IGRT1 technologies

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Minimal prerequisite for good, efficient radiotherapy

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- Well trained staff
  - medical physicists
  - medical doctors
  - radiation technologiests

- Source of ionizing radiation
  - photons of enough high energy

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- Good dosimetry data
  - skills
  - measurement tools

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  - skills
  - measurement tools
- Abbility to preparae the plan
  - image information
  - conformity

Image information

- Why the image information is so important?

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  - We should know where ionizing radiation should be delivered.
  - To delivere precisely the ionizing radiation we must have dosimetric description of the absorbent.

Image information

- Why the image information is so important?
  - We should know where ionizing radiation should be delivered.
  - To delivere precisely the ionizing radiation we must have dosimetric description of the absorbent.
  - We must be able to check if what we do is what had planned to do.

Image Guided Radiotherapy

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- IGRT
  - the process of frequent two and three-dimensional imaging, during a course of radiation treatment, used to direct radiation therapy utilizing the imaging coordinates of the actual radtiation treatment plan
  - Simply: the utilizing the images to make the actual plan as much as possible identical with what had been planned

Image Guided Radiotherapy

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- But
  - In a broad sens **modern** the entire radiotherapy is driven by images

The aim of the IGRT

Plan

The aim of the IGRT

Realization
without IGRT

The aim of the IGRT

Plan with IGRT

The aim of the IGRT

Plan

Realization without IGRT

Realization with IGRT

Radiotherapy guided by images

- What images?
- 3D images
  - Computerized Tomography
    - Magnetic Resonans
      - Positron Emmision Tomography
      - Ultrasound
  - 2D images
    - electronic portal images

The aim of IGRT

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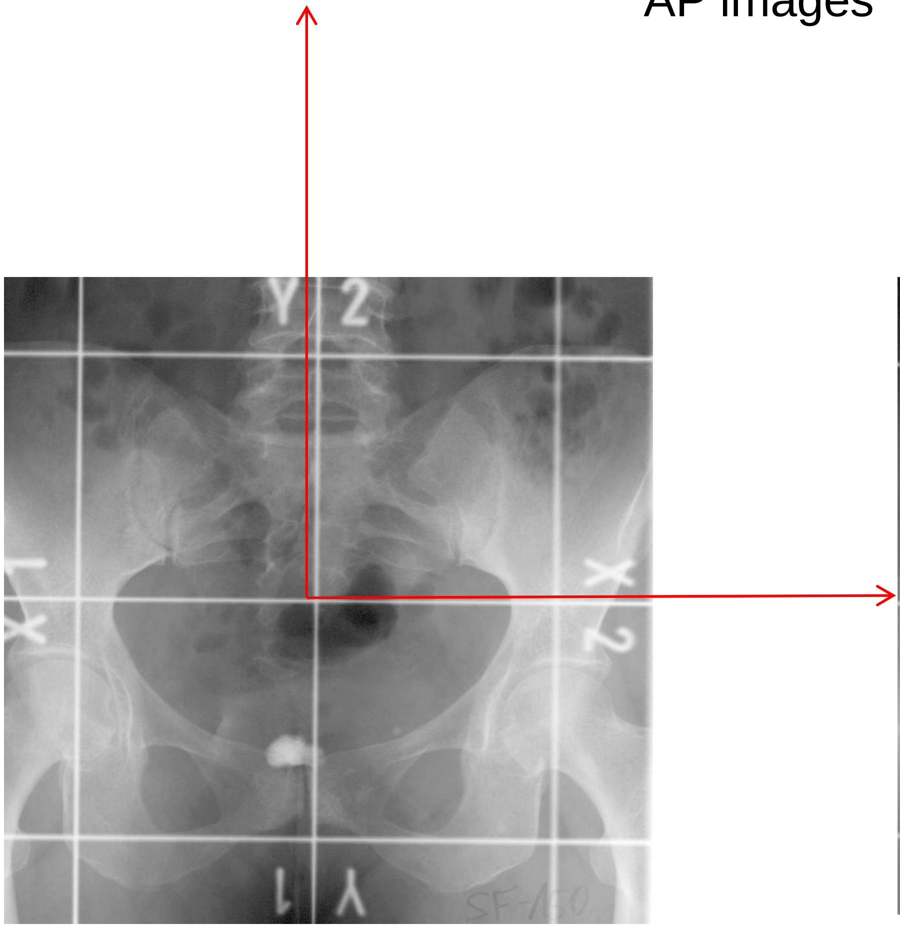
- To make the actual plan as much as possible identical with what had been planned
  - What does it mean?

