IGRT2

How to use image information?

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Verification of radiotherapy

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- In space of dose
  - Comparison of prescribed and delivered dose (dose distribution)
    - Eg. In-vivo dosimetry
- In space of location
  - Portal control
    - image based

Portal control

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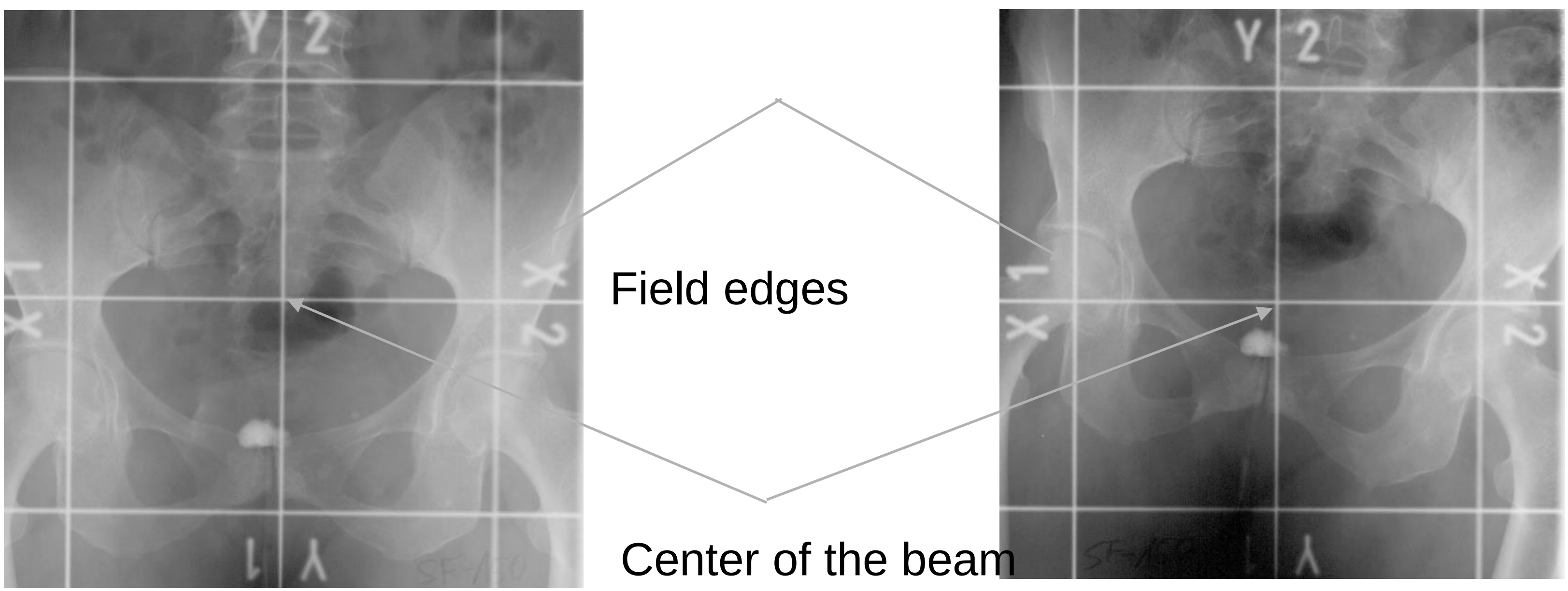
- To minimize the set-up error

- There are systematic and random errors in patient positioning
  - systematic errors deteriorate the dose delivery much more than random errors (3x)
    - The aim of portal control is to minimize the systematic error!

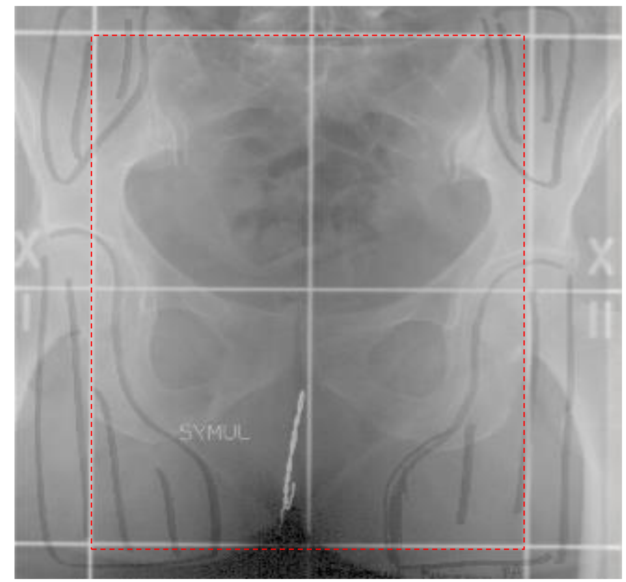
Veryfication of geometry

- Geometry
  - Comparison of
    - reference image and
    - treatment field image



Reference image

- Simultor image



Reference image

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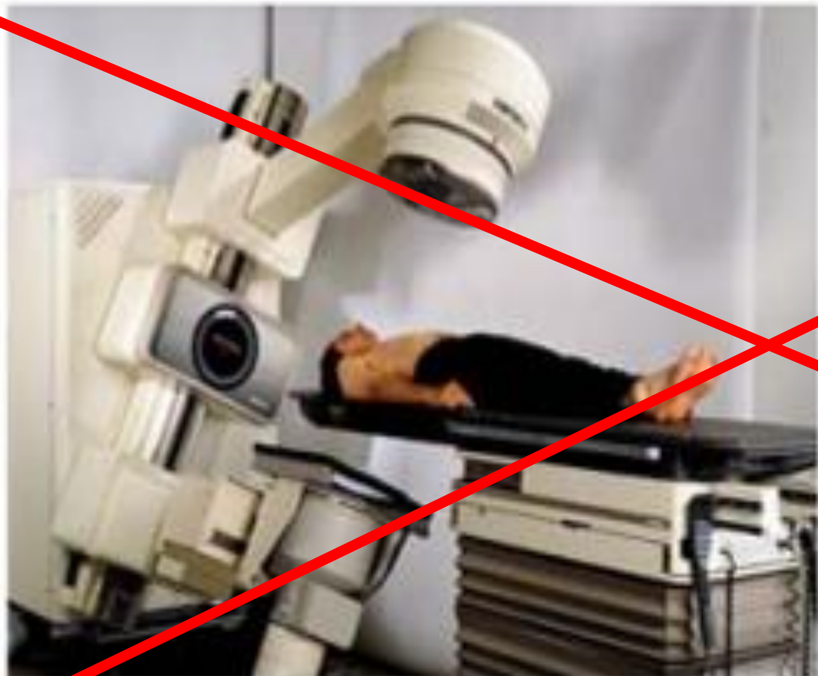
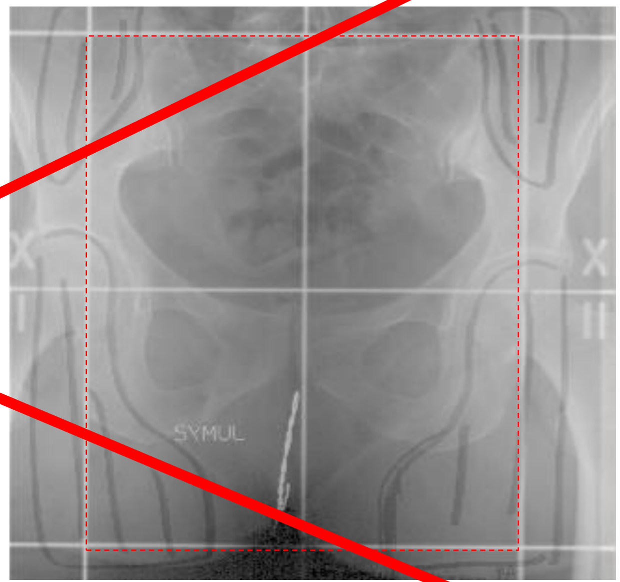
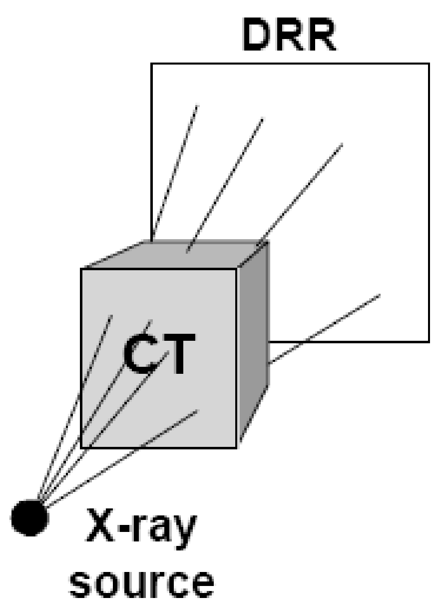
- Simultor image

