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IGRT

ICTP SCHOOL ON MEDICAL PHYSICS
Radiation Therapy:
Dosimetry and Treatment Planning
for Basic and Advanced Applications
ICTP, Trieste 2019

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IGRT1 technologies

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IGRT

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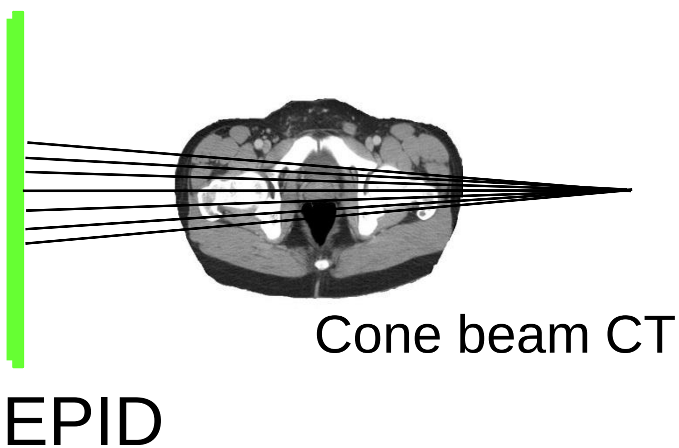
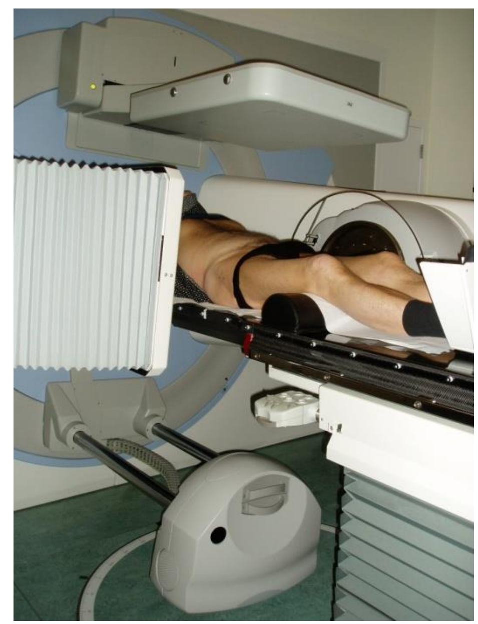
- The aim
  - to ensure that the delivered dose distribution is as close as possible to the planned dose distribution
    - to solve the problem of set-up uncertainties,
    - to resist the changes of patient anatomy during the course of treatment,
    - to resist the changes of position of the target during single treatment session.

ANSWER: imaging

Image-guided radiation therapy (IGRT)

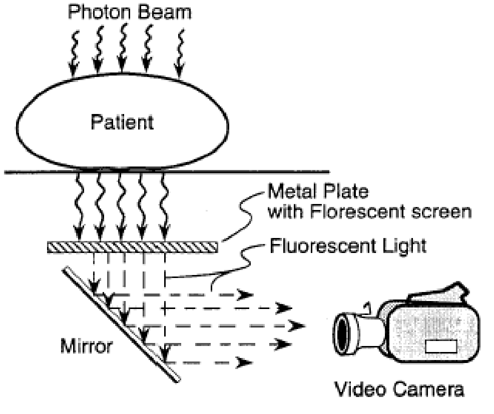
- How does it go
  - the process of frequent two and three-dimensional imaging, before, during a course of radiation treatment
  - adaptation the actual plan to the intendet one





Technologies

- Construction
  - source of ionizing radiation
  - detector
- Systems
  - planar – 2D
  - spatial – 3D



- Ultrasound and laser systems are also used.

Radiation sources

- MV
  - therapetic beam is used
- kV
  - additional source of radiation

What is the essential difference between kV and MV images?

Radiation sources

- MV
  - therapetic beam is used
    - Compton effect
      - very week contrast – no dependence on atomic number
        - differences in radiological thickness only
- kV
  - additional source of radiation
    - a little photoelectric effect, but it is enough to have
      - much better contrast – dependence on the atomic numer
        - bones are visible very well

Contrast

- Definition

$$C = \frac{signal}{mean\_signal} = \frac{\Phi_{P2} - \Phi_{P1}}{(\Phi_{P2} + \Phi_{P1})/2}$$

1-cm-thick bone embeded within 20 cm of soft tissue

100 kVp; contrast 0.5

6 MV; contrast 0.037

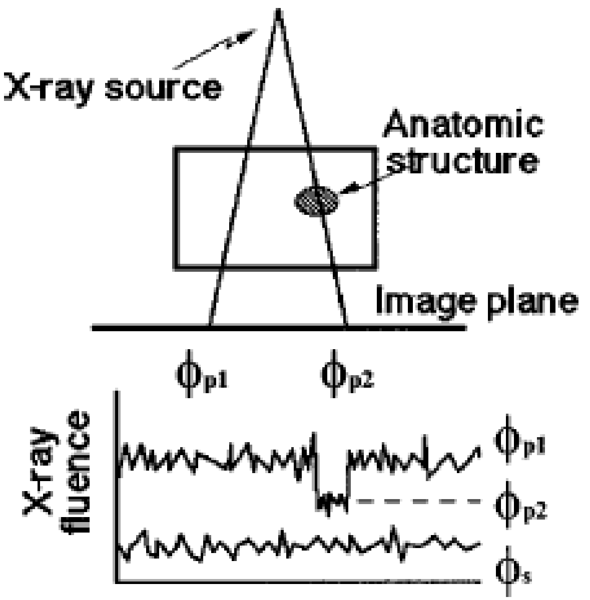
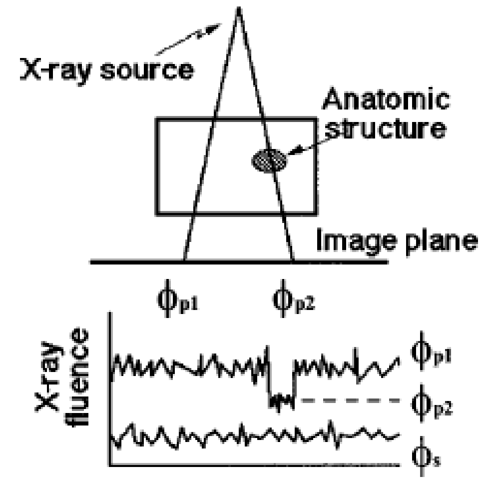


Image detectibility (SNR)

- Signal - to – noise - ratio

$$SNR = \frac{signal}{noise} = \frac{\Phi_{P2} - \Phi_{P1}}{\sqrt{\left(\Phi_{P2} + \Phi_{P1} + 2\Phi_S\right)/2}}$$



$$SNR = \frac{mean \therefore signal}{dispersion} = \frac{\overline{S}}{\sigma}$$

	100 kVp	6 MV	6 MV	6MV	6 MV
Patient dose (cGy)	0.05	0.05	1.00	10.00	55.00
SNR	71	<1	4.8	15	35

AAPM, Task Group 58

Three the most important technical achievements for radiotherapy?