Reference object
planning

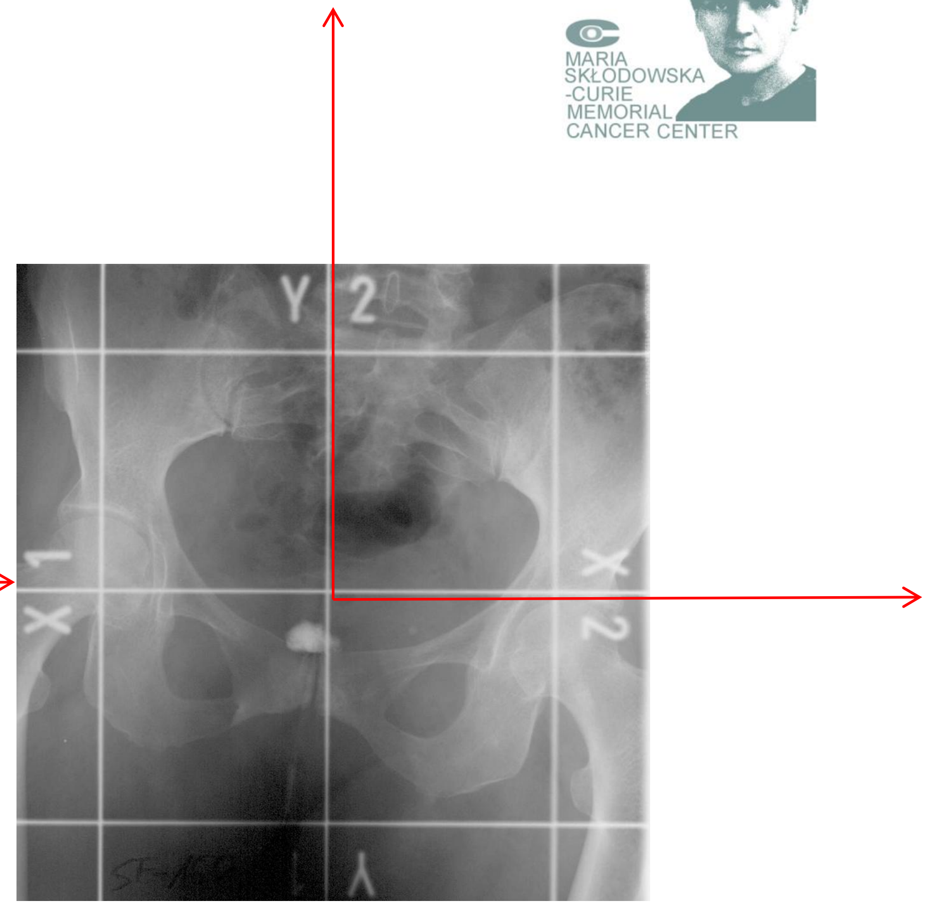
Actual object
treatment

BOTH WITH RESPECT TO THE COORDINATE SYSTEM

AP images



planned



actual

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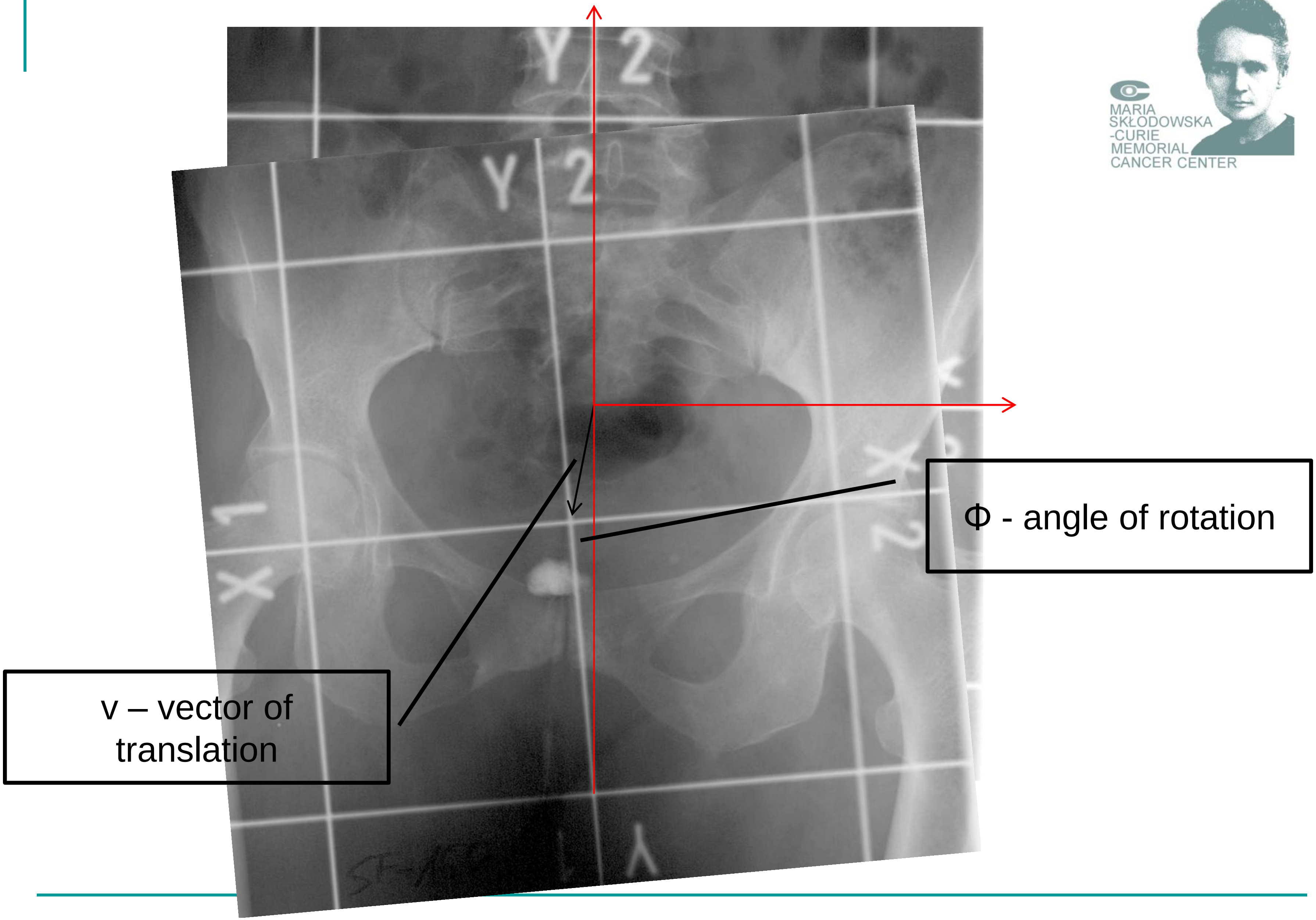
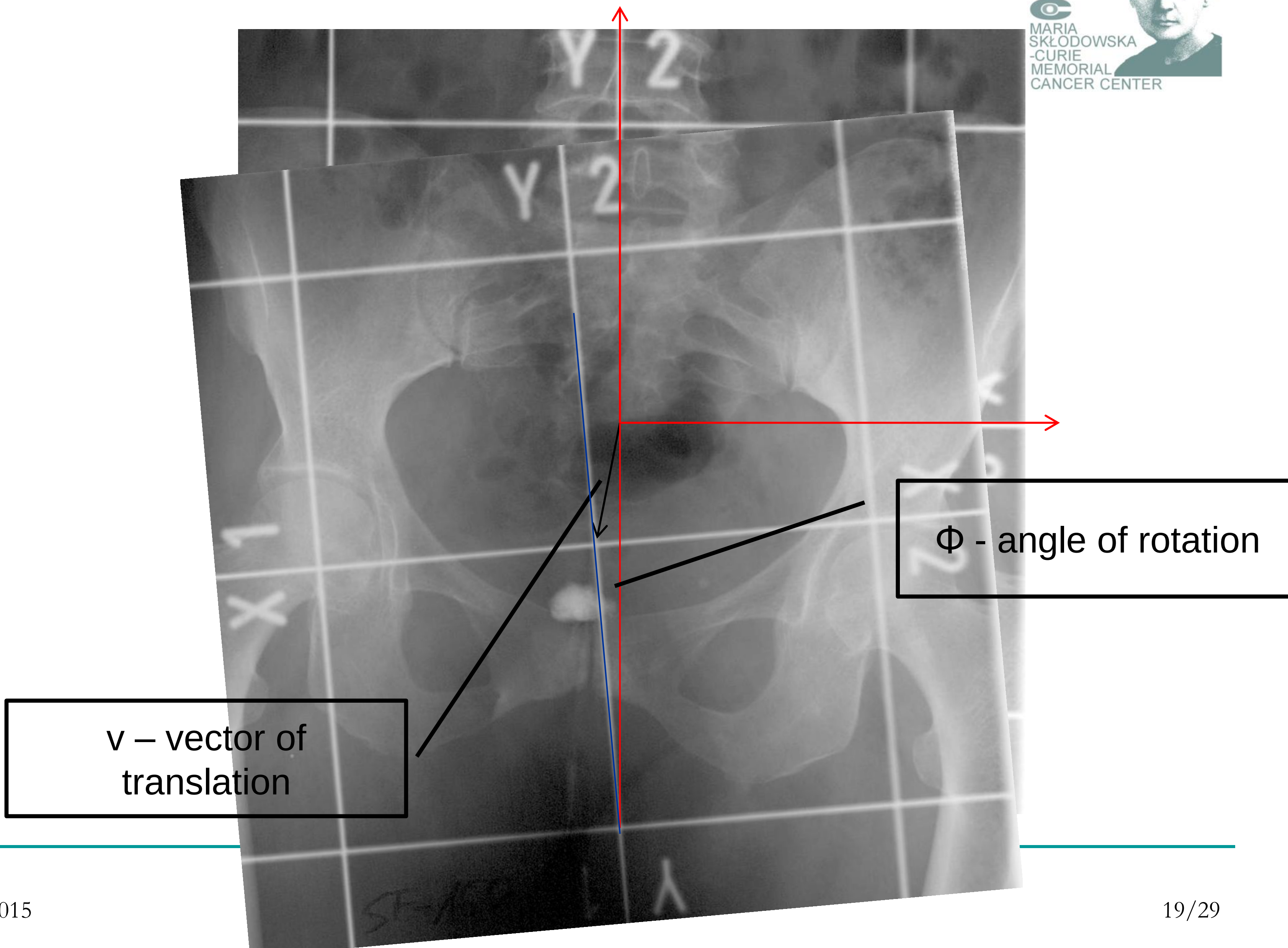
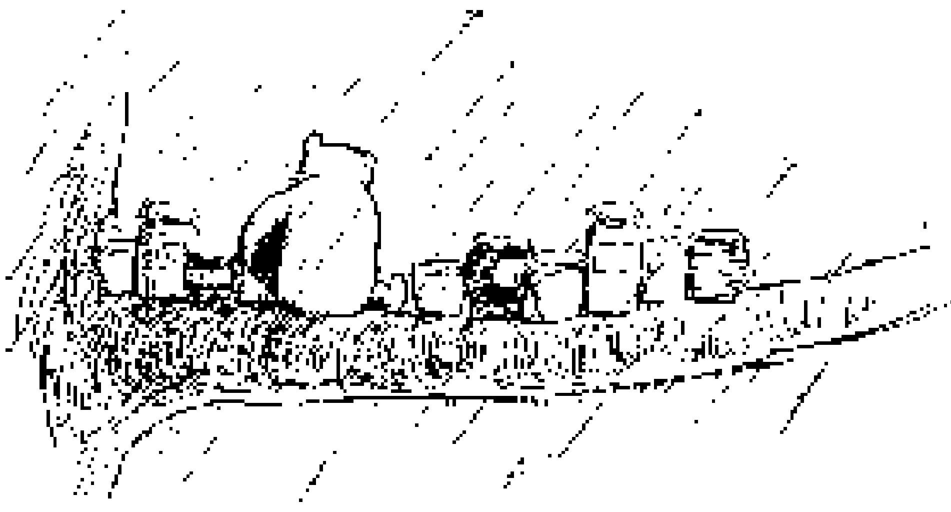