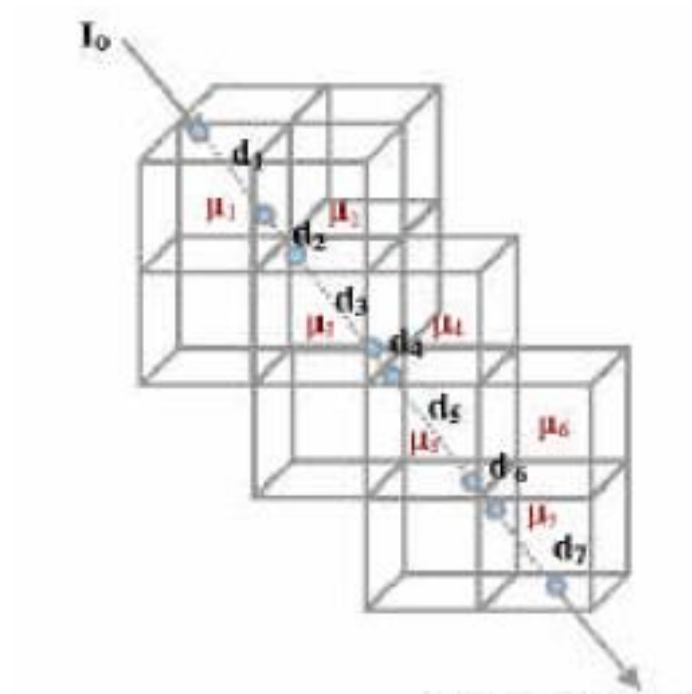




Reference image

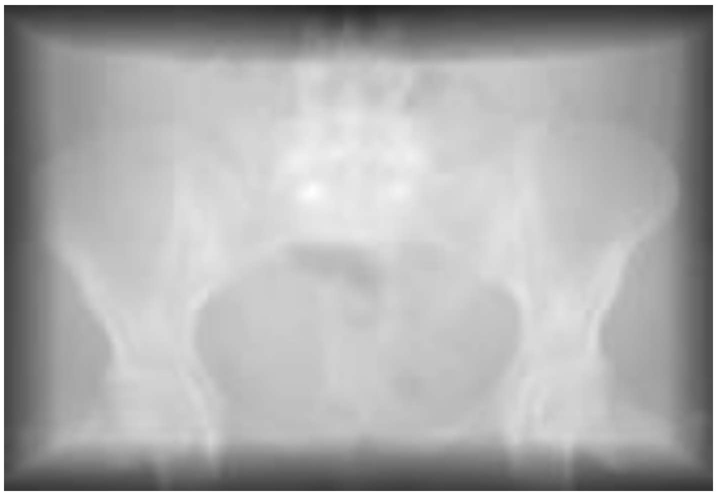
Digitally Reconstructed Image

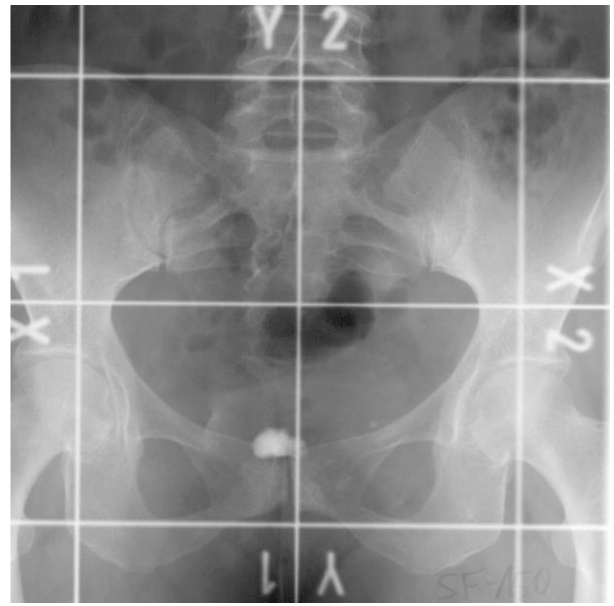




$$I = I_0 \cdot \left(e^{-(\mu_1 \cdot d_1 + \mu 2 \cdot d\,2 + \mu 3 \cdot d\,3 + \mu_4 \cdot d_4} \right)$$

DRR
digitally reconstructed radiograph

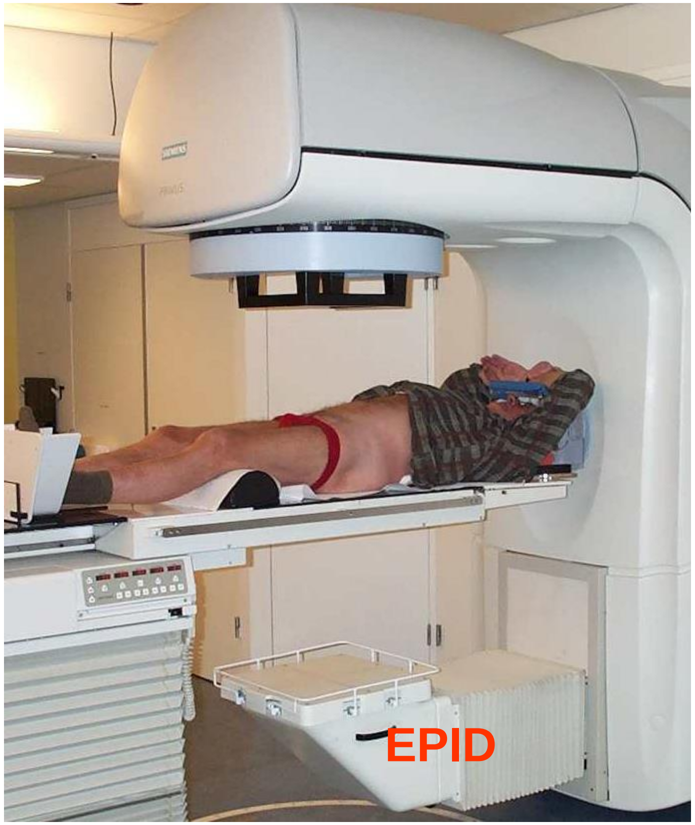


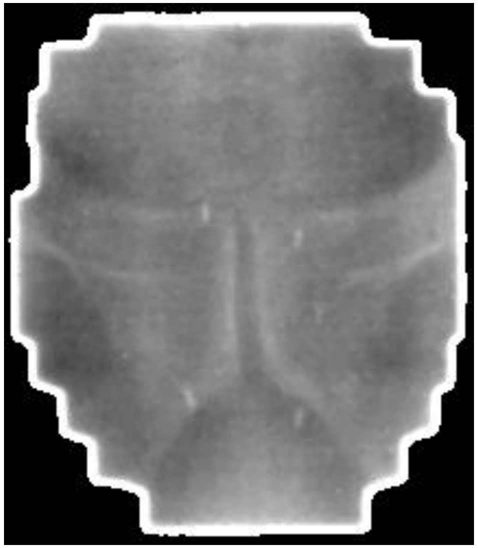


Quality of DRR

- Depends on
  - slice separation
    - it is recommended to use 3 mm slice separation
    - but
  - 3 mm slice separation makes contouring very tedious
    - interpolation tools
      - these tools must be checked !