Three the most important technical achievements for radiotherapy?

- CT
- EPID
- IMRT

Commisioning and QA of EPIDs

- What must be verified
  - mechanical and electrical safety
    - safety of mounting the EPID; risk of dropping the device on a patient (for older detachable systems)
    - operation of collision systems (EPIDs are expensive!)
  - geometrical reproducibility
    - the center of EPID should conform to the central axis
  - image quality
    - spatial and contrast resolution
  - software performance

Commisioning and QA of EPIDs

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- Vendors usually recommends some tests
- Calibration should be made regularly
  - dark current or noise (image acquired without beam)
  - uniformity of the image
    - for open field intensity across the beam should be uniform
    - dead pixels

Commisioning and QA of EPIDs

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- Linearity
  - distortion of images should be eliminated (simple phantoms with regularly placed objects)
- Image quality
  - specialized phantoms are used
    - Aluminium Las Vegas (AAPM)
    - PTW phantom

Journal of Applied Clinical Medical Physics, Vol 12, No 2 (2011)

A quality assurance phantom for electronic portal imaging devices

Indra J. Das[1,2,a], Minsong Cao[1], Chee-Wai Cheng[1,2], Vladimir Misic[3], Klaus Scheuring[4], Edmund Schüle[4], Peter A.S. Johnstone[1,2]

Strahlentherapie und Onkologie — Technical Note

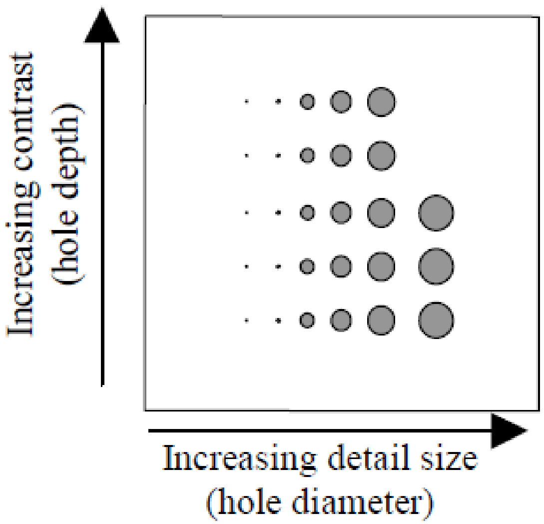
Quality Control of Portal Imaging with PTW EPID QC PHANTOM®

Csilla Pesznyák[1], Gábor Fekete[2], Árpád Mózes[3], Balázs Kiss[4], Réka Király[1], István Polgár[1], Pál Zaránd[1], Árpád Mayer[1]

Las Vegas http://www.ws.aplus.pl/tomografia/EPID_image_quality.pdf

EPID QC phantoms

- Las Vegas phantom



- PTW phantom

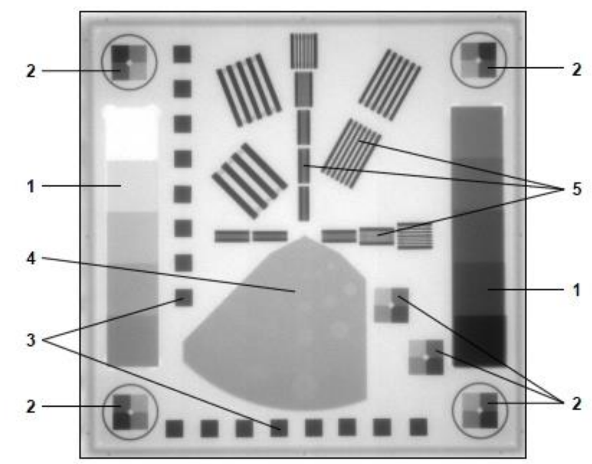


Fig. : Test patterns in PTW EPID QC Phantom

EPIDs' software

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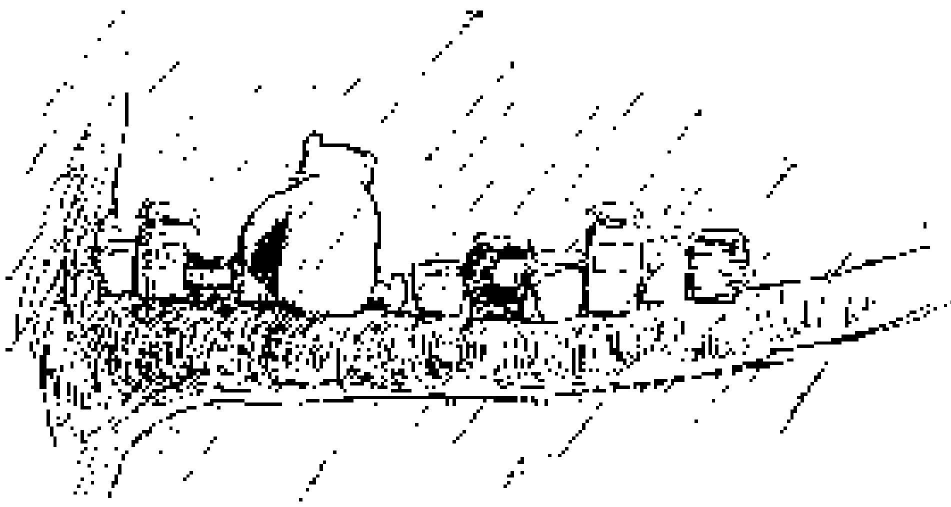
- Image quality may be improved with
  - channging window and level
  - more sophisticated digital filtering techniques
  - for edge detection of bones
    - high pass filter
    - Canny and Sobel

  - How we recognize objects?

