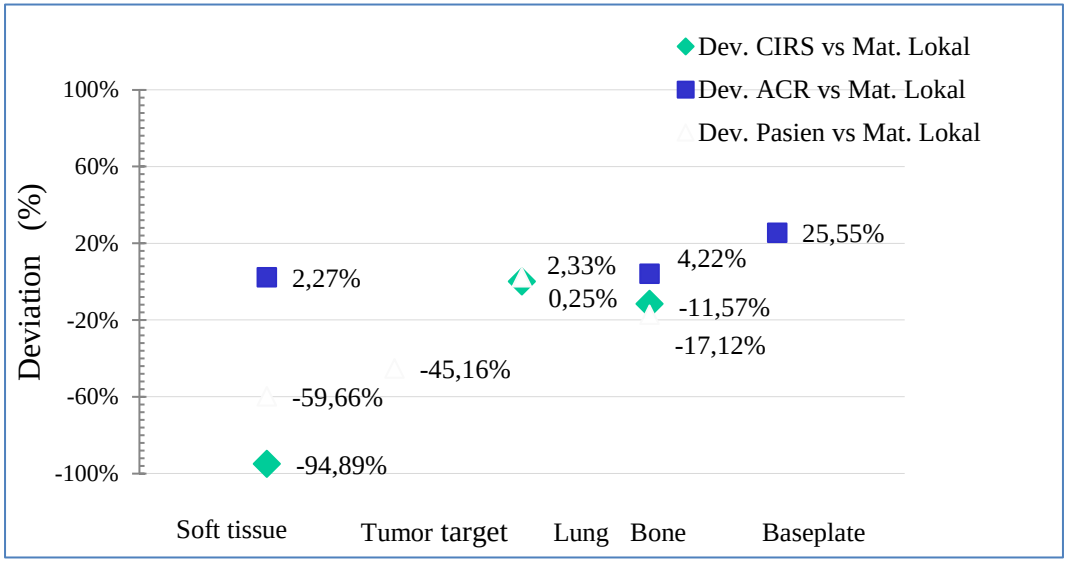
Materials	Organ simulation	Density of CIRS (g/cm^3)	Density of local material (g/cm^3)	Deviation (%)
Acrylic (PMMA)	Soft tissue	1.04	1.103 ± 0.001	-5.74
Acrylic (PMMA)	Tumor target	1.06	1.103 ± 0.001	-3.93
Teflon (PTFE)	Bone	1.91	1.883 ± 0.001	1.41
Cork	Lung	0.21	0.217 ± 0.001	-3.26
Polyethylene (PE)	Baseplate	-	0.977 ± 0.001	-

CT number (HU) of local material, CIRS, ACR and patient

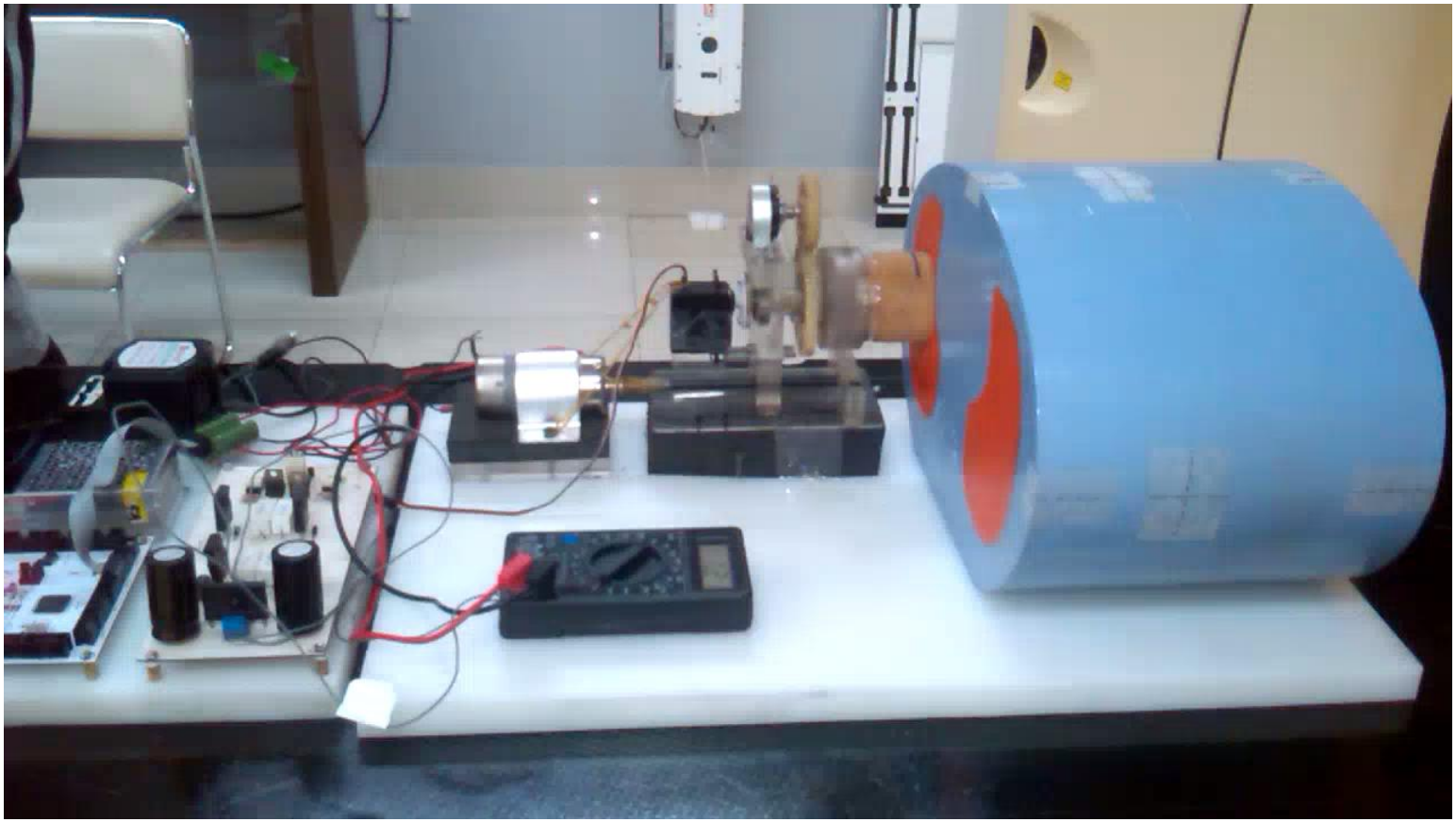


Organ	CT number (HU)			
	Local material	CIRS	ACR	Patient
Soft tissue	117.333 ± 1.528	6.000 ± 2.000	120	47.333 ± 3.215
Tumor target	103.333 ± 2.517	-	-	56.667 ± 5.831
Lung	-792.660 ± 2.082	-794.660 ± 2.517	-	-811.110 ± 54.654
Bone	916.333 ± 1.528	810.333 ± 5.508	955	759.444 ± 42.217
Baseplate	-75.667 ± 1.528	-	-95	-