Portal images

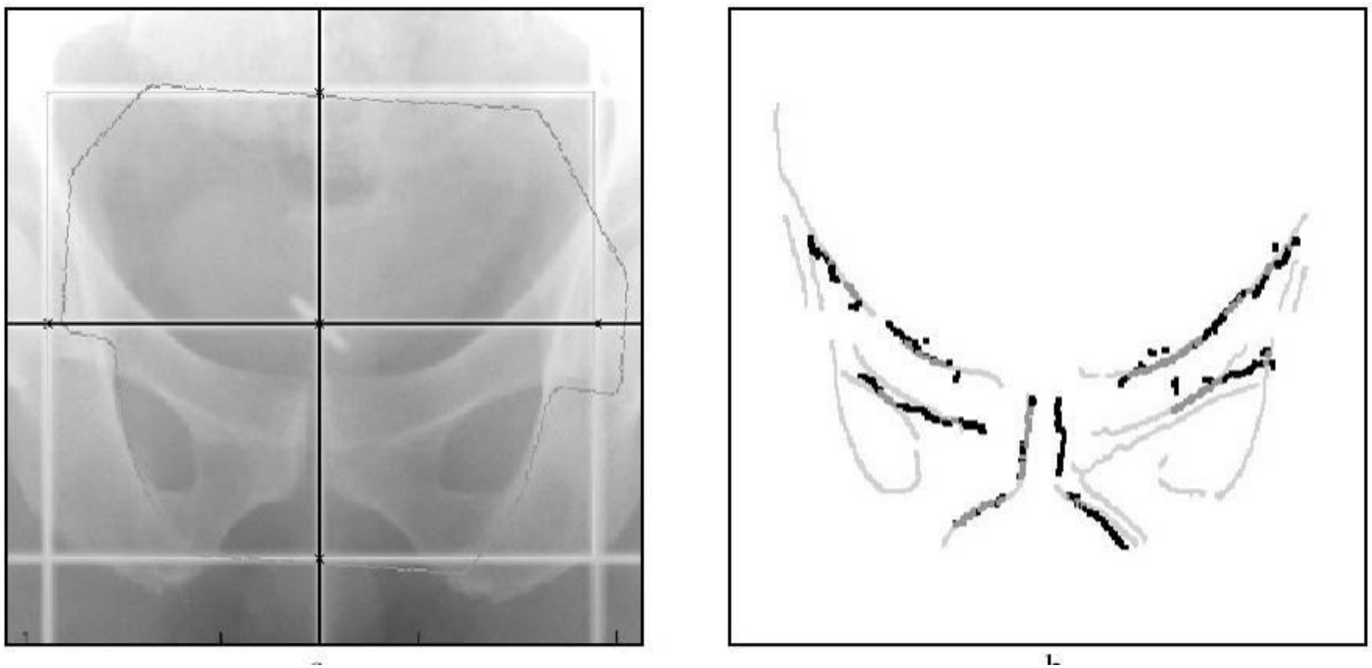




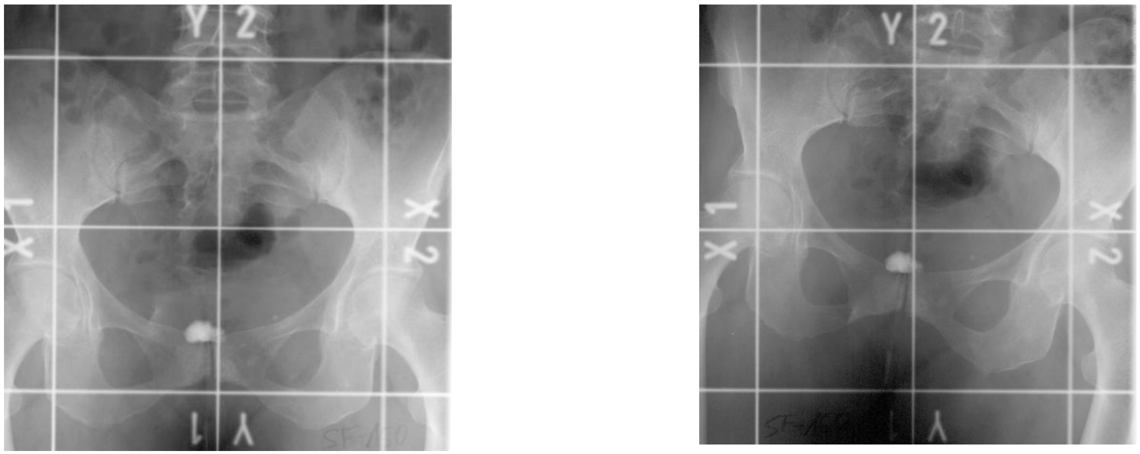
Courtesy of B.Heijmen

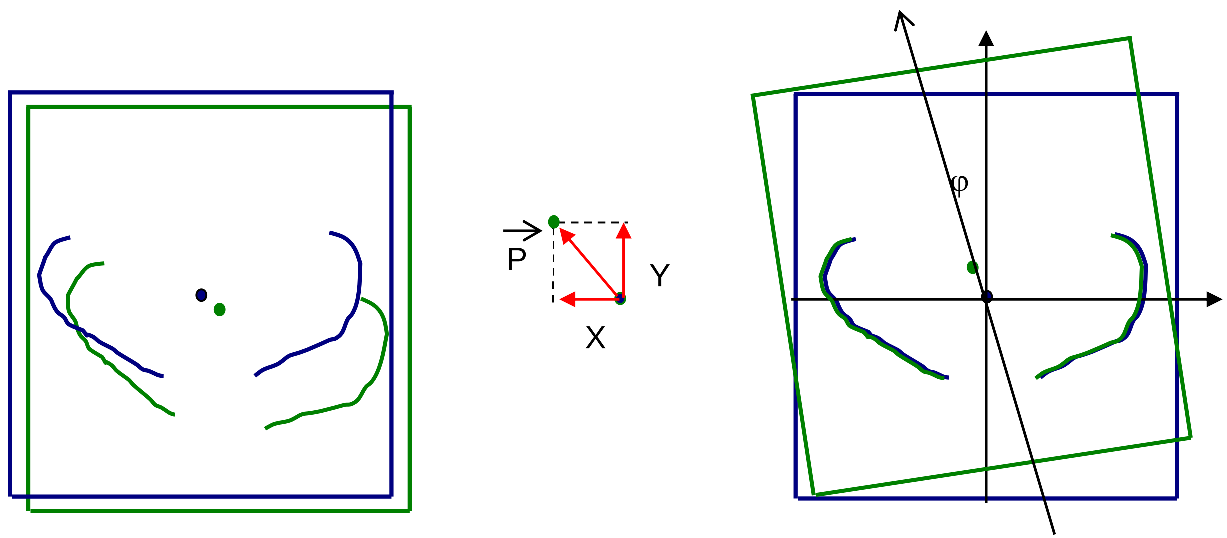
Edges

zero of the second derivative of intensity

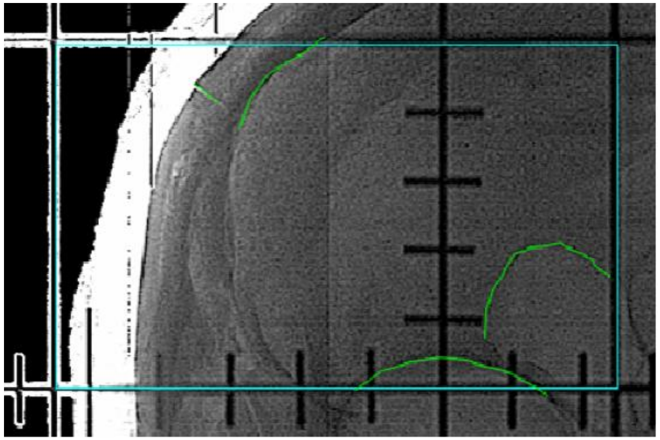


Matching of reference and portal images

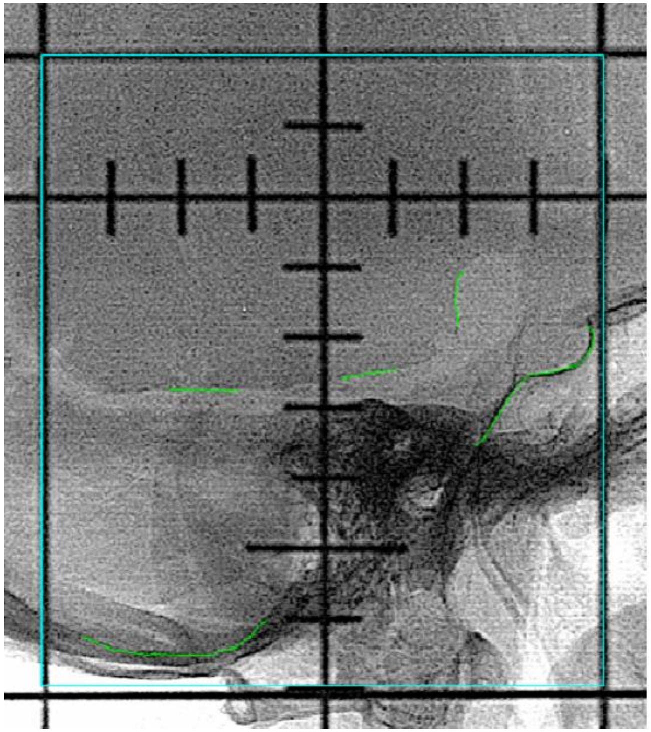




Structures to be matched brain

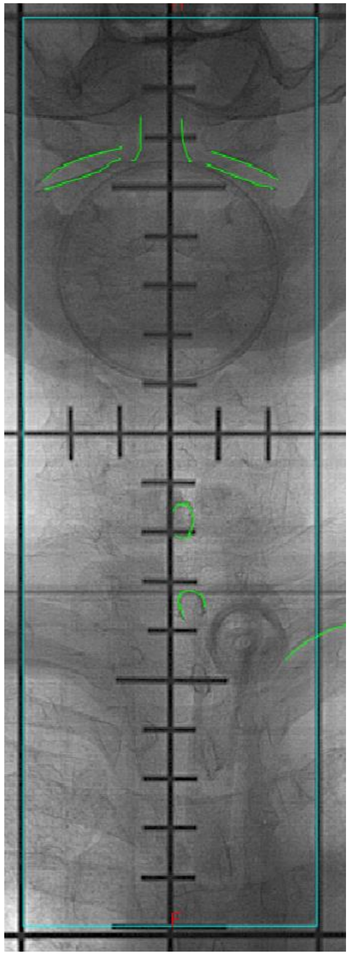


AP



lateral

Structures to be matched H&N



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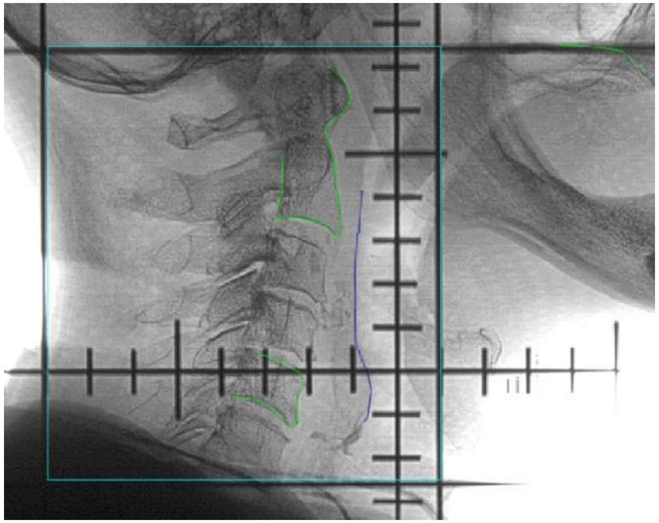
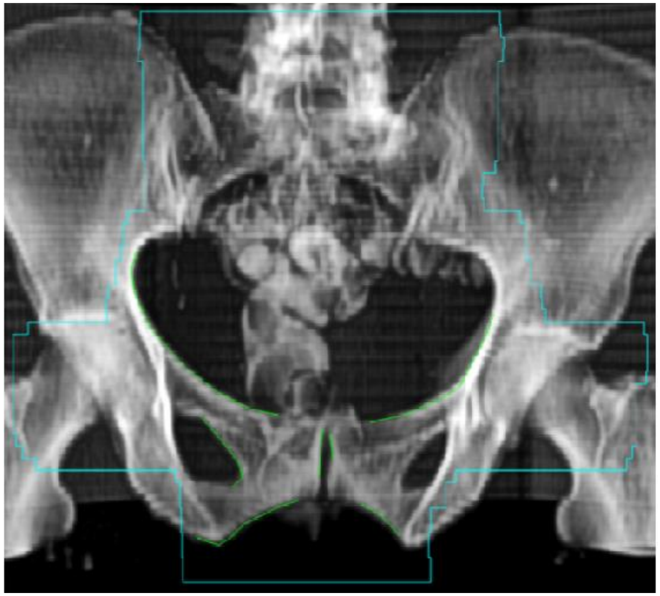
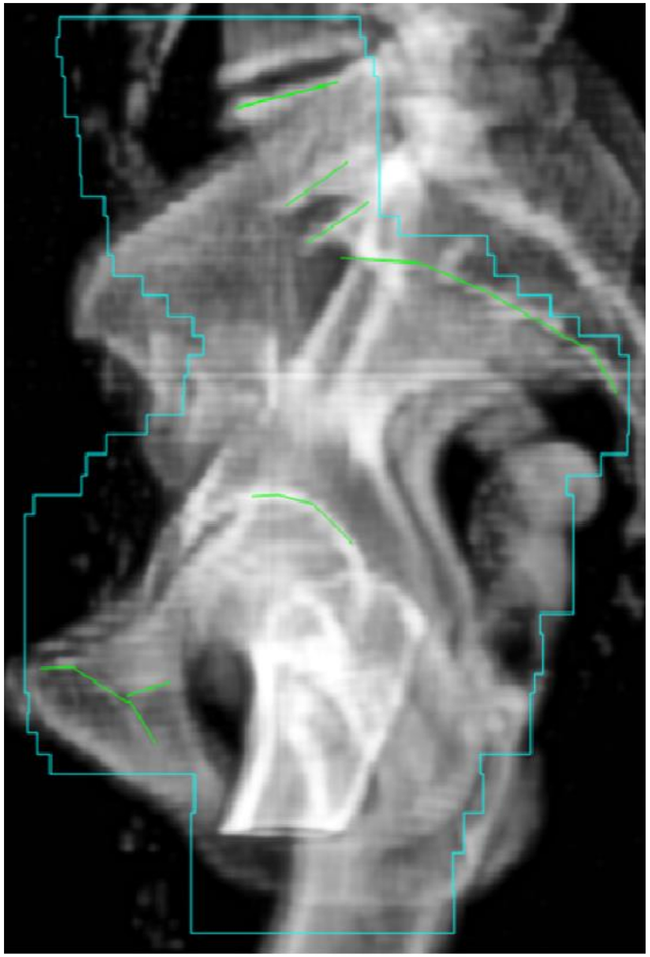