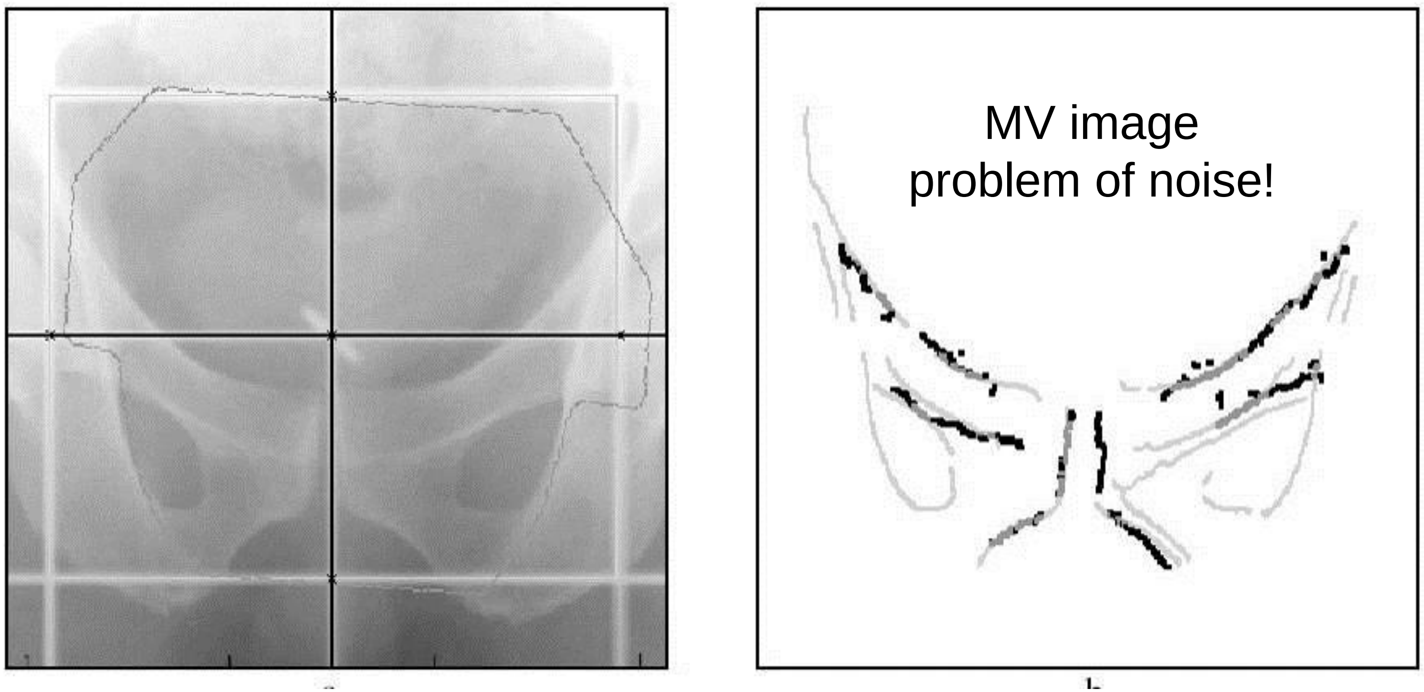
*www.cse.unr.edu/~bebis/CS791E/Notes/**EdgeDetection**.pdf*

How objects are recognized?
We all are experts!



Recognition is driven by edges!

Edges



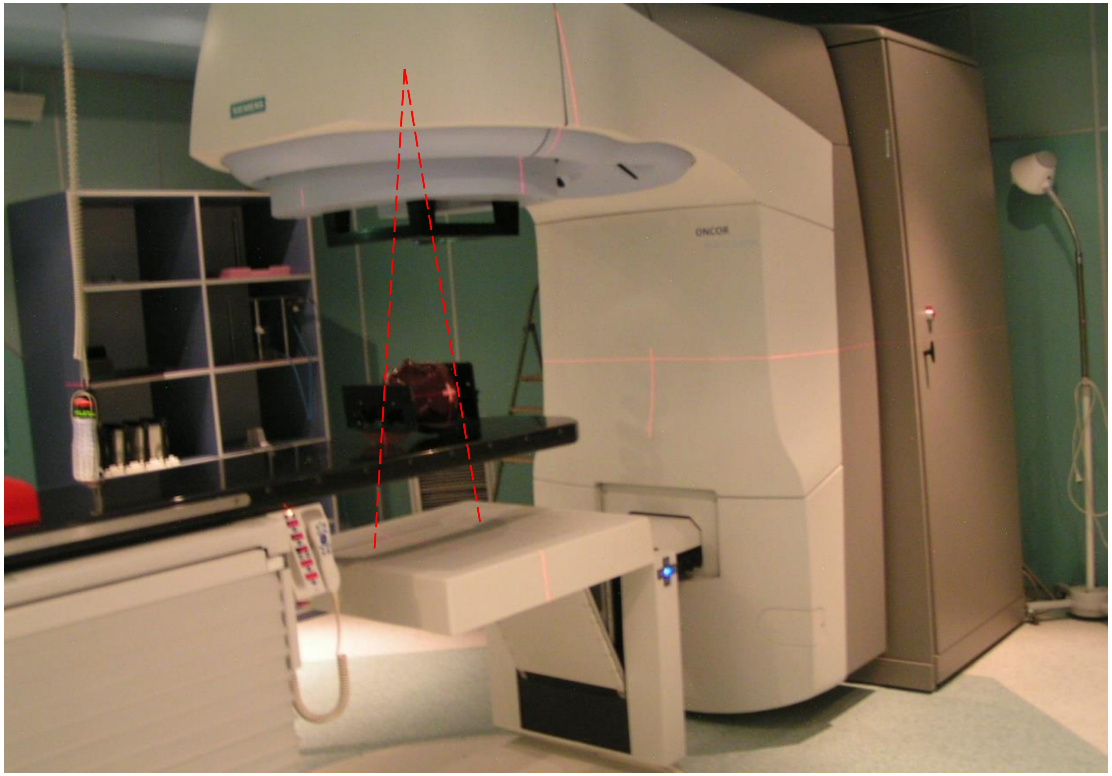
Edge is a second derivative of intensity.