What can we do?

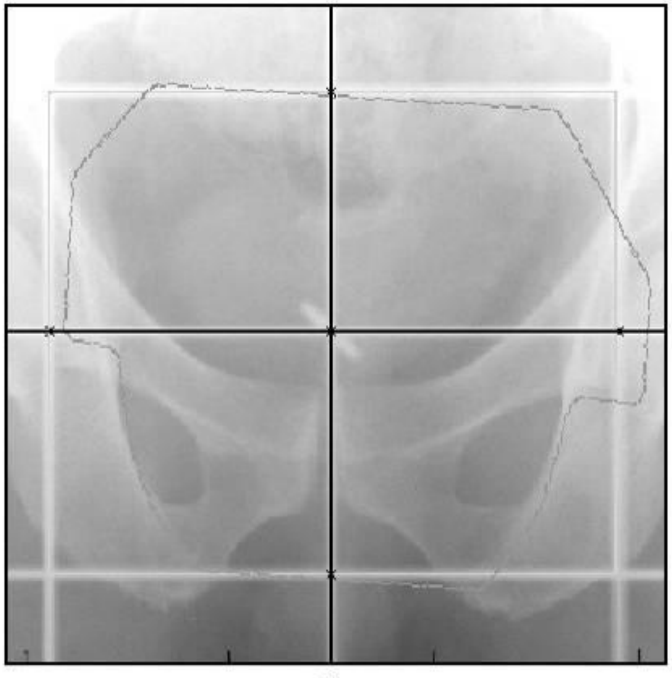


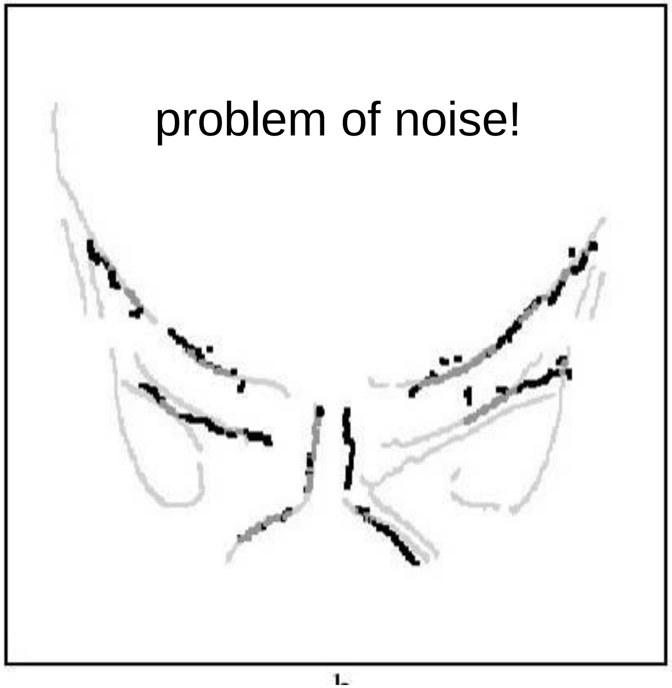
How objects are recognized?
We all are experts!