lateral

Structures to be matched pelvis



AP



lateral

Correction strategies

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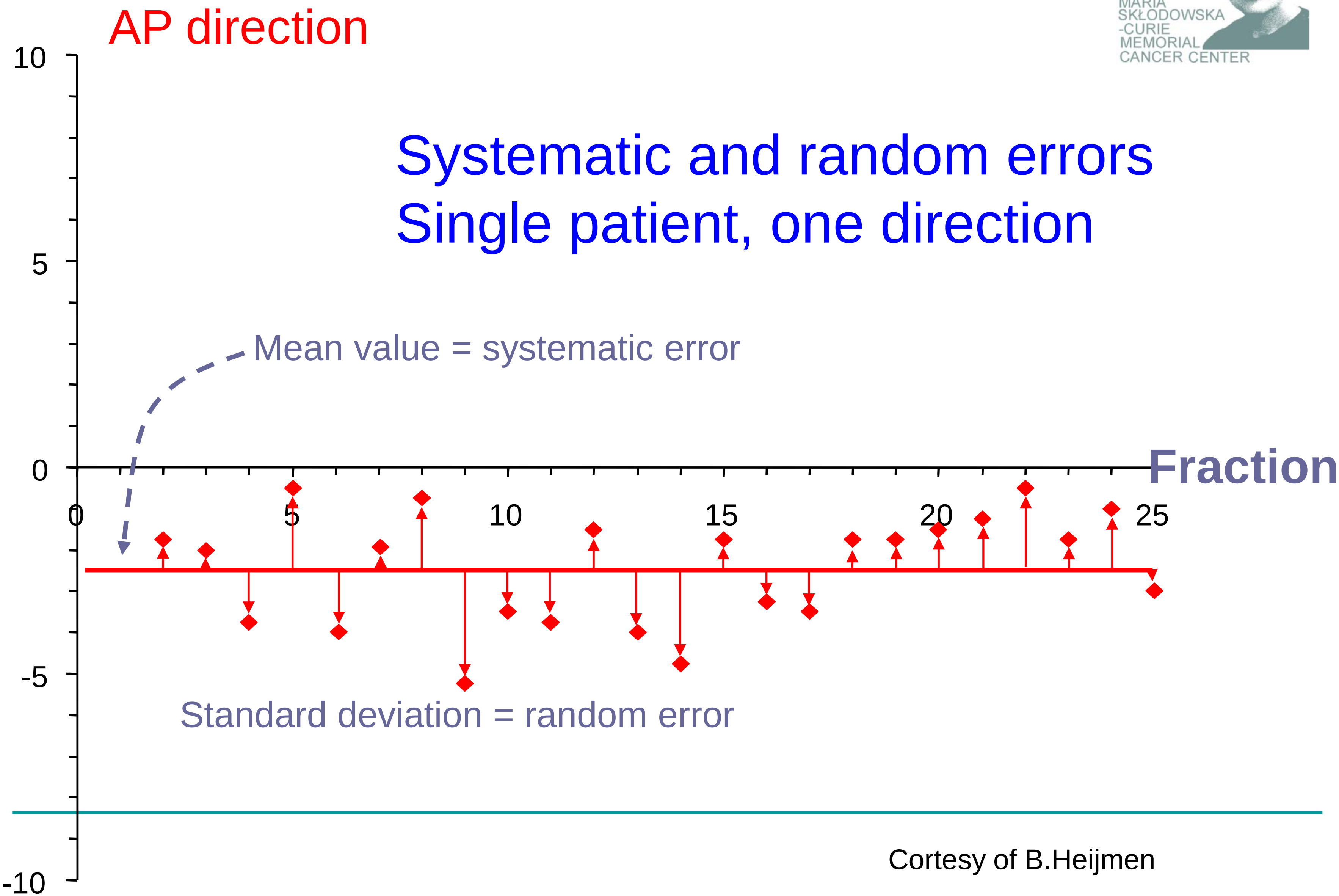
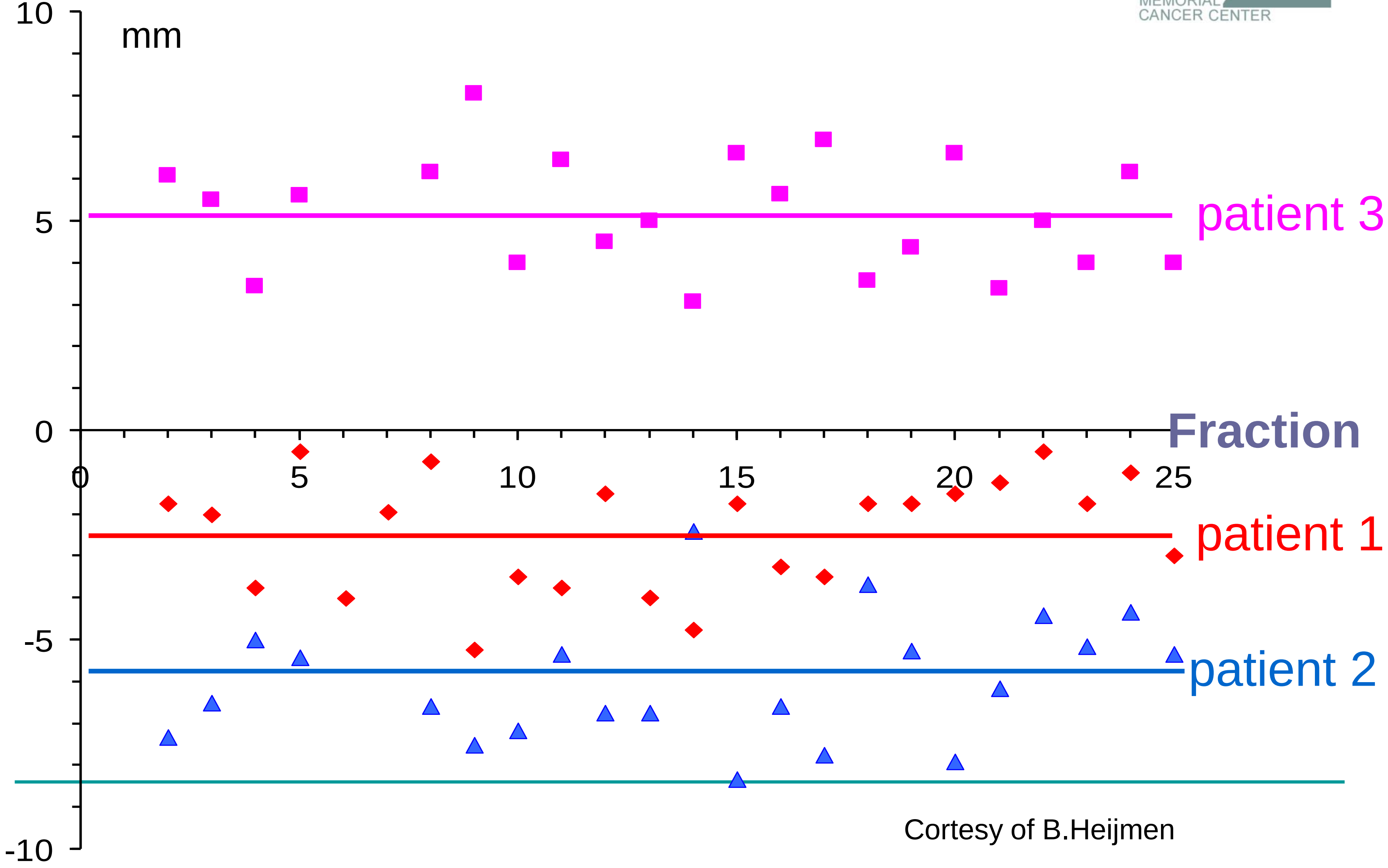
Systematic and random errors
Single patient, one direction