Improving quality of images

- kV radiation

The idea and first solution.
Haynes Radiation

2D system for set-up control



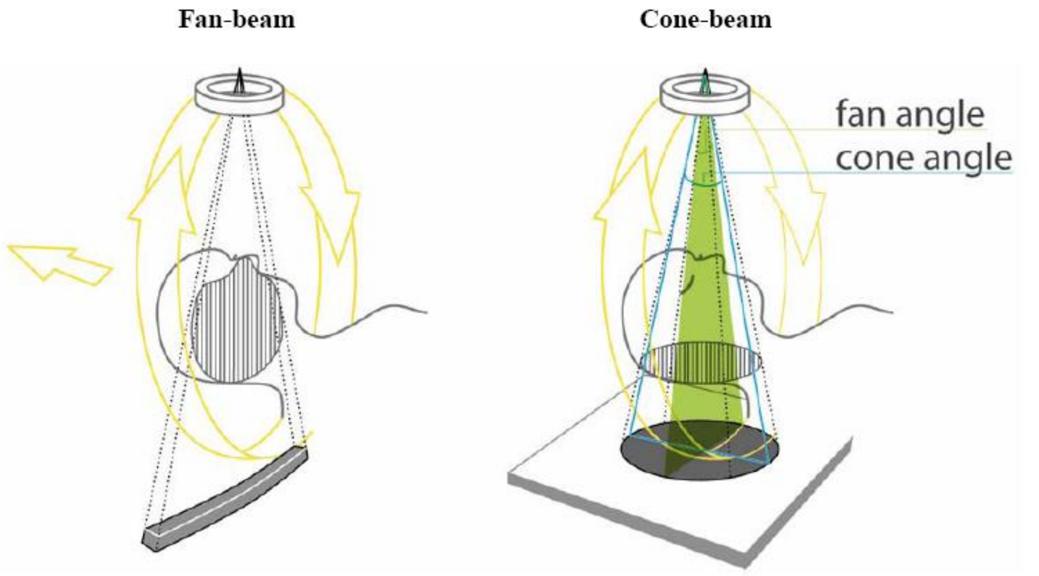
1 MU – 3 MU

3D Technology

- A set of 2D images → 3D image
  - Computerized tomography
    - conventional (on rails) tomograph
    - cone beam tomograph
    - MV cone beam CT

3D Technology cone beam CT

<< 1 sec



~ 1 min

Difference between the fan (narrow) beam and cone-beam tomography.

$$SNR_{fan} > SNR_{cone}$$

3D Technology cone beam CT

- With kilovoltage radiation
  - Elekta –
  - Varian - On Board Imaging
  - Specialized software for image registration

Detector - EPID

Rtg lamp

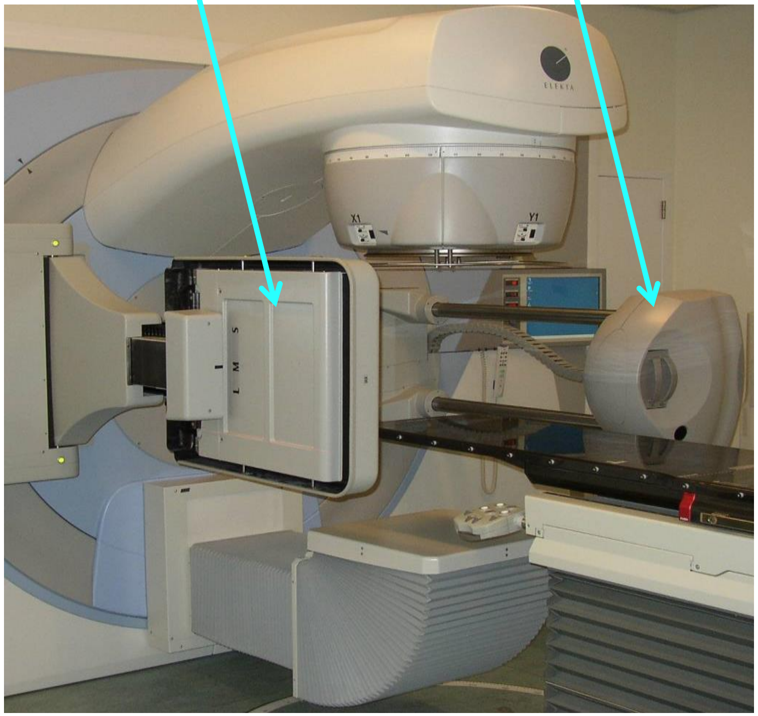


Image quality

- Worse than for conventional CT
  - smaller SNR
- Good enough for soft tissue registration in some clinical situations
  - distortions due to patient movement