Recognition is driven by edges!

Edges





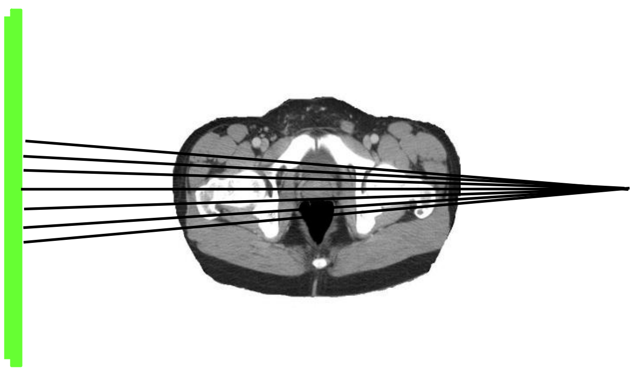
Edge is a second derivative of intensity.

Verification of a treatment plan geometry

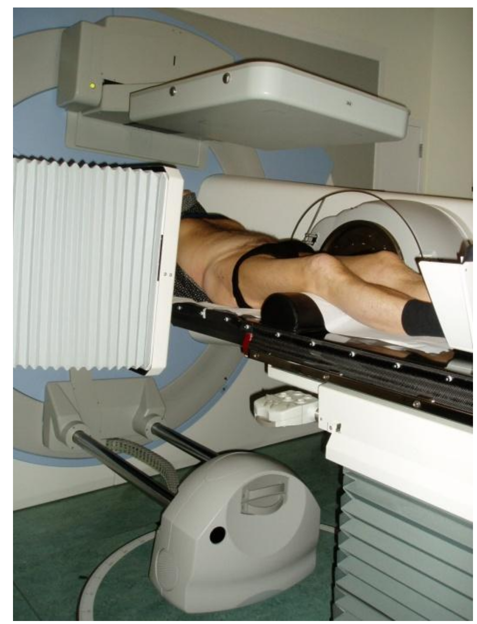
- Involves
  - comparison of a portal image acquired during (prior) a treatment fraction

with

  - a reference image



EPID



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

http://en.wikipedia.org/wiki/Edge_detection

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 regulary
  - dark current or noise (image acquired without beam)
  - uniformity of the image
    - for open field intensity across the beam should be uniform

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

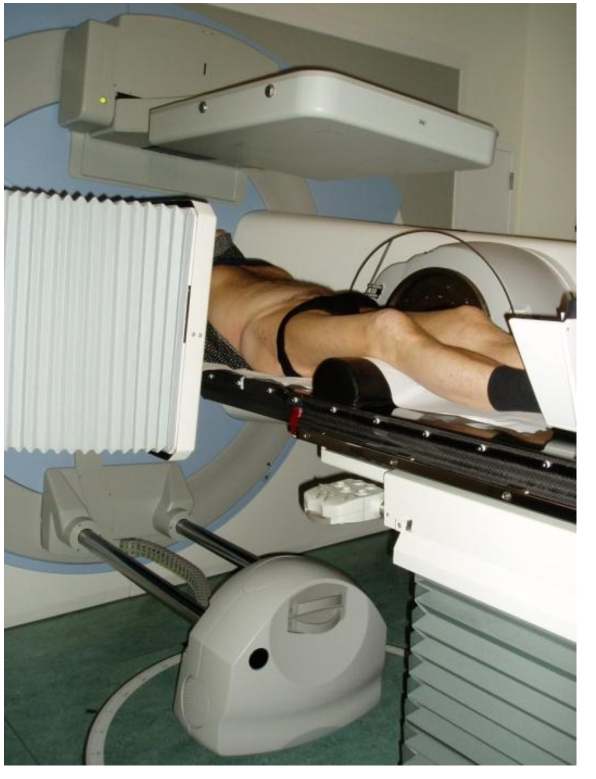
Quality Control of Portal Imaging with PTW EPID QC PHANTOM®

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

Orthogonal portal images

- MV image
- kV image



Orthogonal portal images

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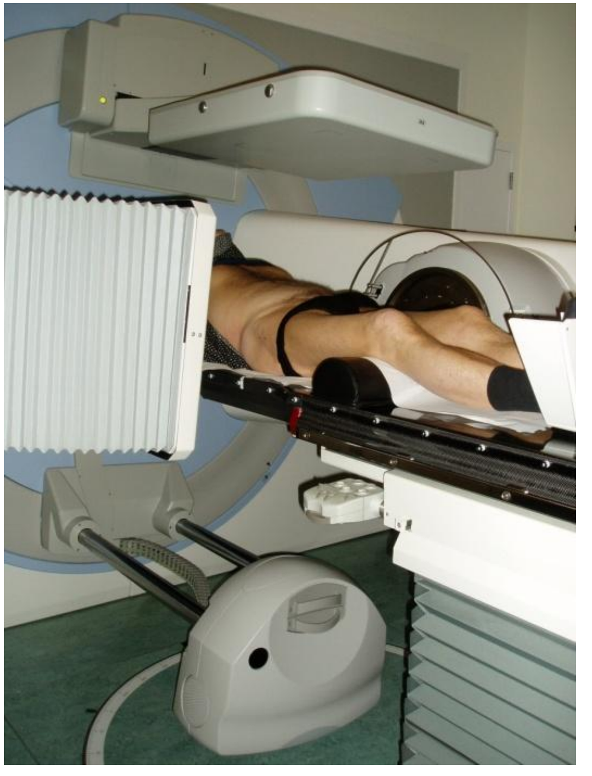

Is both images quality the same?
But, if not, which is better and why?