Cortesy of B.Heijmen

Systematic and random errors
For a few patients



Cortesy of B.Heijmen

Systematic and random errors – 2D

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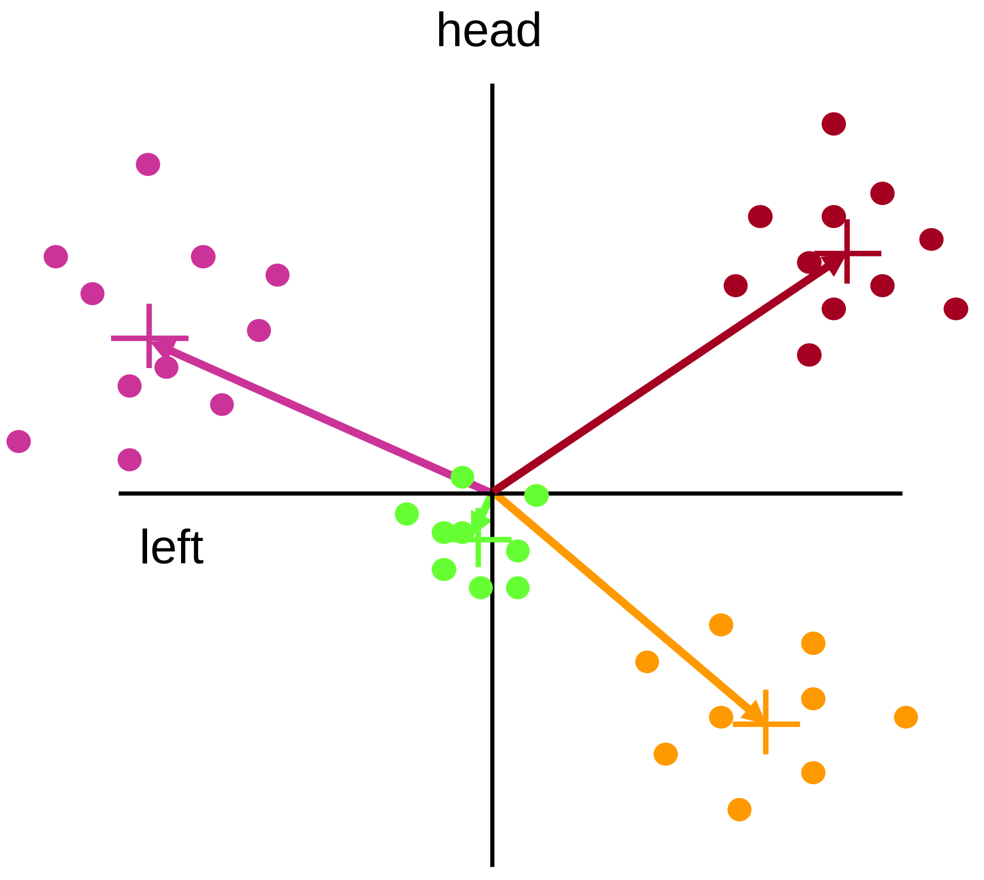


Cortesy of B.Heijmen

Systemic and random errors
Group of „similar” patients

Mean group error

$\mathbf{M_x}$: $\langle m_{i,x} \rangle \approx 0$

$\mathbf{M_y}$: $\langle m_{i,y} \rangle \approx 0$

Distribution of systematic errors

$\boldsymbol{\Sigma_x}$: $SD(m_{i,x})$

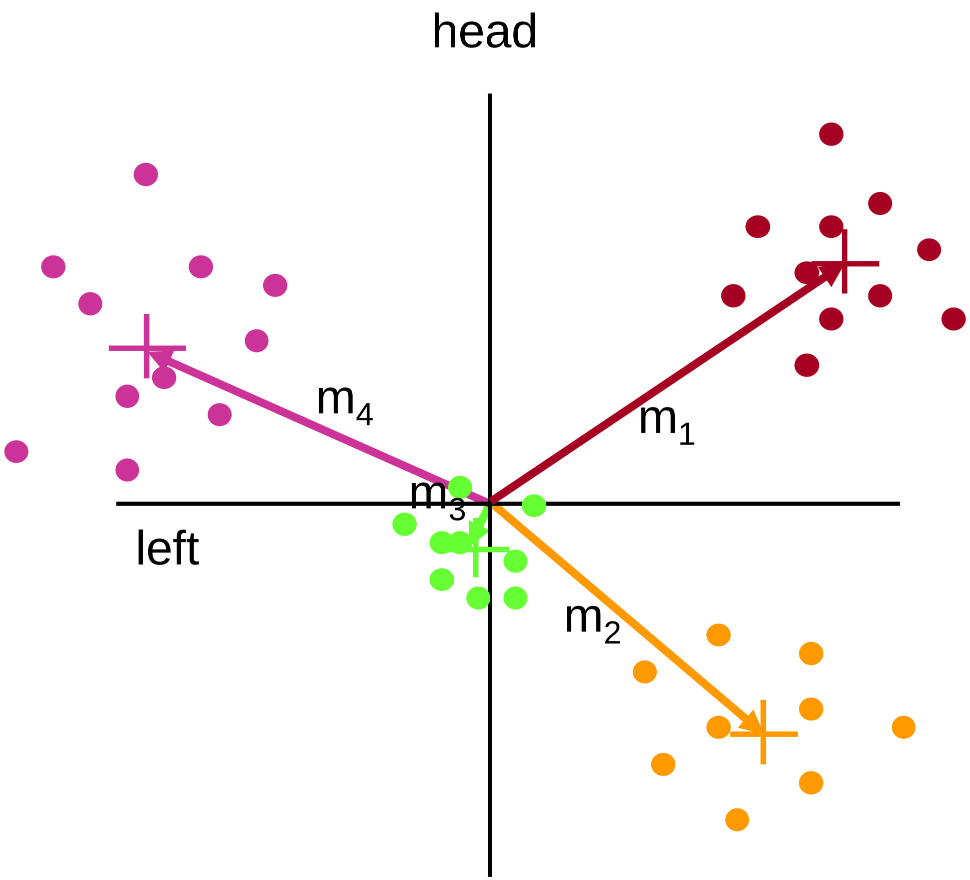
$\boldsymbol{\Sigma_y}$: $SD(m_{i,y})$

Random group error

$$\sigma_x = \frac{1}{N}\sqrt{\sum_i \sigma_{i,x}^2}$$

$$\sigma_y = \frac{1}{N}\sqrt{\sum_i \sigma_{i,y}^2}$$

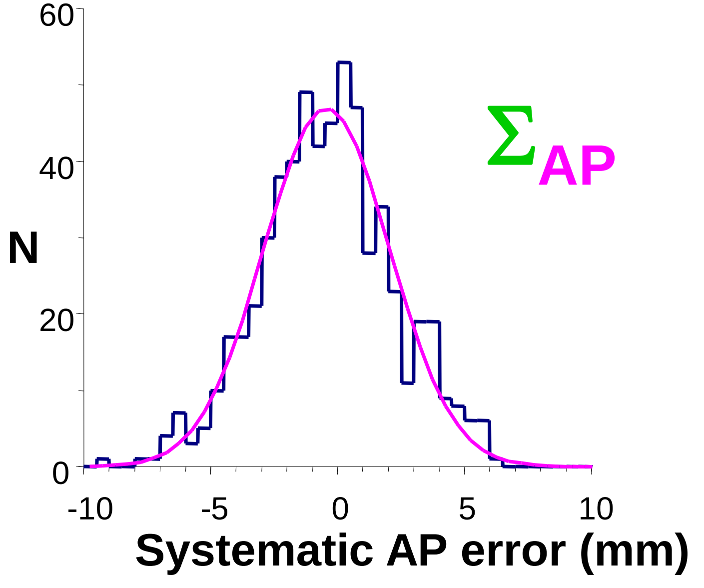
A few patients

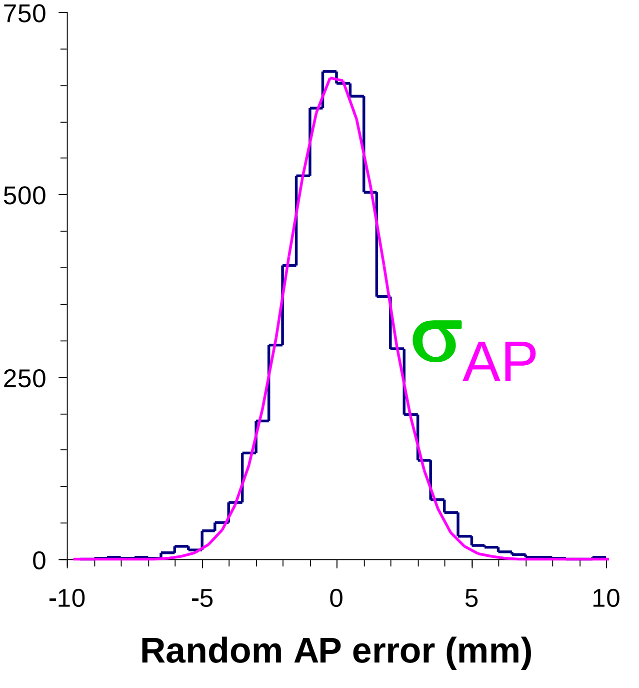


Cortesy of B.Heijmen

Distribution of errors

600 prostate patients





(De Boer and Heijmen, IJROBP, 2001)

Strategies

On-line protocols

- measure and correct in the same fraction

Off-line protocols

- measure during first few fractions

correct if needed

•

•SAL Shrinking Action Level (Amsterdam)

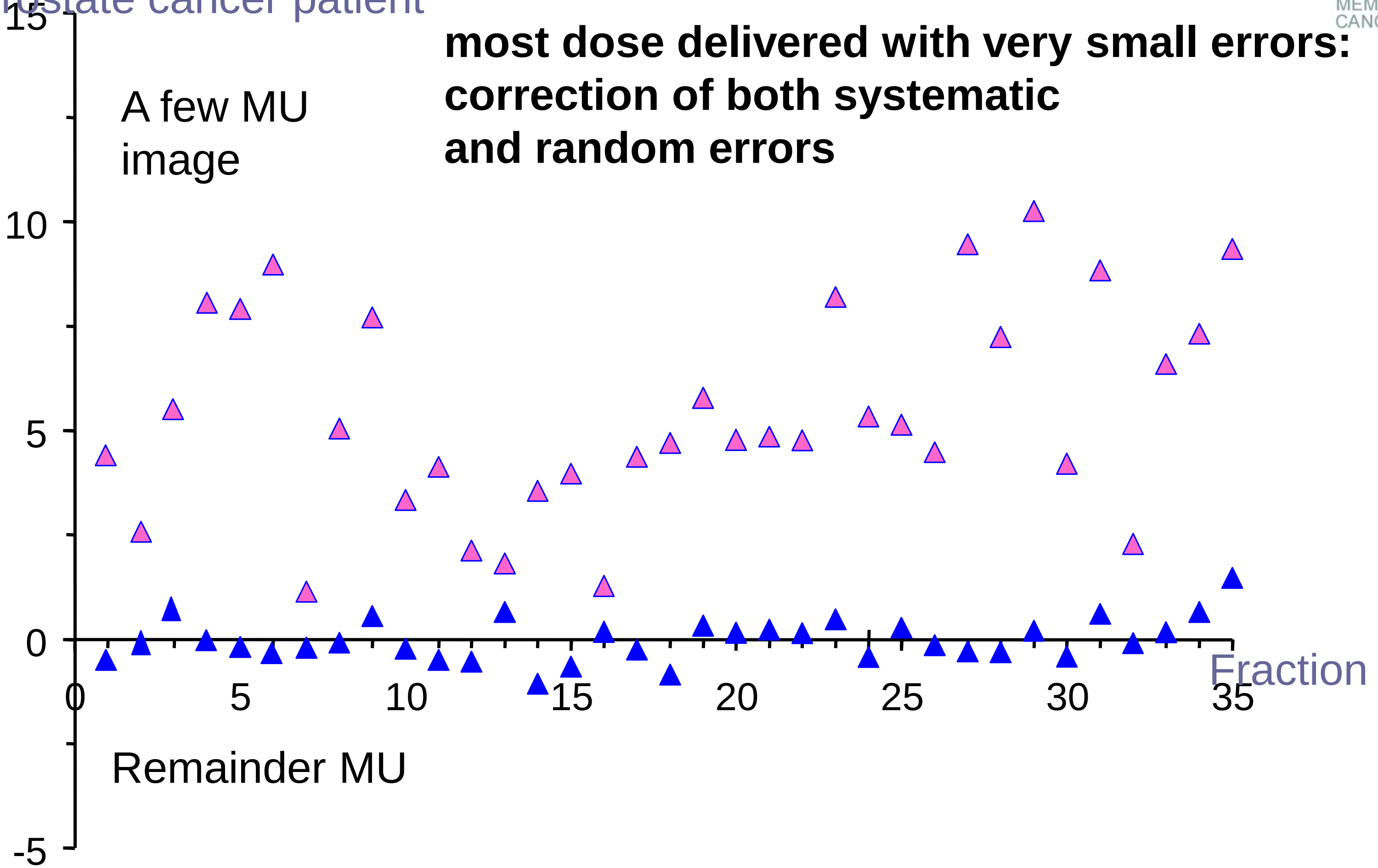
• NAL No Action Level (Rotterdam)