Amer, et al. The British Journal of Radiology, 80 (2007), 476–482

Megavoltage Cone Beam CT

treatment beam

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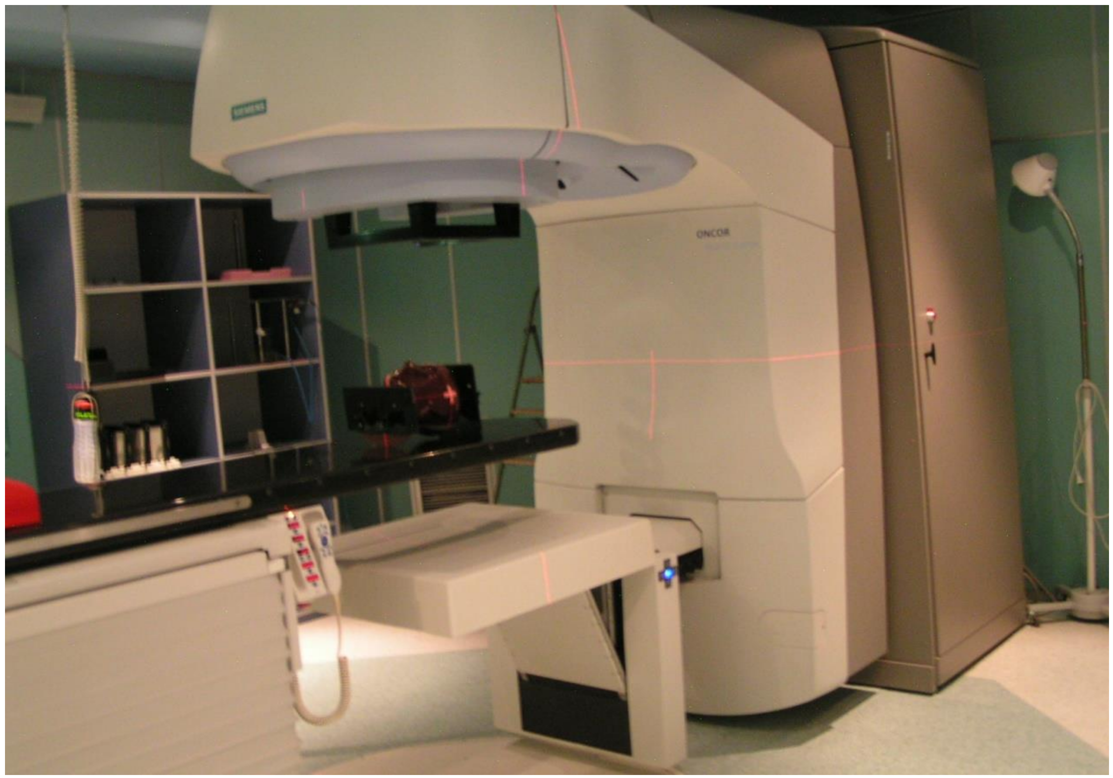
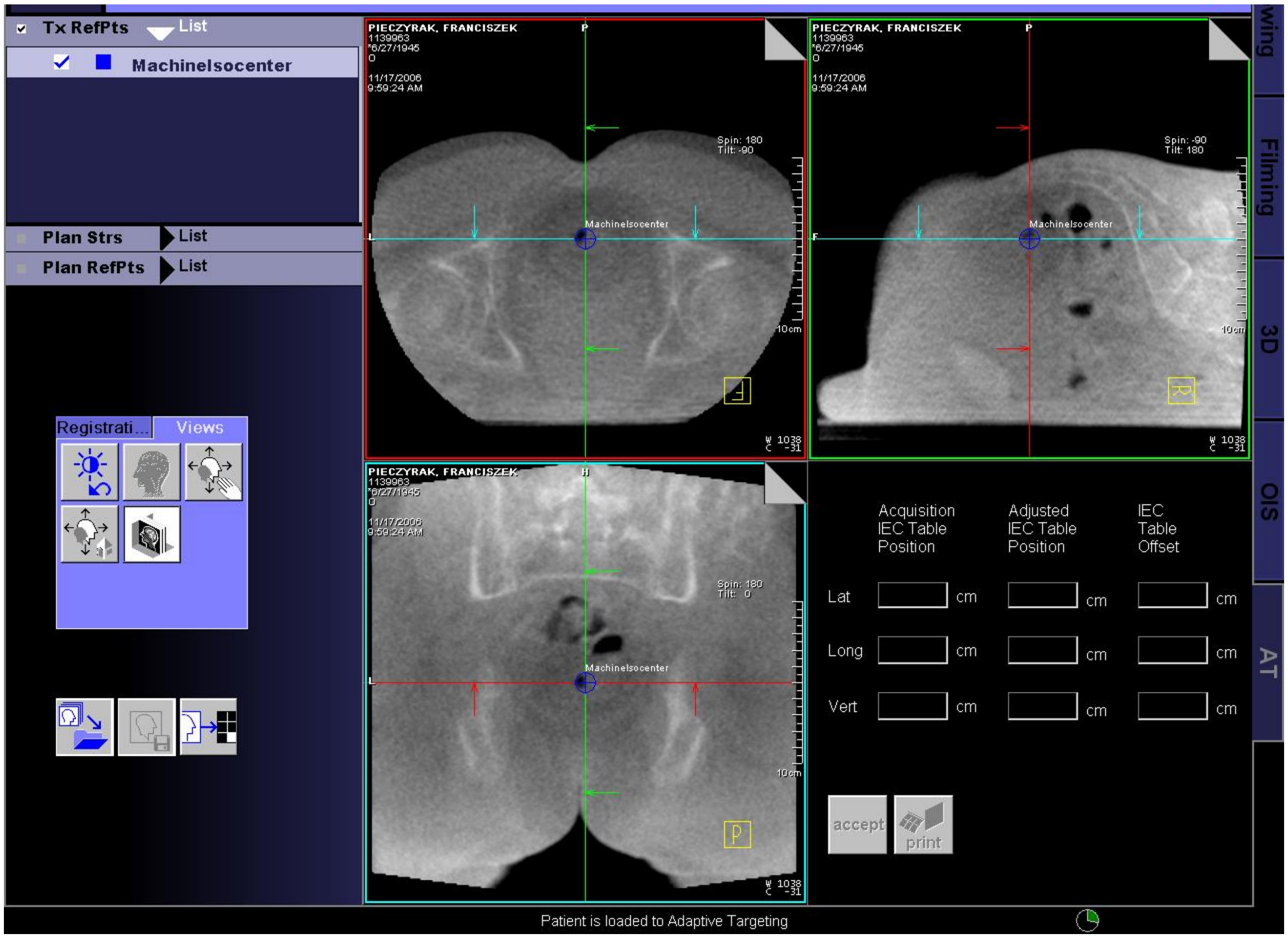


Megavoltage Cone Beam CT
image quality



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Improving quality of images

- kV radiation

The idea and first solution.
Haynes Radiation

CyberKnife

Exact Track BrainLab

IGRT in practice

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- When and why?
  - Set-up control
    - interfraction differences
    - intrafraction differences
  - Adaptive treatment
    - new idea in radiotherapy
      - to match the treatment plan to actual anatomy
  - Special procedures

IGRT examples

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- Preparation for treatment

Marian System – OptiNav technology

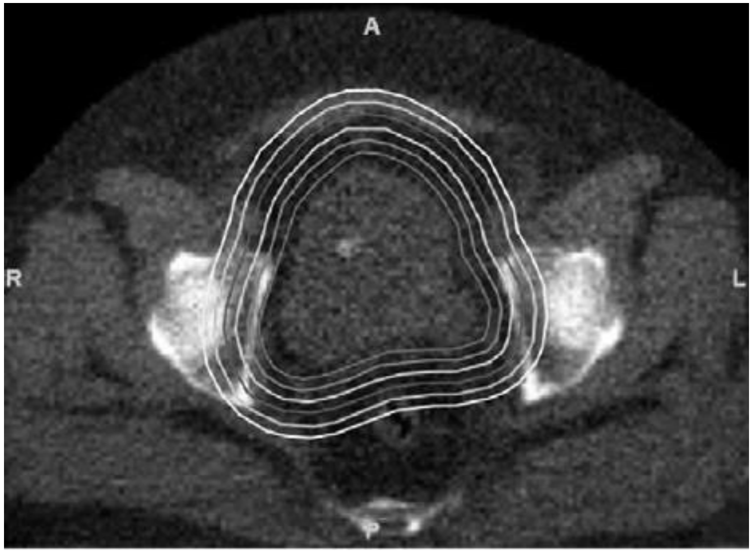
IGRT examples

- CBCT performed before treatment
  - set-up control
    - bone matching
      - two perpendicular portals
    - soft tissue matching
      - prostate
      - SBRT liver
      - gynecological cancers