The physics of portal MV imaging

What we can an can't expect from EPIDs?

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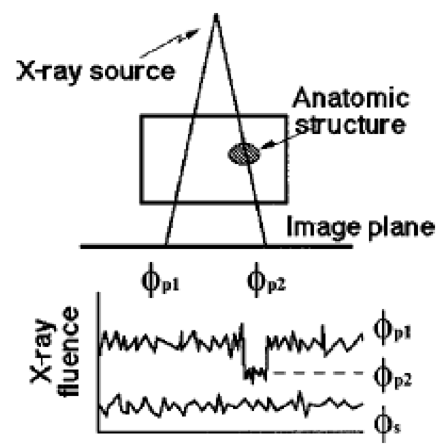
- MV image quality is inherently poorer
  - Contrast: how much an object stands out from its surroundings

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



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

100 kVp; contrast 0.5

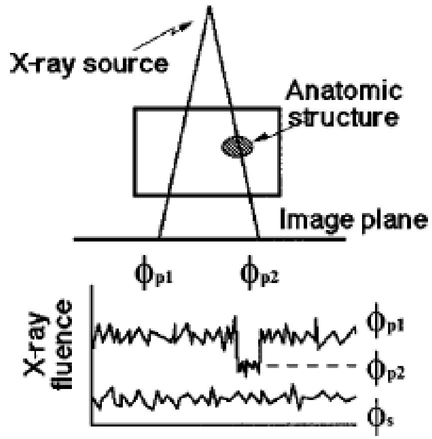
6 MV; contrast 0.037

https://www.aapm.org/pubs/reports/rpt_75.pdf

The physics of portal MV imaging

What we can an can’t expect from EPIDs?

- Image quality („detectibility”) is determined by the signal-to-noise-ratio (SNR)



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

Calculated SNR and patient doses at diagnostic and therapeutic X-ray energies

	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

The physics of portal MV imaging

What we can an can’t expect from EPIDs?

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- Quantum efficiency – detective quantum efficiency (DQE)
  - „a measure of how efficient the imaging system is at transferring the information contained in the radiation beam incident upon the detector”

$$DQE = \frac{SNR^2_{output}\left(f_{spatial}\right)}{SNR^2_{input}\left(f_{spatial}\right)}$$

The smaller is DQE the **larger dose** is needed for a given SNR!

AAPM, Task Group 58

Improving quality of images

- kV radiation

The idea and first solution.
Haynes Radiation

CyberKnife

Exact Track BrainLab

3D Technology

- Principle is the same
  - Reference image (set of images) is compared with treatment image (set of images)
    - more information is accessible
- 2D images → 3D images
  - Computerized tomography
    - conventional (on rails) tomograph
    - cone beam tomograph
    - MV cone beam CT

3D Technology cone beam CT

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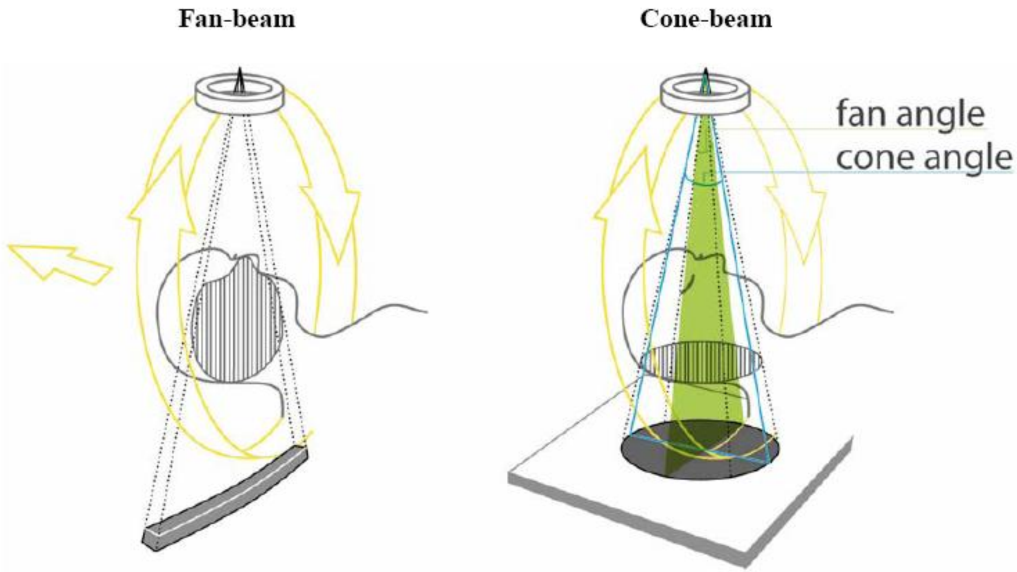
<< 1 sec



~ 1 min

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

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

Why?

3D Technology cone beam CT

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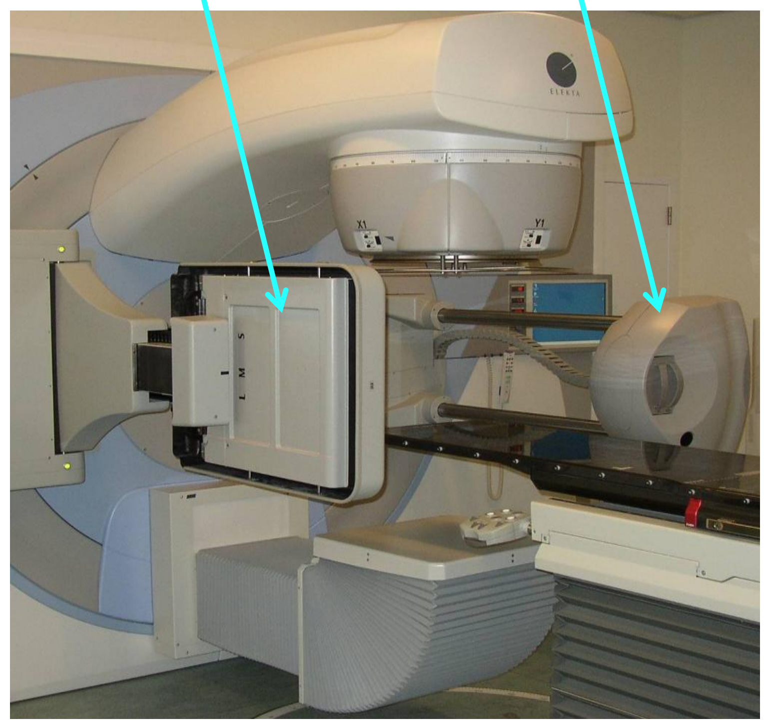
- With kilovoltage radiation
  - Elekta –
  - Varian - On Board Imaging
  - Specialized software for image registration