• eNAL extended NAL

On-line correction

AP displacements (mm)

Prostate cancer patient



Data for on- off-line corrections

- 2D
  - EPID
- 3D
  - 2 orthogonal iamges
  - CT type control
    - kV cone beam CT
    - MV cone beam CT
    - CT on rails

NAL (de Boer and Heijmen, IJROBP, 2001)

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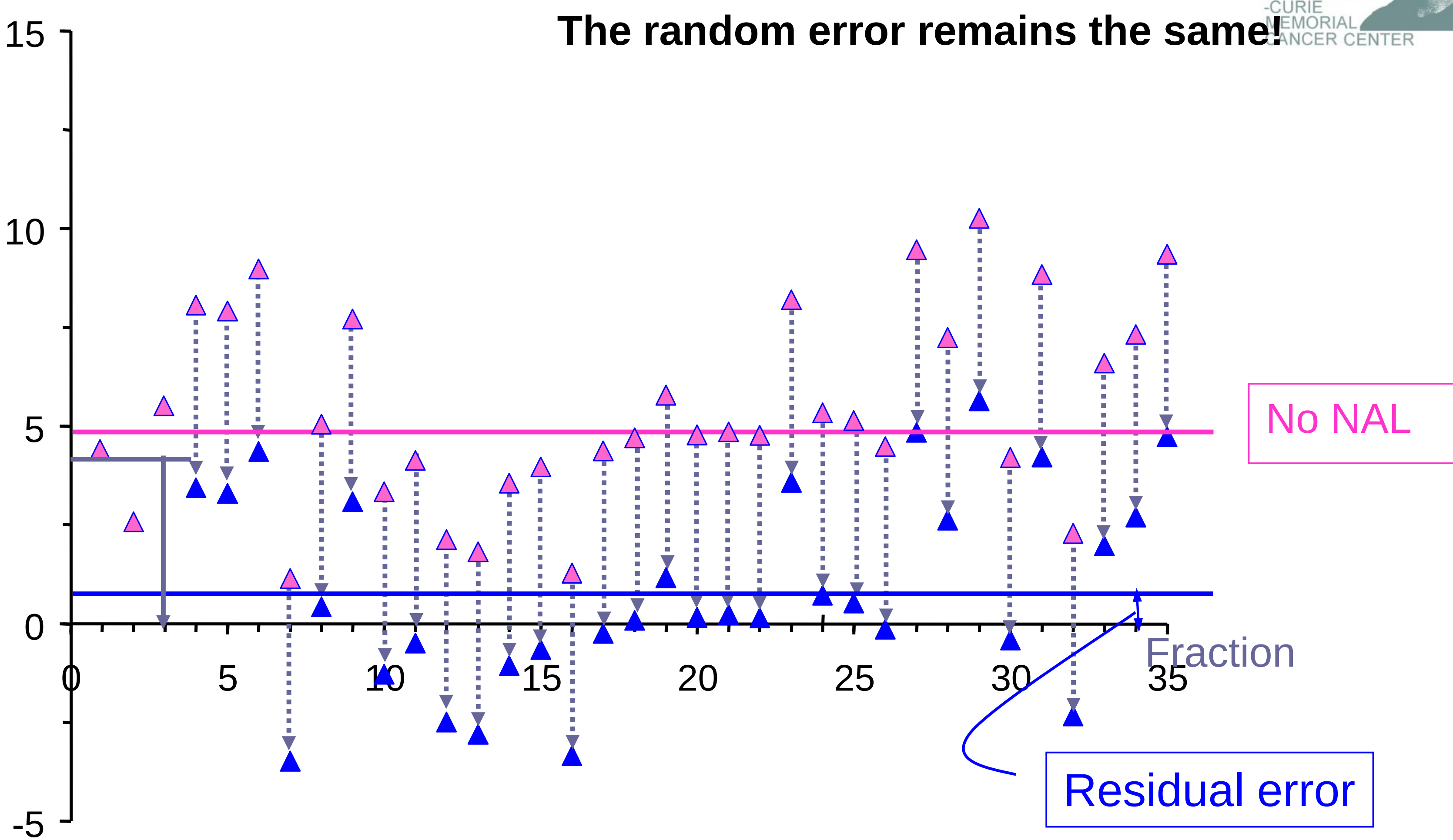
- Fraction 1,2, and 3
  - set-up a patient according to protocol
  - portal control, (m_{ix},m_{iy},m_{iz}), i =1 ,2,3
- before 4th fraction
  - calculate the systematic error $(m_{x,mean},m_{y,mean},m_{z,mean})$
- from 4th fraction on
  - set-up a patient according to prtocol
  - shift couch with $-(m_{x,mean},m_{y,mean},m_{z,mean})$
  - irradiate

de Boer and Heijmen, Med. Phys. 2002

No Action Level



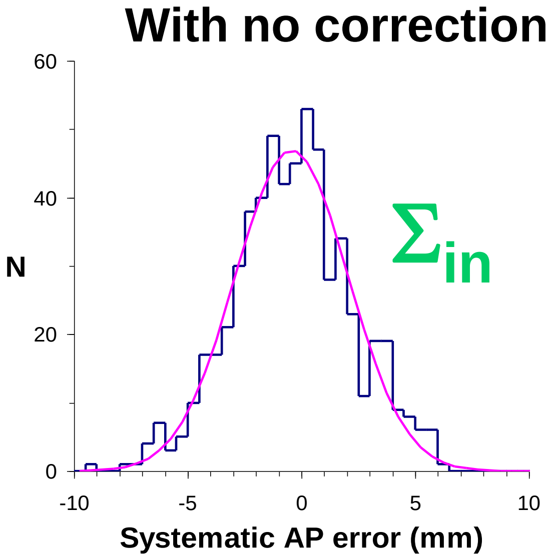
: initial error after set-up

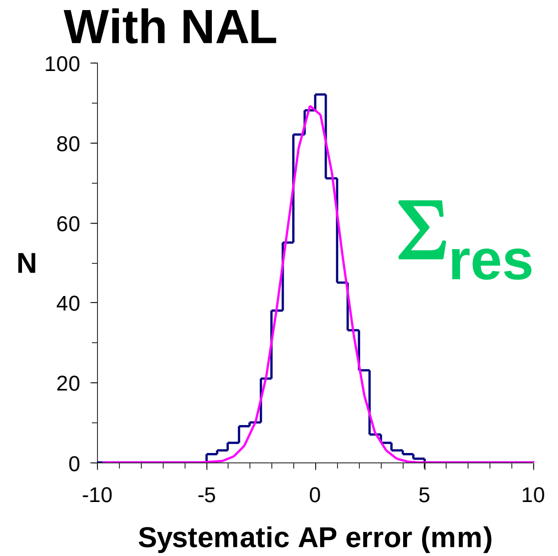
: error after correction

Residual error estimate

$\Sigma_{res} \approx \sigma/\sqrt{N}$

NAL results





600 prostate patients

(De Boer and Heijmen, IJROBP, 2001)

How precise may be radiotherapy?

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Residual (after NAL) bony anatomy displacements [mm]:

		LR	CC	AP
Prostate[1]	σ	1.7	1.5	1.6
	Σ_{res}	1.1	1.1	1.1
Cervix[2]	σ	2.6	2.9	2.7
	Σ_{res}	1.2	1.7	1.6
Lung[3]	σ	2.0	2.4	2.4
	Σ_{res}	1.3	0.6	1.2
head & neck[4]	σ	1.6	1.6	1.4
	Σ_{res}	1.0	1.1	1.2

(1) De Boer et al. 2002

(2) Kaatee et al. 2002

(3) De Boer et al. 2003

(4) De Boer et al. 2004

Why on-line verification is not recommended?