CT number (HU) deviation of local material, CIRS, ACR and patient

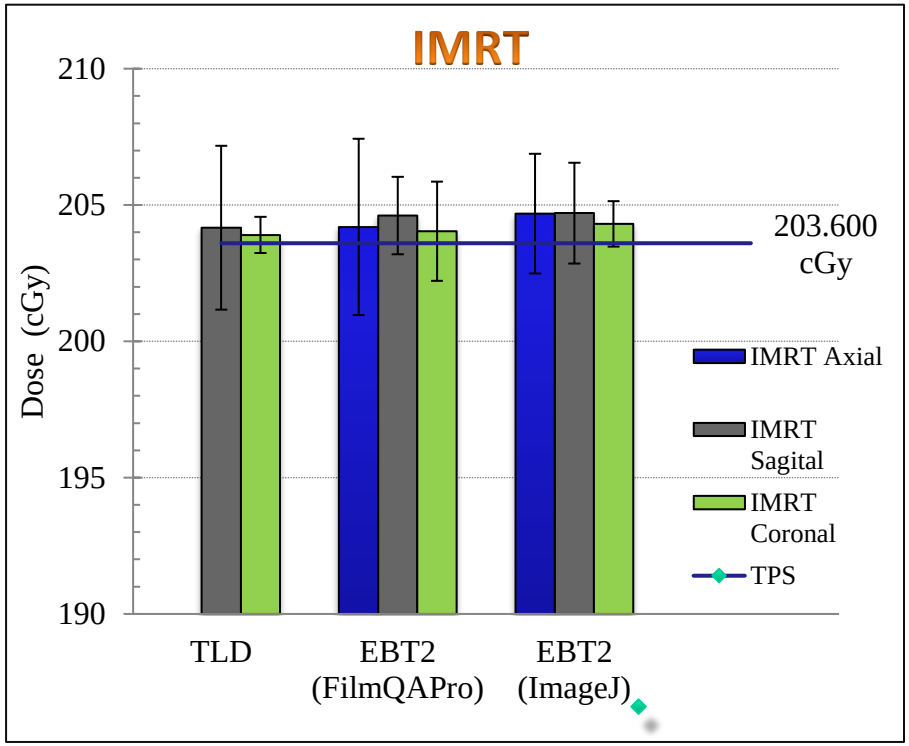


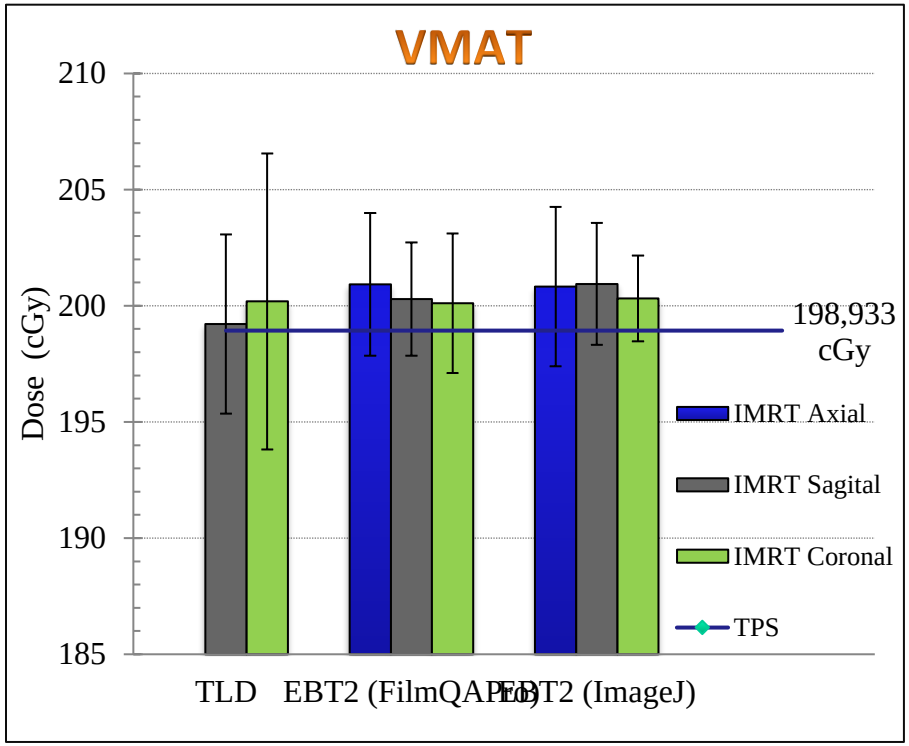
Organ	CT Number Deviation (%)		
	CIRS vs Local Material	ACR vs Local Material	Patient vs Local Material
Soft tissue	-94.89	2.27 (3 HU)	-59.66
Tumor target	-	-	-45.16
Lung	0.25 (2 HU)	-	2.33 (16 HU)
Bone	-11.57	4.22 (39 HU)	-17.12
Baseplate	-	25.55	-



Translation motion	Periods
9,3 mm	2,3 sekon
20 mm	3,44 sekon
30 mm	4,22 sekon

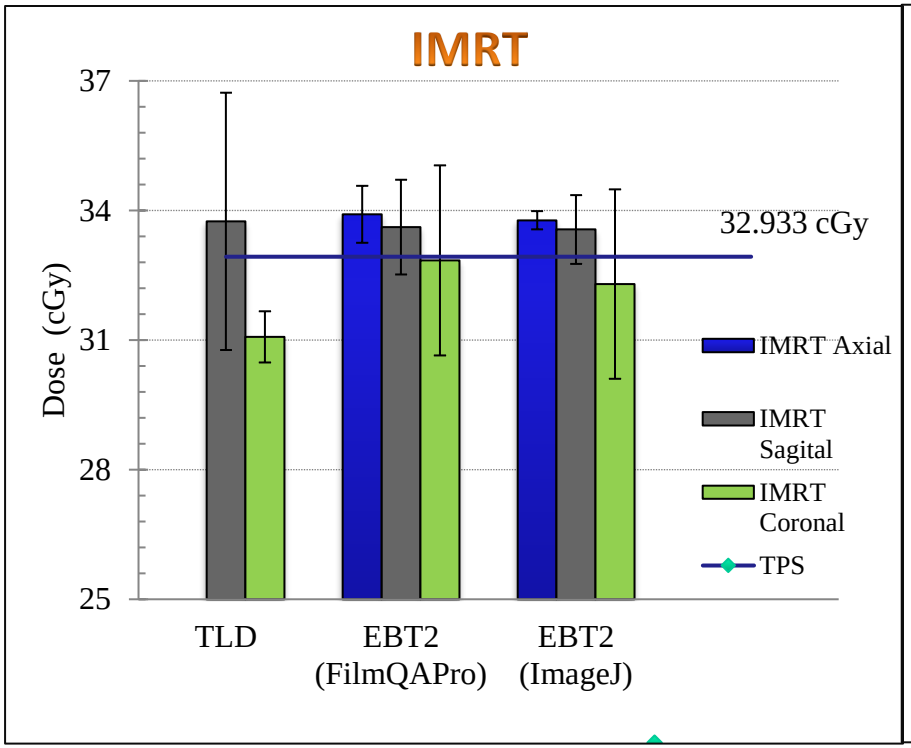
Ratio of mean dose value in tumor target

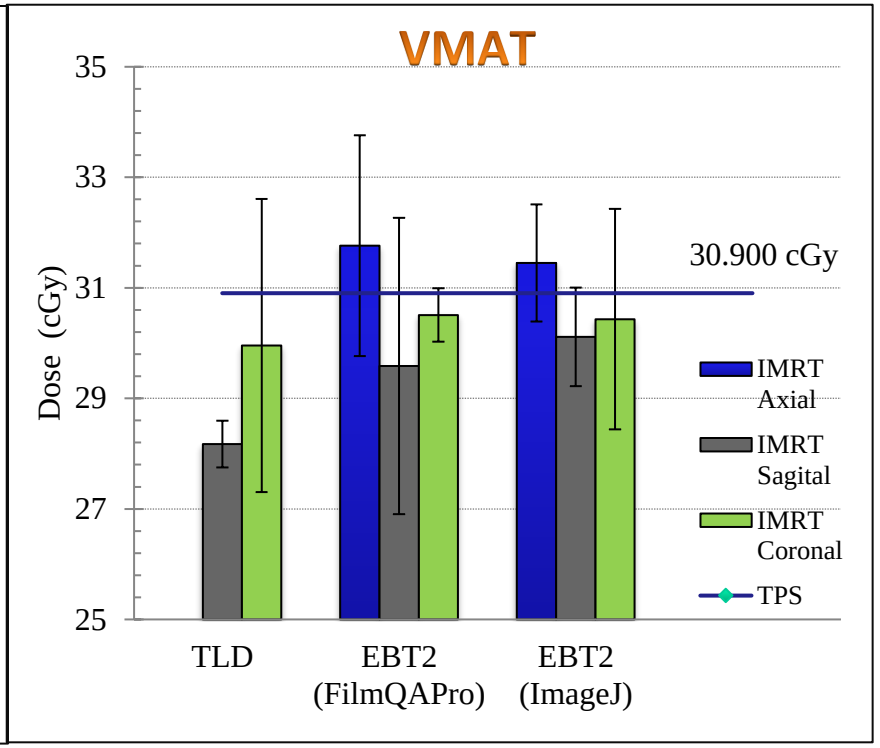




Mukhlisin et al (2017)

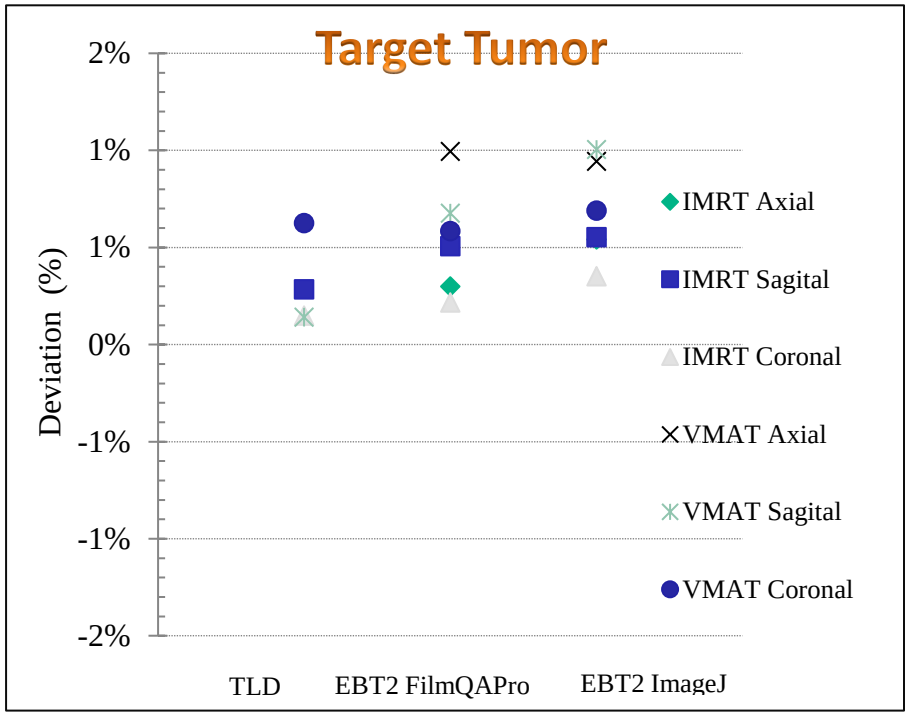
Ratio of mean dose value in spinal cord

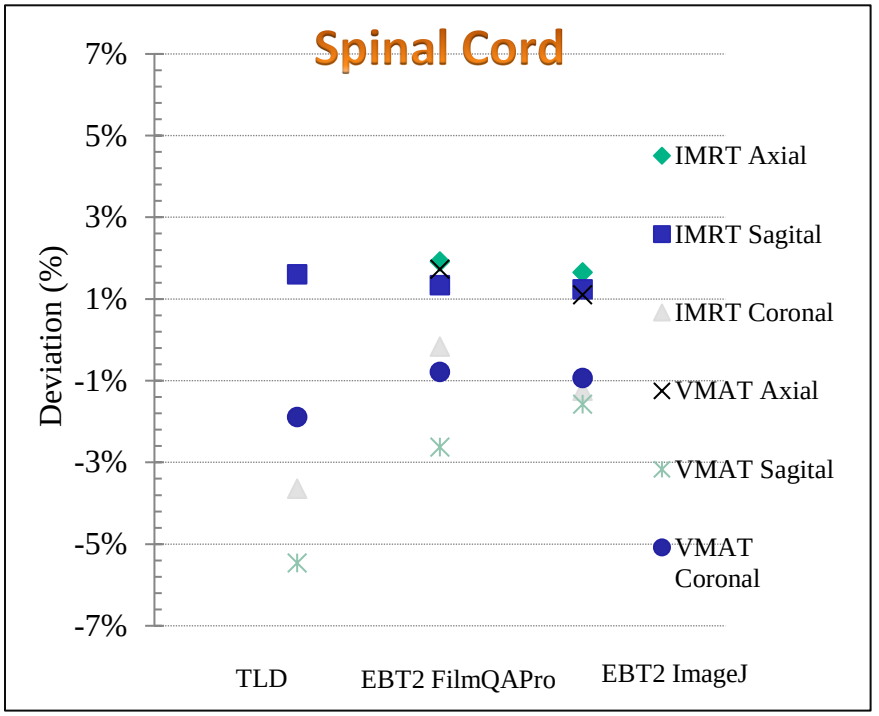




Mukhlisin et al (2017)

