
ESTRO
School
Welcome to
Advanced Skills
for
Modern Radiation Therapy
- RTT only -


Copenhagen 2016
Second run!
HAVFRUEN

REGION H

Rigshospitalet

Patients at the department:

- Around 4-5000 patients are treated per year
- >1500 patients are PET/CT scanned for treatment planning by the PET dep't
- ~800 patients are MR scanned

Techniques used at the department:

- Stereotactic Radiotherapy (1996)
- IMRT (2000)
- IGRT (2002)
- Respiratory Gating (2002)
- RapidArc® (2008)

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Visit tomorrow at 16.15h!

REGION H

Rigshospitalet

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- Stereotactic Radiotherapy (1996)
- IMRT (2000)
- IGRT (2002)
- Respiratory Gating (2002)
- RapidArc® (2008)

- **Coffee & lunch will be served outside lecture room**
- **You are welcome to go to the yard during the breaks**
- **Toilets are downstairs**

Get a printout from Melissa with your own code

Only few power sockets available, please bring a fully charged device

Rigshospitalet

Techniques used at the department:

- Stereotactic Radiotherapy (1996)
- IMRT (2000)
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- RapidArc® (2008)

REGION H

Rigshospitalet

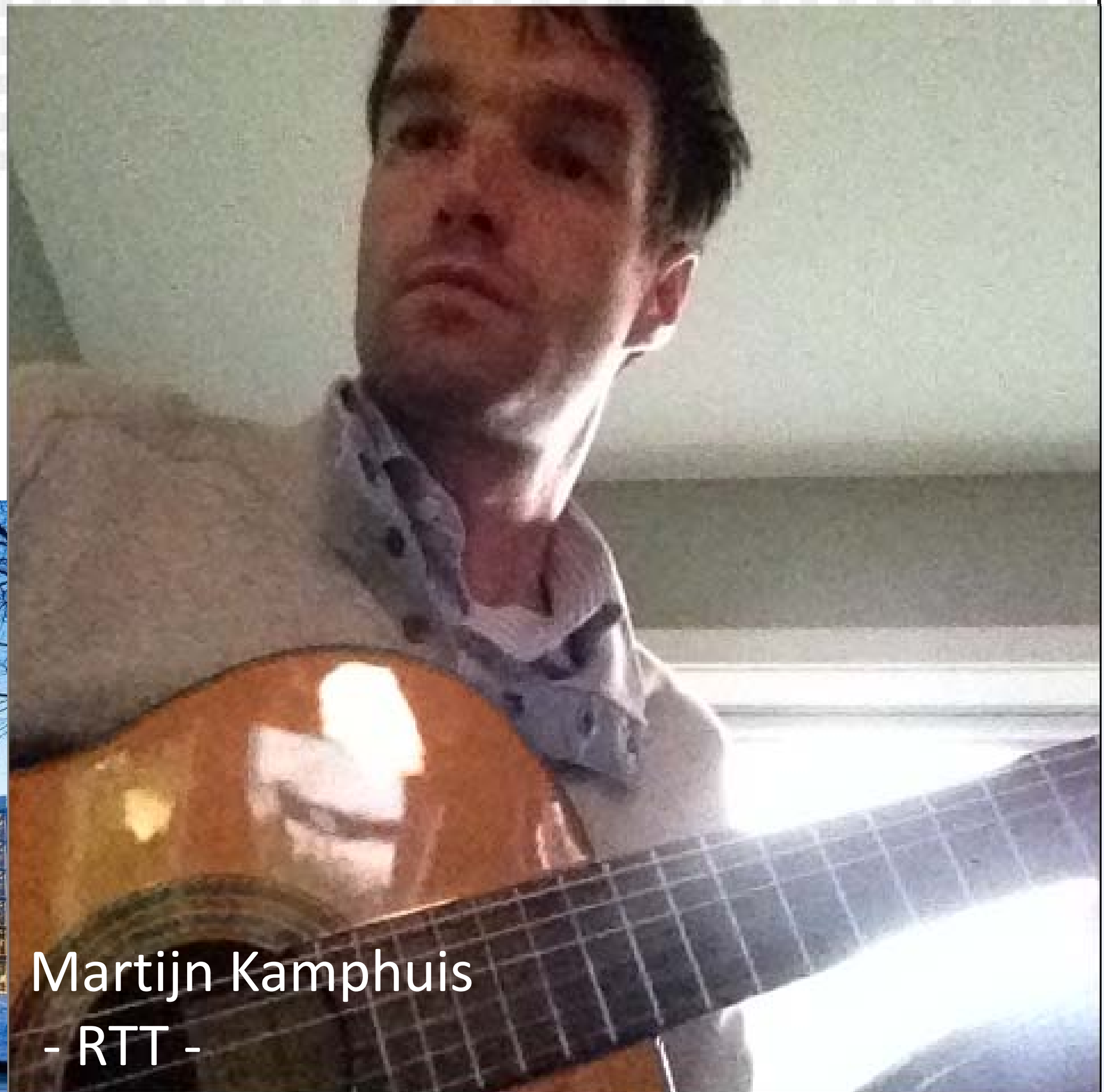
ESTRO – project manager

REGION H

Rigshospitalet

The Faculty

amc



REGION H

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The Faculty

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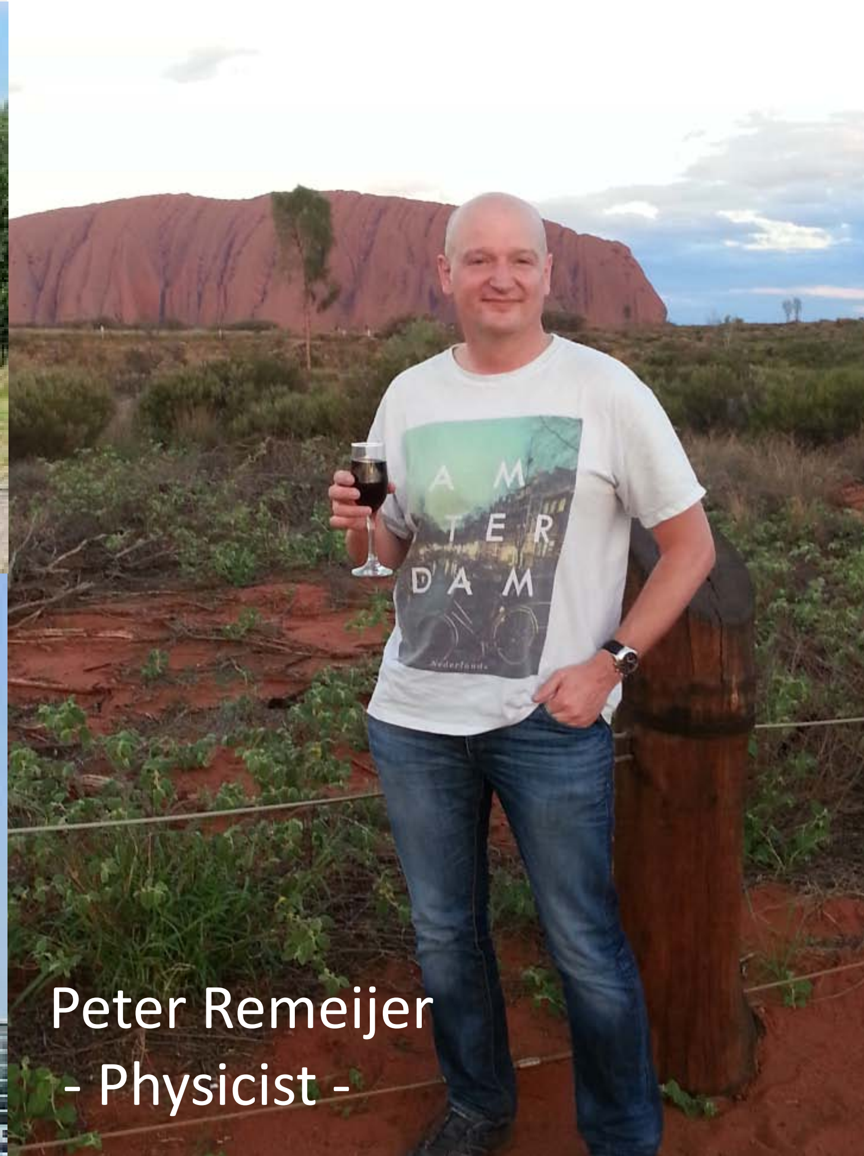
NKI-AVL



Peter Remeijer
- Physicist -

Rigshospitalet

The Faculty

Elizabeth ‘Liz’ Forde
- RTT -

TRINITY COLLEGE DUBLIN

REGION H Rigshospitalet

The Faculty

Jose Luis Lopez
- Physician -

REGION H Rigshospitalet

The Faculty

REGION H Rigshospitalet

Participants

12	Netherlands
7	Denmark
5	Poland
3	Austria
3	Geece
2	UK
2	Italy
2	Iceland
2	Slovenia
2	Ireland
2	Iran
1	Germany
1	Singapore
1	Russia
1	Australia
1	Bosnia
1	New Zealand
1	France

ESTRO School

REGION H Rigshospitalet

Program

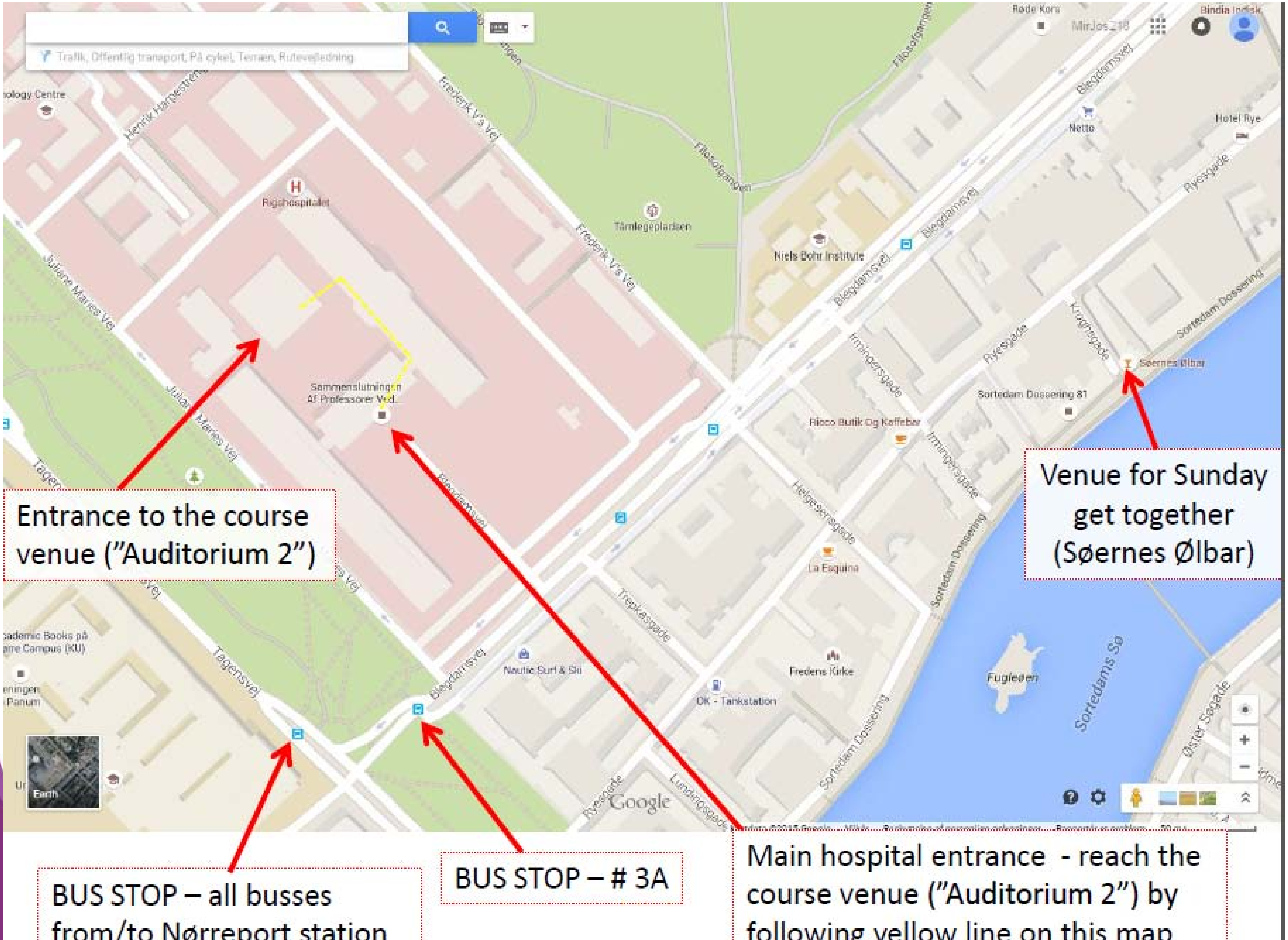
4.5 days

24 lectures ~30 minutes

5 workshops

1 site visit

2 social events


Trafik, Offentlig transport, På cykel, Terræn, Rutevejledning
Røde Kors
Henrik Harpestrengs Vej
Frederik V's Vej
Filosofgangen
Blegdamsvej
Netto
Hotel Rye
Rigshospitalet
Tåmlegepladsen
Niels Bohr Institute
Juliane Maries Vej
Sammenslutningen Af Professorer Ved...
Ryesgade
Kroghsgade
Søernes Ølbar
Sortedam Dossering 81
Irmingersgade
Rioco Butik Og Kaffebar
Helgesensgade
La Esquina
Sortedam Dossering
Trepkasgade
Tagensvej
Nautic Surf & Ski
Fredens Kirke
OK - Tankstation
Fugleøen
Sortedams Sø
Øster Søgade
Earth
Google
Entrance to the course venue ("Auditorium 2")
Venue for Sunday get together (Søernes Ølbar)
BUS STOP – all busses from/to Nørreport station
BUS STOP – # 3A
Main hospital entrance - reach the course venue ("Auditorium 2") by following yellow line on this map


Social Event
- Boat tour -

REGION H

Rigshospitalet

Program

 - *All* steps of modern Radiation Therapy -

Rigshospitalet

Turning Point

Evaluation forms: Link sent by Melissa!

REGION H Rigshospitalet

Laptops – workshops

- Delineation - sunday
- Margin calculation - monday
- Safety issues & prospective risk analysis - wednesday

Questions?

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WWW.ESTRO.ORG/SCHOOL

RTT's Perspective on modern Radiation Therapy

Rianne de Jong *RTT,*
Academic Medical Centre
Amsterdam

NKI-AVL
Het Nederlands Kanker Instituut
Antoni van Leeuwenhoek Ziekenhuis

Copenhagen, 2015

m.a.j.dejong@amc.uva.nl

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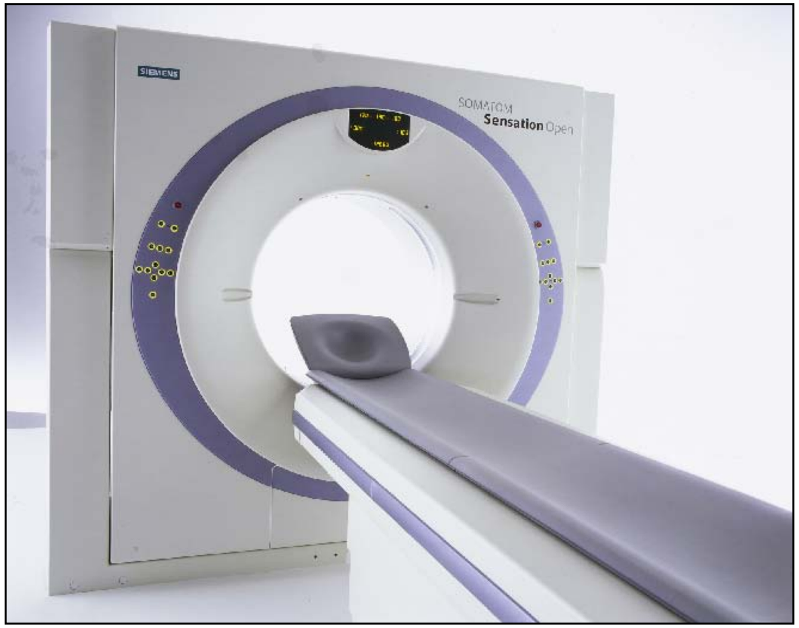
Introduction

Changes over the last years

Simulation:

from fluoroscopy to CT

2 D

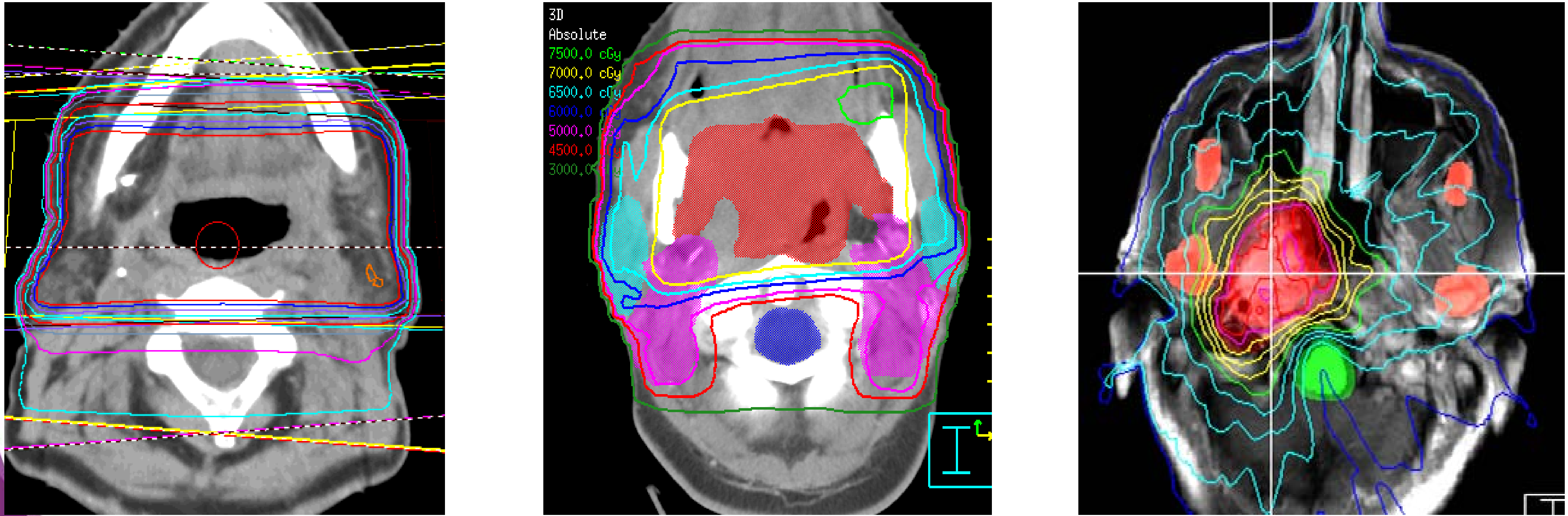


3 D

Introduction

Treatment planning:

from conventional to conformal to IMRT & arc therapy



Introduction

Treatment machine:

From patient set-up with skin marks to additional patient set-up verification

- Portal imaging (2D MV)
- Kilo voltage imaging (3D kV)

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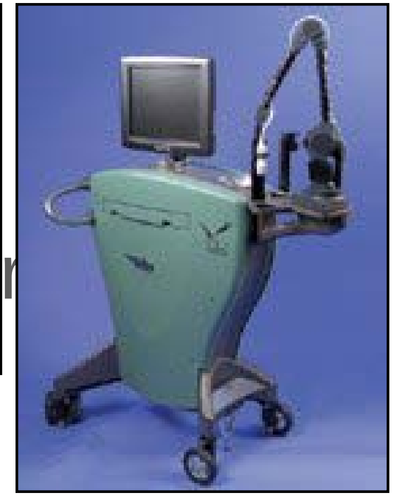

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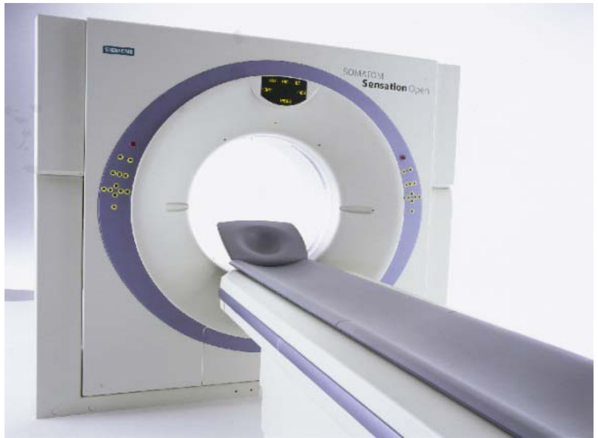
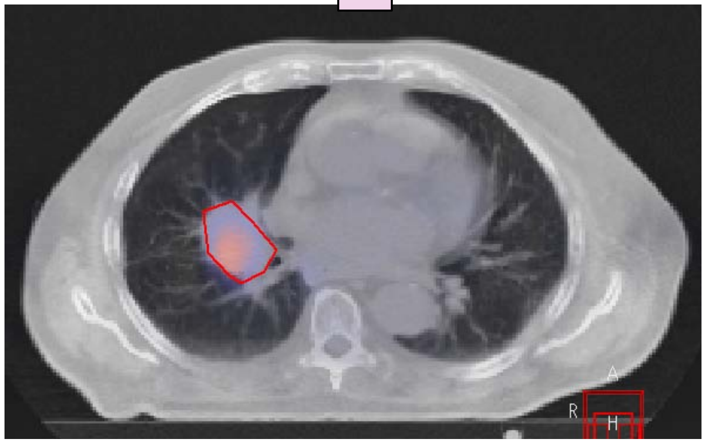
Introduction

Tattoo, align and scan patient





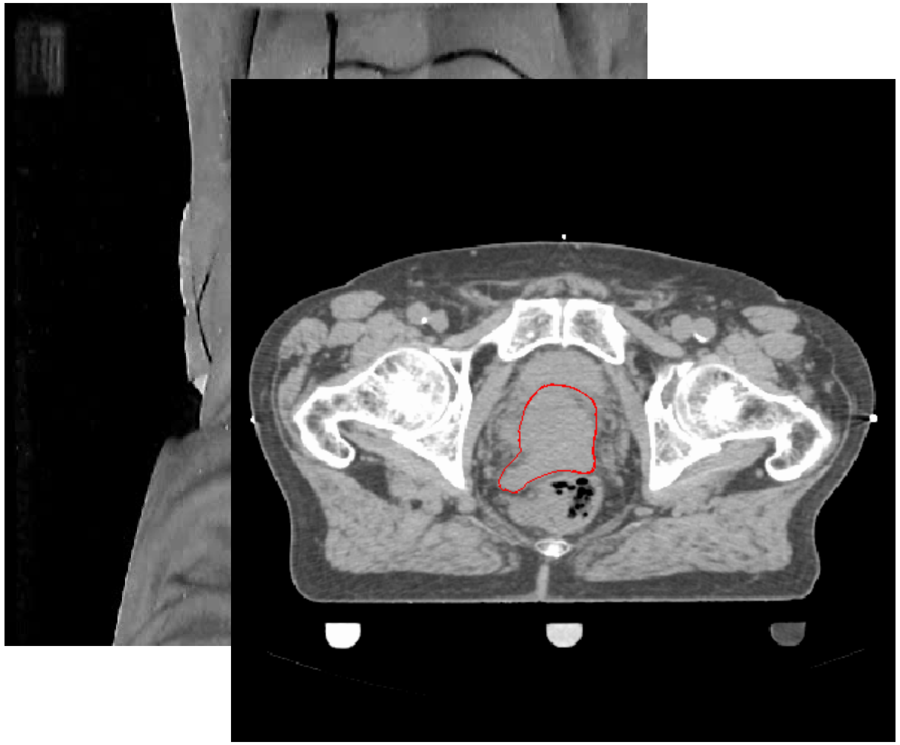
Draw target and plan treatment on RTP

Align patient on machine on tattoos and treat (many days)