Examples of IGRT

- Plan of the day
  - dose distribution matched to the actual anatomy

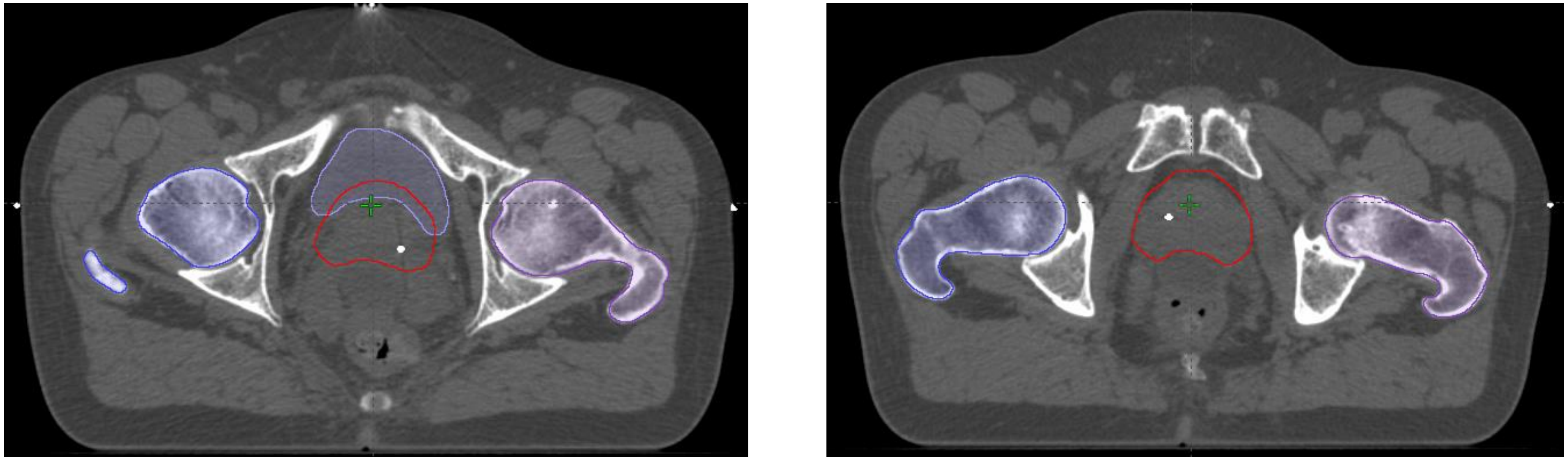
‘Plan of the day’ adaptive radiotherapy for bladder cancer using helical tomotherapy



Vedang Murthy Radiotherapy and Oncology 99 (2011) 55–60

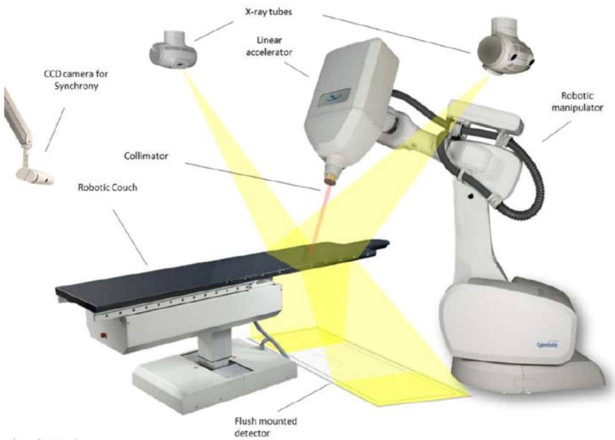
Examples of IGRT

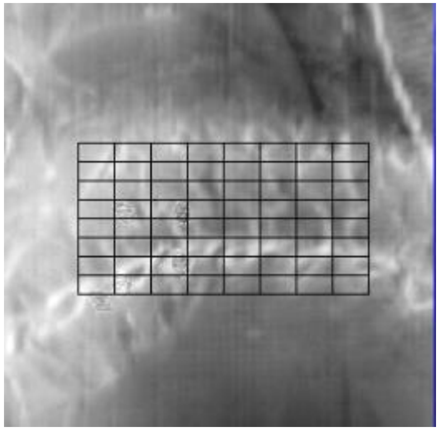
- Prostate
  - Gold fiducials
    - Inter- and intrafraction movement