Percentage of dose deviation (TPS vs Measurement)



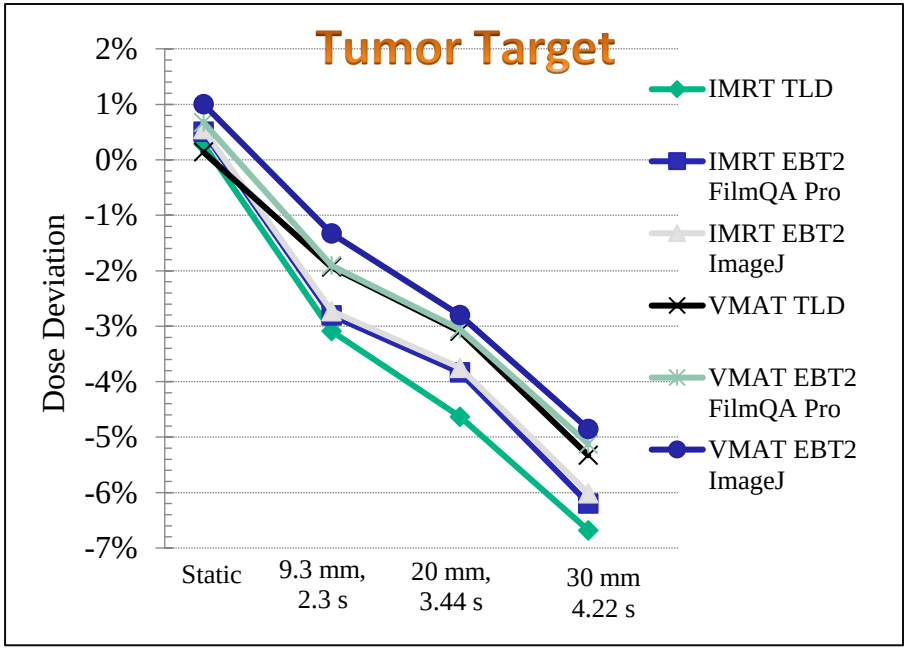


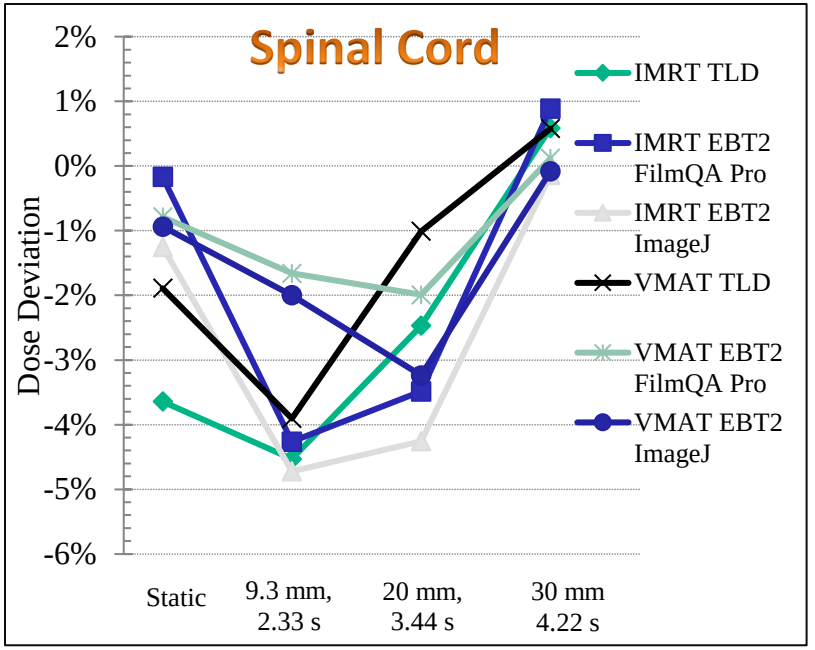
	IMRT	VMAT
Tumor Target	0.15 to 0.55%	0.14 to 1%
Spinal Cord	-3.64 to 1.65%	-5.47 to 1.73%

- The percentage of dose discrepancy between TPS and measurement in target tumor is closed to tolerance level of ICRU recommendation (-5% and +7%), as well AAPM recommendation (±5%).

Mukhlisin et al (2017)

Percentage dose deviation in dynamic tumor target and spinal cord (TPS vs Measurement)





- The increasing of tumor target amplitude could **increase** the dose deviation of tumor target.
- The increasing of tumor target amplitude could **decrease** the dose deviation of spinal cord.

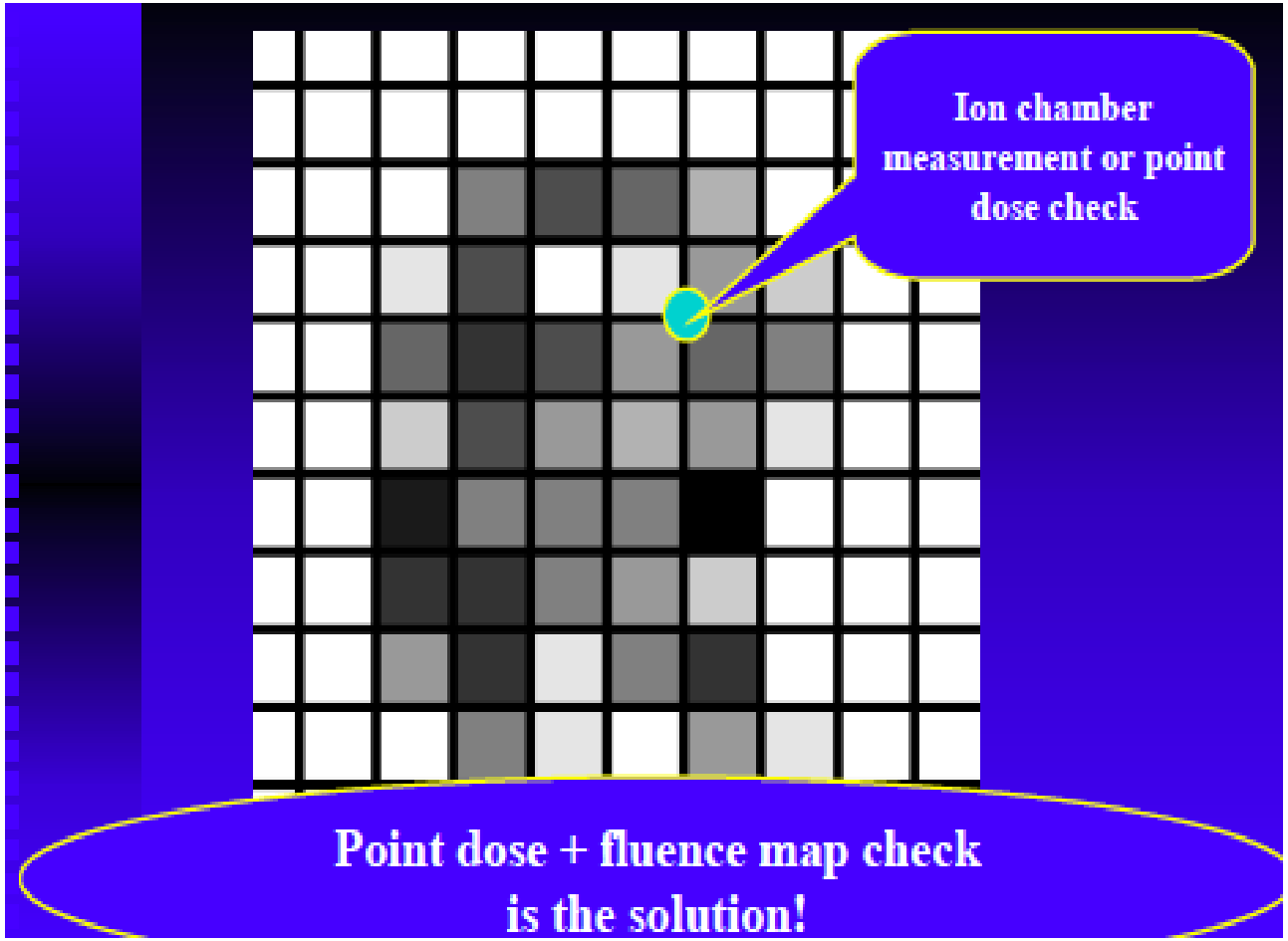
Conclusion

- According to this experiment result, interplay effect **decreases mean dose of tumor target** in both IMRT and VMAT treatment.

- This result is in accordance with previous experimental research by Jiang et al., Berbeco et al., Boopathy et al., Ong et al., and Ceberg C., et al., which stated that interplay effect will cause underdosage dosimetry in tumor volume.

Reseachers	Years	Departments	Motion Amplitude	Motion Periods	Results	
Jiang et al.	2003	Department of Radiation Oncology, Massachusetts General Hospital and Harvard Medical School, Boston, MA 02114, USA	20 mm (SI)	3.5 - 4 s	2-3% (IMRT)	Underdosage
Berbeco et. al.,	2006	Department of Radiation Oncology, Massachusetts General Hospital and Harvard Medical School, Boston, MA 02114, USA	20 mm (SI)	3.5 - 4 s	2-4% (IMRT)	Underdosage
Boopathy et. al.	2010	Medical Physics Department, Cancer Institute (WIA), Tamil Nadu 600032, India	25 mm (SI)	4 s	5 - 10% (VMAT)	Underdosage
Ong et. al.,	2011	Department of Radiation Oncology, VU University Medical Center, Amsterdam, The Netherlands	5 mm (SI)	5 s	1-2% (VMAT)	Underdosage
			25 mm (SI)	5 s	5% (VMAT)	Underdosage
Ceberg C., et. al.,	2013	Department of Medical Radiation Physics, Lund University, Skåne University, Hospital, Malmö, Sweden	10 mm (SI)	4s	4% (VMAT)	Underdosage
This Work	2015	Departmen of Physics, University of Indonesia	9.3 mm	2.3s	3% (IMRT) 2% (VMAT)	Underdosage
			20 mm	3.44s	4% (IMRT) 3% (VMAT)	Underdosage
			30 mm	4.22s	6% (IMRT) 5%(VMAT)	Underdosage

Is the point dose measurement enough for IMRT/ VMAT?