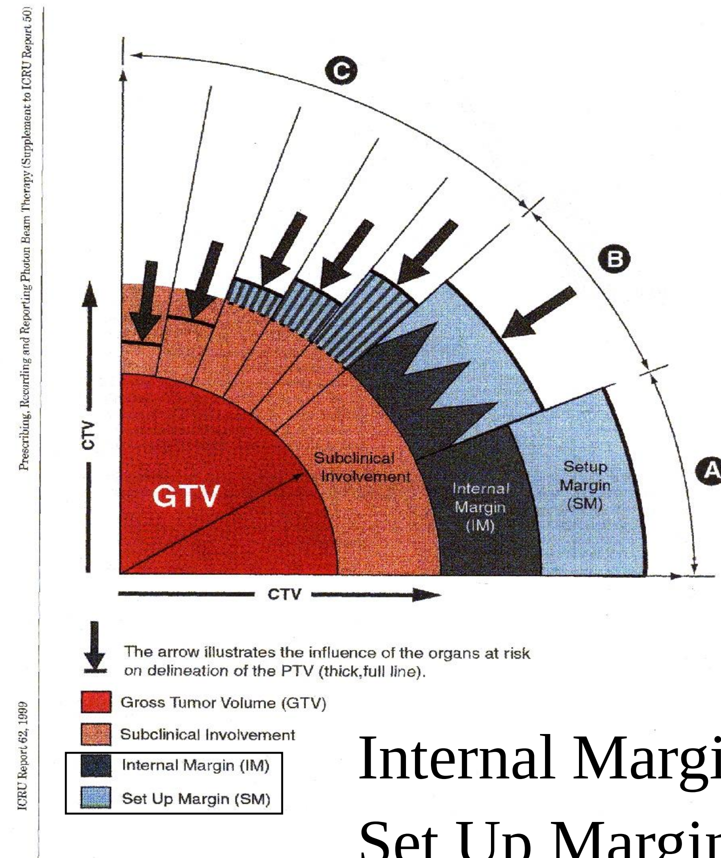
- Because
  - It is time consuming.
  - Systemtic error influence on the margin three times more than random error.

- However,
  - It might be resonble if
    - random error is large
    - very high accuracy is needed.

Margins

- Set-up margin
  - to compensate set-up errors
    - errors measured with respect to external coordinate system (laser system)
- Internal margin
  - to compensate movement of the target caused by physiology (eg. breathing)
    - errors measured with respect to internal anatomy coordinate system (eg. pubis symphisis)

ICRU 62
Definitions



Internal Margin

Set Up Margin

How to add margins?

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- If set-up and internal errors may be treated as not correlated, than we add errors in quadrature

$$\Delta_{tot} = \sqrt{\left(\Delta_{set-up}\right)^2 + \left(\Delta_{internal}\right)^2}$$

systematic

$$\sigma_{tot} = \sqrt{\left(\sigma_{set-up}\right)^2 + \left(\sigma_{internal}\right)^2}$$

random

Margins

- Two formulas

$$M = 2 \cdot \Delta_{tot} + 0,7 \cdot \sigma_{tot}$$

To cover the CTV for 90% of the patients with the 95% isodose (analytical solution).
Herk Red, 47: 1121 - 1135, 2000

$$M = 2,5 \cdot \Delta_{tot} + 0,7 \cdot \sigma_{tot}$$

Margin size which ensures at least 95% dose is delivered to (on average) 99% of the CTV.
Stroom, Red, 43: 905-919,1999

Implementation of geometry control

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- The most important task in radiotherapy department
  - „Lens of quality”
- This can’t be an incidental action
  - This must be a program for the systematic monitoring and evaluation of the various aspects of radiotherapy quality

Data

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- Must be collected and regurarly analysed
  - feed back is a must
    - in our department ones a year all results are presented to doctors, radiation technologiests and physicists
  - big errors must be analysed as quickly as possible
    - conclusions must be drawn
  - group systematic errors (mean of means) play an important role in general evaluation of the quality of work and quality of equipment
    - group systematic error should not be different from zero

Breathing and related problems

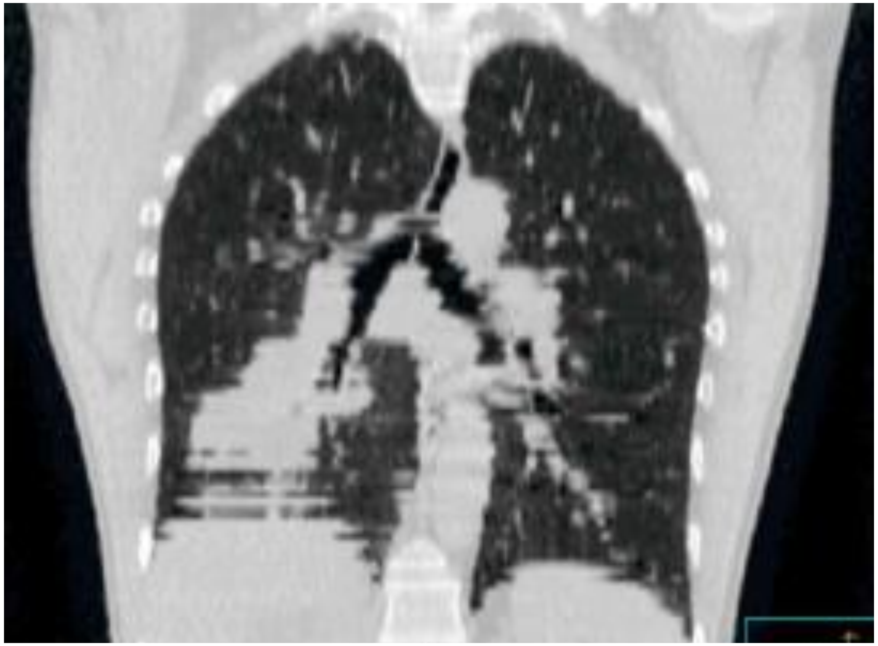
TABLE II. Abdominal motion data. The mean range of motion and the (minimum-maximum) ranges in millimeters for each site and each cohort of subjects. The motion is in the superior-inferior (SI) direction.

		Breathing mode	
Site	Observer	Shallow	Deep
Pancreas	Suramo (Ref. 57)	20 (10–30)	43 (20–80)
	Bryan (Ref. 59)	20 (0–35)	-
Liver	Weiss (Ref. 66)	13±5	-
	Harauz (Ref. 67)	14	-
	Suramo (Ref. 57)	25 (10–40)	55 (30–80)
	Davies (Ref. 58)	10 (5–17)	37 (21–57)
Kidney	Suramo (Ref. 57)	19 (10–40)	40 (20–70)
	Davies (Ref. 58)	11 (5–16)	-
Diaphragm	Wade (Ref. 68)	17	101
	Korin (Ref. 64)	13	39
	Davies (Ref. 58)	12 (7–28)	43 (25–57)
	Weiss (Ref. 66)	13±5	-
	Giraud (Ref. 63)	-	35 (3–95)
	Ford (Ref. 76)	20 (13–31)	-