Detector - EPID

Rtg lamp

Image quality

- Worse than for conventional CT
  - smaller SNR
- Good enough for soft tissue registration in most 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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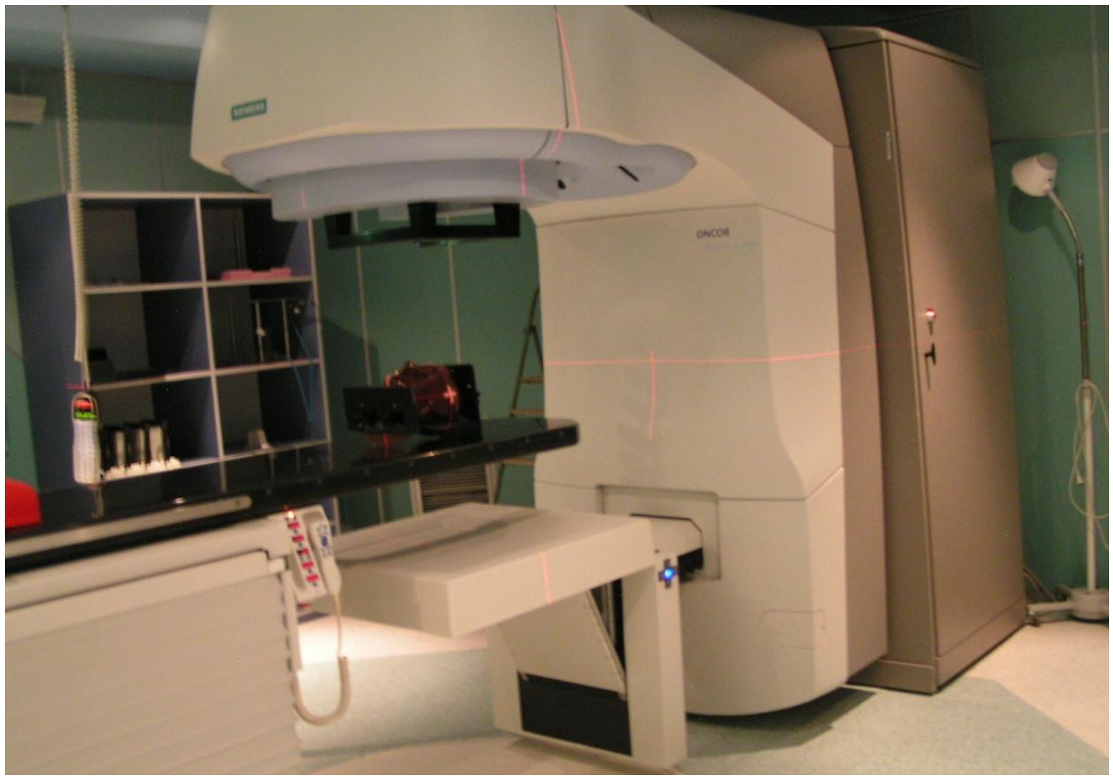
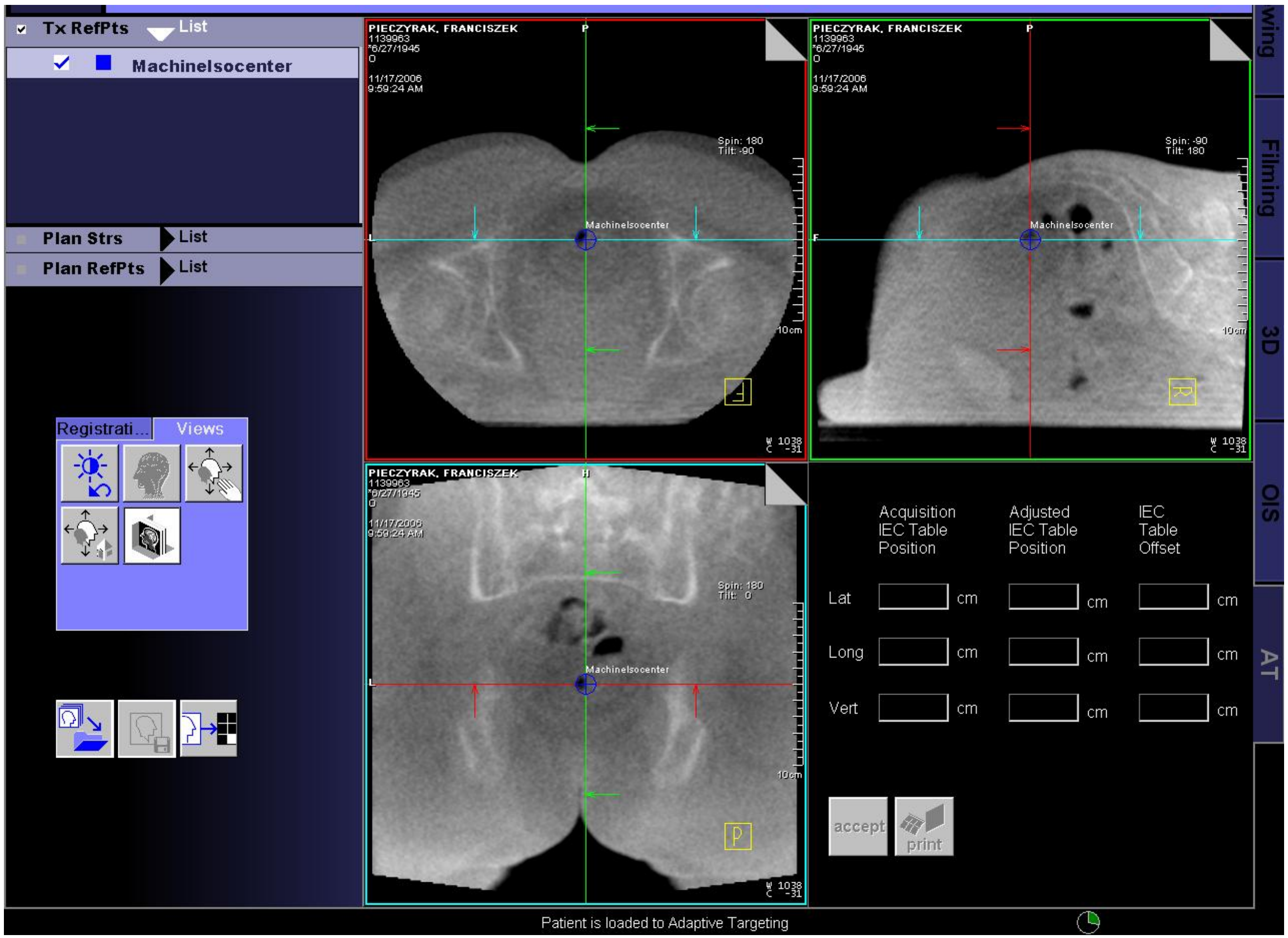