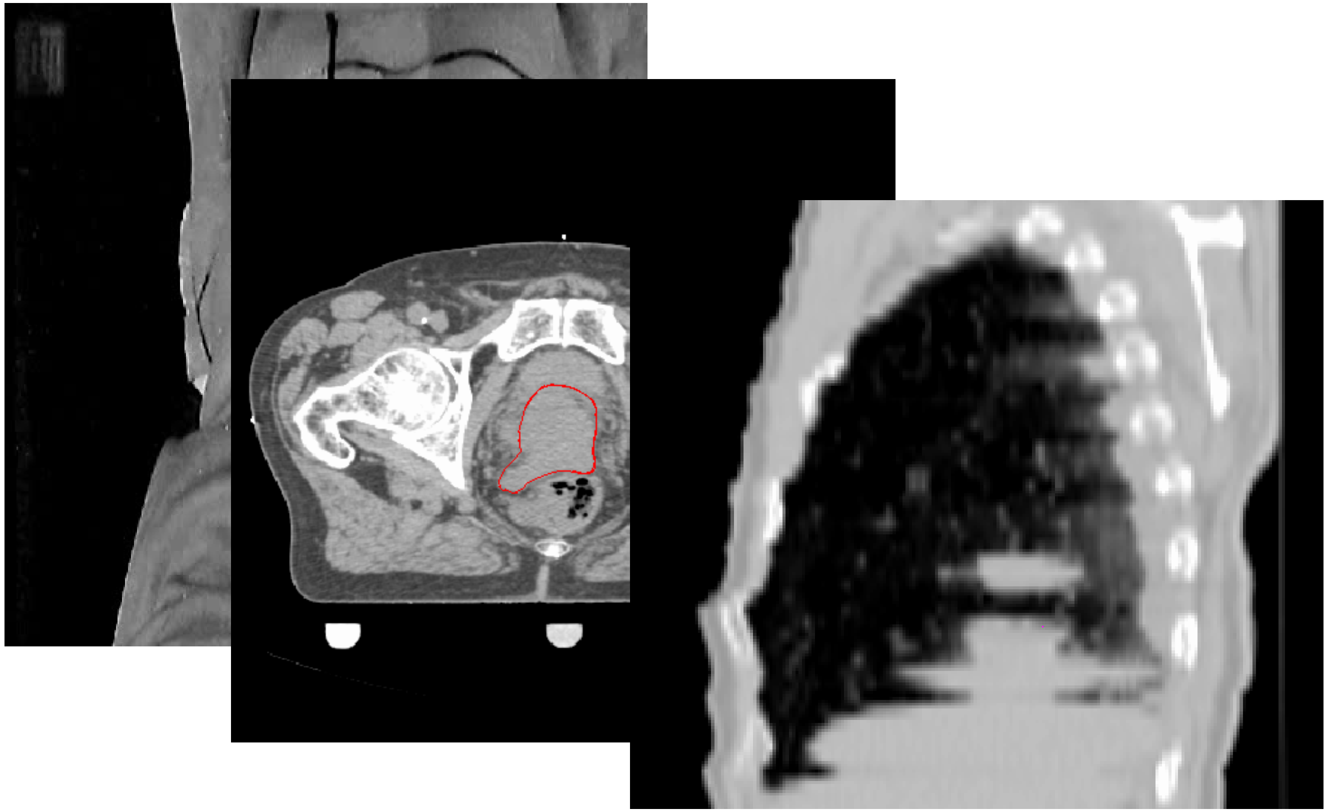
In principle this procedure should be accurate…

Introduction

Introduction



Introduction



Introduction

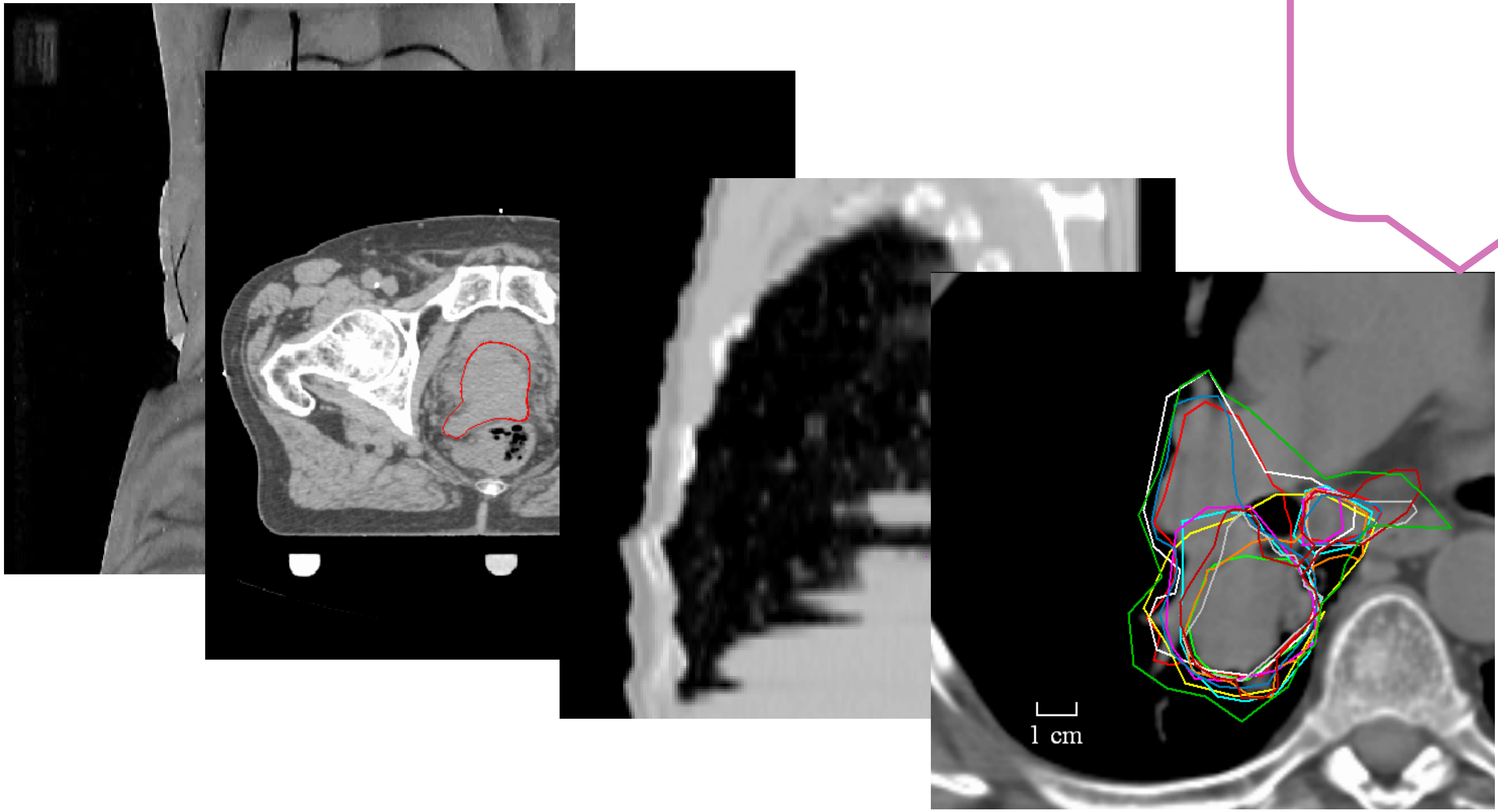
Workshop

Sofia

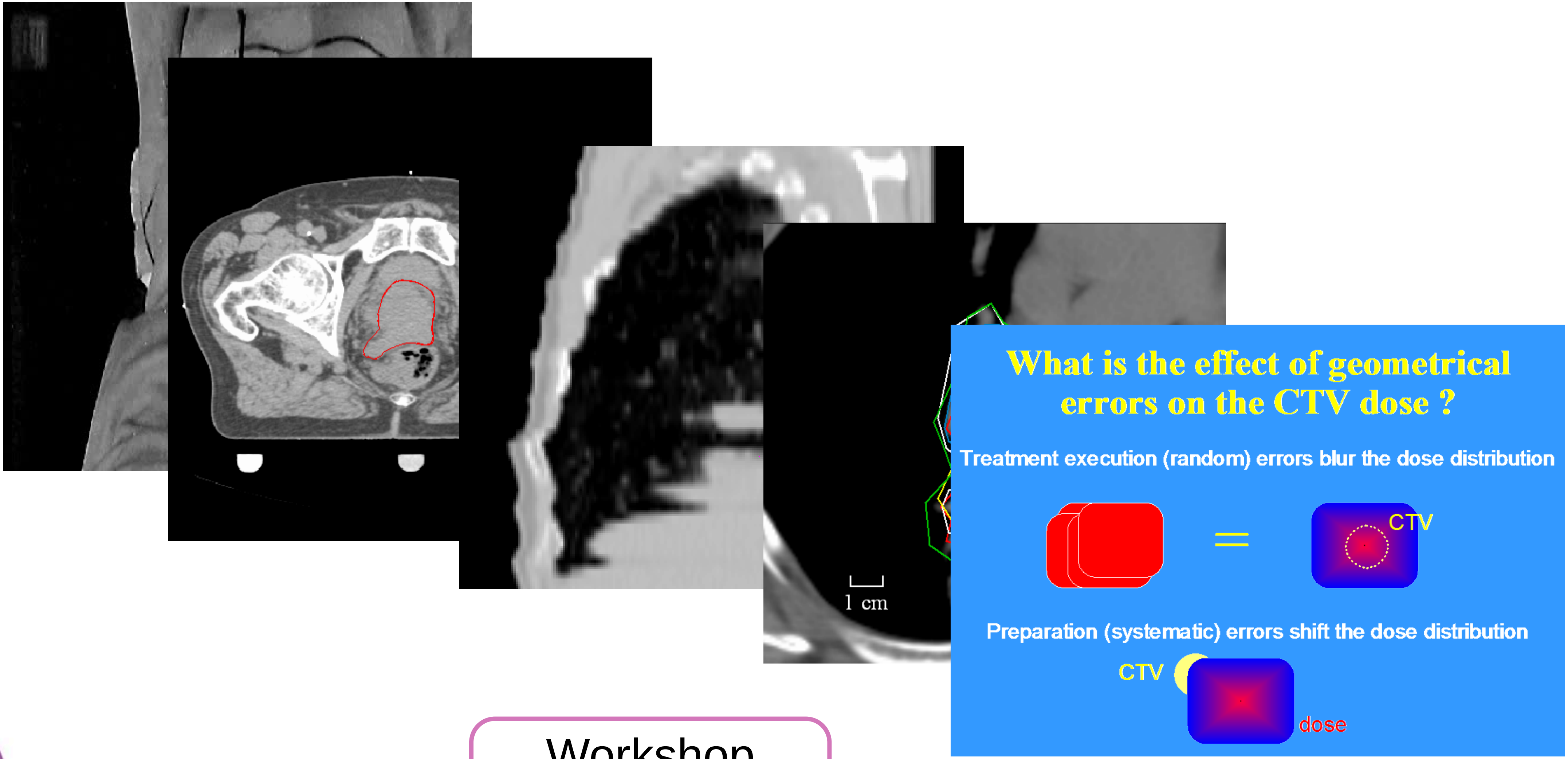
Elizabeth

Jose

Peter



Introduction



Workshop
Peter

RTT's Job

The RTTs job

- Patients education
  - Pre-treatment imaging
- Simulation
- Treatment Planning
- Treatment
  - *Image guidance*
  - *Research & Development*

→ Some sort of specialization in one step of the treatment chain:

Sometimes controversial: all-round RTT is considered optimal job description.

Patient education

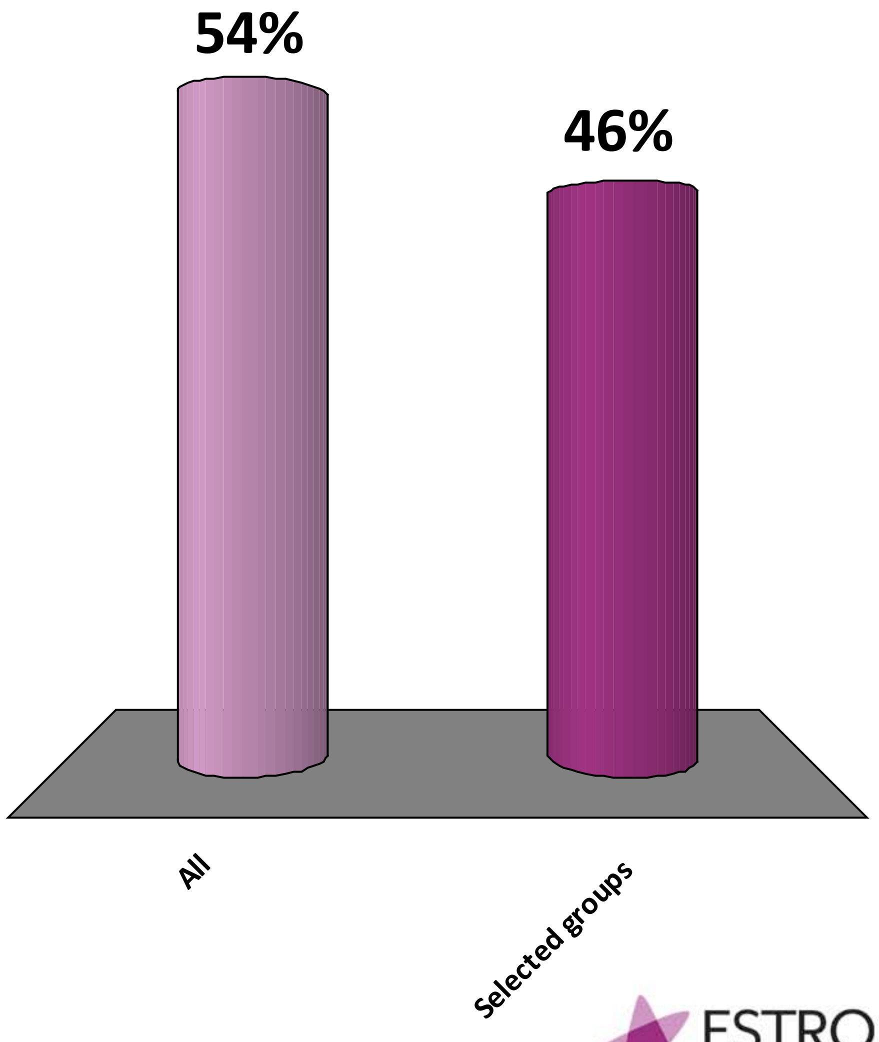
2 departments, 2 solutions:

AMC	AvL
• 4 RTTs	3 RTT’s assistent
• 20%	80% time spent
• 30%	100% patient coverage
• Combined	not combined with working on treatment machines

Only 1 slide…? *Very important to the patient!*

How many patients receive patient education?
- Personal by RTT

A. All
B. Selected groups

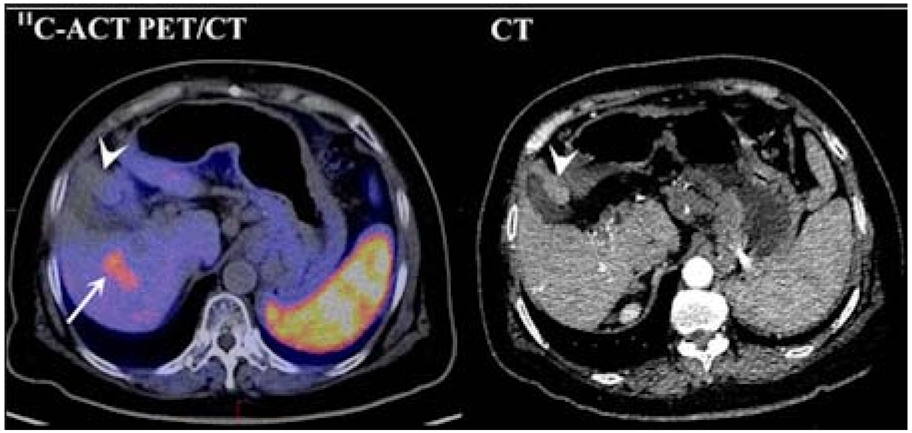


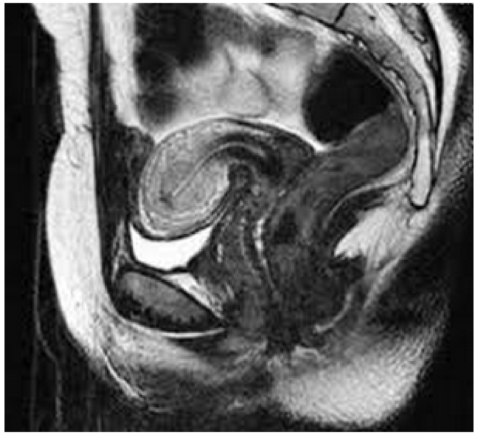
Pre-treatment Imaging: PET/MRI/CT

Often combined use with radiology department:

Always one RTT from radiation therapy

- Trained in delivering contrast agents
- Focused on patient positioning: registration images for delineation





Simulation CT

RTTs working on CT combined with working on the treatment machines

Sub group only working on CT

- Contrast agents
- 4D CT
- Breath hold CT

Treatment Planning

RTTs working on Treatment Planning combined with working on the treatment machines.

Sub group working treatment planning only – research and development.

Physicist only in the loop when outside of tolerance or hypo fractionated treatment schemes

Physician have to sign off on the plans

- Multi modality registrations
- Delineation of Organs at Risk
- IMRT $\longrightarrow$ VMAT (all curative intent treatments)

Treatment

3 RTTs per machine when breaks are scheduled

4 RTTs per machine for full program

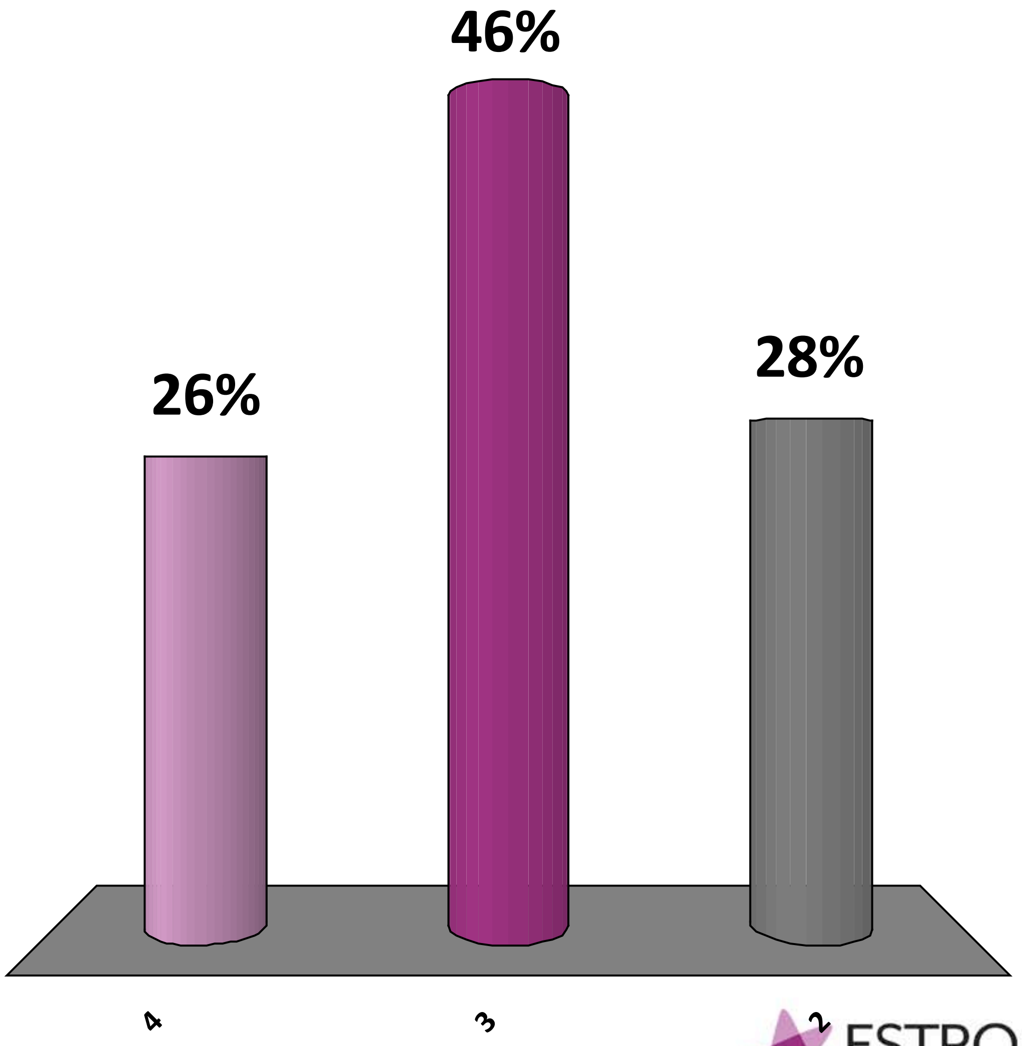
→ 2 RTTs per machine…

How many RTT's @ treatment machine?
- not including students

A. 4

B. 3

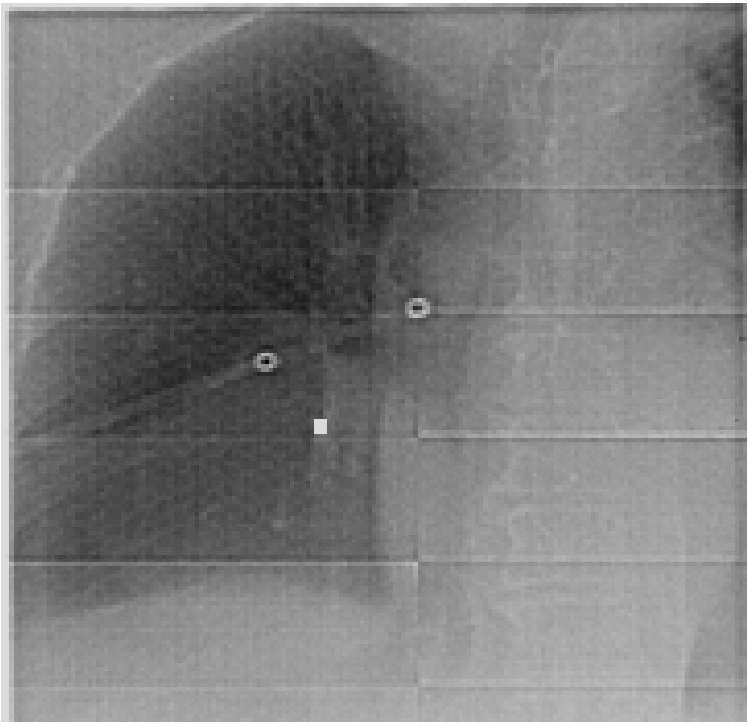
C. 2



Patient Support

Support patients and their relatives and friends:

During RT in RTT's working area for support and transparency

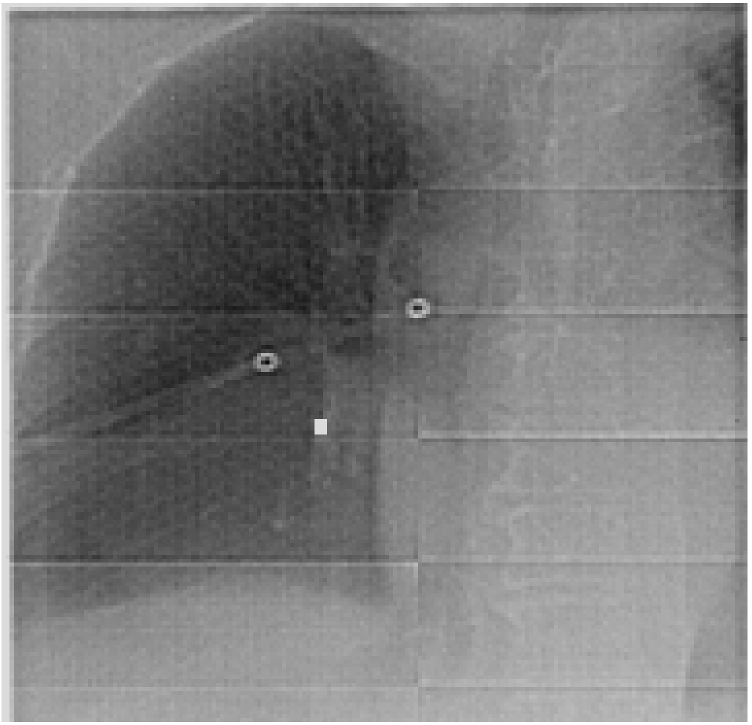


Portal image

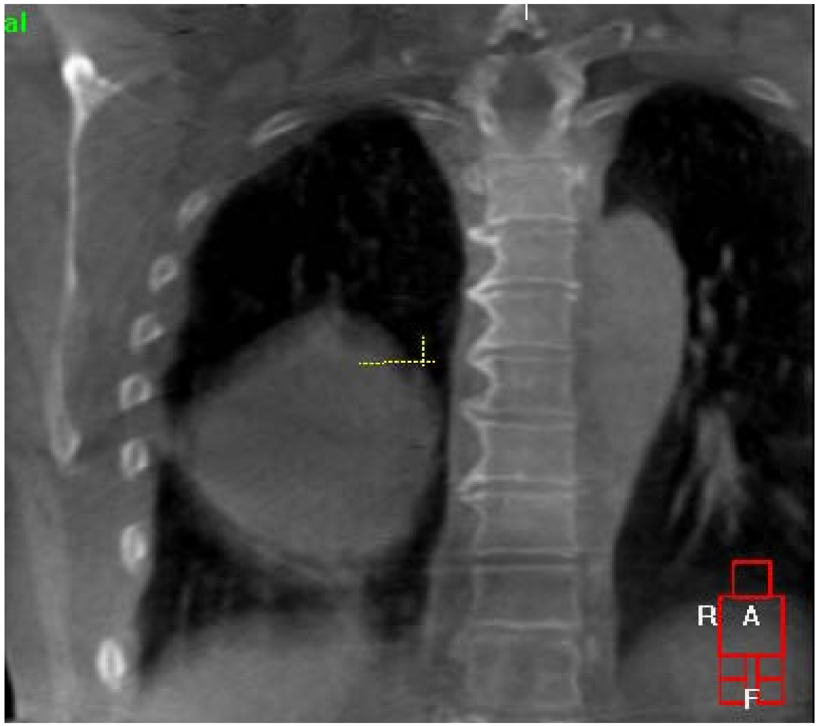
Patient Support

Support patients and their relatives and friends:

During RT in RTT's working area for support and transparency



Portal image



CBCT image

Starting IGRT (3d)

IGRT

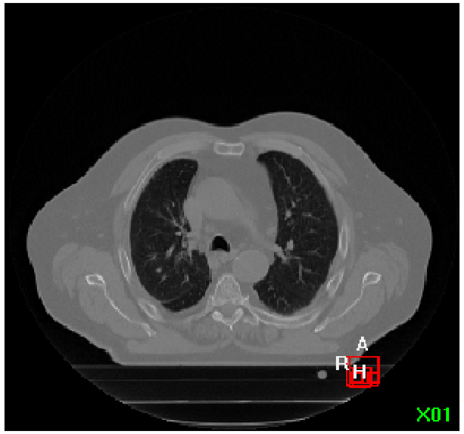
- It is at the end of the treatment chain
- It involves all RTTs! Not only working on the treatment machine
- It requires understanding of all steps in radiation therapy
- It is still evolving: MRI-linac!