2D Verification : film

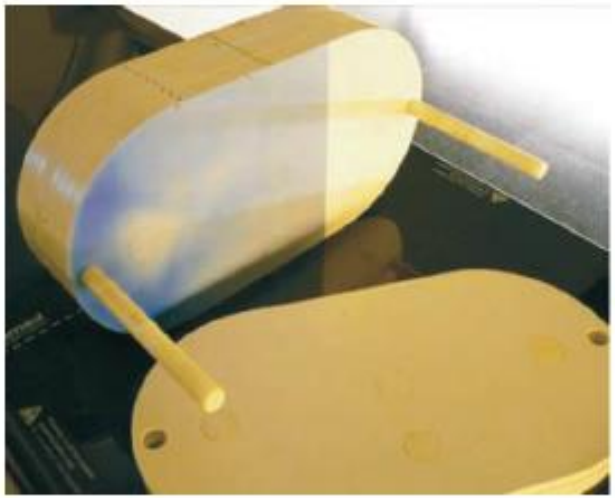


Figure 3.6 QUASIMODO CarPet phantom with Gafchromic EBT film after the delivery of a 5-arc IMAT treatment of an elongated tumour adjacent to the thorax wall.

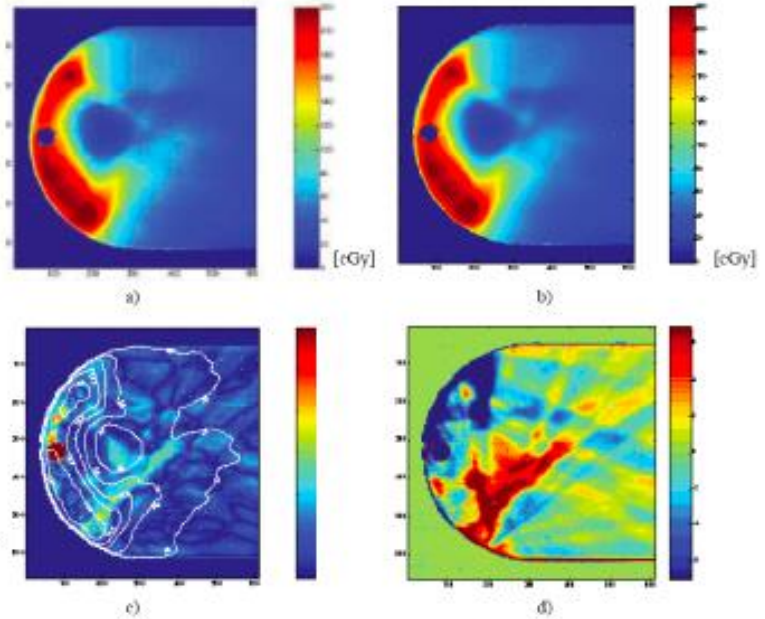


Figure 3.7 Comparison of a) computed and b) measured dose distribution using radiochromic film in the transverse plane through the isocentre. Panel c) shows the distribution of gamma values (3%, 3 mm) on which computed isodose lines have been superimposed. Panel d) shows the film-measured dose (panel b) minus the computed dose (panel a) expressed as a percentage of the reference dose (200 cGy).

2D Verification : 2D Detectors Array

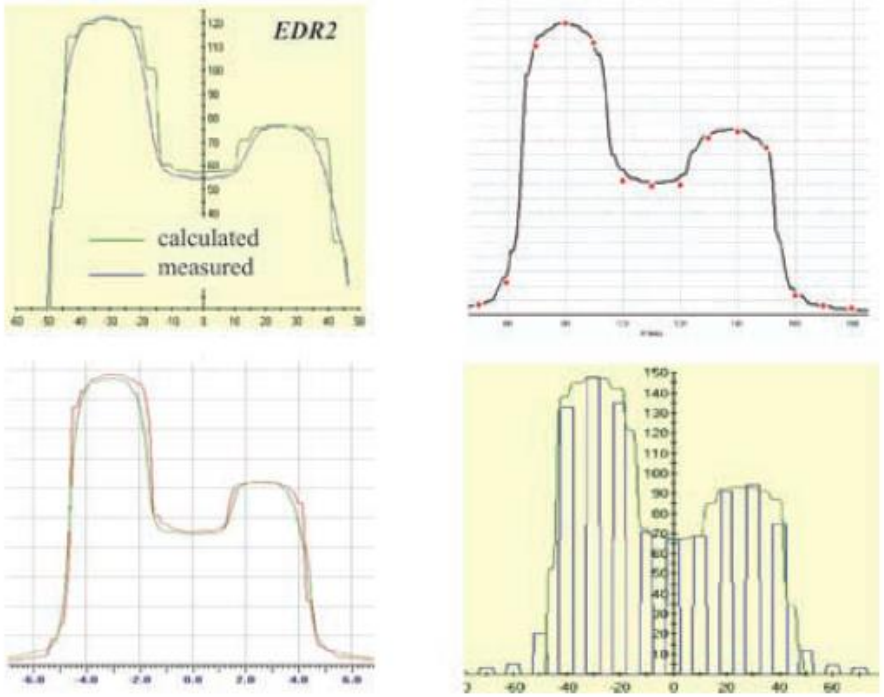
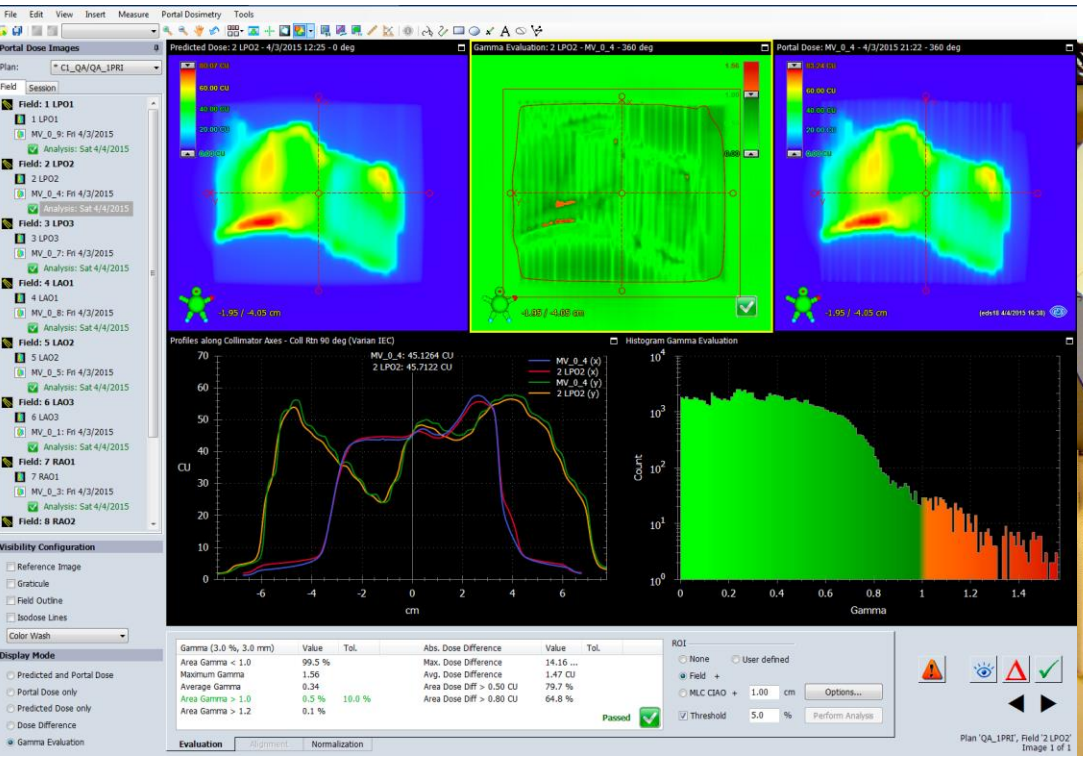
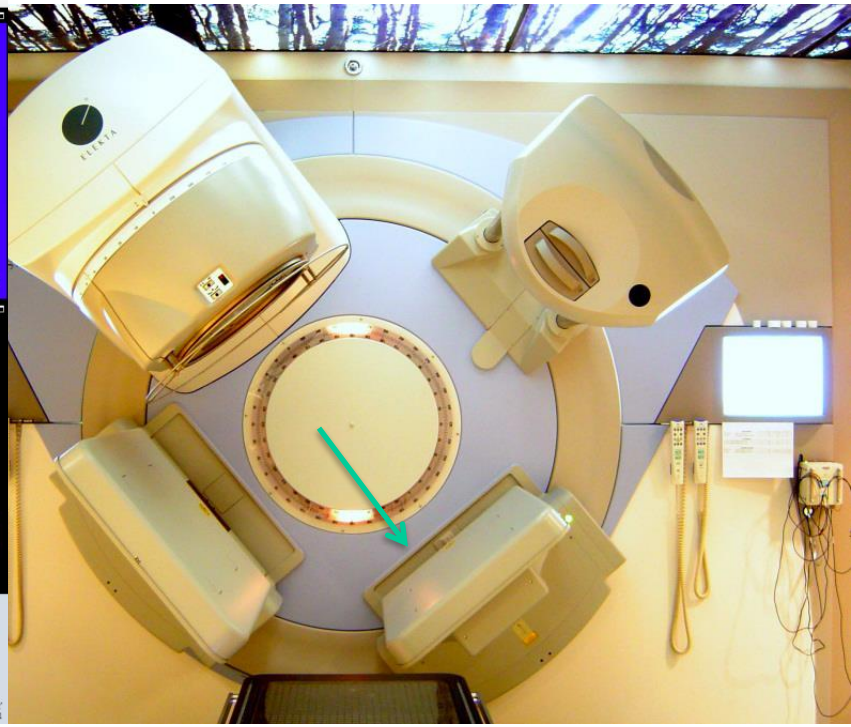