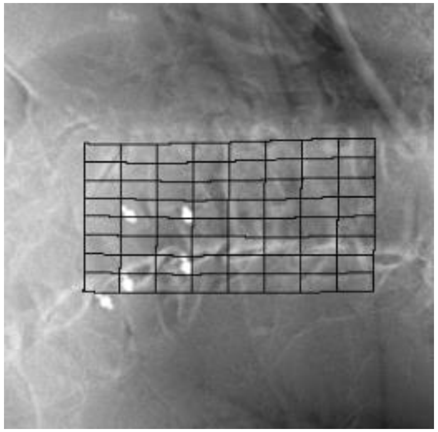


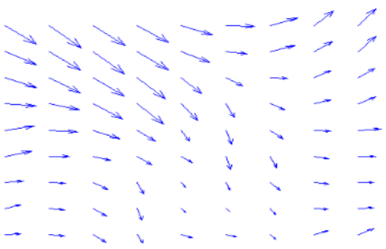
CyberKnife

- Specialized software
  - Synchrony
  - Xsight Lung
  - XSight Spine





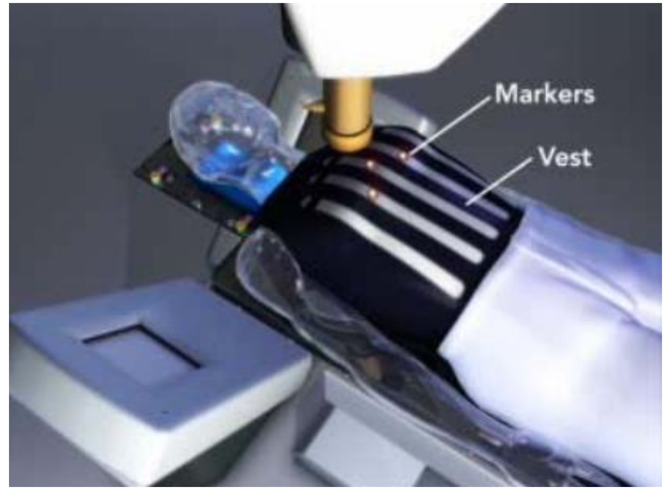


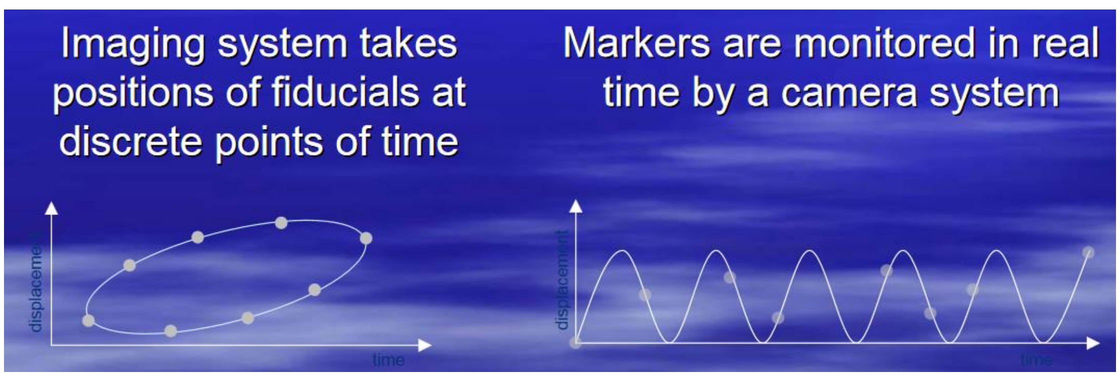


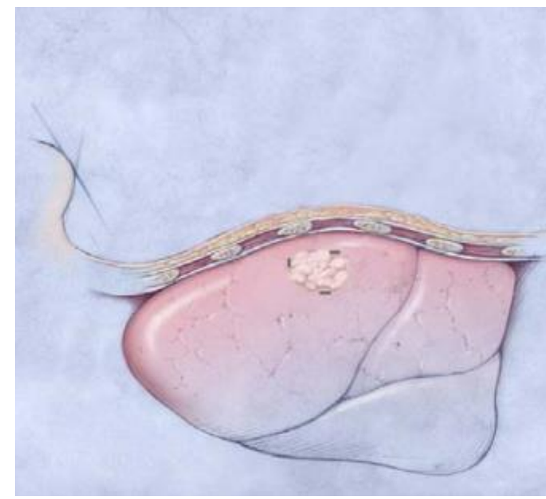
Deformable registartion

CyberKnife

- Synchrony



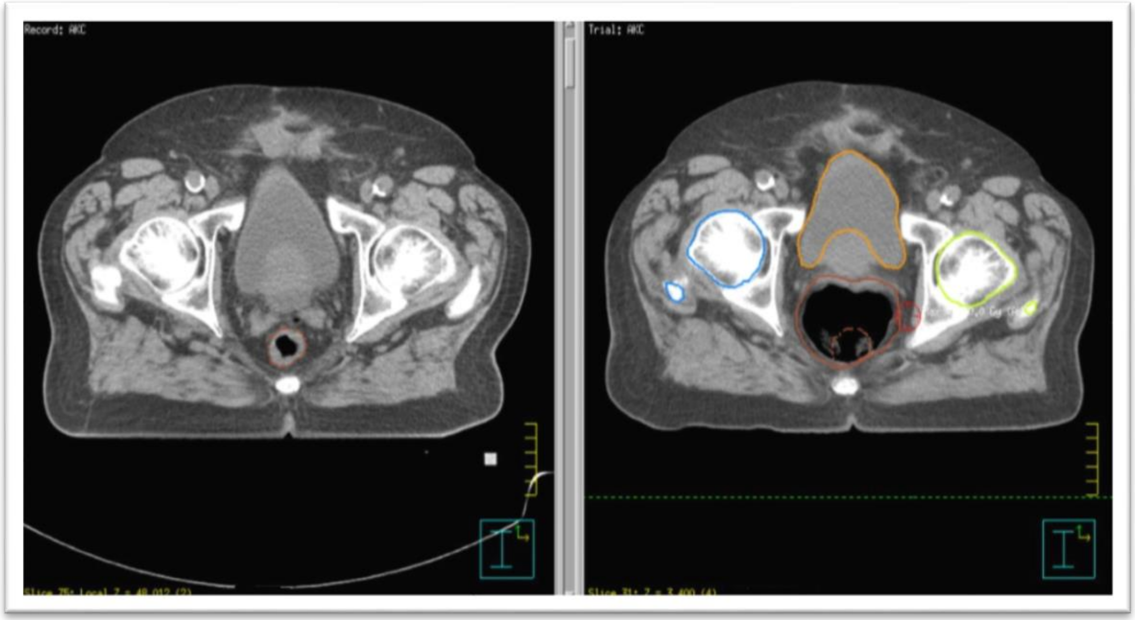




Courtesy of Accuray

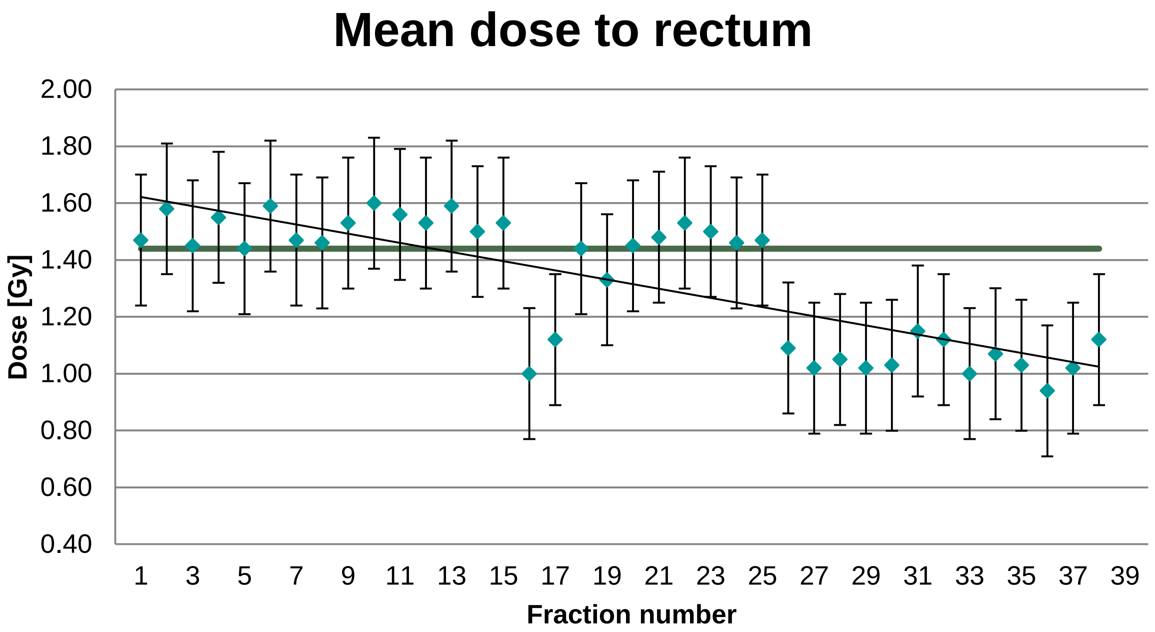
Reliable evaluation of treatment effect

- Rectum dose



Planning Treatment

Mean dose to rectum



PhD Anna Grzelec

Concomitant dose in IGRT

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- The only dose quantity that allows any intercomparison of stochastic risk between the different imaging scenarios … is **effective dose**, which combines the quality and distribution of radiation throughout the body with its effect on a number of specific organs.
  - If 10,000 individuals received 0.01 Sv each over background during their life, 4 additional deaths would occur of the 2,000 that would naturally occur; (0.01 Sv – 1 cGy – 10 mSv)

The management of imaging dose during image-guided radiotherapy: Report of the AAPM Task Group 75, Medical Physics 34, Oct, 2007

Radiation protection of a patient
Effective dose

$$E = \sum_{T} \left(w_T \cdot w_R \cdot D_{T,R} \right)$$

- w_T= tissue weighting factor
- w_R= radiation weighting coefficient
- $D_{T,R}$= average absorbed dose to tissue T

for radiation used in conventional radiotherapy $w_R = 1$

Effective dose

For photons and electrons $W_R = 1$

Organ/Tissue	W_T	Organ/Tissue	W_T
Bone marrow	0.12	Lung	0.12
Bladder	0.04	Liver	0.04
Bone Surface	0.01	Oesophagus	0.04
Brain	0.01	Salivary glands	0.01
Breast	0.12	Skin	0.01
Colon	0.12	Stomach	0.12
Gonads	0.08	Thyroid	0.04
Liver	0.05	Remainder	0.12

Doses from CBCT

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Dose from Elekta XVI kV cone-beam CT.

Parameter	Head	Chest
Mean dose at center (mGy)	29	16
Mean skin dose (mGy)	30	23
Effective dose (mSv)	3.0	8.1

M. K. Islam, T. G. Purdie, B. D. Norrlinger, H. Alasti, D. J. Moseley, M. B. Sharpe, J. H. Siewerdsen, and D. A. Jaffray, "Patient dose from kilo-voltage cone beam computed tomography imaging in radiation therapy," Med. Phys. 33, 1573–1582 (2006).