Implementing CBCT

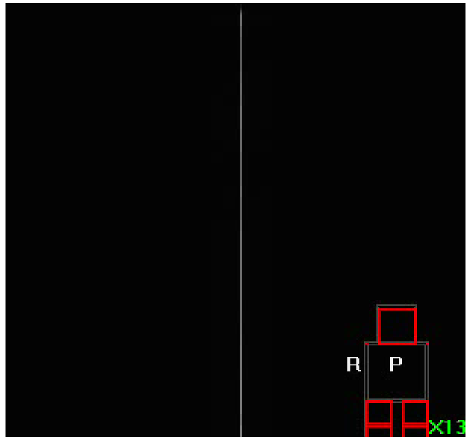
June 2003:

- 4 RTT’s
- 2 Physicists
- Patient program in the morning
- CBCT in the afternoon
- 8 months of validation

Implementing CBCT: validation of the system



3D match



Cross validation

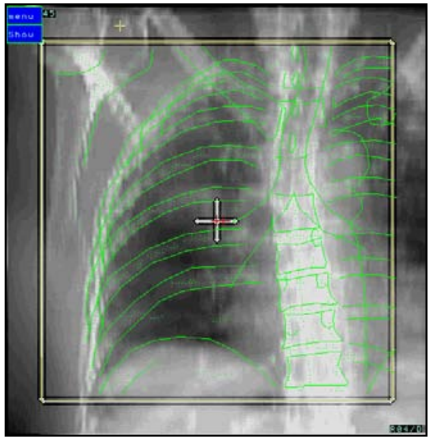
Planning CT

same ?

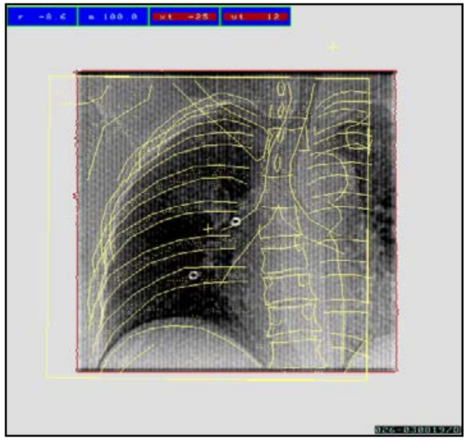
Cone beam CT

DRR +Template

MV image

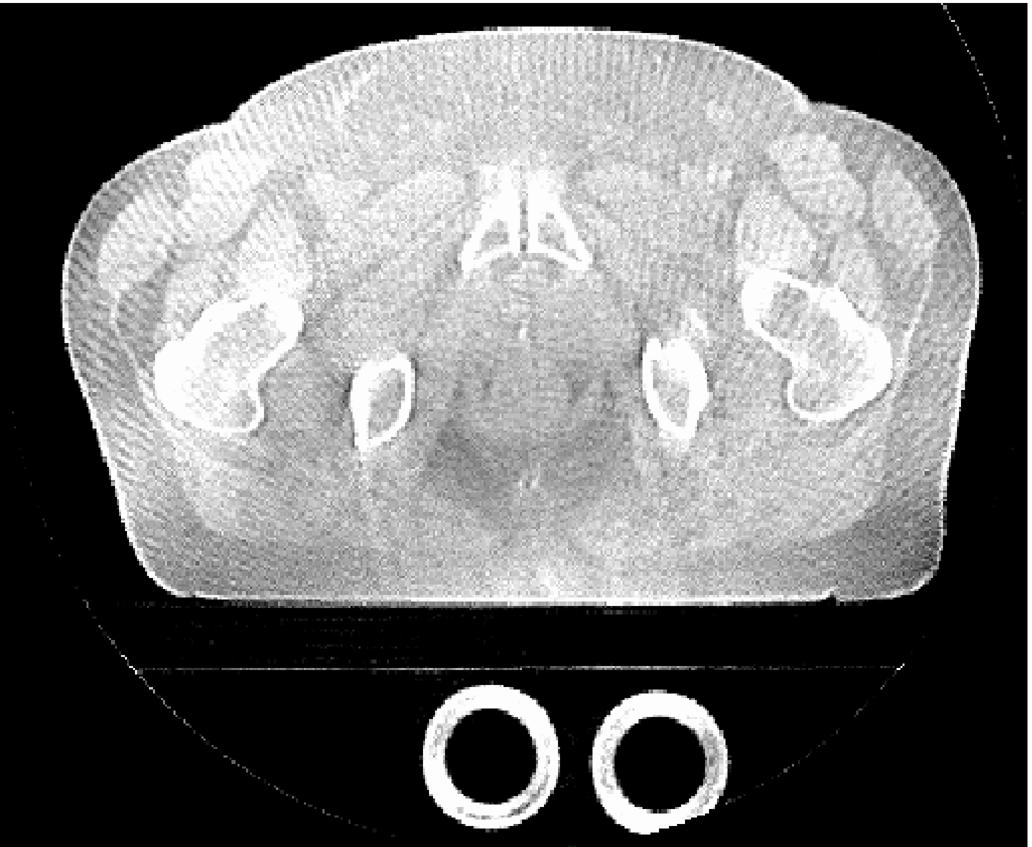


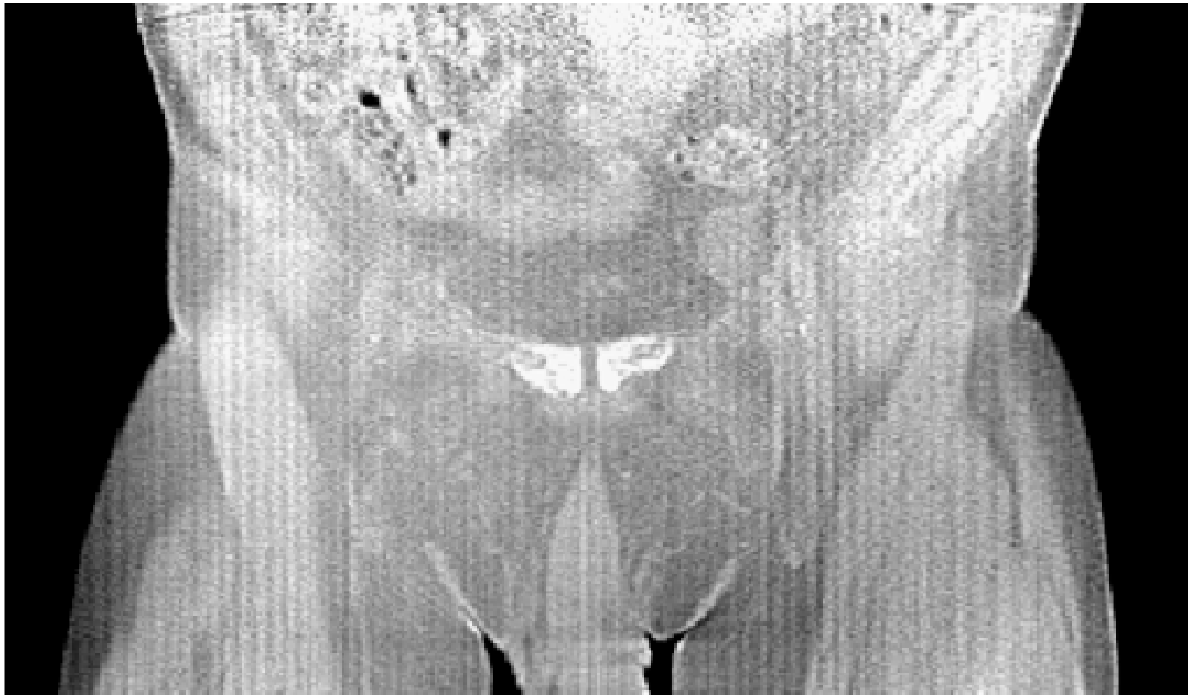
2 x 2D match AP/LAT



Implementing CBCT:
designing imaging presets

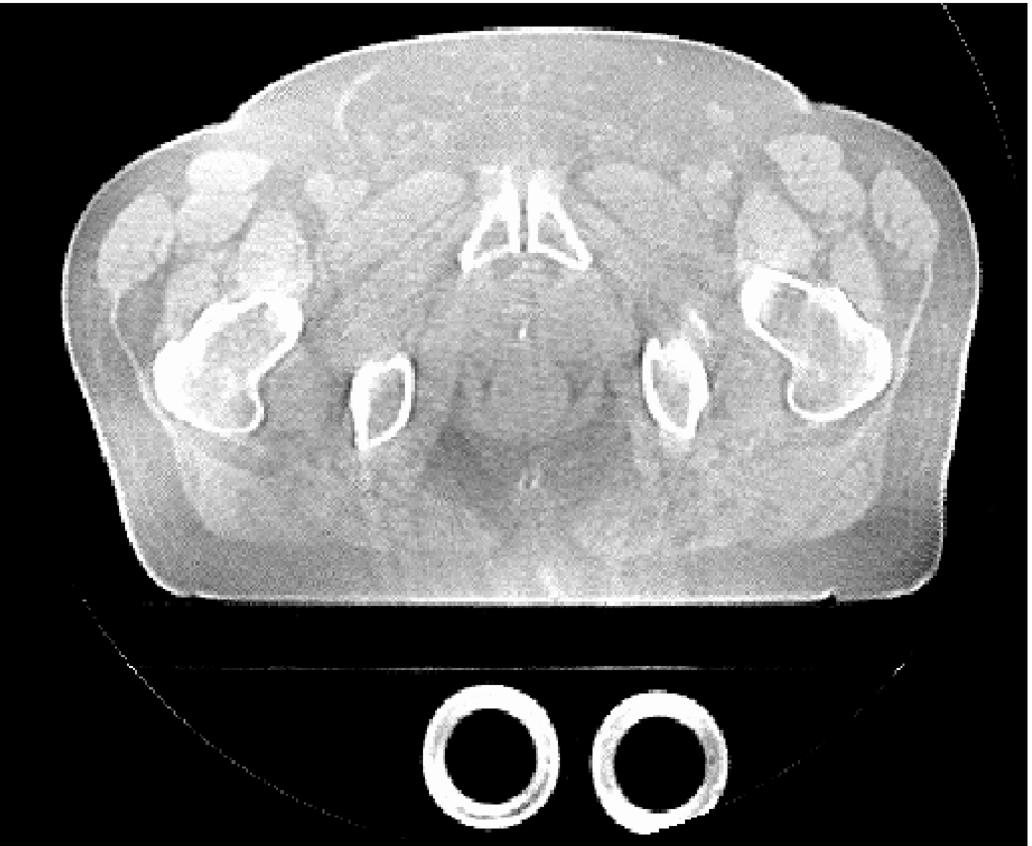
320 Projections 1.5 - 3 cGy





Implementing CBCT: validation of the system

640 Projections 1.5 - 3 cGy



Implementing CBCT: role of RTT

- Understanding basic physics and technical aspects of new imaging modality
  - IQ: artefacts

- Implementing in daily workflow
  - Protocols, manuals and working instructions

- Setting up training program for RTT's

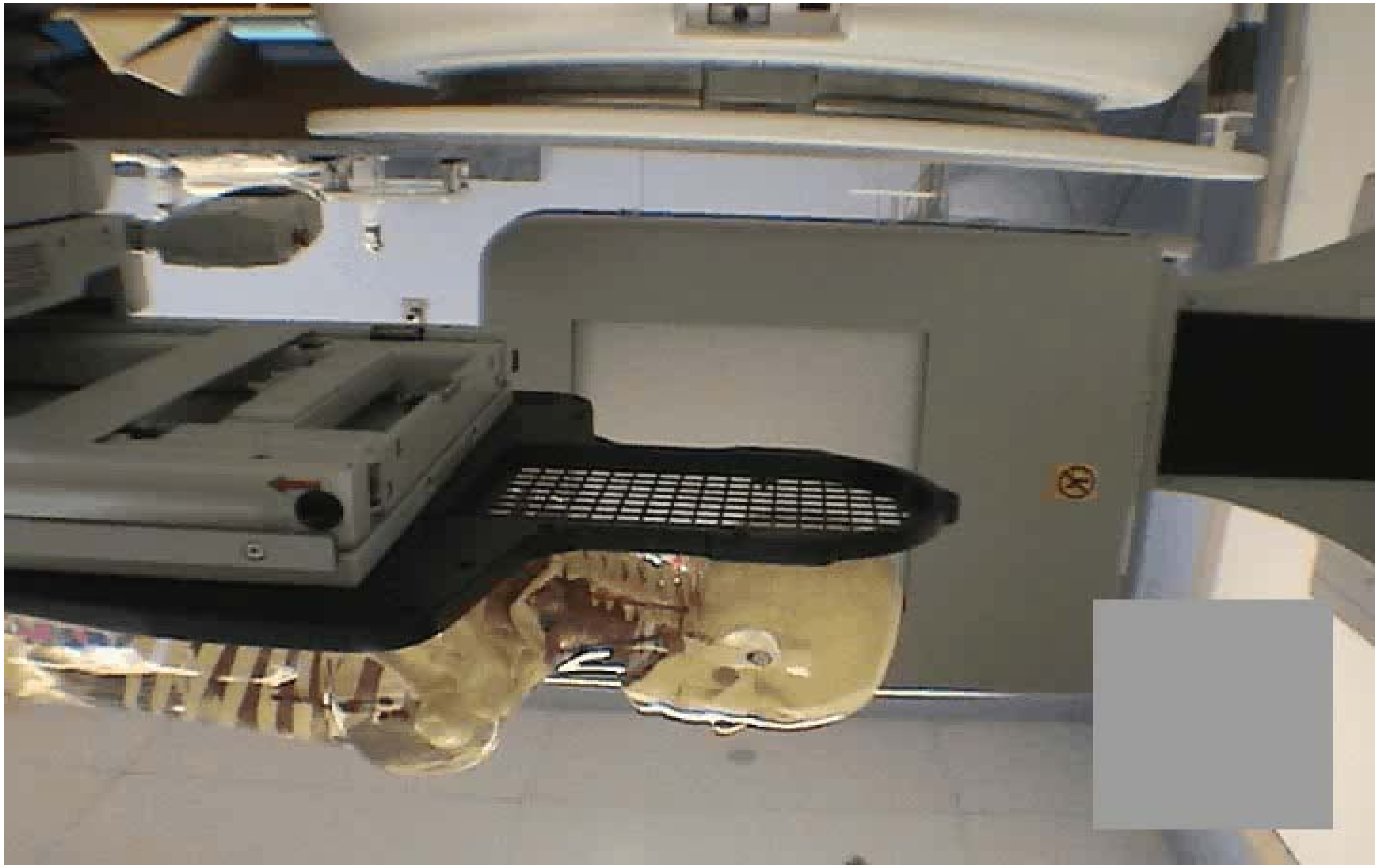
Starting clinical use of CBCT

RTT's responsibilities:

- Acquisition of CBCT
- Registration bony anatomy (CBCT)
- Evaluation registration (CBCT)
- Evaluation of treatment **!**
- Execute decision rules off-line and on-line protocols

→ Same as portal imaging and a bit extra

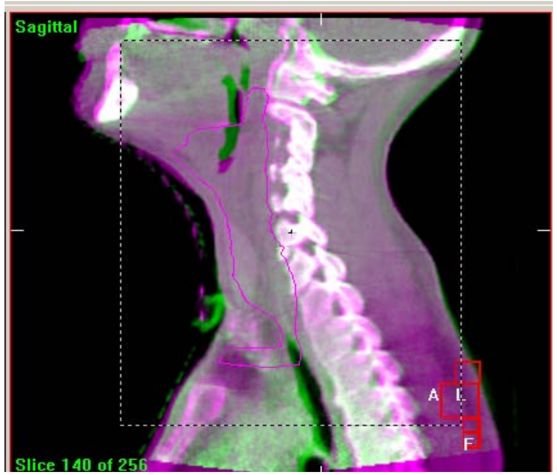
Clinical daily routine

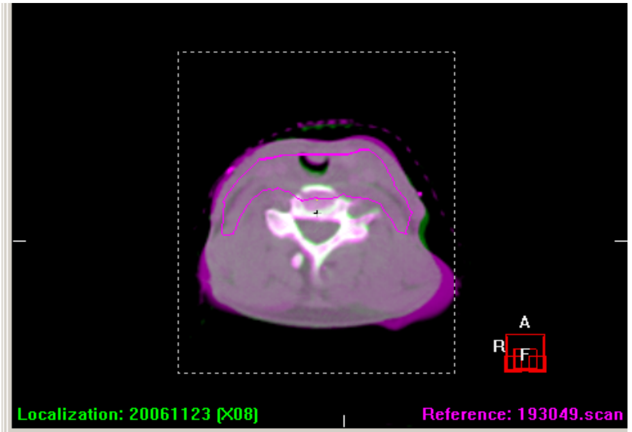


Courtesy to Doug Moseley (PMH) Jan-Jakob Sonke (AvL)

Princess Margaret Hospital

Clinical daily routine - registration

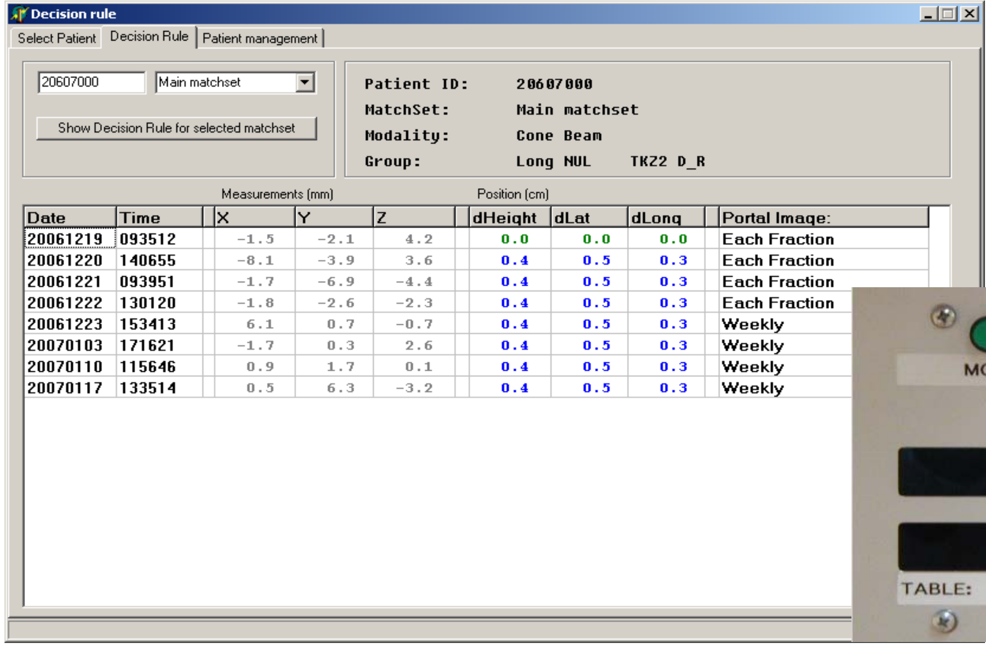




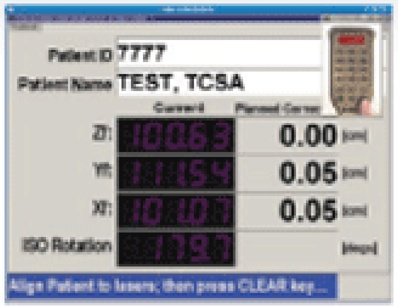
Automatic registration

CBCT scan

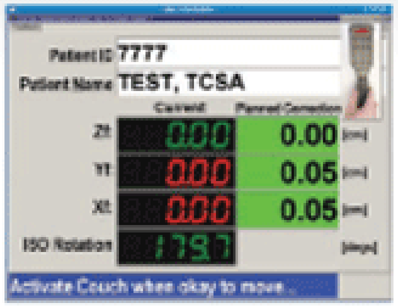
KV imaging – off/online correction



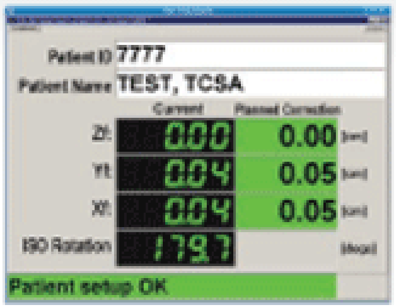
Date	Time	X	Y	Z	dHeight	dLat	dLong	Portal Image:
20061219	093512	-1.5	-2.1	4.2	0.0	0.0	0.0	Each Fraction
20061220	140655	-8.1	-3.9	3.6	0.4	0.5	0.3	Each Fraction
20061221	093951	-1.7	-6.9	-4.4	0.4	0.5	0.3	Each Fraction
20061222	130120	-1.8	-2.6	-2.3	0.4	0.5	0.3	Each Fraction
20061223	153413	6.1	0.7	-0.7	0.4	0.5	0.3	Weekly
20070103	171621	-1.7	0.3	2.6	0.4	0.5	0.3	Weekly
20070110	115646	0.9	1.7	0.1	0.4	0.5	0.3	Weekly
20070117	133514	0.5	6.3	-3.2	0.4	0.5	0.3	Weekly