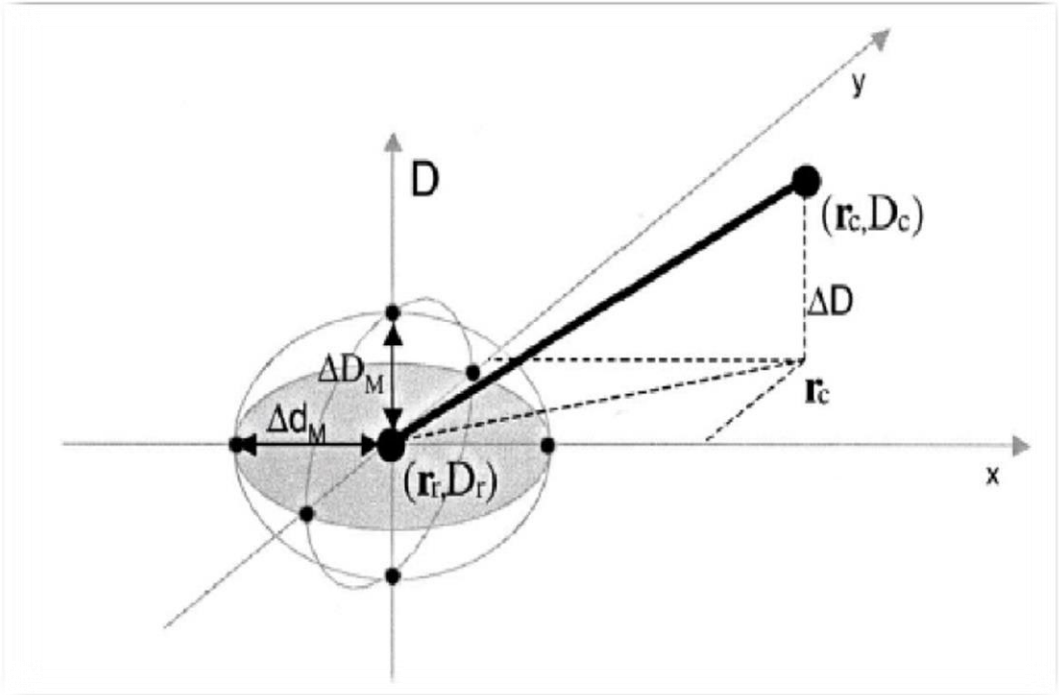
Figure 3.8 Example of an IMRT verification (for the same intensity profile) performed with different commercial 2D detector arrays. All intensity profiles marked as "calculated" refer to IM profiles obtained with the TPS. Measurements were made at 10cm water equivalent depth with radiochromic film (EDR2, left upper), a diode array (Mapcheck, right upper), a scintillation detector (I'mRT, left lower) and an ionisation chamber array (Seven29, right, lower). The 10 cm water equivalent depth included the inherent build-up of the 2D detector arrays. For comparison EDR2 film measurements are shown as well (from Wiezorek *et al.*, 2005).

2D Verification : EPID





Gamma index Definition

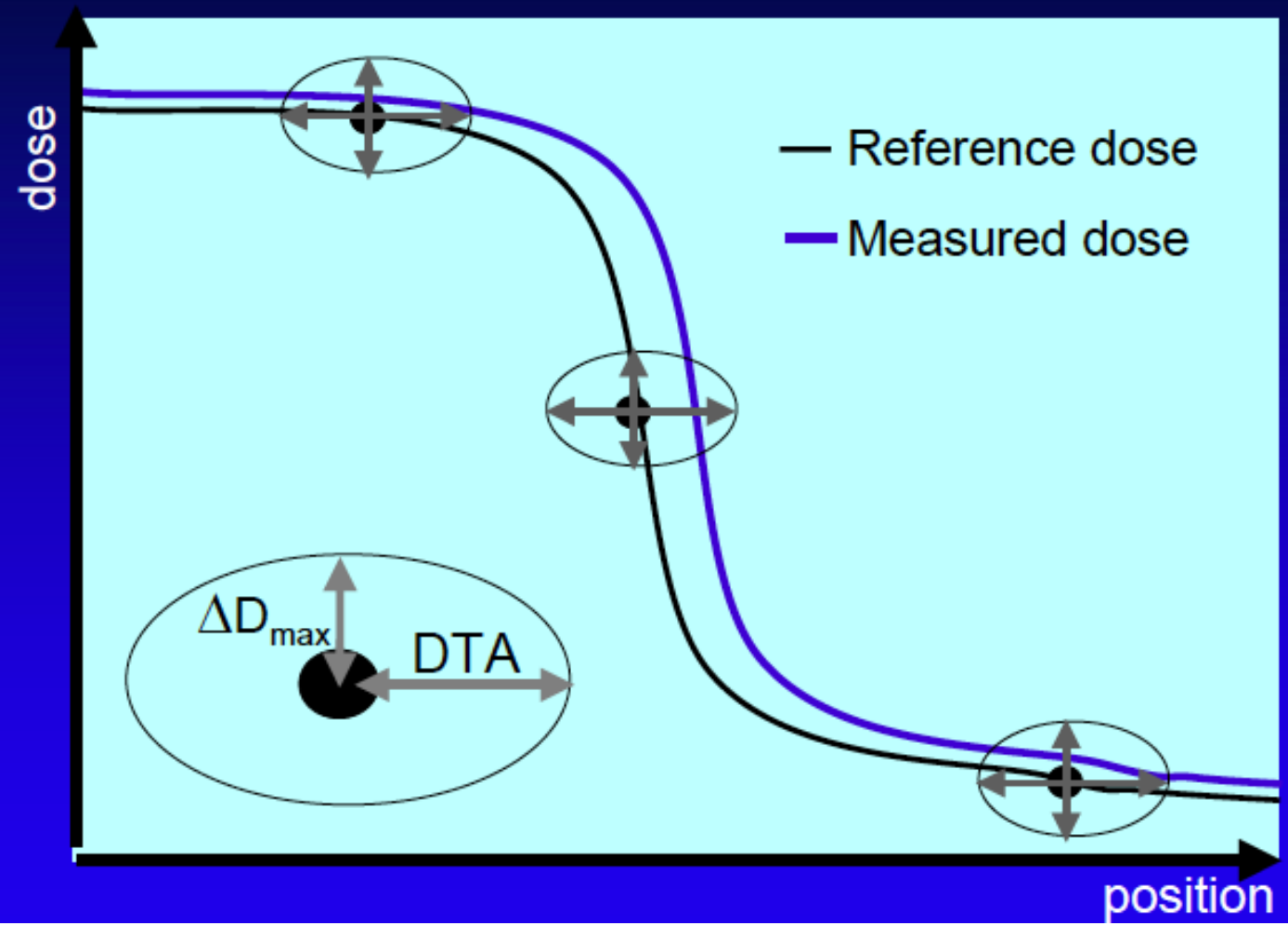


- $\Delta \boldsymbol{D_M}$ = Accept *dose difference* dan $\Delta \boldsymbol{d_M}$ = *Dose to agreement* (DTA)

Report of an ESTRO working group," *Radiother. Oncol.*, vol. 76, p. S101, 2005.

Gamma metric

$$\Gamma(\vec{r}_e,\vec{r}_r)=\sqrt{\frac{r^2(\vec{r}_e,\vec{r}_r)}{\Delta d^2}+\frac{\delta^2(\vec{r}_e,\vec{r}_r)}{\Delta D^2}}$$



acceptance criteria:

ΔD_{max} (e.g. 3 %)

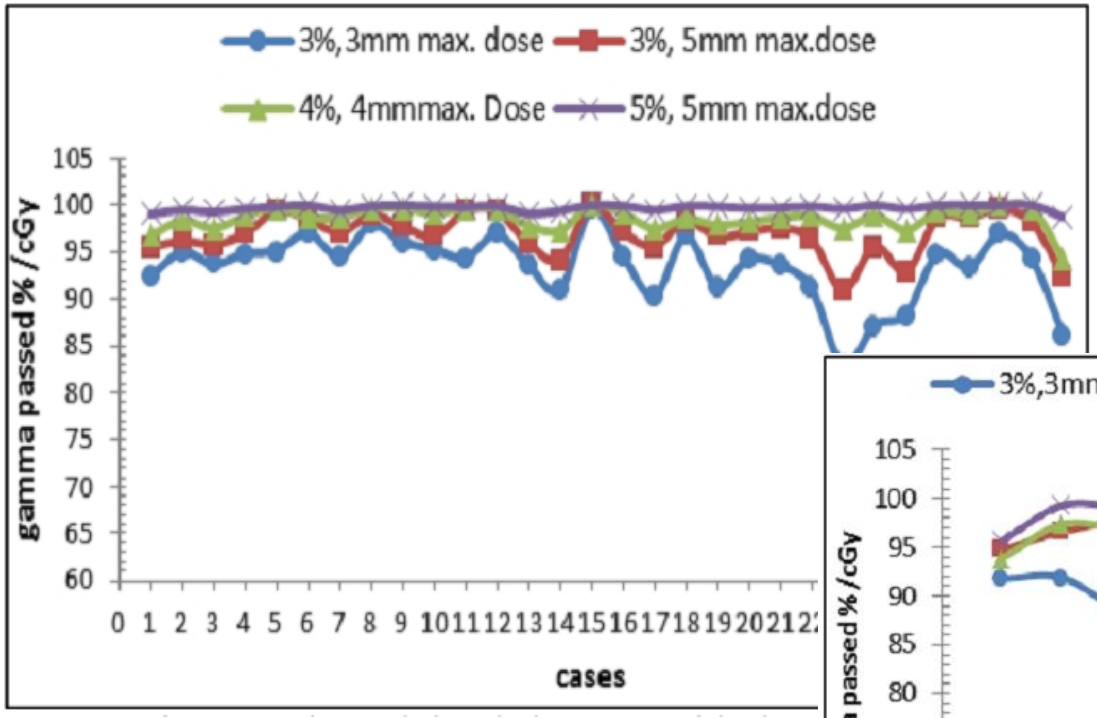
DTA (e.g. 3mm)