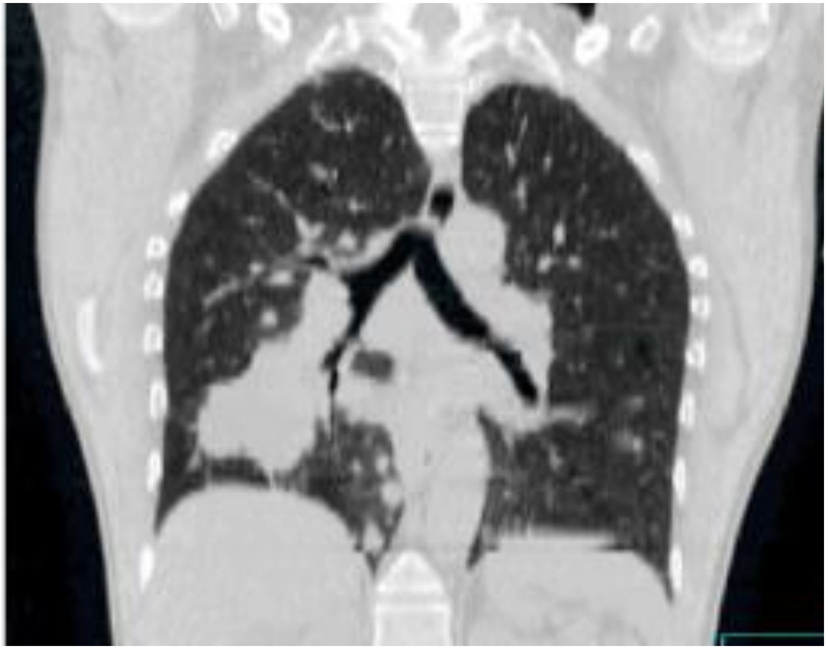
CT for planning

- Artefacts

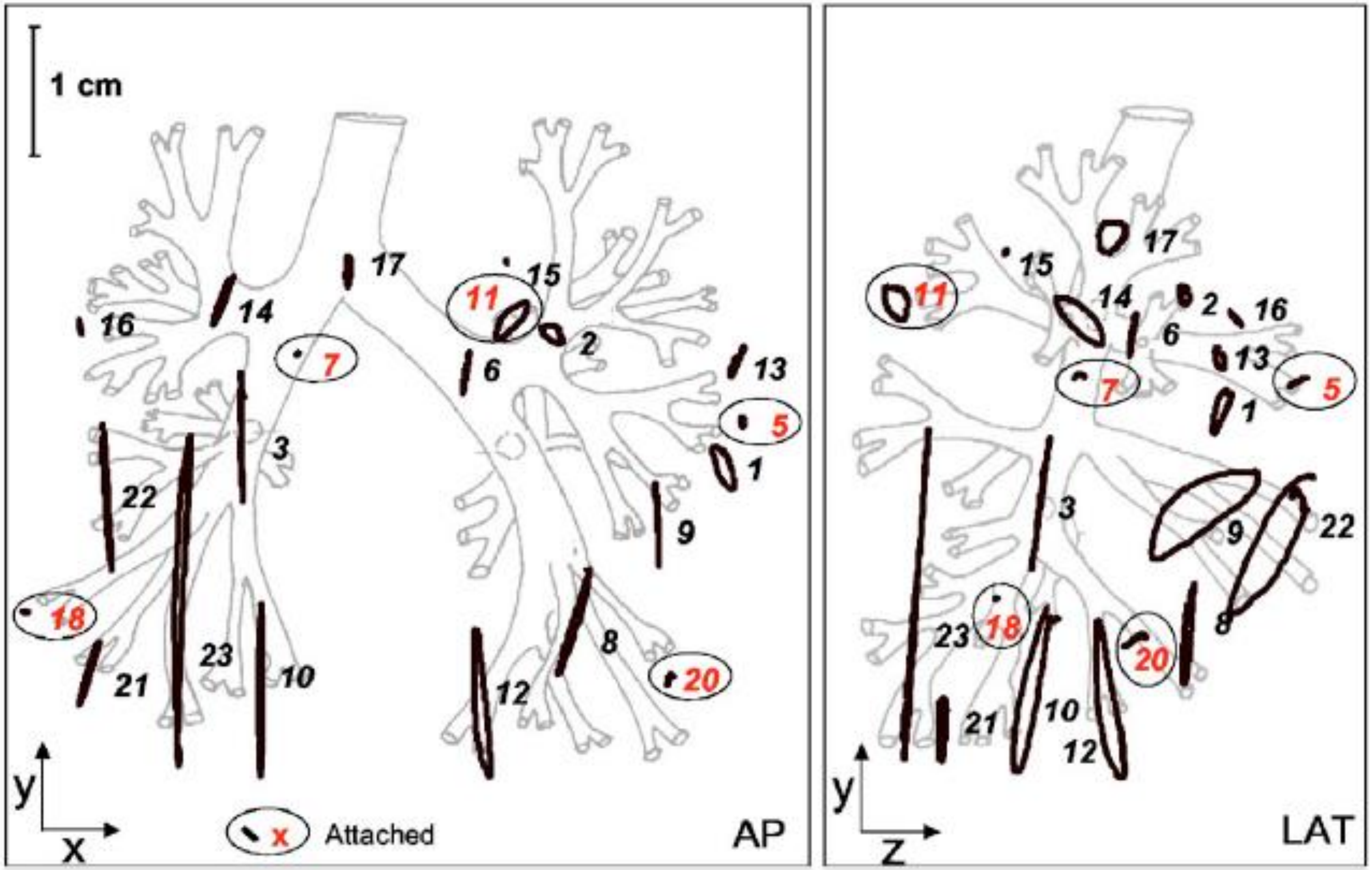
without breathing control



with breathing control



Changes of GTV position



In relations to bronchial tree

CT for planning

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- With breathing control

RPM system

Pattern of breathing

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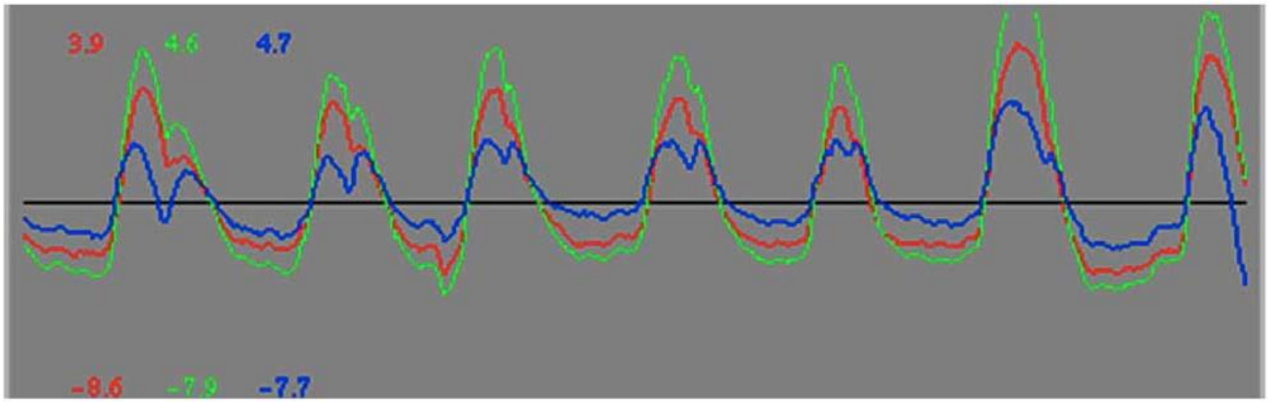
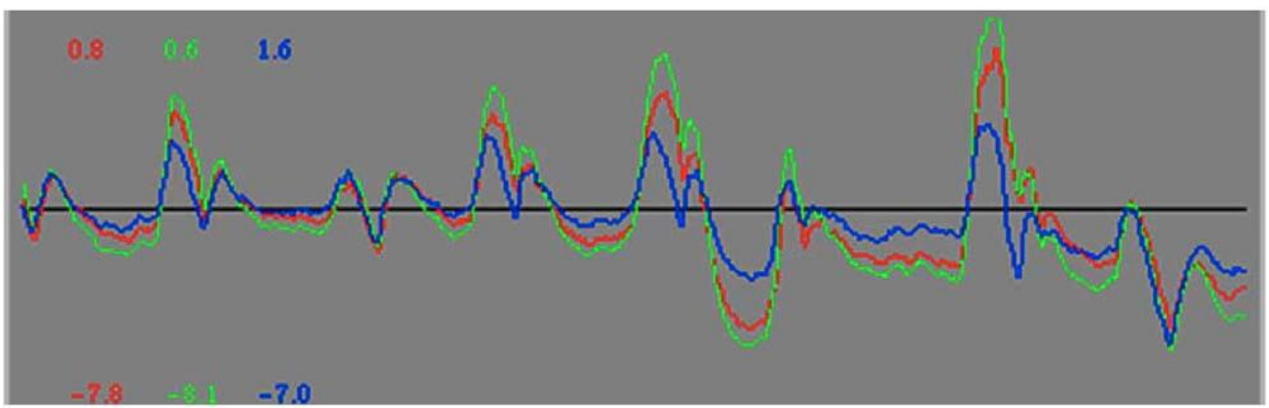


(a)

Patient A



(b)

Patient B

Deep-inspiration breath hold technique

- DIBH
  - for patients with left breast cancer
    - for some of tchem (they have to inhale and keep inhale for some time 10 – 15 sec)

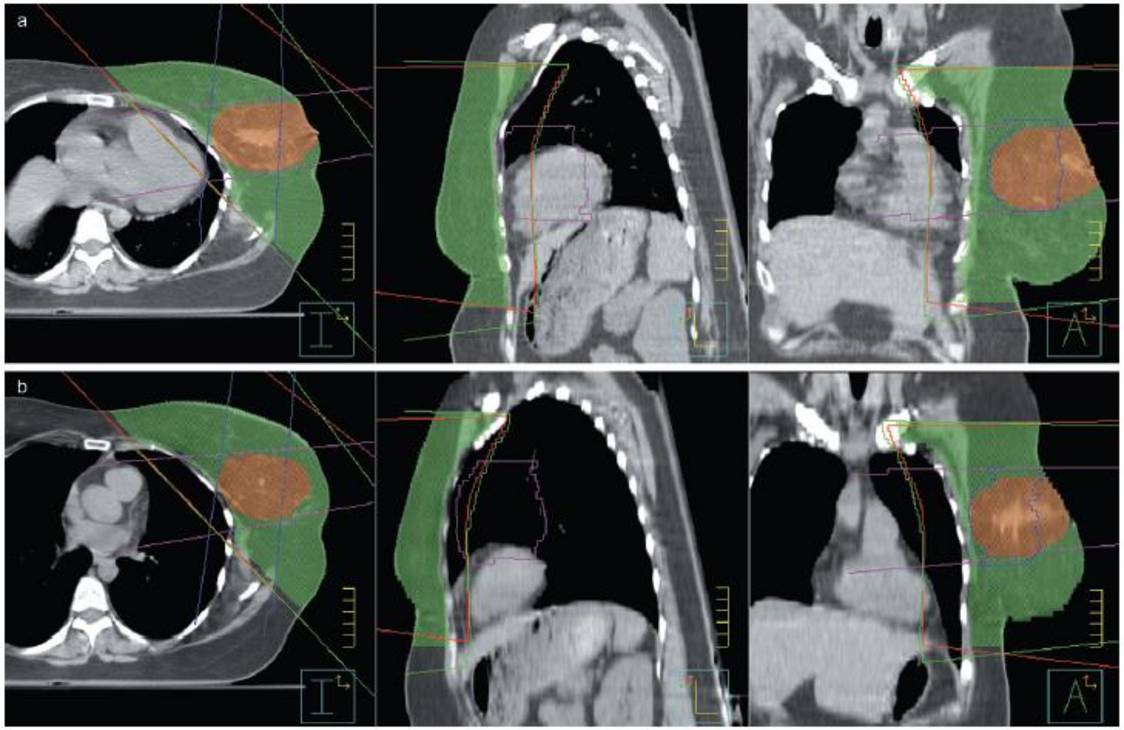


Fig. 2. Axial, sagittal and coronal images of one patient (a) FB (b) DIBH showing the displacement of the breast PTV (green) and boost PTV (orange) away from the heart in DIBH and the inferior movement of the heart in the DIBH image in line with diaphragmatic expansion. Tangential and SIB beams are displayed.

DIBH - advantages

Table 1. Comparison of volume and dosimetric data for FB and DIBH plans for left-sided adjuvant breast radiotherapy

	DIBH mean	FB mean	*P*-value
Total lung volume (cc)	2051	1126	$P < 0.0001$
Left lung V20 (Gy)	22.1	23.2	$P = 0.1366$
Mean left lung dose (Gy)	12.77	13.41	$P = 0.0584$
Heart V30 (Gy)	2.45	7.06	$P < 0.0001$
Mean heart dose (Gy)	3.96	6.88	$P < 0.0001$
Irradiated heart volume (cc)	2.1	36.9	$P < 0.0001$
Maximum heart depth (cm)	1.17	2.08	$P < 0.0001$
Mean LAD PRV dose (Gy)	21.94	33.67	$P < 0.0001$
Maximum LAD PRV dose (Gy)	45.62	51.59	$P = 0.0032$
Mean contralateral breast dose (Gy)	0.61	0.63	$P = 0.4758$
Boost volume (cc)	286	272	$P = 0.0006$

DIBH, deep inspiration breath hold; FB, free breathing; LAD, left anterior descending coronary artery; PRV, planning risk volume.

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Thank you for your attention!

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