Align



Setup



Treat

Managing IGRT (3d)

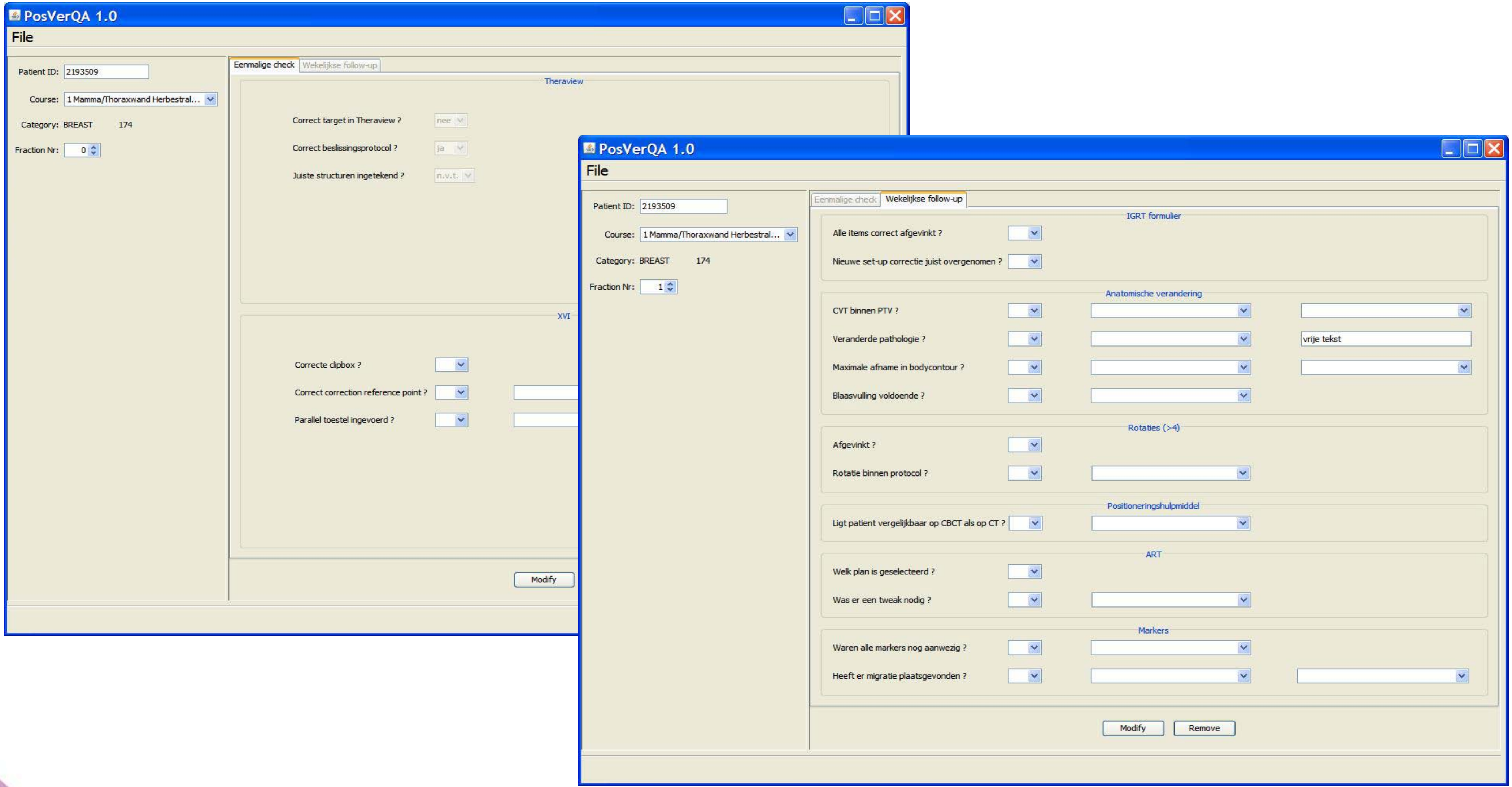
Managing CBCT

@AMC

5 RTT's with a focus on IGRT:

- **Track, check patients**
- First contact of changes occur
- Training and education
- Manuals and protocols
- Data collection & handling

Track & check patients



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Managing CBCT

@AMC

5 RTT's with a focus on IGRT:

- Track, check patients
- **First contact of changes occur**
- Training and education
- Manuals and protocols
- Data collection

Anatomical Changes

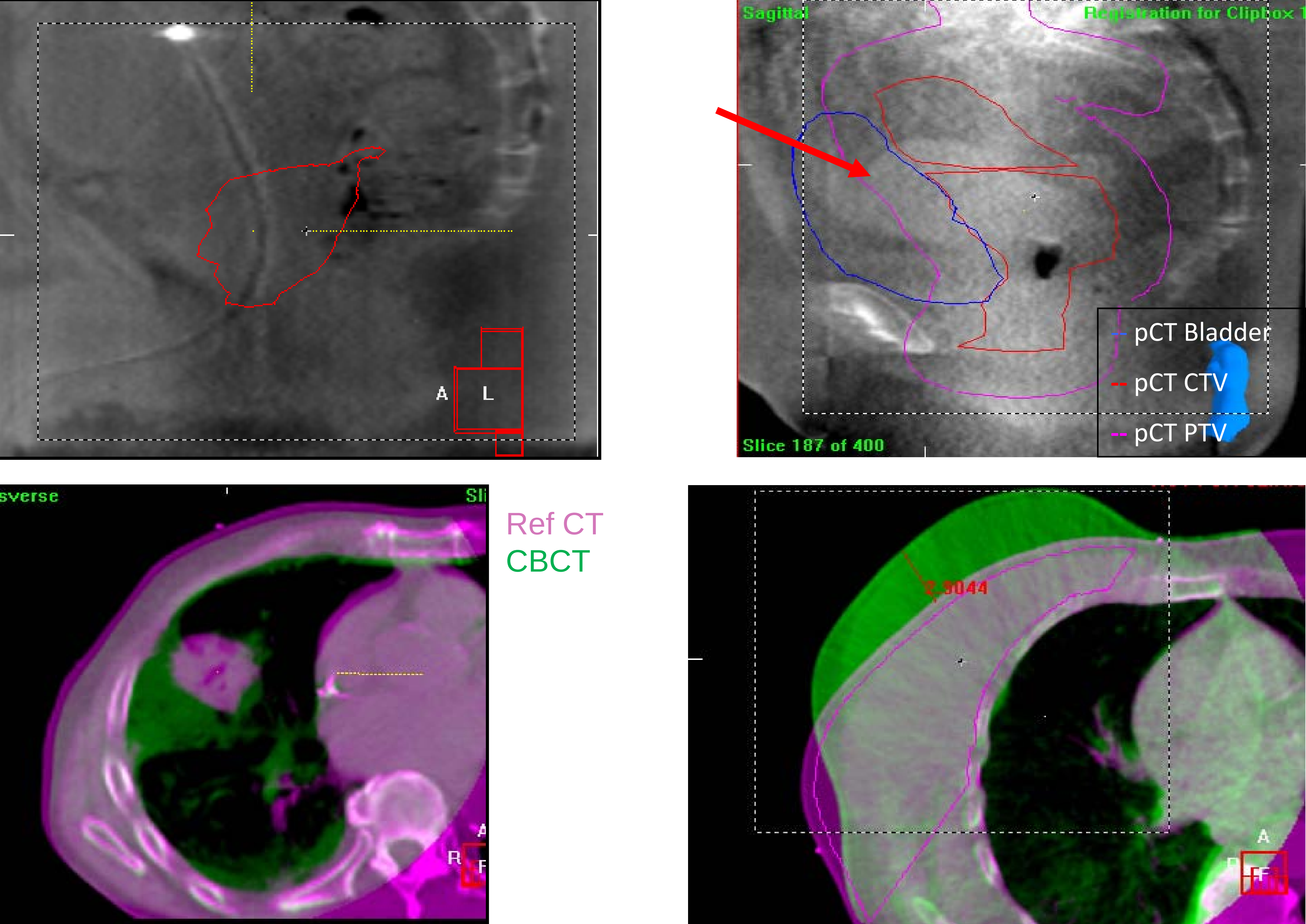
RTT should be trained in:

Recognizing patient changes/anatomical changes that have an influence on radiation treatment: Target coverage and/or dose distribution

&

RTT should have:

a management system for anatomical changes that flag the changes that may need intervention of some sort.



A
L
Sagittal
Registration for Clipbox
Slice 187 of 400
pCT Bladder
pCT CTV
pCT PTV
Ref CT
CBCT
2.9044
A
R
F

Anatomical Changes

The important questions:

1: Is the target volume (CTV or GTV) within PTV?

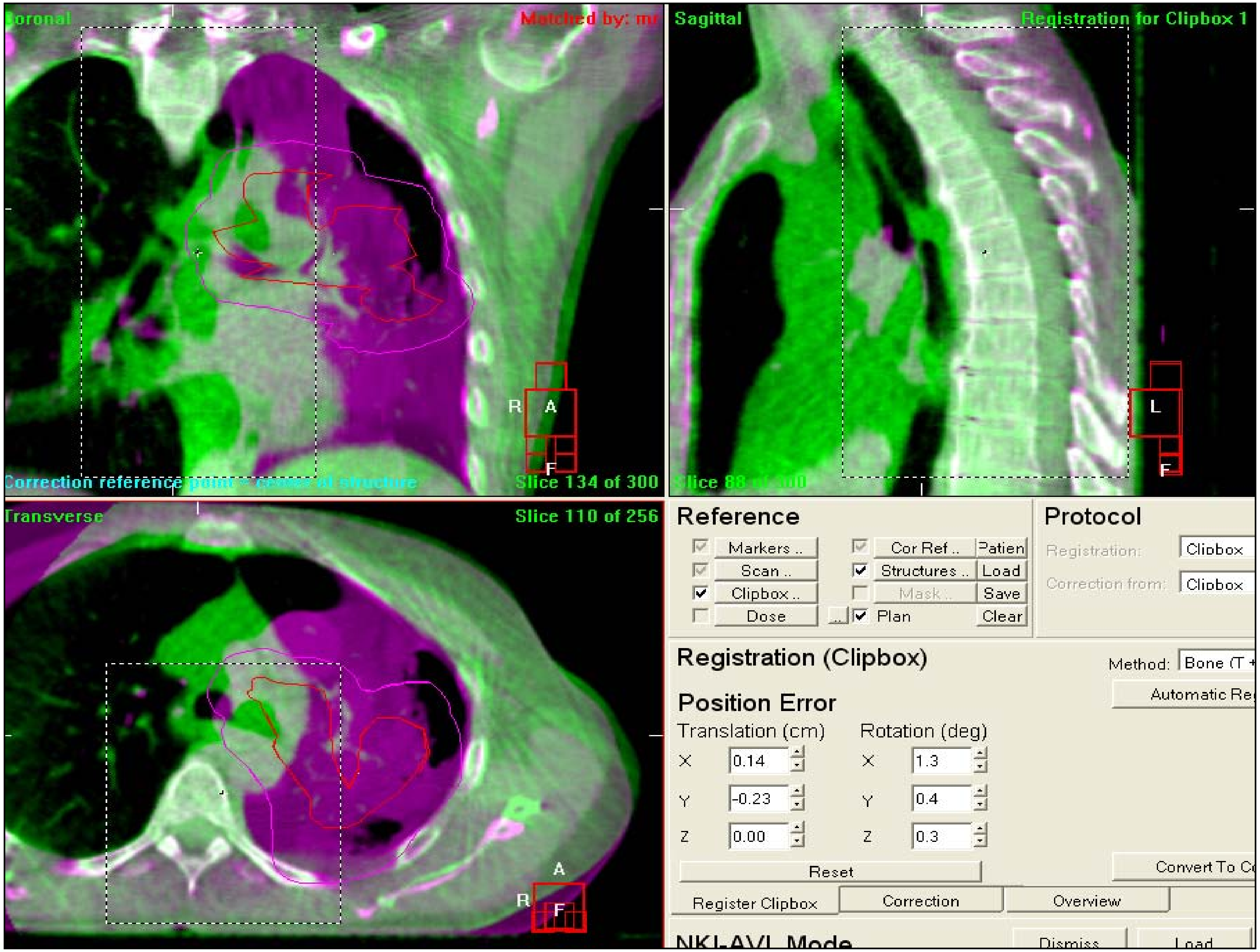
2: Is the dose distribution compromised?

(green)	Level green, no action needed.
(yellow)	Level yellow, the radiation oncologist is notified by email, but no response is required to continue treatment.
(orange)	Level orange, the treating radiation oncologist (or back-up colleague) is informed by email and a response is required before the next fraction.
(red)	Level red changes, the radiation oncologist must be consulted immediately before the treatment fraction is allowed to be delivered.

ANTONI VAN LEEUWENHOEK
NEDERLANDS KANKER INSTITUUT

http://www.avl.nl/media/291805/xvi_engelse_protocols_16_7_2014

Level 1 Atelectasis resolved



GTV is not within PTV

Dose distribution is compromised

Anatomical Changes

Or keep it very simple:

Contact the IGRT-group when

- GTV is outside of PTV
- Anatomical changes > 1 cm

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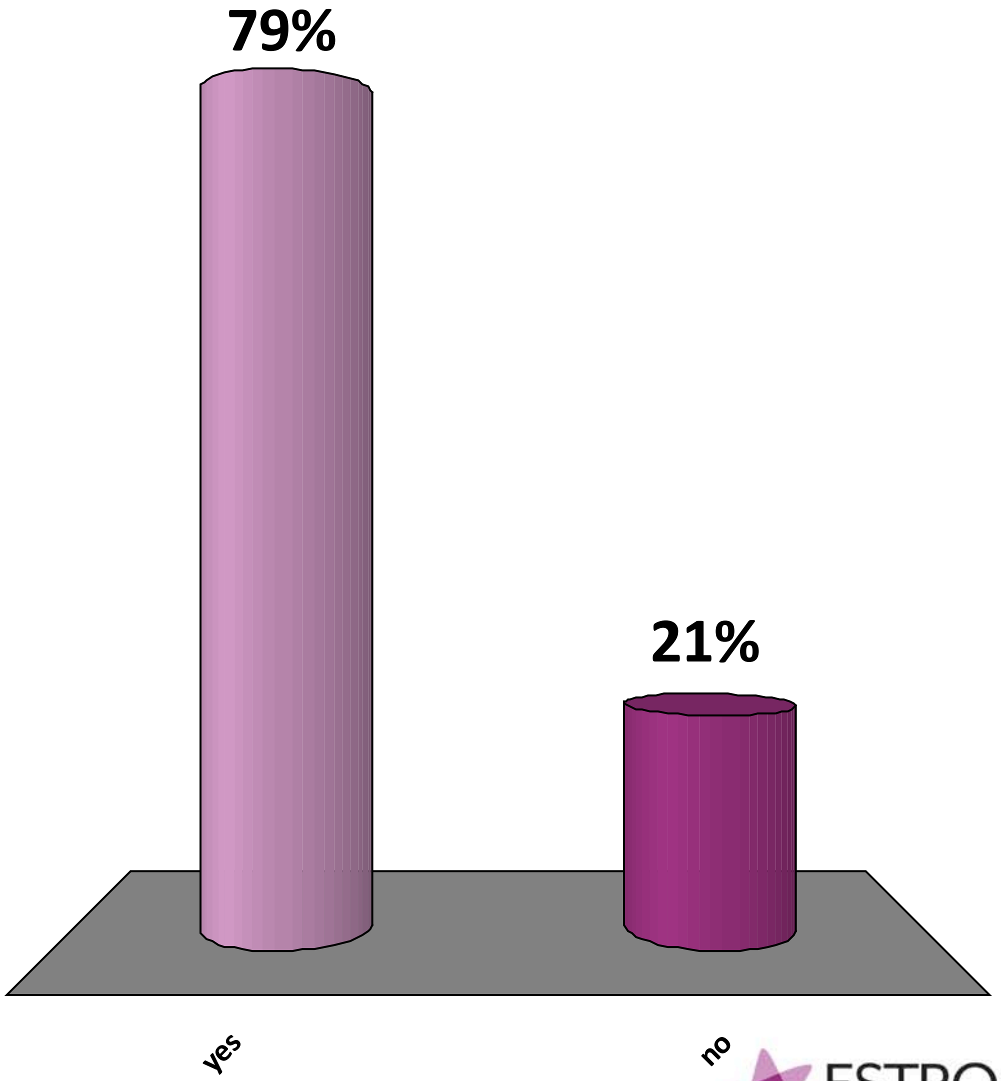
Do you have a support system for anatomical changes?

A. yes

B. no



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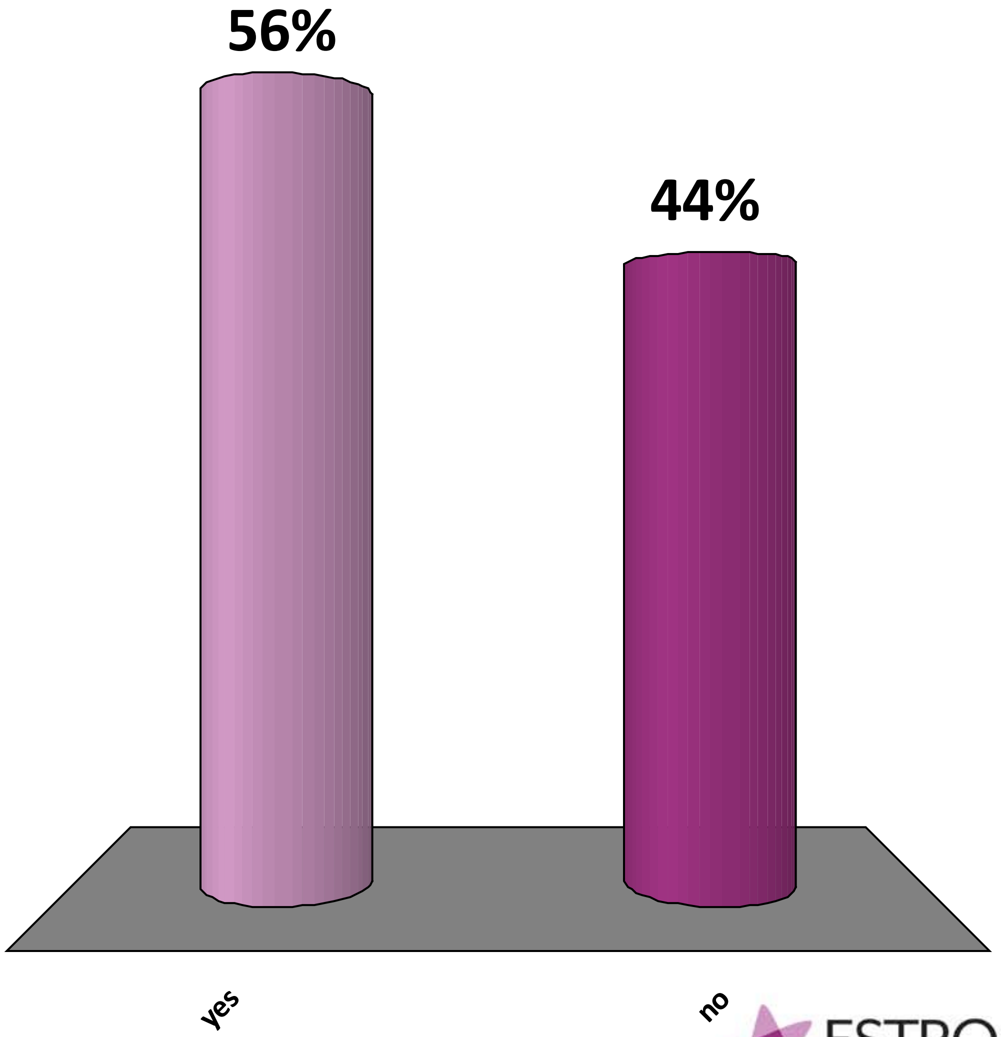
Is the RTT the first contact person?

A. yes

B. no



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Managing CBCT

@AMC

5 RTT's with a focus on IGRT:

- Track, check patients
- First contact of changes occur
- **Training and education**
- Manuals and protocols
- Data collection

Managing CBCT

3 lectures (1h)

- Theraview: Portal imaging system and decision rule management system
- geometrical errors & correction strategies
- CBCT incl artefacts, image quality

2 Workshop (2x1.5h) in registration and image evaluation

Challenge: it affects all RTT's, so large group needs to be trained and kept up to date!

Managing CBCT

@AMC

5 RTT's with a focus on IGRT:

- Track, check patients
- First contact of changes occur
- Training and education
- **Manuals and protocols**
- **Data collection**

Managing CBCT

5 RTT's:

- Track, check patients
- First contact of changes occur
- Training and education
- **Manuals and protocols**
- **Data collection**

→ These RTT's also work in the clinic

Implementing IG&ART

Research department → Clinic

Multi disciplinary group to implement, research and evaluate IGRT protocols:

- Physicists
- Physicians
- RTT's
- Software developers
- Post-docs/PhD students

Introducing IGRT

Also applicable for development and implementation in other steps of the radiation therapy chain!

RTT :

Evaluation of bulk of data: for example

- Inter fraction set up variability
- Intra fraction stability
- Organ motion or deformation
- Testing new (software) tools

Design & implementation new protocols

Training and education in house

Protocols and manuals

Clinic!