Megavoltage Cone Beam CT
image quality



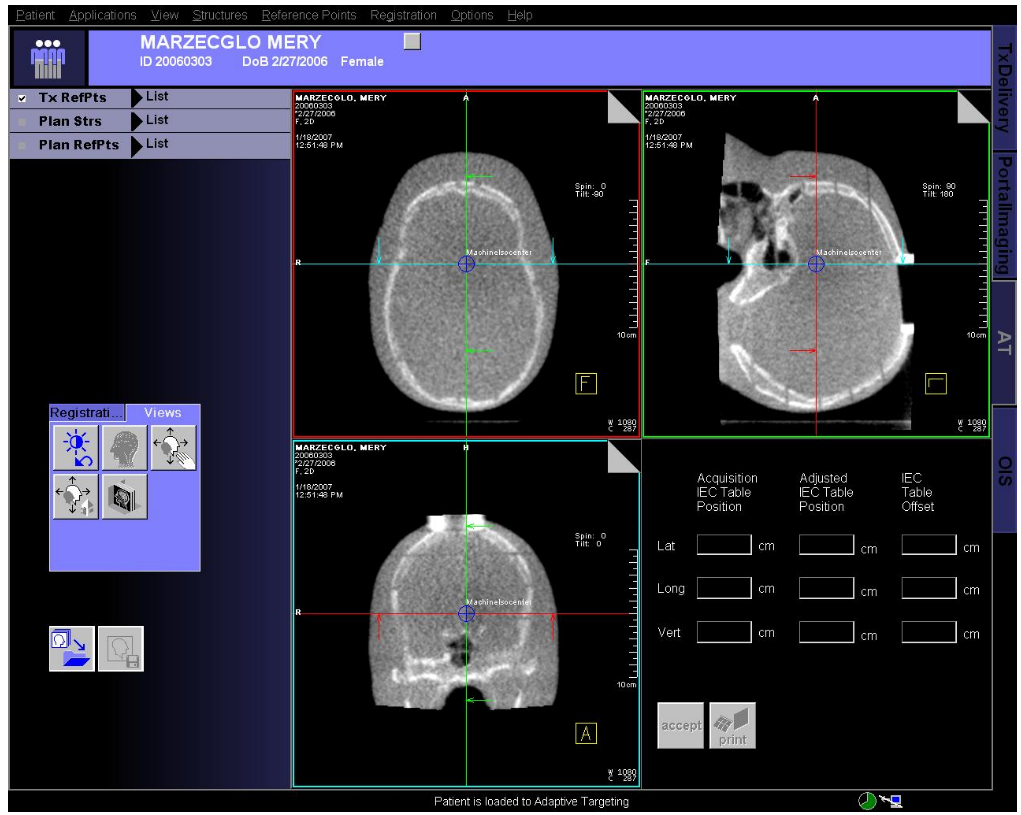
MVCBCT

image quality

- Dependence on dose

3 MU protocol

dose ~ 0.01 mSv



CT on rails

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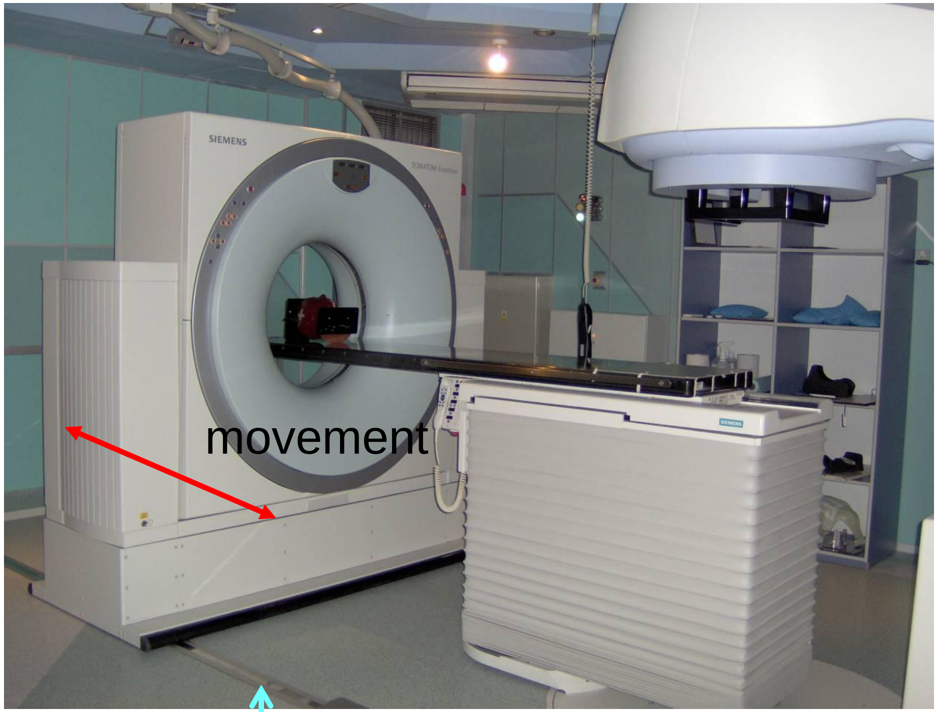

rail

Holycross Cancer Center
Kielce, Poland

Concomitant dose in IGRT

- 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.