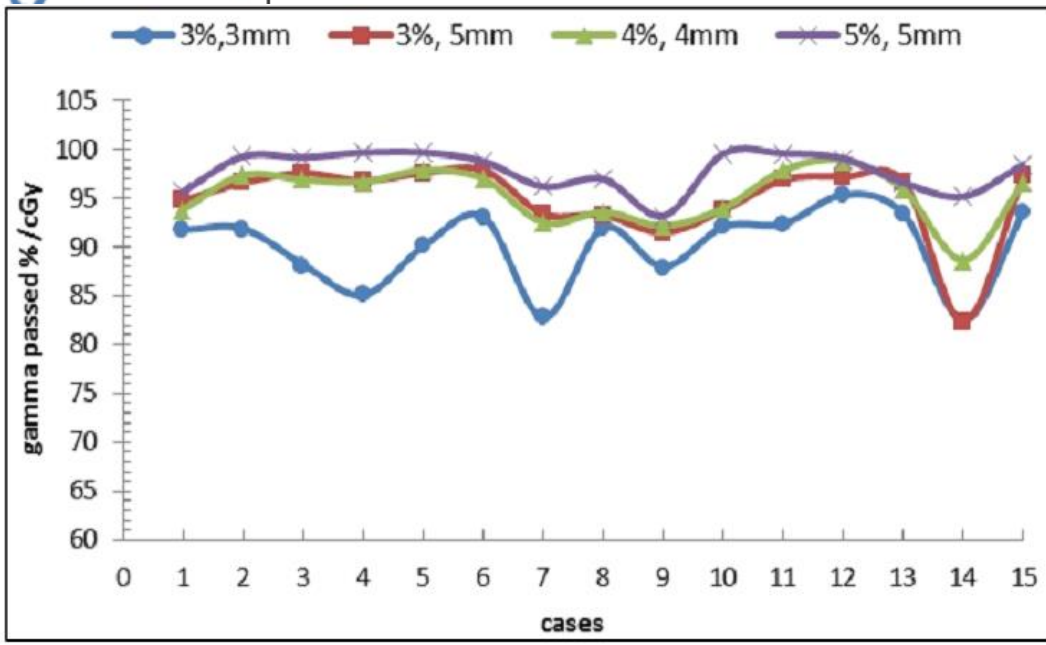
- $\gamma < 1$ =>
- $\gamma > 1$ =>

Medical Physics, Vol. 25, pp, 656-661

Criteria of Gamma Index

- 3%/3mm is the most common criteria chosen for gamma index (Nelms & Simon, 2007)
- AAPM TG-119 (IMRT commissioning) recommends a 90% pass rate for 3%/3mm for per field analysis
- Stricter criteria may be more sensitive to dosimetric / MLC errors

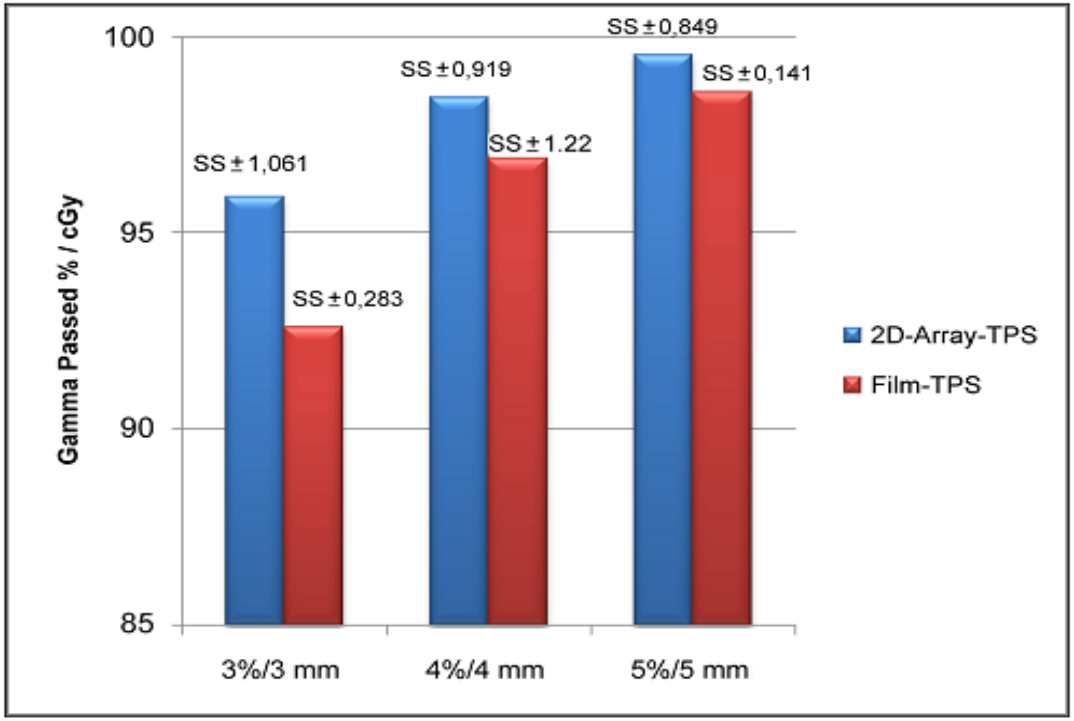




- The used 2D Array and EBT2 for the experiments.
- The average of gamma Index (3% DD /3 mm DTA) is 92,48 ± 4,60 (2D array)
- The average of gamma Index (3% DD /3 mm DTA) 88.45 ± 4.04 (FILM)