Shifting responsibilities @ treatment machine

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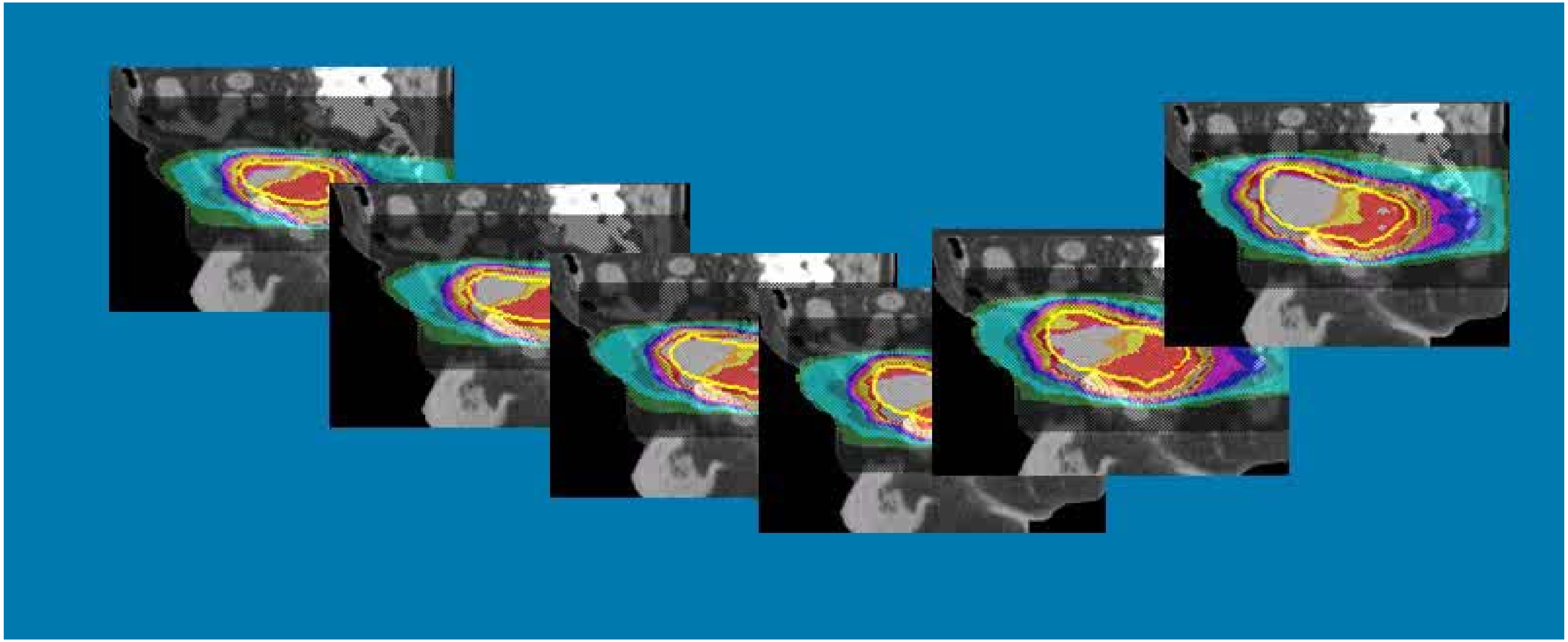
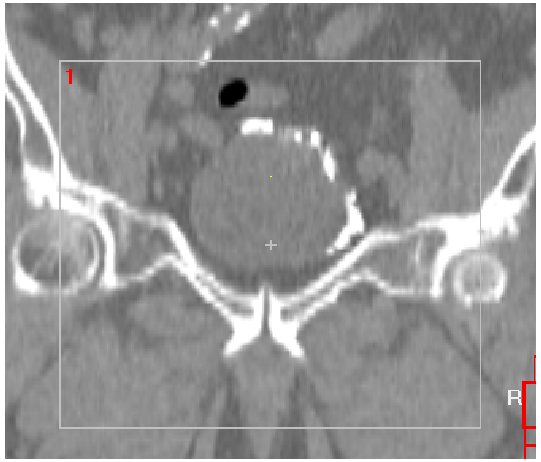
ART: Library of Plan

Dealing with daily volume changes



Courtesy Danny Schuring,
Catharina Ziekenhuis, Einhoven

Treatment Procedure



- Lipiodol demarcation of tumor by urologist
- Full & empty bladder CT scan
- Instructions to ensure full bladder
  - Good hydration prior to treatment
  - Empty bladder 1 hr before treatment
  - Drink 2 – 3 glasses
  - Continuous steering during treatment
- Cone-beam CT at start of treatment
- Selection of “plan of the day” based on bladder filling

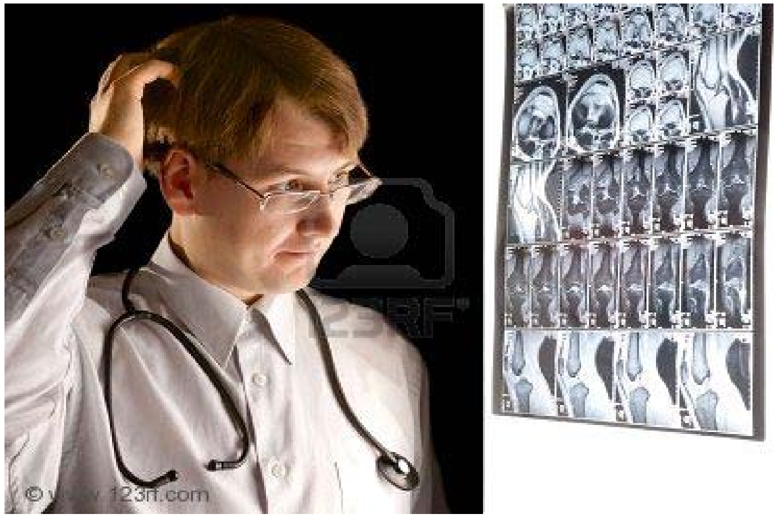
Courtesy Danny Schuring,
Catharina Ziekenhuis, Einhoven

Daily plan selection

- Daily plan selection at linac

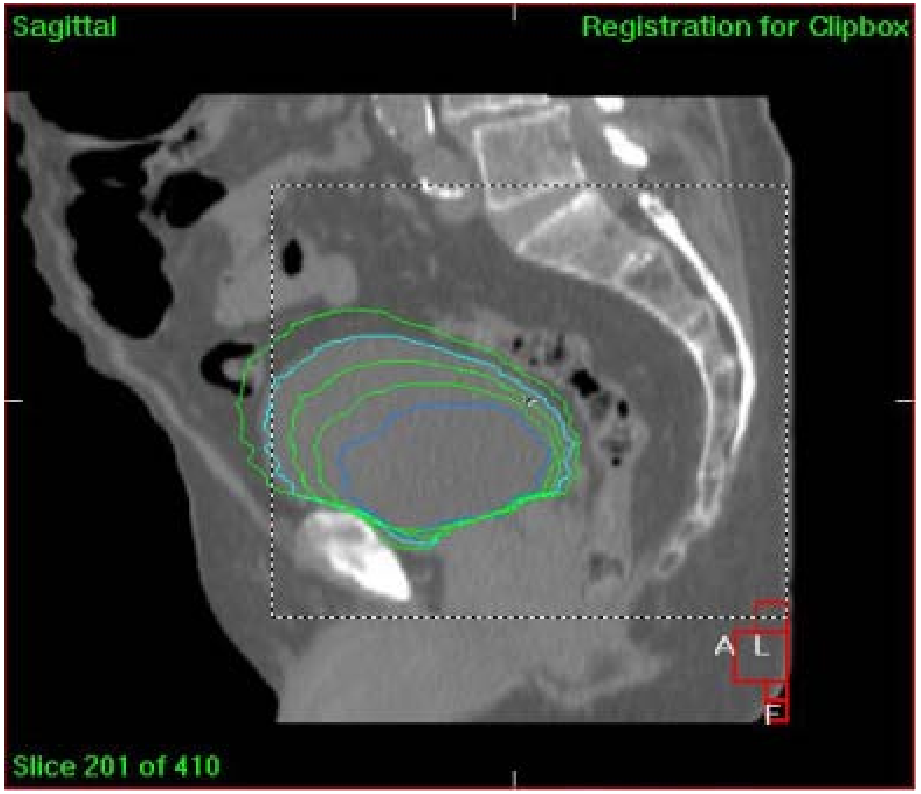
  ⇓

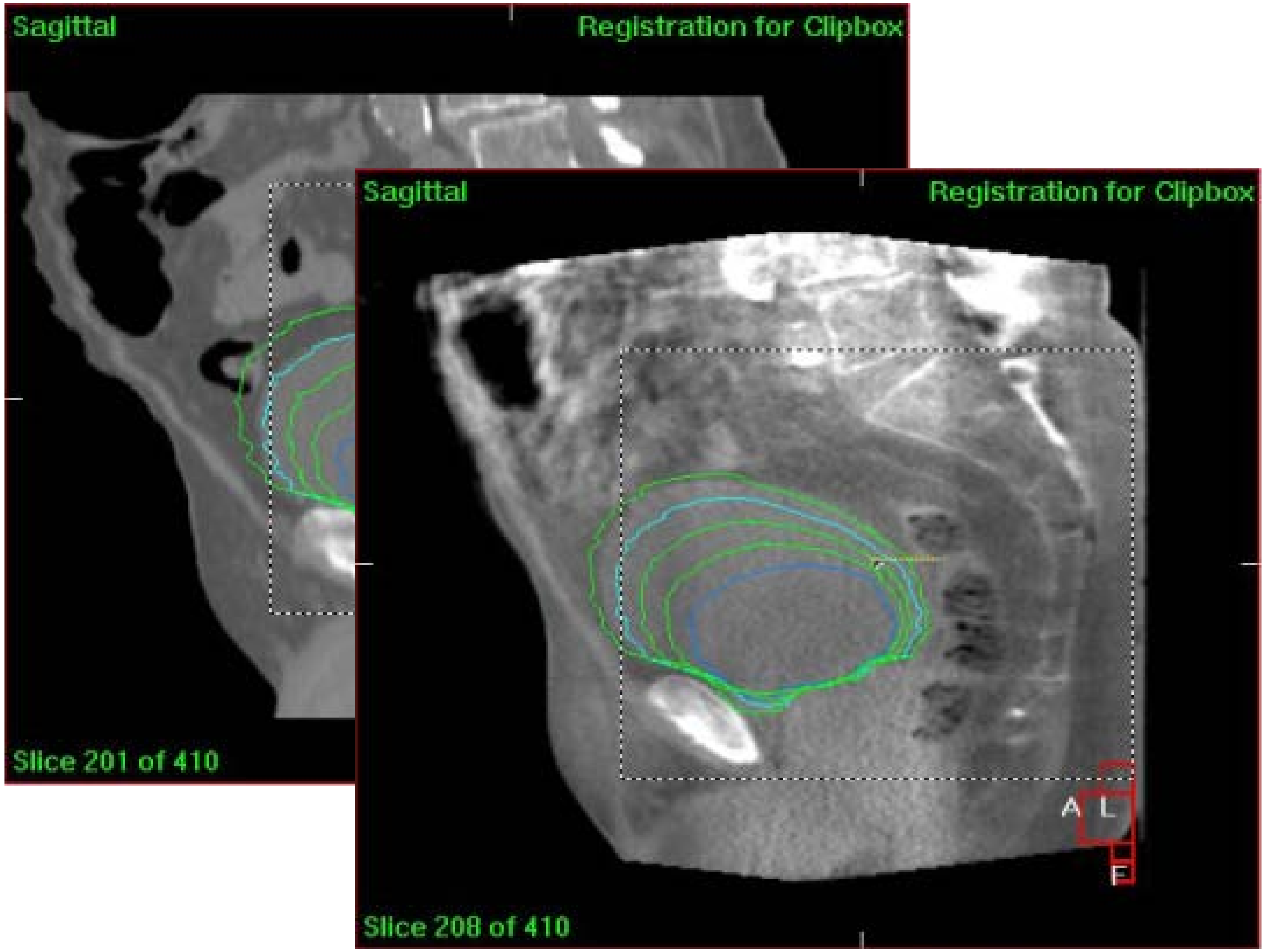
  Shift in responsibilities!

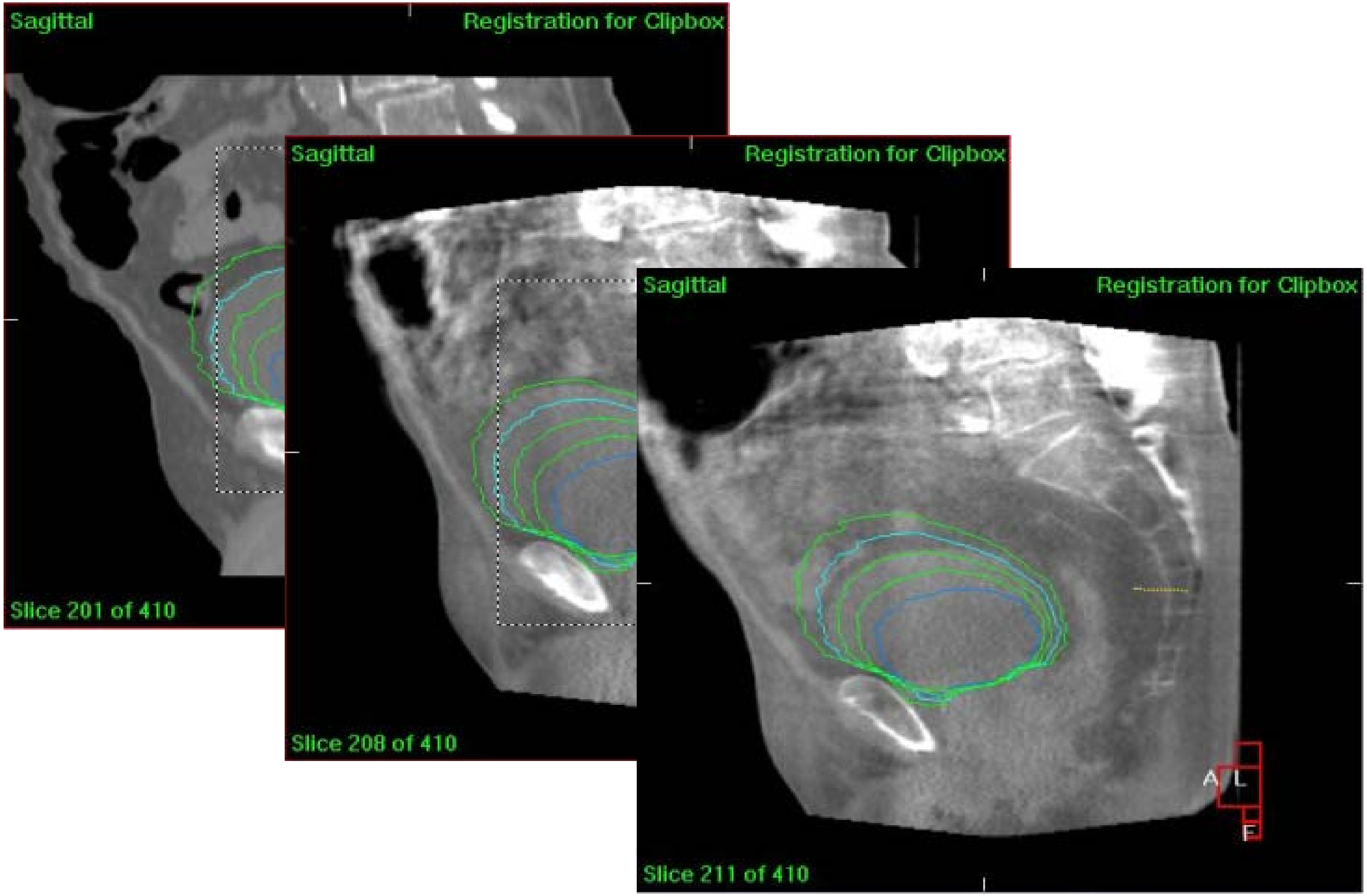


- Current practice: selection by physicist or specialized technologist

Courtesy Danny Schuring,
Catharina Ziekenhuis, Einhoven


Sagittal
Registration for Clipbox
Slice 201 of 410
A
L
F


Sagittal
Registration for Clipbox
Slice 201 of 410
Sagittal
Registration for Clipbox
A
L
F
Slice 208 of 410



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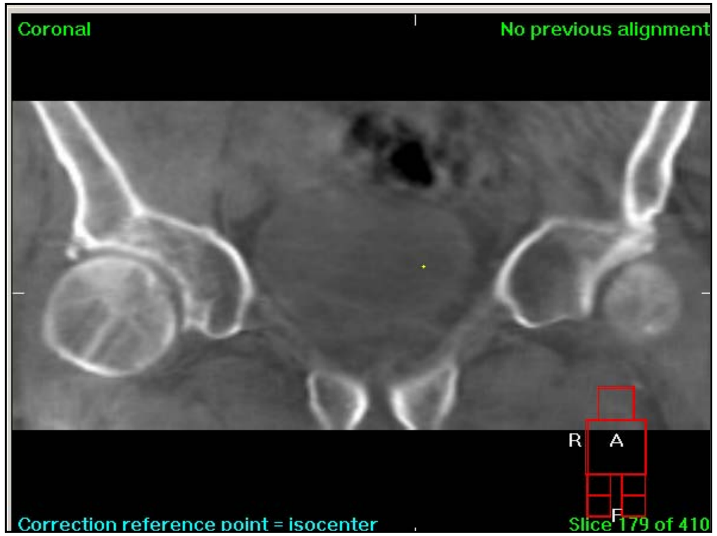
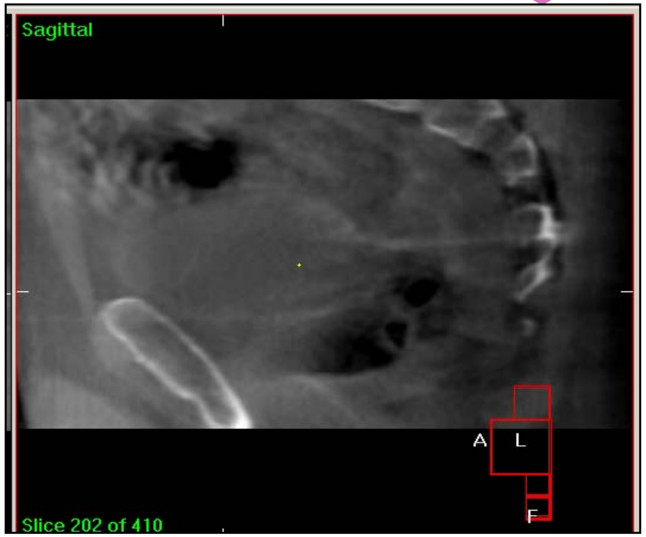
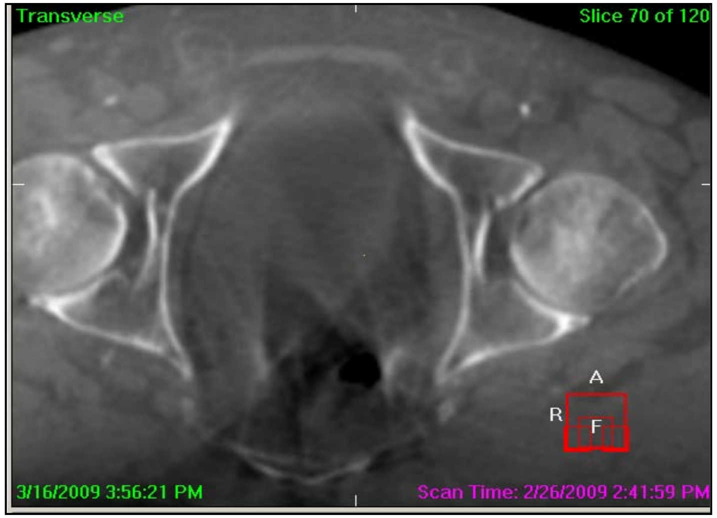
XVI quality

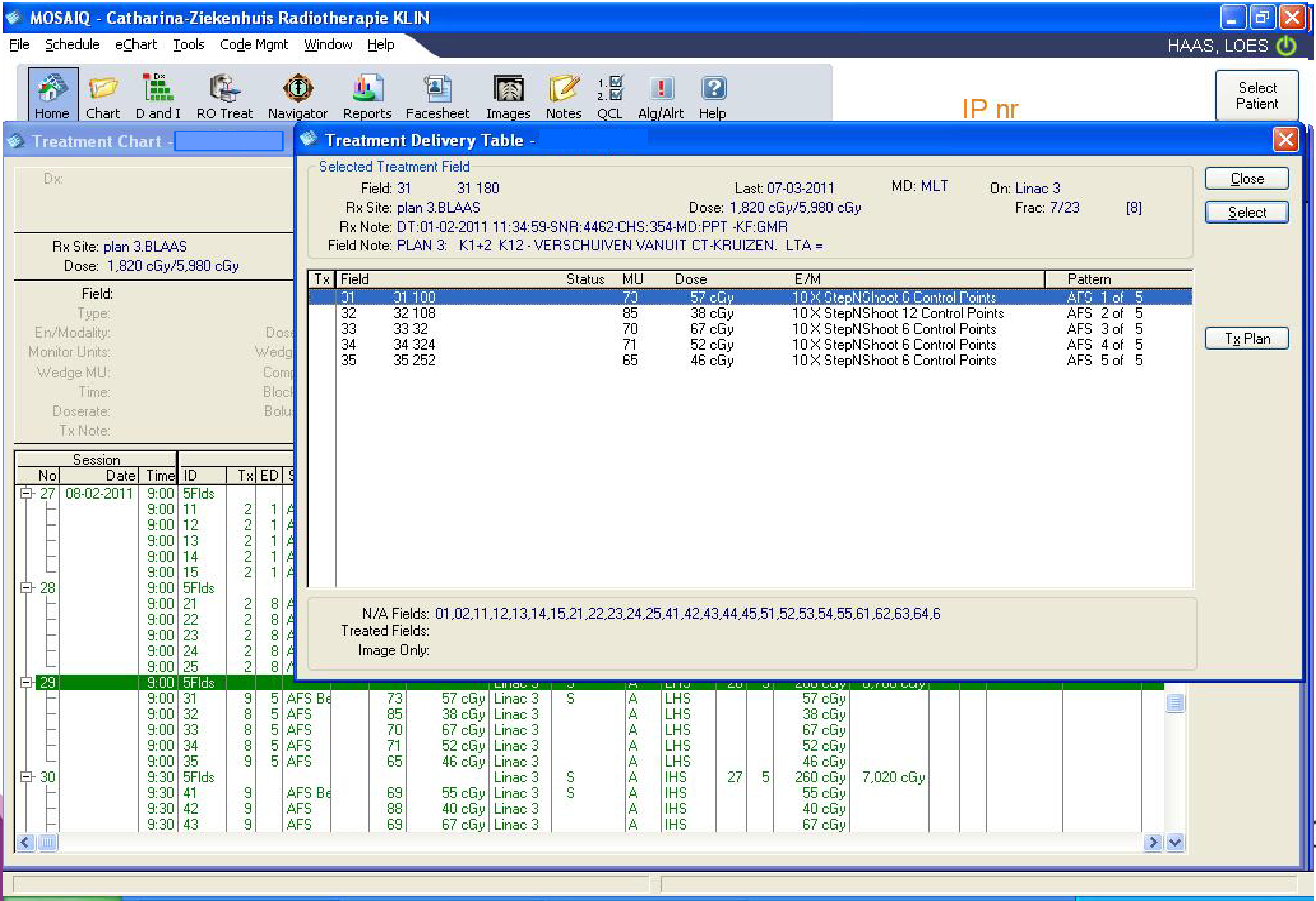
Workshop Rianne



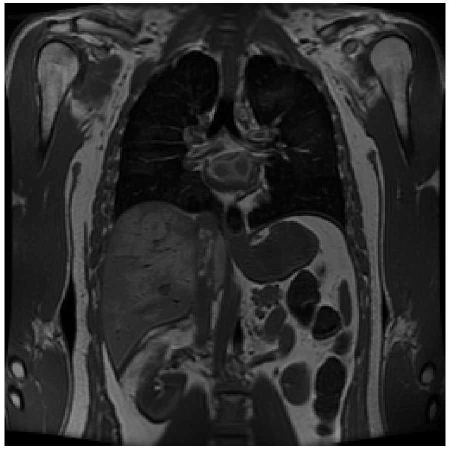




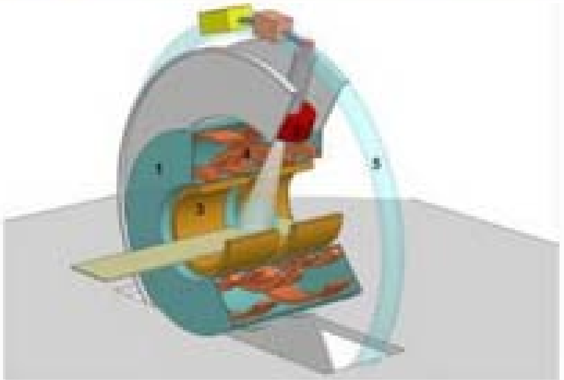
Plan selection in Mosaiq



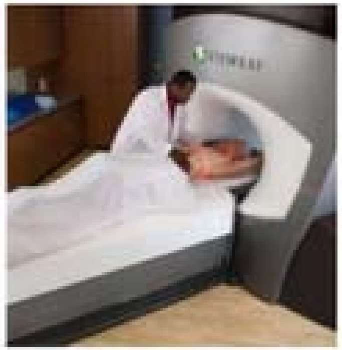
1 step further; MR inside the treatment room