Murphy, M.J., et al., *The management of imaging dose during image-guided radiotherapy: report of the AAPM Task Group 75. Med Phys, 2007.* ***34(10):*** p. 4041-63.

Doses from portal control

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Effective dose from 6 MV portal images 18 cm x 15.6 cm taken at SSD=88 cm.

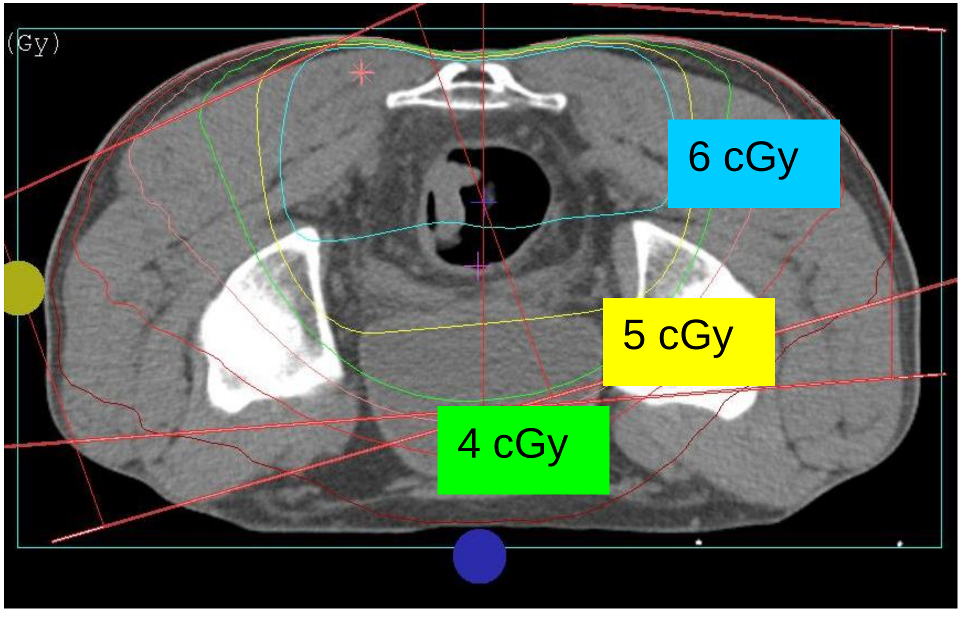
Port View	Gender	Effective Dose E (mSv/MU)
AP pelvis	Male	0.34
	Female	0.52
Lat pelvis	Male	0.32
	Female	0.7
AP chest	Male	1.74
	Female	1.8
Lat chest	Male	2.56
	Female	2.23
Lat neck	N.A.	0.12

X2

P. Waddington and A. L. McKensie, “Assessment of effective dose from concomitant exposures required in verification of the target volume in radiotherapy,” Br. J. Radiol. **77, 557–561 2004.**

Concomitant dose MCBCT

Irradiation of rectum patient
8 MU protocol



In practice for MVCBCT we use about 4 MU.

Doses from CBCT

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- To be accounted for in total dose delivered to a patient?
  - different policies

- My opinion: in general there is no reason to take into account the CBCT concomitant dose unless CBCT is performed each fraction
  - on-line protocol

Summary

- The modern radiotherapy is imaged based
  - CT information for planning
    - fusion with other modalities
- Several solutions
  - visualizing high contrast objects
    - bones
    - gold markers
  - visualizing low contarst objects
    - soft tissue

Summary

- Several solutions
  - pre-irradiation information (low frequency)
    - inter-fraction changes
  - continuous (high frequency)
    - Intra-fraction changes
  - There are also other very sophisticated solutions
    - very expensive

Summary

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- Good news!
  - in more than 80% of cases (my estimation) conventional portal control with EPID is enough,

  - IF

  - The right proctocols are used, and applied properly
    - the sructure, organization and personel are the most important!

- Thank you very much for your attention!

Images keep alive our memories!