Elwady et al , International Journal of Cancer Therapy and Oncology. 2014

Nalbant et al., . J Nucl Med Radiat Ther, 5:3, 2014



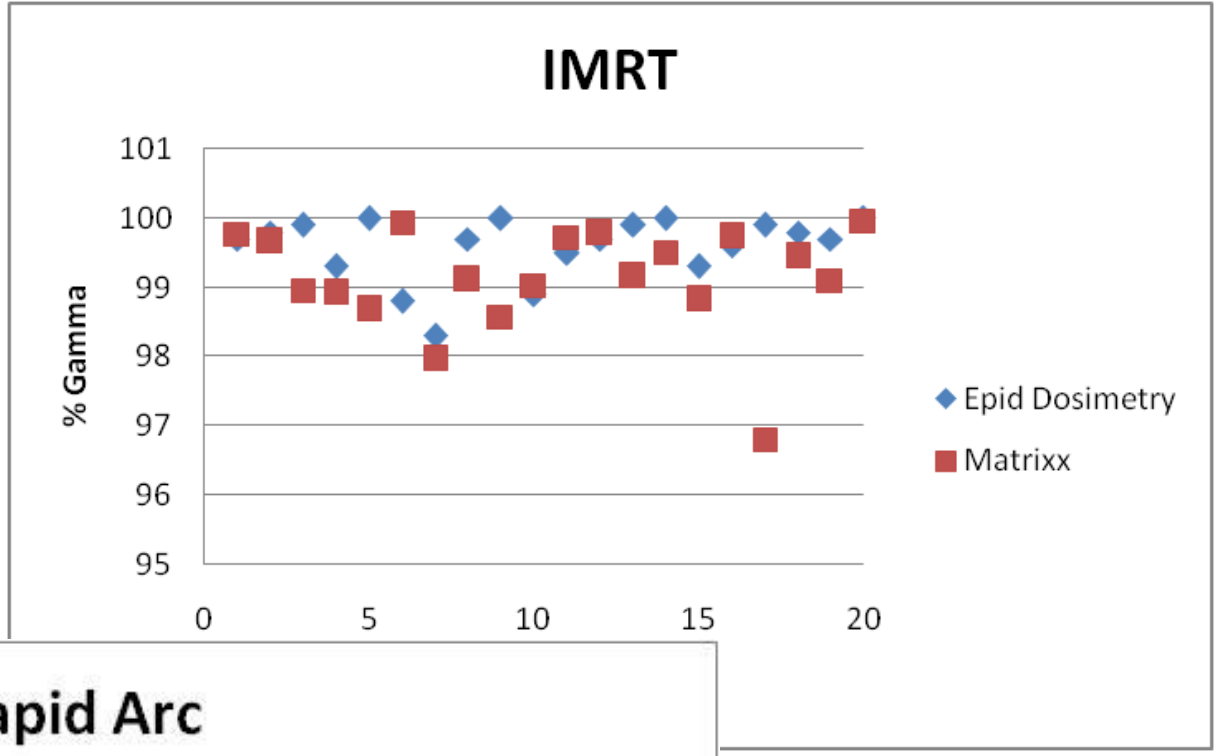
10 Prostate Patients

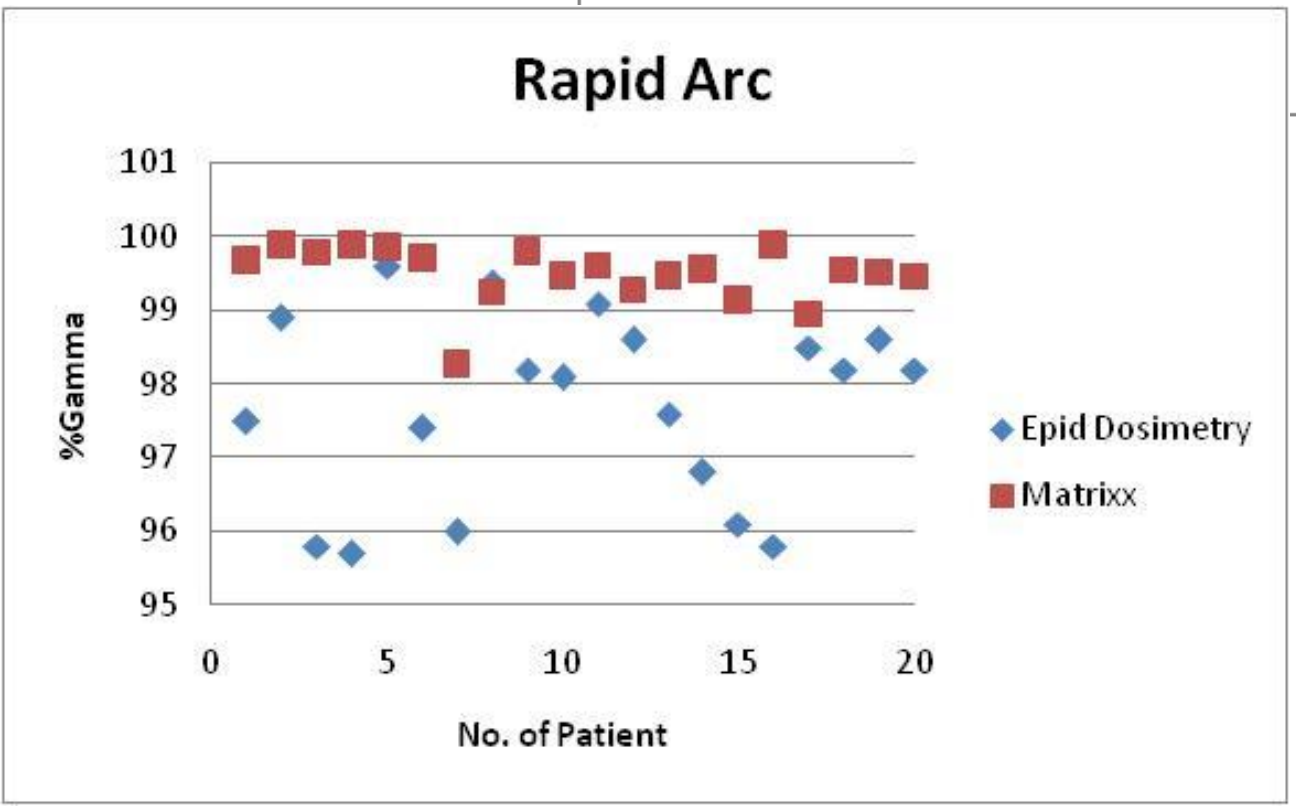
Criteria GI 90%

System	% Detector/pixels passing with γ‹1 and ρc					
	3%/3mm		3%/2mm		2%/2mm	
	mean	min	mean	min	mean	min
PTW 2D-Array	98	86.3	96.2	79.3	90.7	70.9
ArcCHECK	98.4	87.2	97.2	81.6	93.9	74.1
Delta4	96.2	86.6	93.4	78.5	85.5	68.8
Gafchromic	98.1	88.2	94.6	76.5	91.2	70.1
EPID	97.7	77.4	96.2	66.3	93.6	59.1

Miura et al. International Journal of Medical Physics, Clinical Engineering and Radiation Oncology. 117-124, 2014

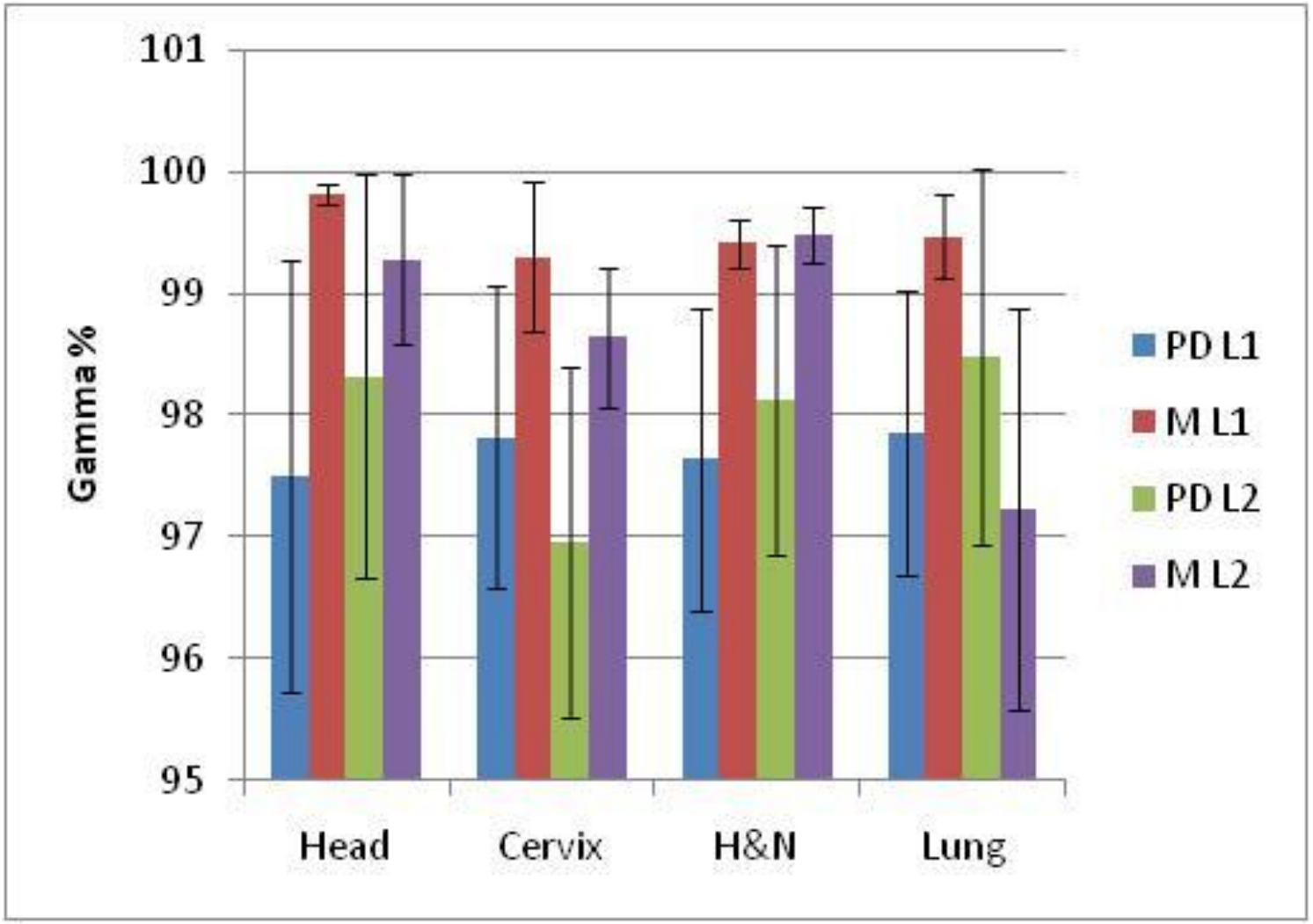
	3mm/3%	2mm/2%
Prostate cancer	99.9% (99.7-100.0)	97.4% (93.8-100.0)
Maxilary sinus cancer	99.9% (99.6-100.0)	97.8% (94.3-99.4)
Malignant pleural mesothelioma	99.2% (98.5-99.0)	**92.0 % (89.3-94.6)**





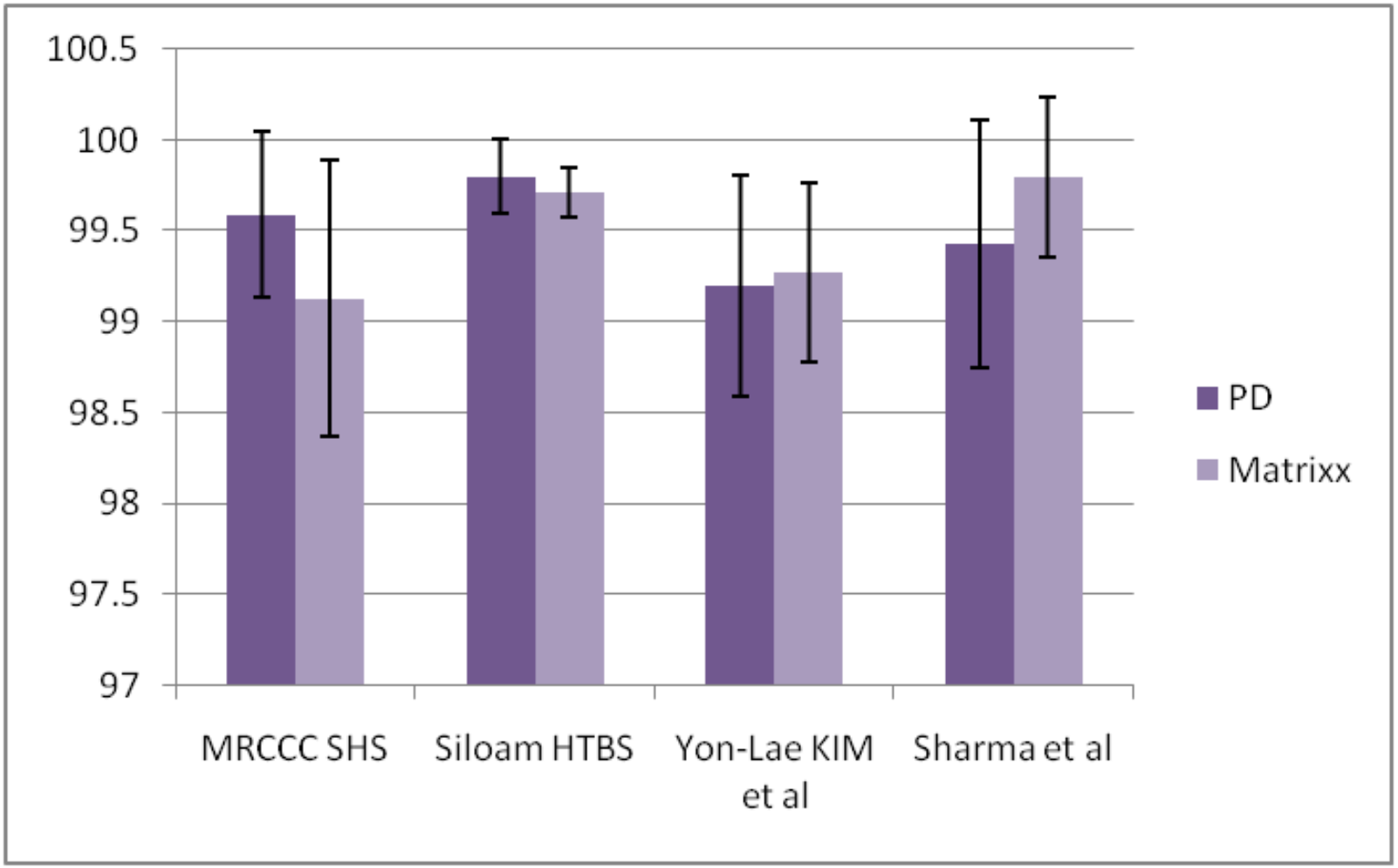
Comparison EPID and Matrixx for IMRT and VMAT