U Utrecht-Philips Elekta



Viewray-MRIdian MRI-Cobalt



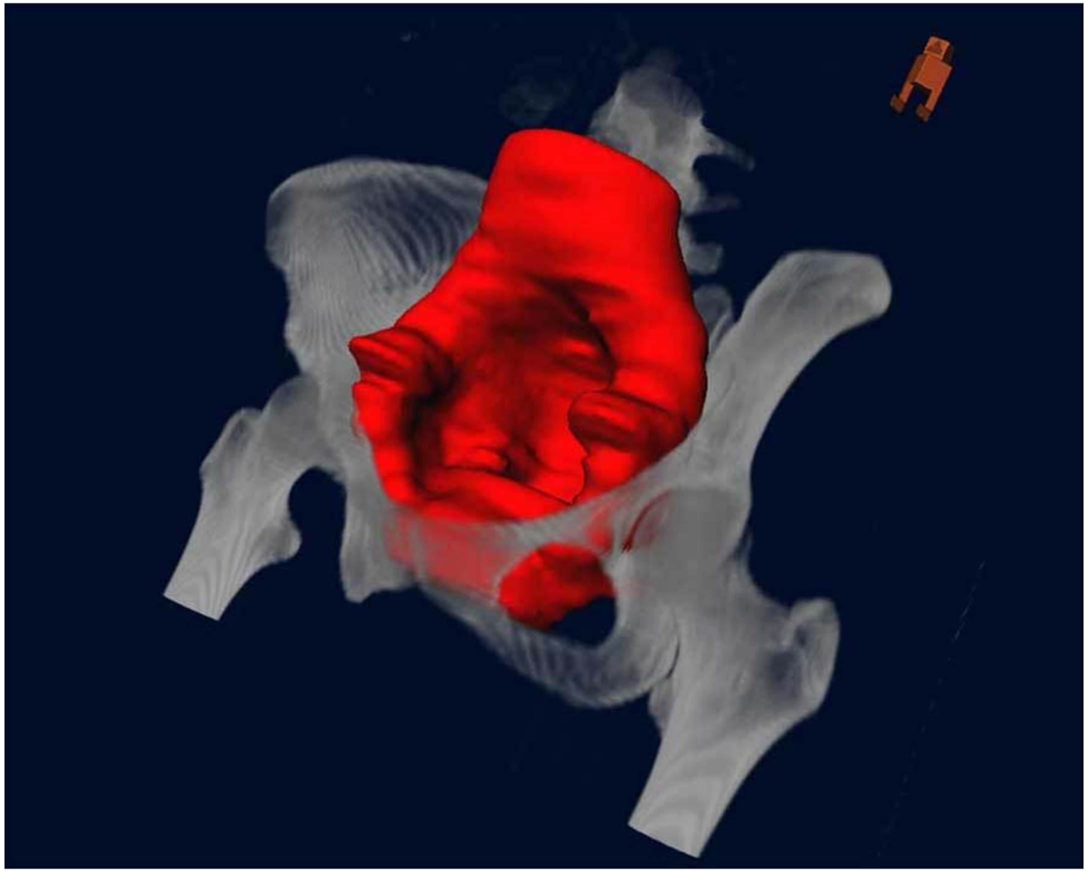
http://www.viewray.com

Diagnostic quality scan at treatment

Allows for:

- online re-planning
- online correction intra-fraction motion
- ART: accumulate doses for adaptation
- Treatment response assessment for adaptation

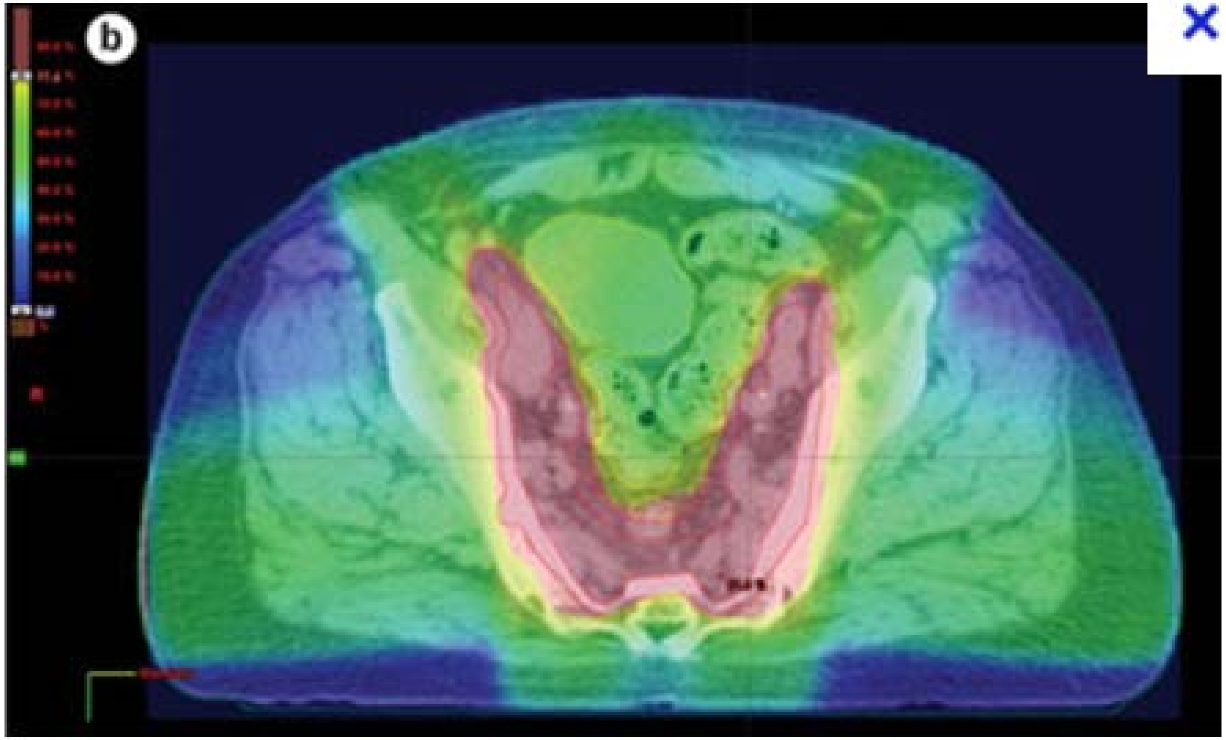
MR for online replanning – needs contouring



Approval of segmentation?

- OAR's
- Target volume

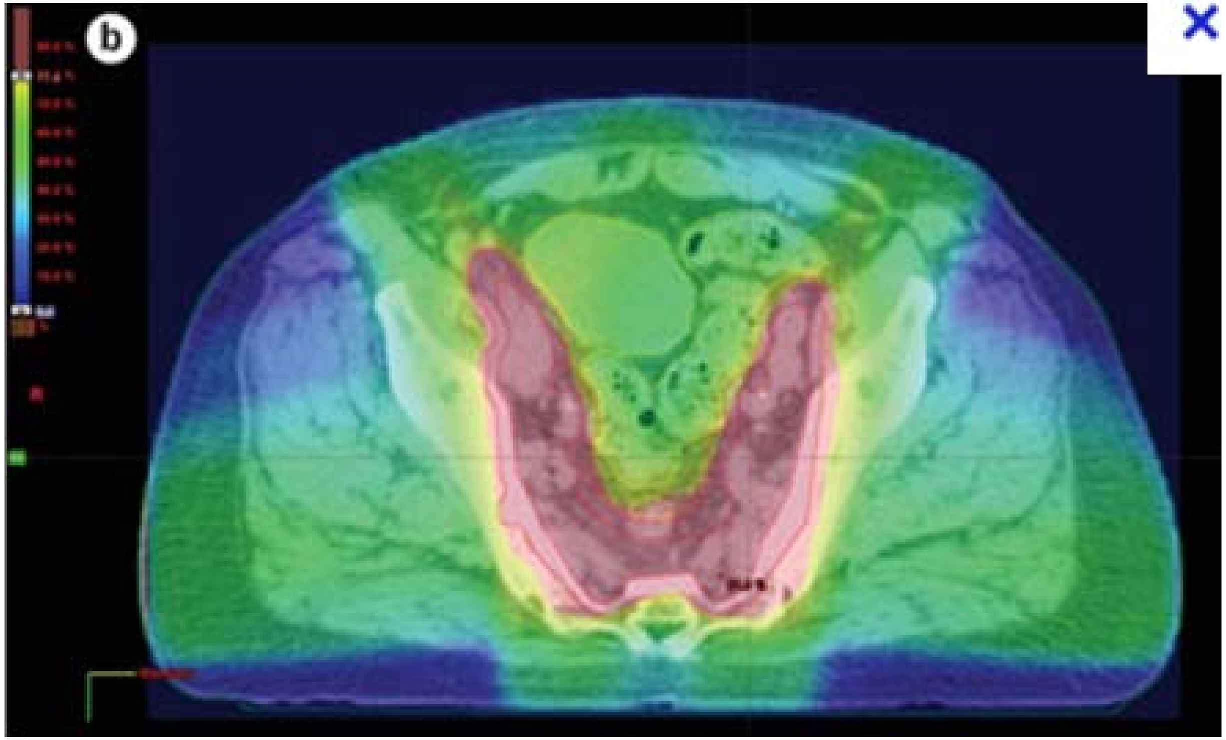
MR for online replanning – needs replanning



Approval of new plan?

- OAR's
- Target volume

MR for online replanning – needs replanning



Approval of new plan?

- OAR's
- Target volume

Treatment planning & IGRT become best friends!

Summary

Modern Radiation Therapy is a multi disciplinary effort

Modern Radiation Therapy has opened up the field for RTTs:

- Patients education
  - Pre-treatment imaging PET/MRI/CT
- CT simulation
- Treatment Planning
  - Research and Development
- Treatment
  - *Image guidance*
- Research & Development

Still evolving!

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Acknowledgments

AMC

Coen Rasch

Koen Crama

Martijn Kamphuis

AvL/NKI

Marcel van Herk

Peter Remeijer

Jan-Jakob Sonke

Anja Betgen

Suzanne van Beek

Catharina Ziekenhuis

Danny Schuring

Questions & Discussion

m.a.j.dejong@amc.uva.nl

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Patient Preparation and Positioning

Martijn Kamphuis MSc, MBA candidate

(Slides: Rianne de Jong)
Academic Medical Center, Amsterdam
Copenhagen 2015

m.kamphuis@amc.nl

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Aim of Patient preparation and positioning

→ <u>Minimize</u> the difference in patient position

1. between simulation and treatment sessions
2. during the treatment session

→ <u>Maximize</u> the distance between target volume and organs at risk

Tools:

- Immobilization and fixation
- Patient compliance

Tools of Patient preparation and positioning

→ Immobilization

Daily set-up reproducibility and stability through the use of fixation or aiding devices

Tools of Patient preparation and positioning

"My diabetic research shows that test subjects are 98% more likely to take their diabetic pills if the pills are covered in chocolate."

Minimize the difference in patient position

→ **<u>Minimize</u> the difference in patient position**

1. **between simulation and treatment sessions**
2. during the treatment session

→ <u>Maximize</u> the distance between target volume and organs at risk

Tools:

- Patient compliance
- Immobilization and fixation

Aim of Patient preparation and positioning

→ **Minimize** **the difference in patient position between simulation and treatment sessions: *inter*-fraction motion**

Tools:

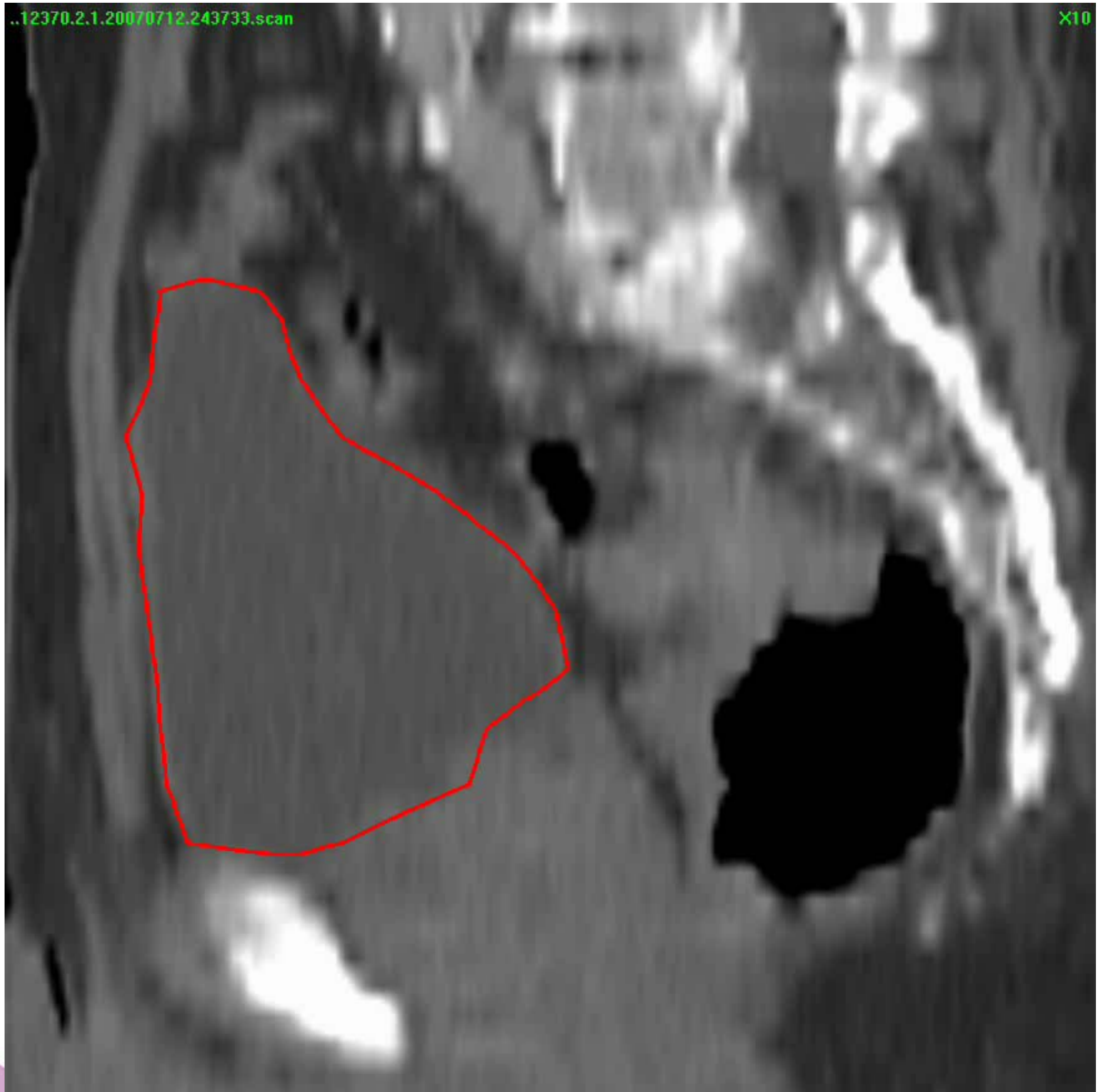
Patient compliance:

- Pelvic patients using diet / drinking protocol

Immobilization and fixation:

- Head&Neck using head support
- Lung using 4D CT.

Pelvic patients: dietary protocol

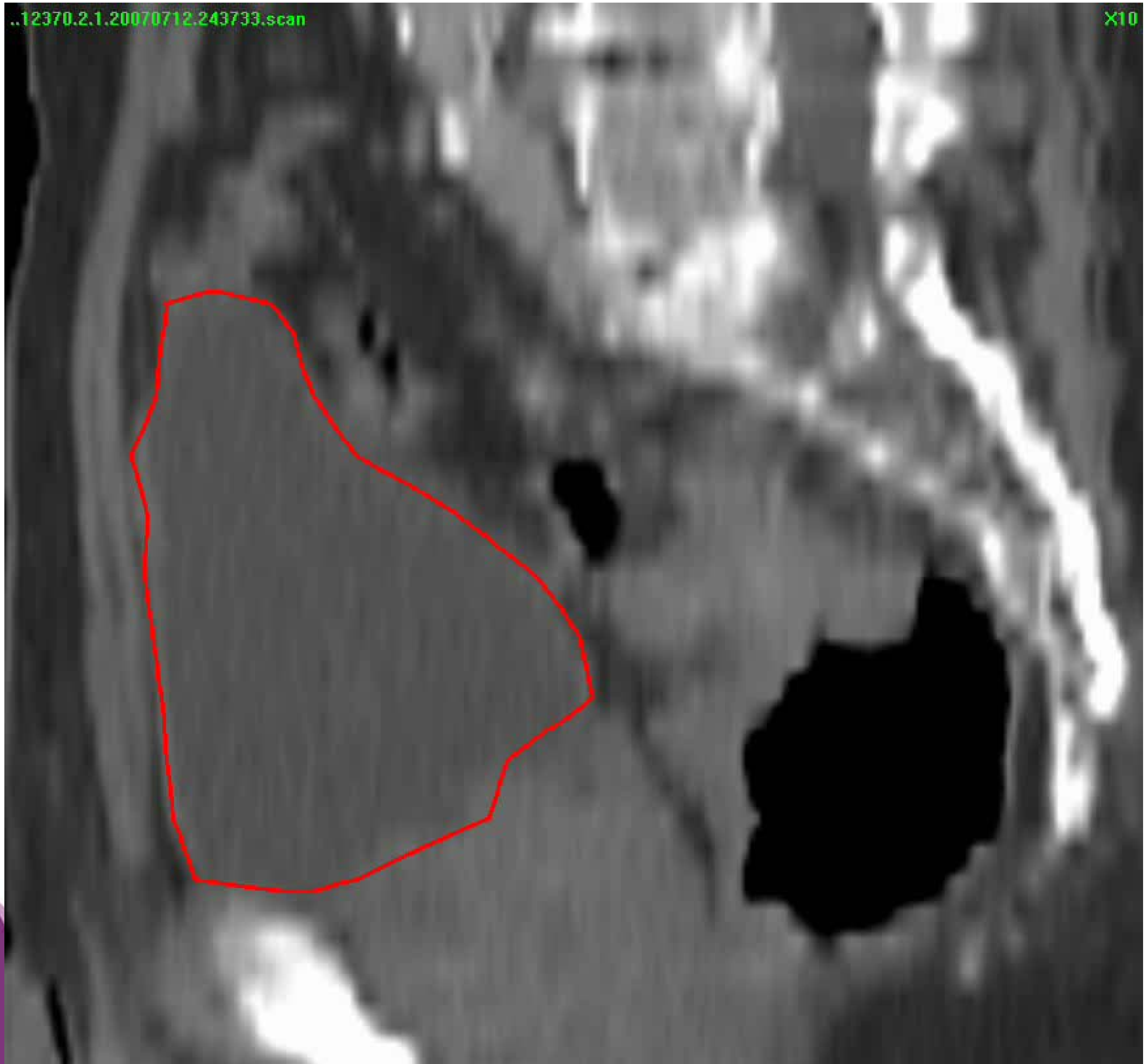


Series of repeated CT scans in rectum patients

Bladder filling over different fractions

Without diet

Pelvic patients: dietary protocol



Series of repeated CT scans in rectum patients

Bladder filling over different fractions

Without diet

Prostate patients

Reconstructed

CBCT

Prostate patients

Reconstructed

CBCT

Prostate patients

To improve image quality:

Dietician

- Mild regimen of laxatives
- Diet

Fixed treatment times

Prostate patients

	gas	faeces	moving gas
no diet	68%	61%	45%
with diet	42%	23%	22%

- reduced percentage of faeces and gas
- reduced percentage of moving gas, hence improved image quality

Prostate patients

Lips et al. Ijrobp 2011

- 739 patients without diet, 205 patients with diet
- Diet instructions on leaflet
- No reduction of **intrafraction** movement

McNair et al. 2011

- 22 patients using questionaires
- Rectal filling consistency not improved
- Diet + fixed treatment times, **no laxatives**

Conclusion:

- Drinking and dietery protocol are needed for clear patient communication **BUT**
- **Won't solve the whole problem of intra/interfraction motion (adational tools are needed)**

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Aim of Patient preparation and positioning

→ **<u>Minimize</u> the difference in patient position between simulation and treatment sessions: *inter*-fraction motion**

Tools:

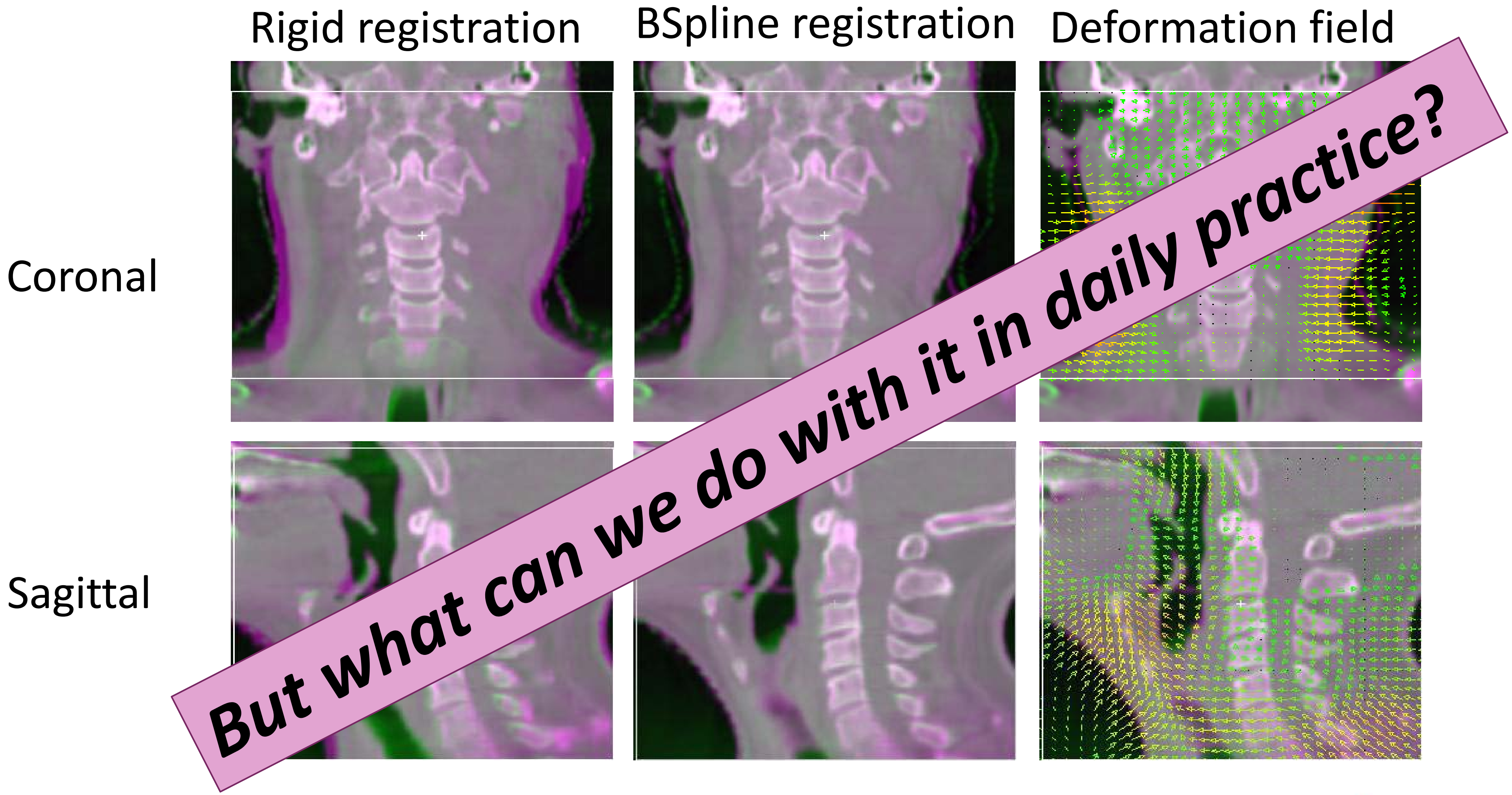
Patient compliance:

- Pelvic patients using diet / drinking protocol

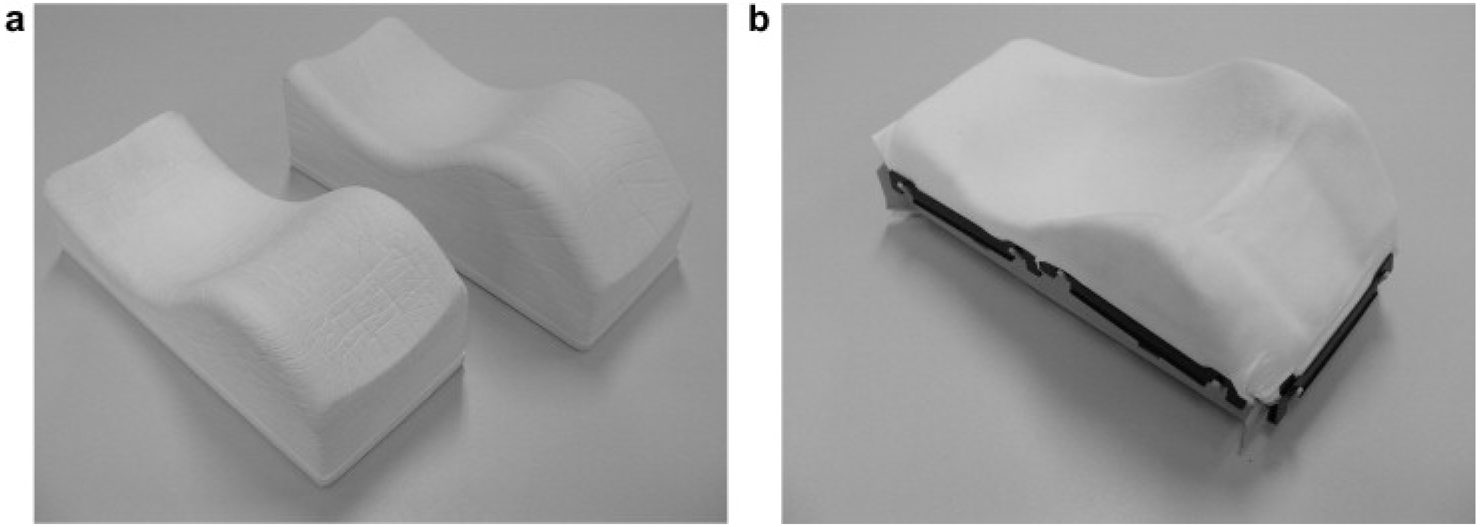
Immobilization and fixation:

- **Head&Neck using head support**
- **Unfortunate differences**

Head&Neck patients: head support



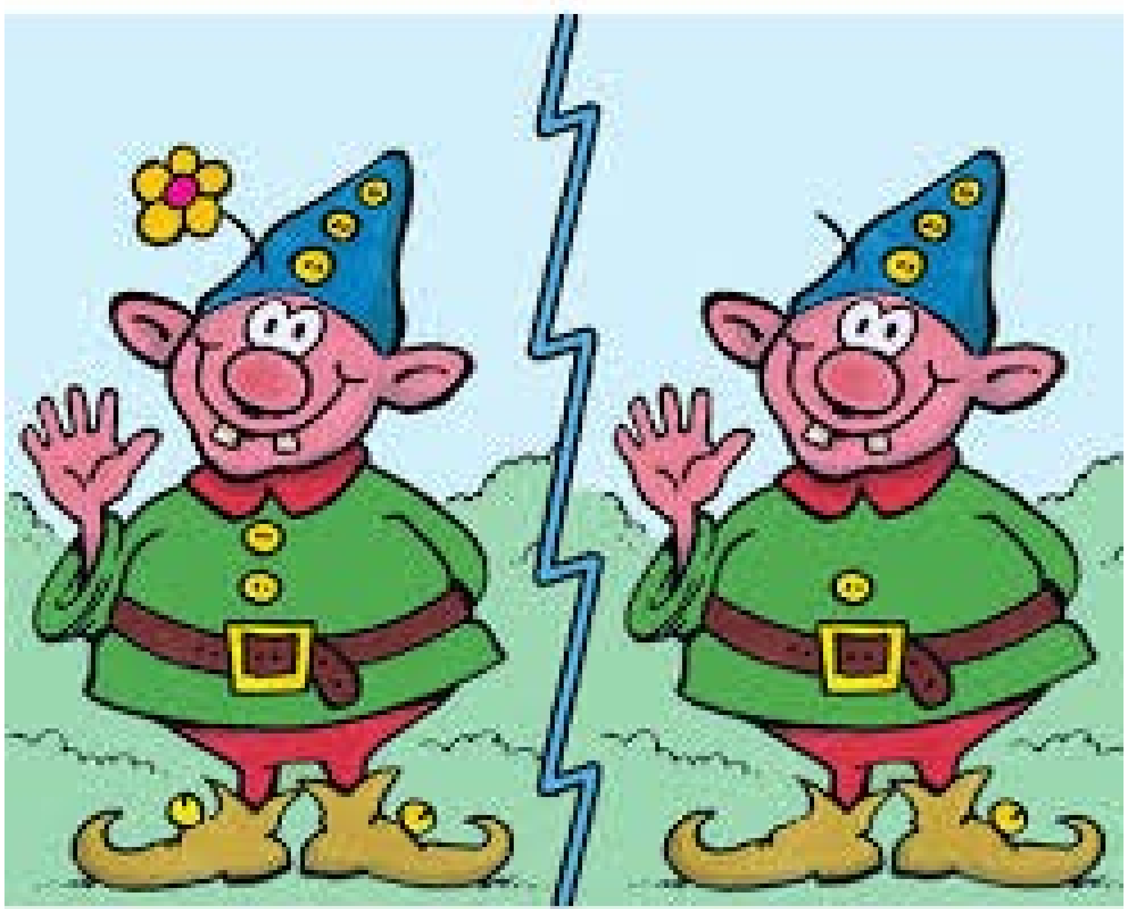
Head&Neck patients: head support



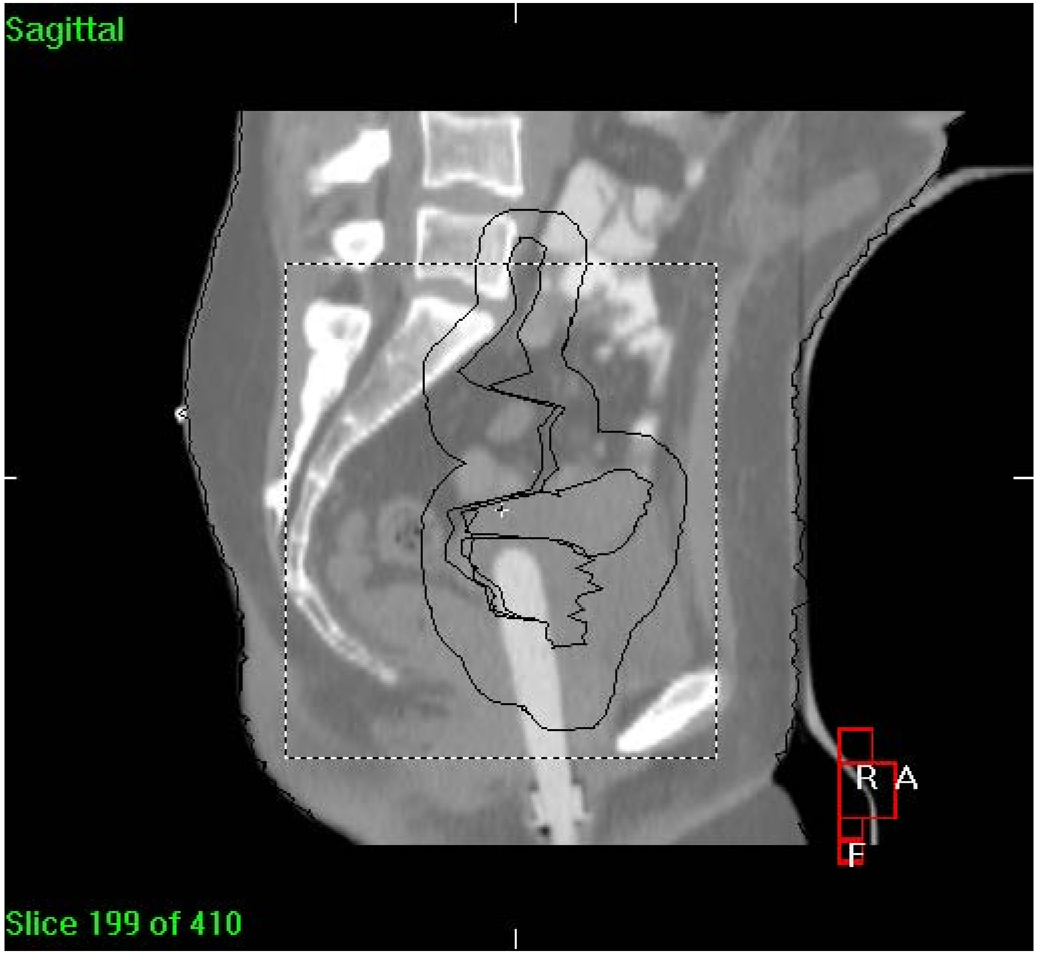
- Reduction of the average difference between fractions in set up of the bony anatomy.
- Reduction in the difference of the shape of the bony anatomy between fraction.

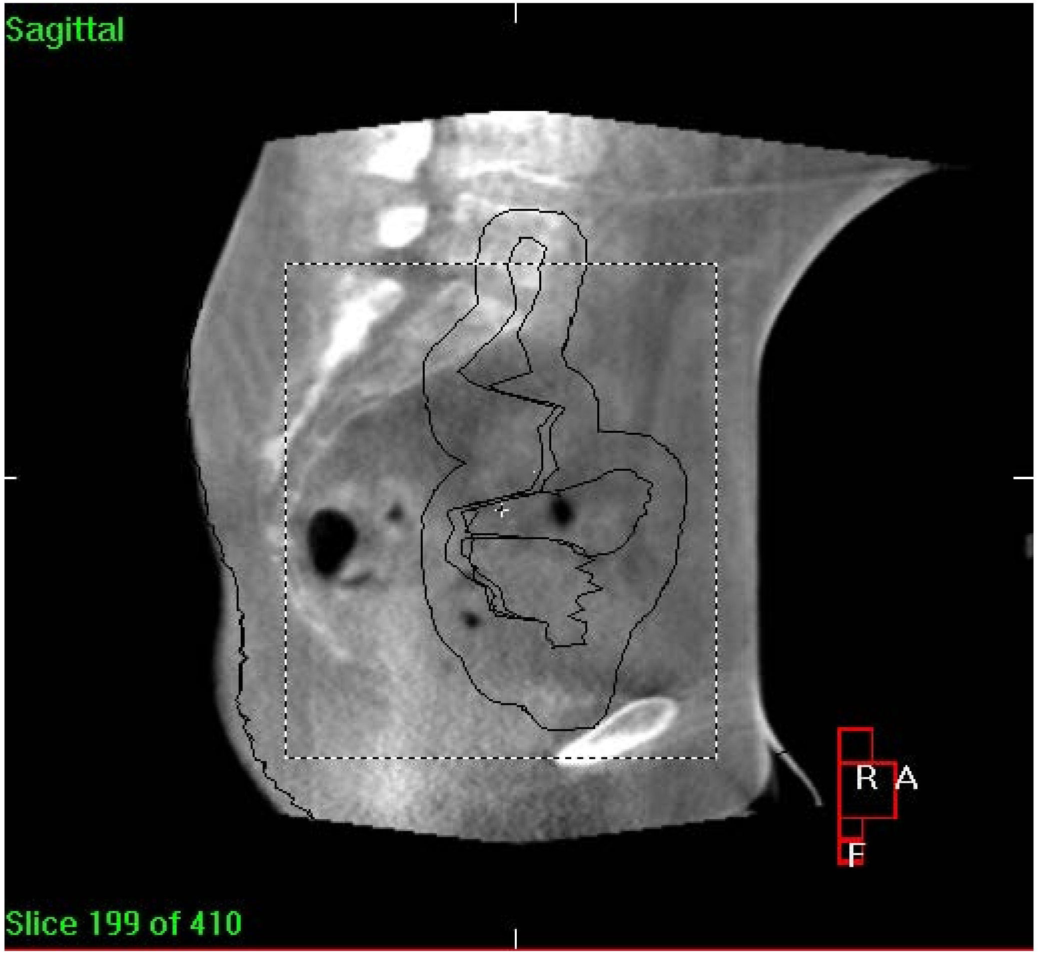
Creating unfortunate differences

- Between CT and treatment

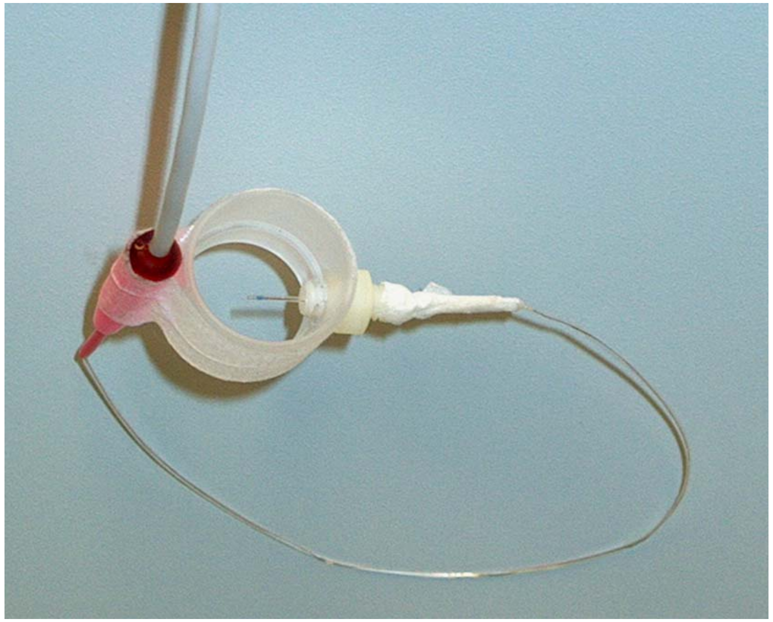


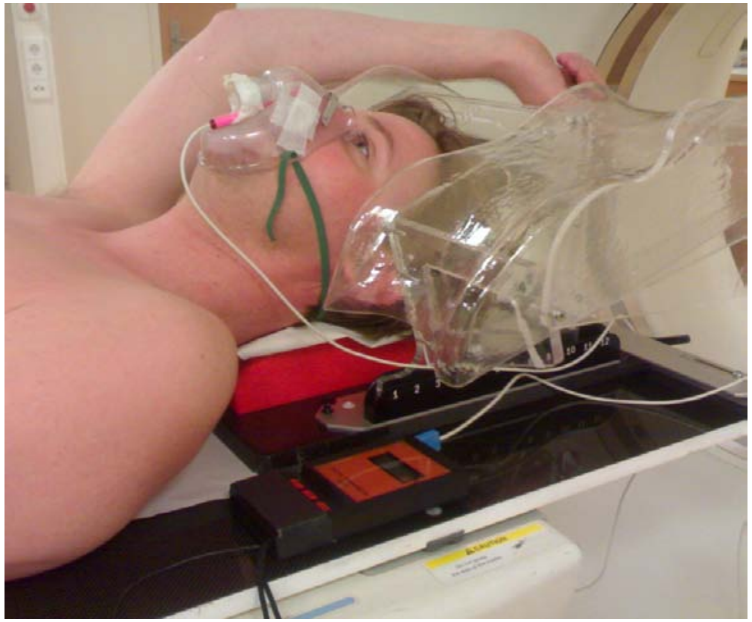
Example 1: Look for differences..





Example 2: Respiratory monitoring system





- 4D CBCT scans with and without oxygen mask
- 3D tumor motion was assessed for tumor mean position and amplitude

Respiratory monitoring system

With oxygen mask

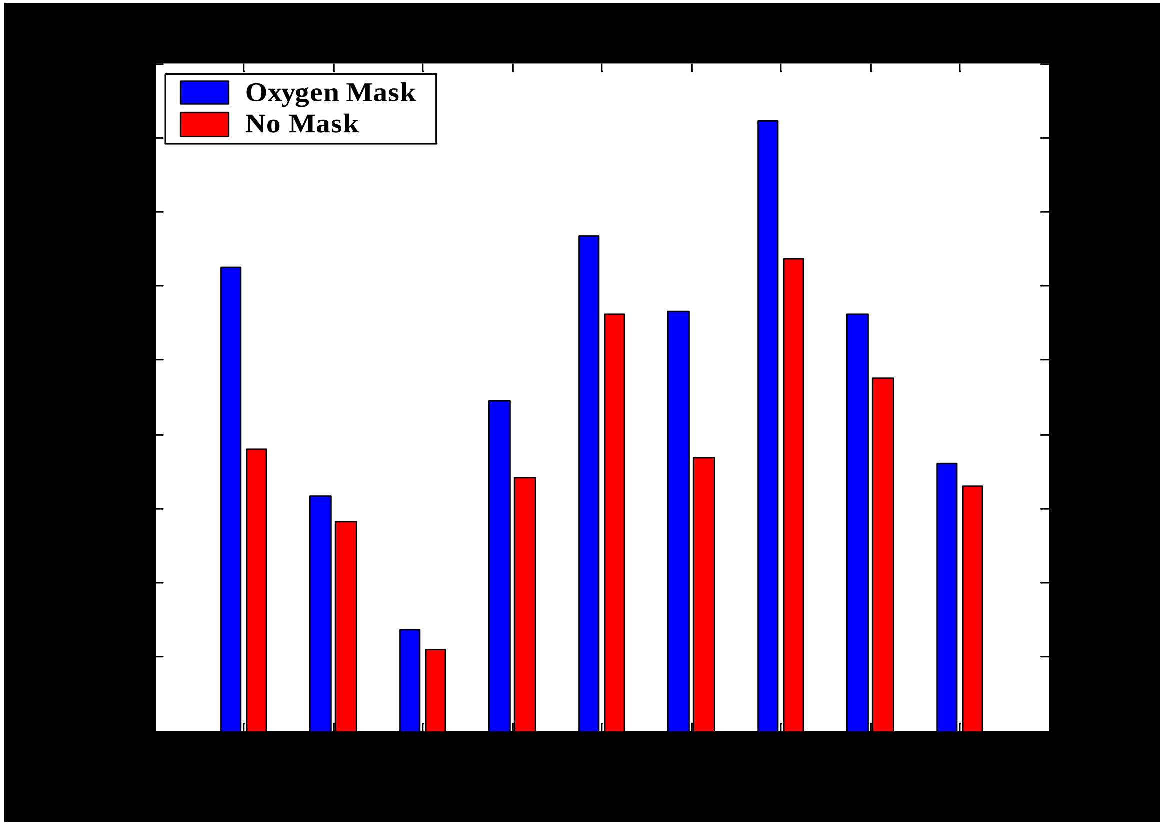
	LR (cm)	CC (cm)	AP (cm)
Σ	0.18	0.23	0.23
σ	0.16	0.19	0.19
Mean	0.06	0.03	0.00

Without oxygen mask

	LR (cm)	CC (cm)	AP (cm)
Σ	0.15	0.21	0.22
σ	0.18	0.17	0.20
Mean	0.04	0.08	-0.09

No significant difference in tumour mean position

Respiratory monitoring system

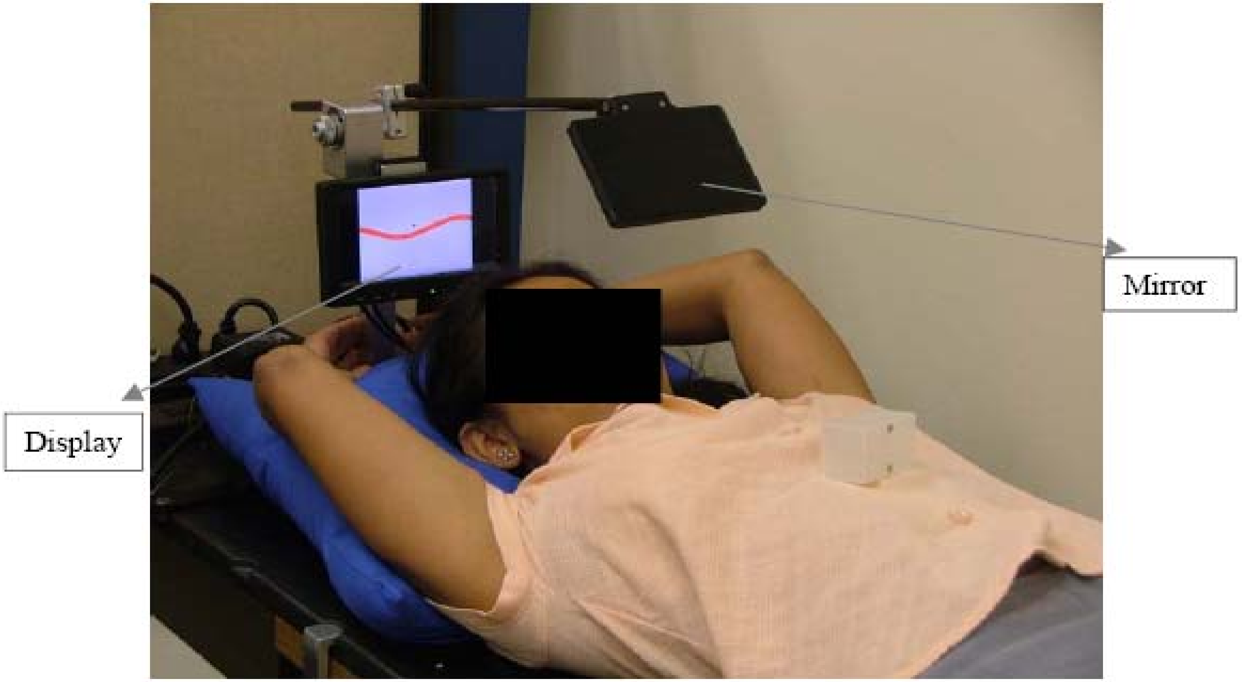


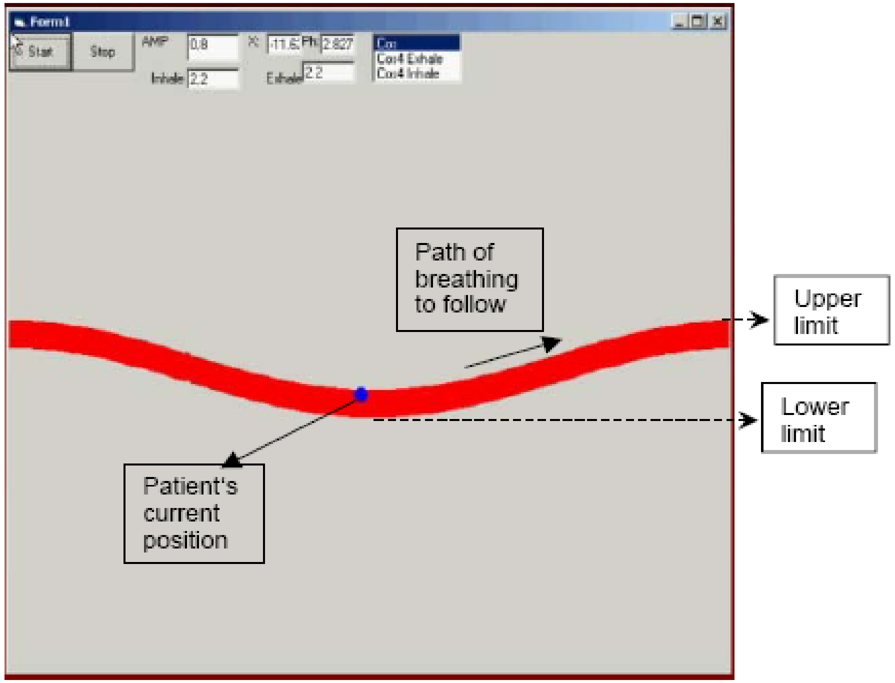
M = 29%, SD = 19%, p = 0.0017

Difference in breathing amplitude!