EFFECTIVE DOSE DEFINITION

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

Effective Dose E (Sv)

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- $H_T = \sum r\ W_R\ D_{T,R}$
- where $D_{T,R}$ is the absorbed dose averaged over the tissue or organ T, due to radiation R
- W_R is the radiation specific coefficient

- $E = \sum t\ w_T\ H_T$

where H_T is defined above; the sum is over all irradiatiated tissues T, w_T is the weighting factor for tissue T.

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

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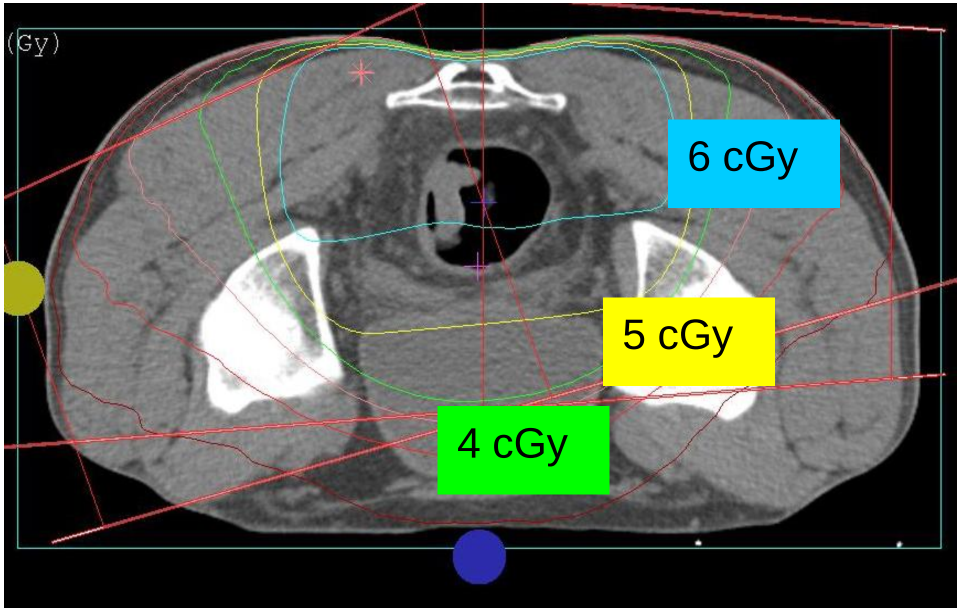
Irradiation of rectum patient
8 MU protocol



Doses from CBCT

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- ALARA principle
  - As low as resonble achievable.
- Does ALARA principle is applicable to radiotherapy?
  - It does, but we should remember that
    - We treat ill persons. The worse complication after treatment is if tumour is not controlled
    - Uncertainty in dose delivery is at the level of 4 – 5%, so additional doses from imaging should be compared with this uncertainty.
    - Imaging allows for diminishing the CTV-PTV margin, what diminishes considerably the dose delivered to a patient.

Doses from CBCT

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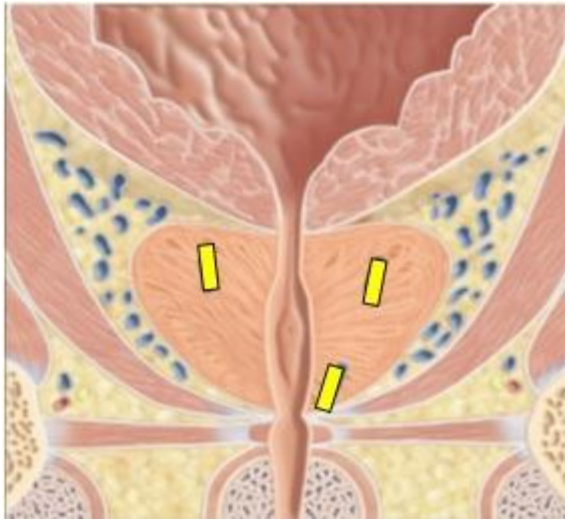
- To be accounted for in total dose delivered to a patient?
  - different policies

- 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

Other methods

images or surrogate of images

- Markers indicated of tumor position
  - gold markers



Other methods
images or surrogate of images

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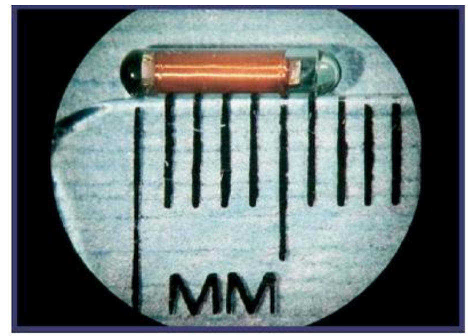
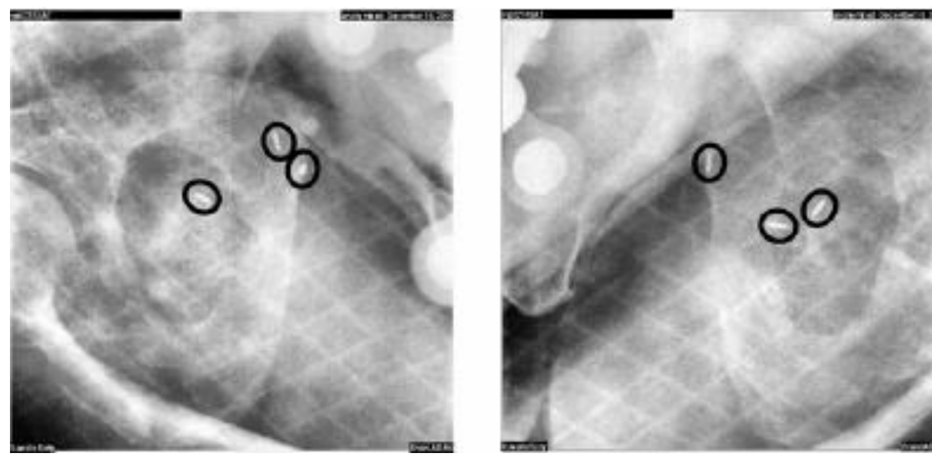
- Transponders





Other methods
skin surface as a surrogate

- Sentinel

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

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- Several solutions
  - pre-irradiation information (low frequency)
    - inter-fraction changes
  - continuous (high frequency)
    - Intra-fraction changes

  - imaging per se
  - surrogate
    - markers
    - skin

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!