Prabangkara (2016)



Prabangkara et al (2016)

IMRT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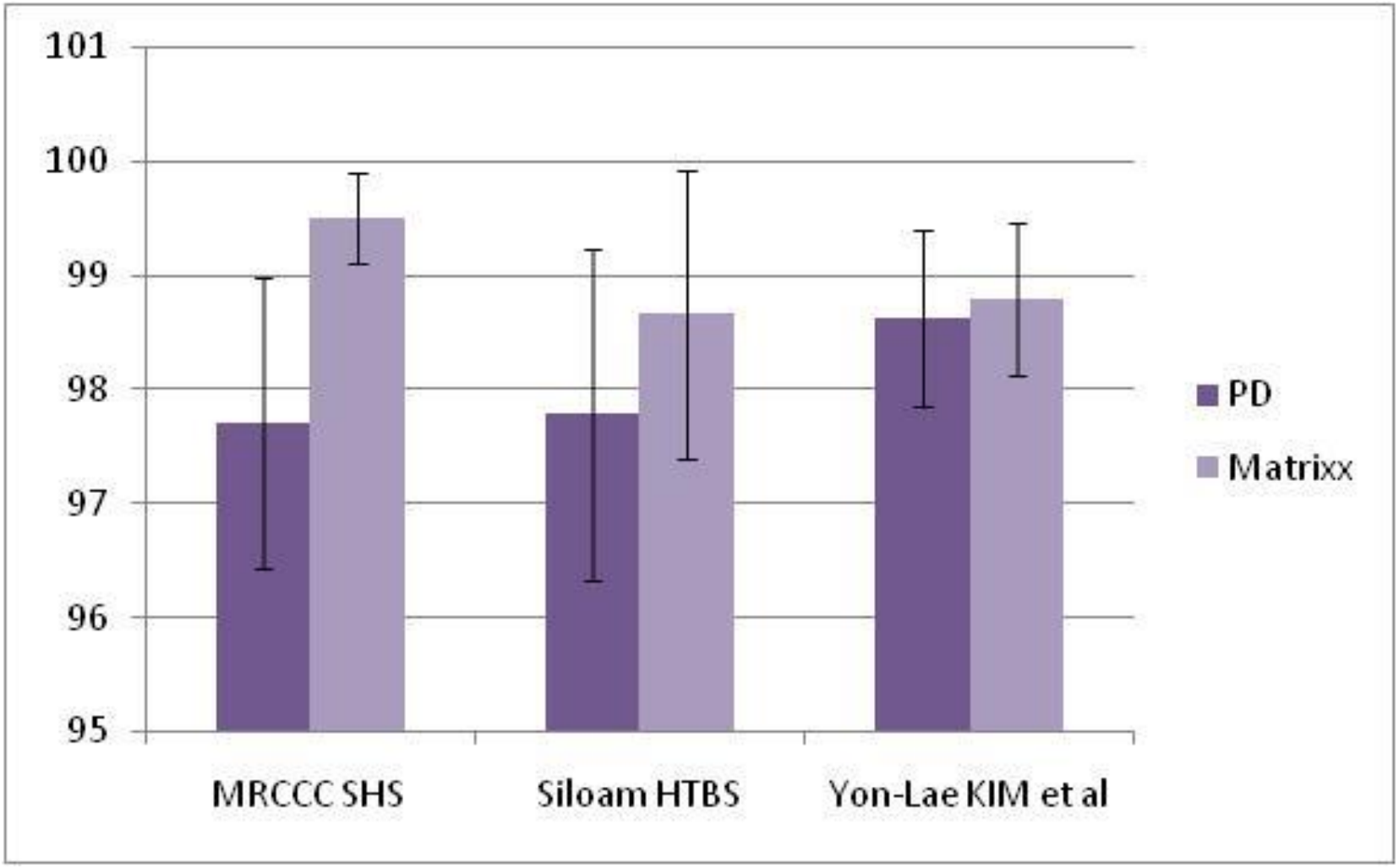
97
MRCCC SHS
Siloam HTBS
Yon-Lae KIM et al
Sharma et al
PD
Matrixx

VMAT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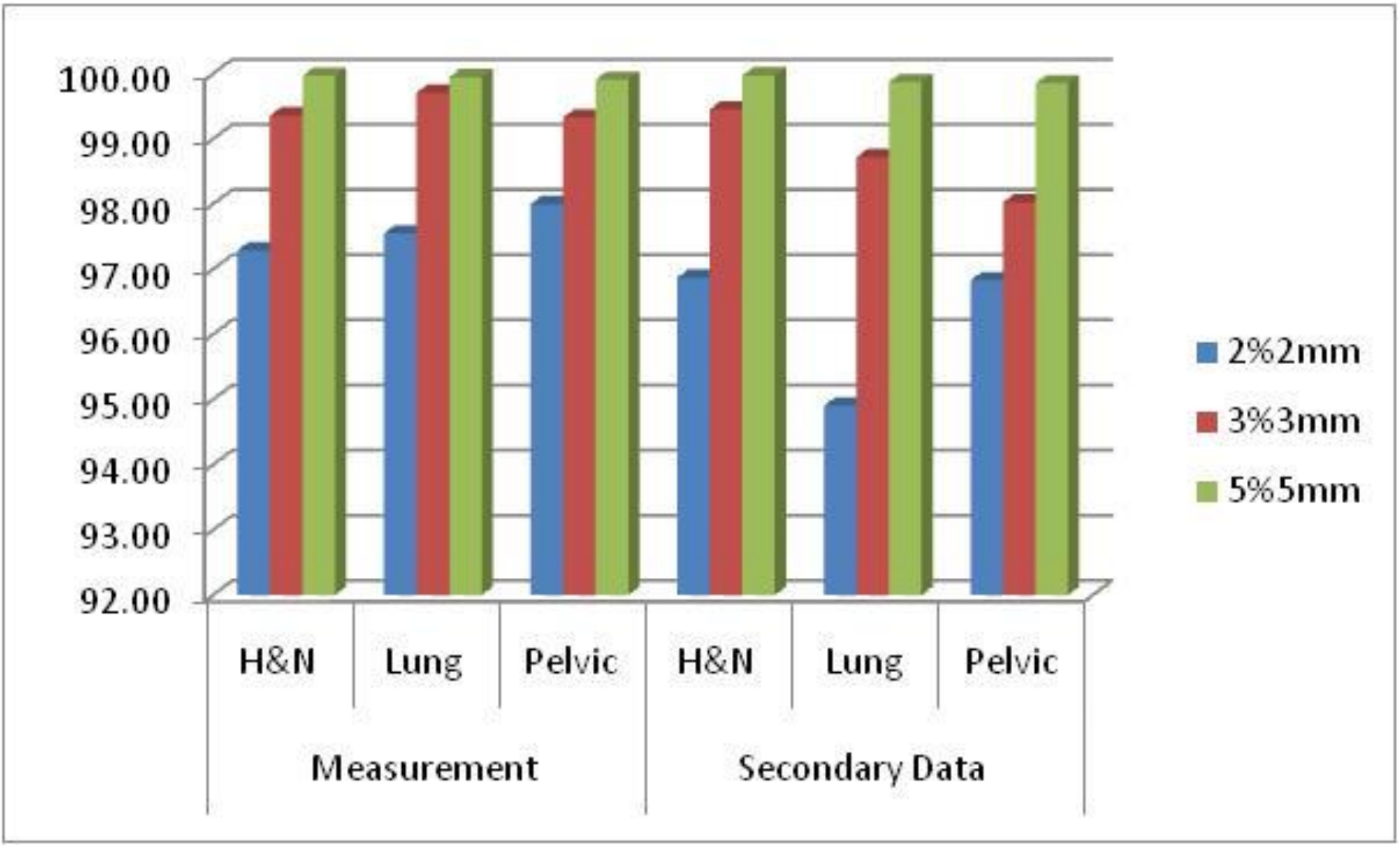
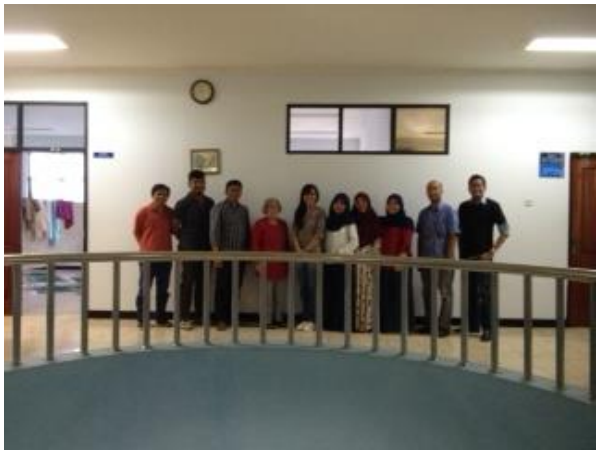
Siloam HTBS
Yon-Lae KIM et al
PD
Matrixx



Silvia, et al (2015)

Take Home Message

- Imaging modalities development has contributed in the radiotherapy development
- Point dose measurement is sample measurement from 3 dose distribution
- We sometime found big uncertainty in point measurement because it will depend on homogeneity, conformity of dose distribution, and also physical properties of medium and detectors
- Planar dose measurement or 3D dose measurement is alternative methods if we found the big uncertainty in our point dose verification measurement



Thank You ★ Terima Kasih

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