J. Wolthaus, M. Rossi

Respiratory monitoring system





R. George

Respiratory monitoring system

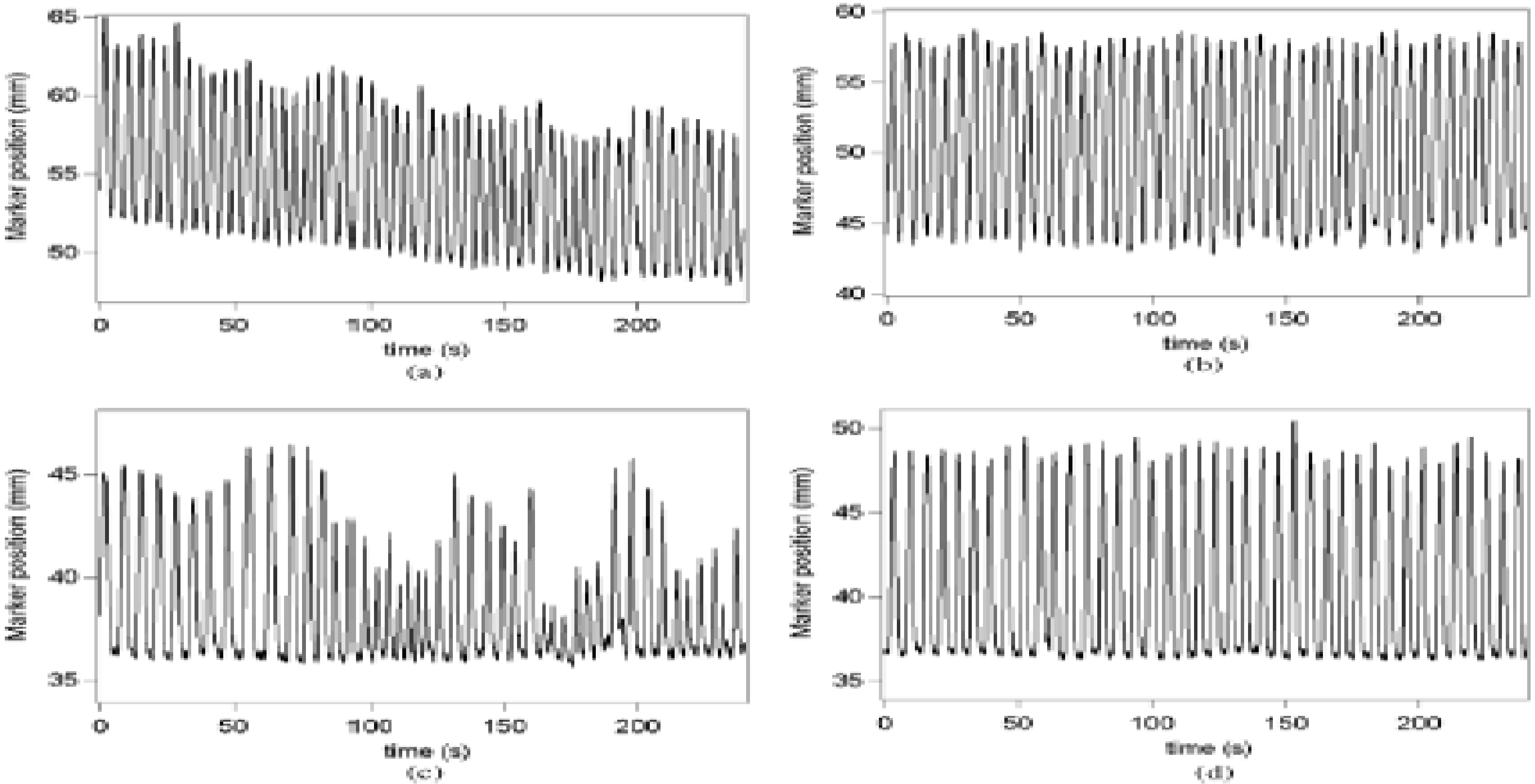


Figure 2. Example of time dependence of breathing trace acquired during free breathing (a) and (c) and audio–visual coaching (b) and (d). Data sets (a) and (b) belong to one volunteer while (c) and (d) belong to another. The free breathing data exhibit baseline shifts (a) and irregular breathing (c). Those problems were eliminated with breath coaching (b, d).

Neicu et al. 2006

Aim of Patient preparation and positioning

→ **<u>Minimize</u> the difference in patient during the treatment session: *intra*-fraction motion**

Tools:

Increasing patient compliance:

- Practical session SBRT

Immobilization and fixation:

- Lung using 4D CT.

Practical session

In case of hypofractioned RT:

- Patient visit the linac
- Session is completely performed but no Gray's are given

Advantages:

- Patient gets acquinted with workflow
- Set-up accuracy can be assesed:
  - ➢ is the intra# motion acceptable?
- Is it do able for the patient?
- Is the image quality sufficient?
- Precautions can be made:
  - ➢ Pain/stress relief
  - ➢ Additional margins/replanning

Stability with prolonged treatment time

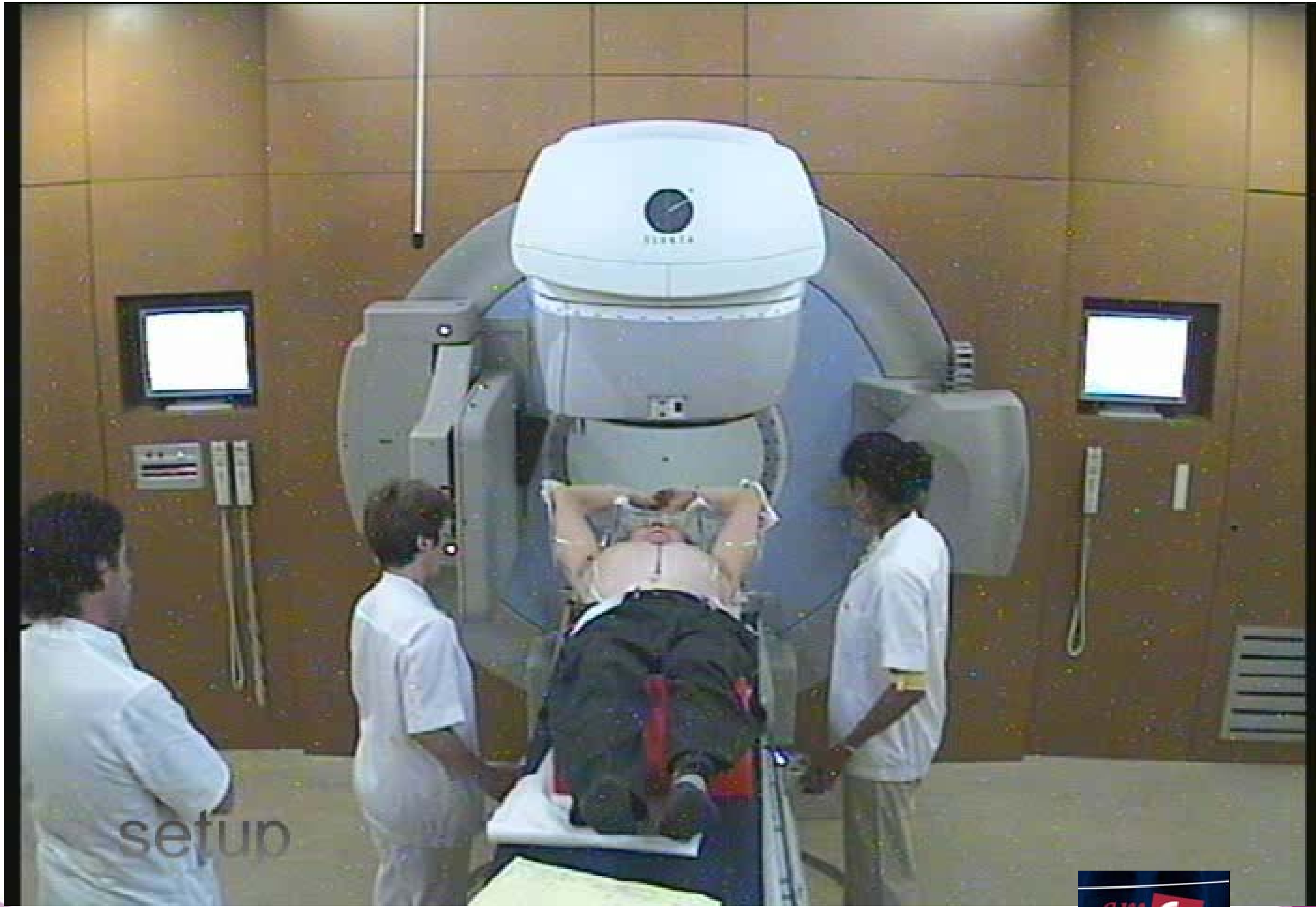
Hypo fractionated lung

On-line lung tumor match with CBCT: 3 x 18 Gy

(first protocol design without arc therapy and inline scanning)

Aligning the patient:	5 min
First CBCT scan:	4 min
Registration:	5 min
Manual table shift:	3 min
Second CBCT scan:	4 min
Evaluation CBCT scan:	1 min
Beam delivery:	25 min
Post treatment CBCT scan:	4 min

Stability with prolonged treatment time



Antoni van Leeuwenhoek Hospital

100x real speed

Stability with prolonged treatment time

Stability with prolonged treatment time

Antoni van Leeuwenhoek Hospital

Stability with prolonged treatment time

Stability with prolonged treatment time

59 Patients, 3 fractions per patient

		LR (mm)	CC (mm)	AP (mm)
Residual Inter-fraction	GM	0.2	0.6	-0.6
	Σ	0.8	0.8	1.0
	σ	1.1	1.1	1.4
Intra-fraction	**GM**	**0.0**	**1.0**	**-0.9**
	Σ	**1.2**	**1.3**	**1.9**
	σ	**1.2**	**1.4**	**1.7**

Minimize the difference in patient position

→ Minimize the difference in patient position

1. between simulation and treatment sessions
2. during the treatment session

→ **Maximize the distance between target volume and organs at risk**

Tools:

- **Immobilization and fixation**
- **Patient compliance**

Minimize the difference in patient position

→ **Maximize the distance between target volume and organs at risk**

Tools:

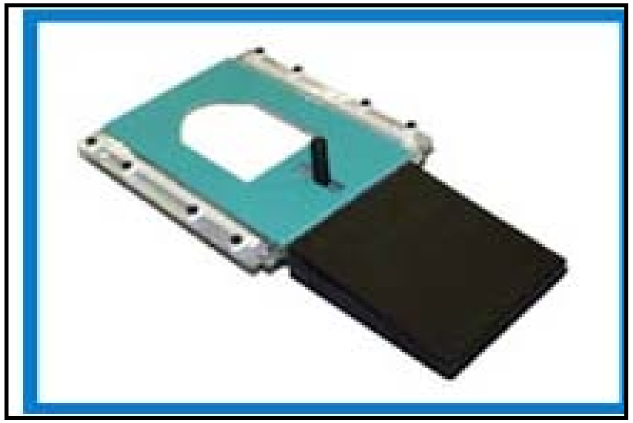
Immobilization and fixation:

- Bellyboard for pelvic patients

Patient compliance:

- Breath hold for breast patients

Belly board pelvic patients



Belly board

Belly board pelvic patients

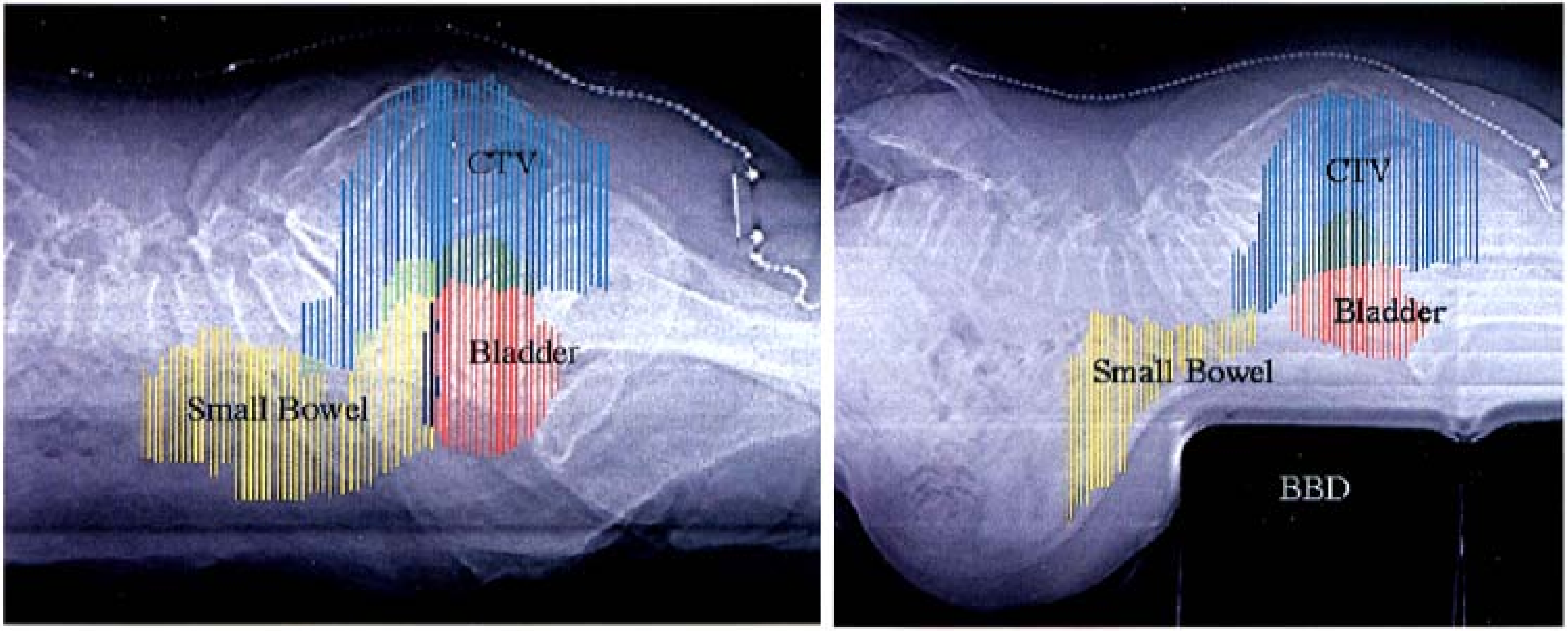
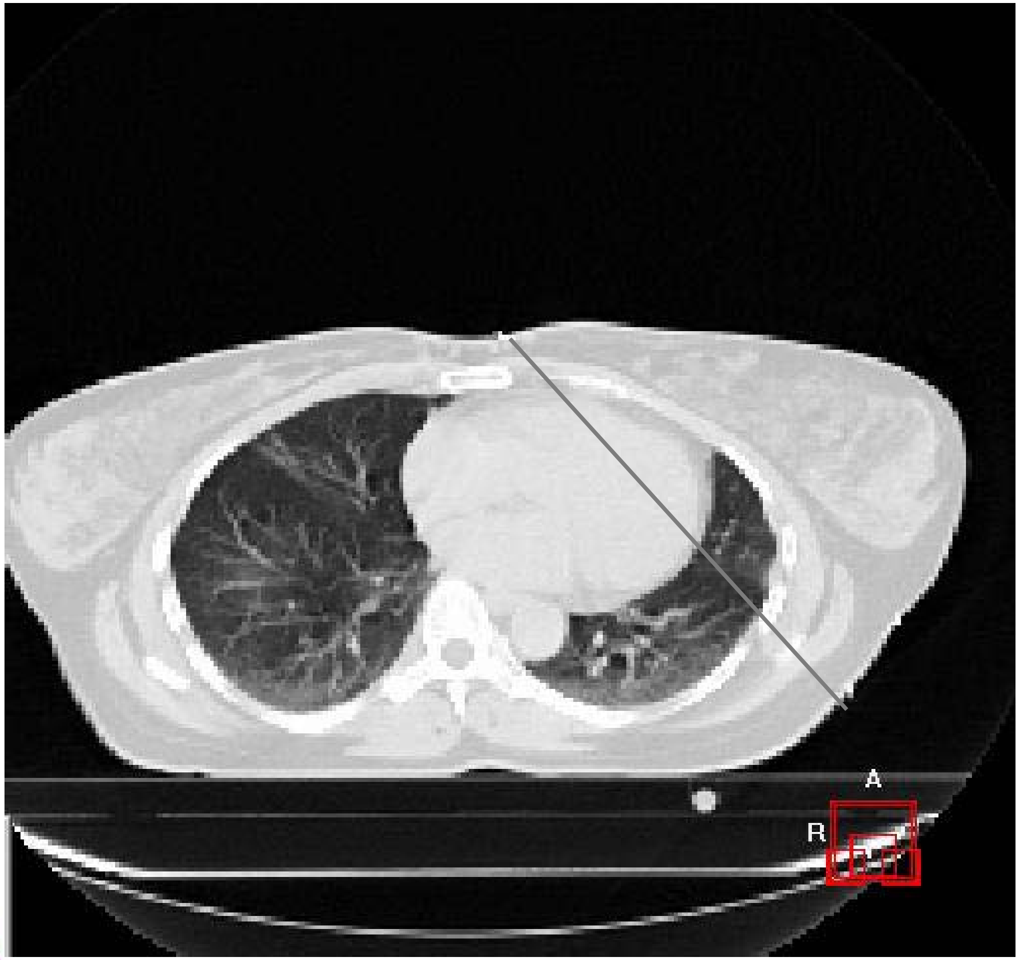


Fig. 2. Pilot localization, lateral view is shown (a) for simulation without BBD and (b) with BBD. The clinical target volume (CTV), small bowel, and bladder are shown. Note a dramatic shift in small bowel in the cephalic direction with the BBD.

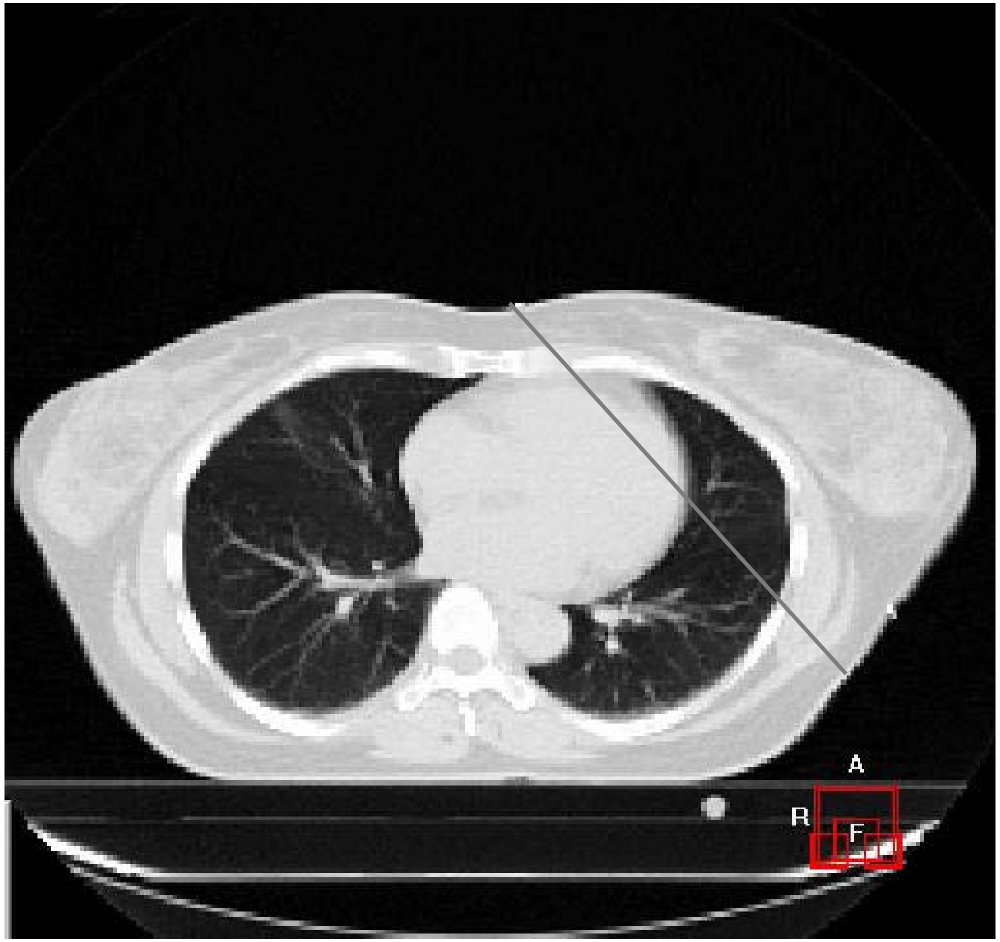
Das *et al*, 1997

Breath hold for breast patients

Normal inspiration

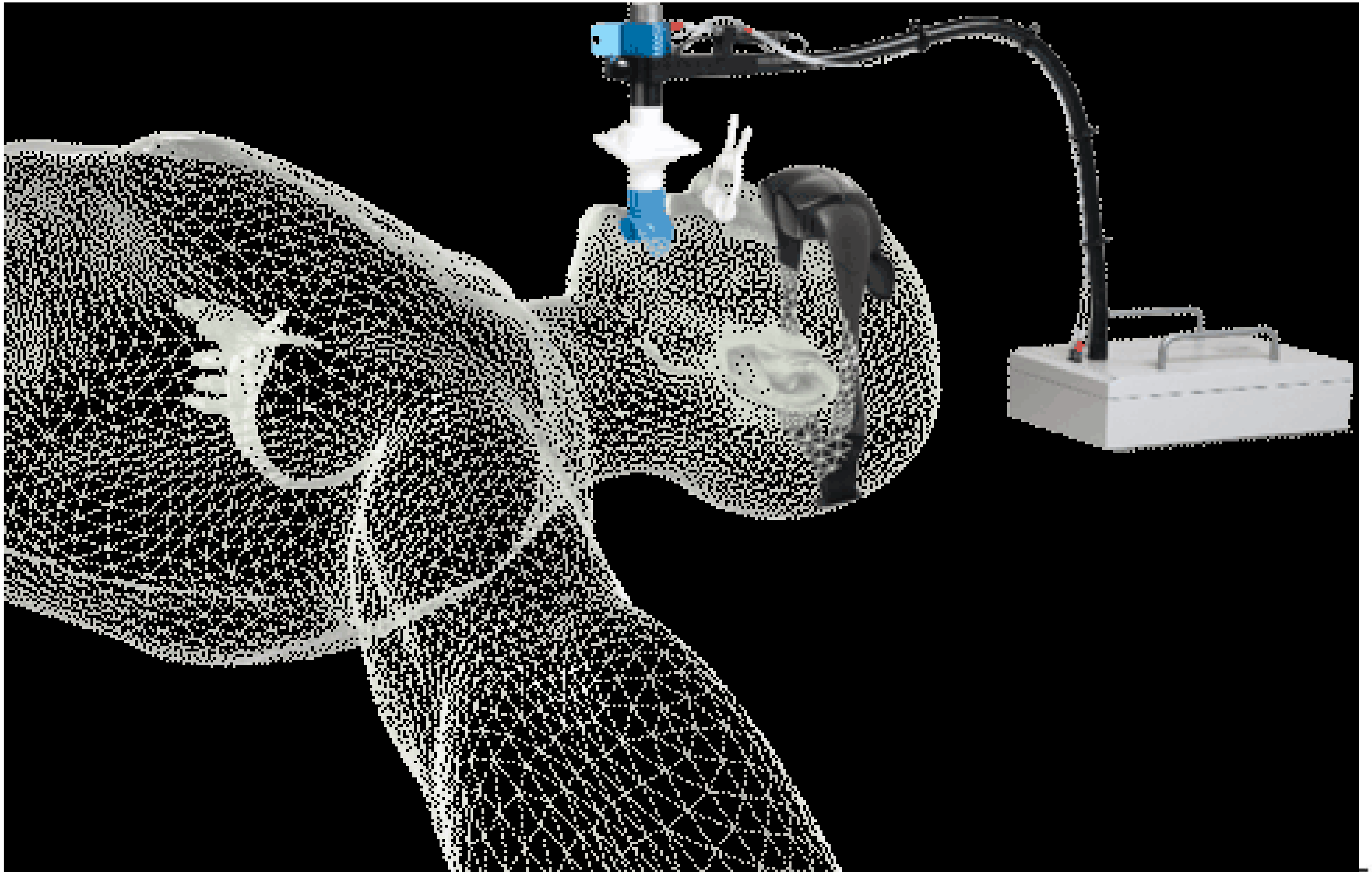


Deep inspiration



J. Sonke

Essential: education & compliance



Conclusion

The first step in radiation therapy is to <u>minimize</u>

- the difference in patients anatomy and set-up between CT en treatment
- the difference in patients anatomy and set-up between treatment days

and to <u>maximize</u>

- patient stability
- the distance between target volume and organs at risk

Conclusion

The first step in radiation therapy is to minimize

- the difference in patients anatomy and set-up between CT en treatment
- the difference in patients anatomy and set-up between treatment days

and to maximize

- patient stability
- the distance between target volume and organs at risk

IGRT & ART?

Rotations

Deformations

Offline protocol

OAR

Conclusion

https://espace.cern.ch/ULICE-results/Shared%20Documents/D.JRA_5.1_public.pdf

‘Recommendations for organ depending optimized fixation systems’

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Pre-treatment imaging

Mirjana Josipovic
Dept. of Radiation Oncology
Rigshospitalet
Copenhagen, Denmark

Advanced skills in modern radiotherapy
June 2015

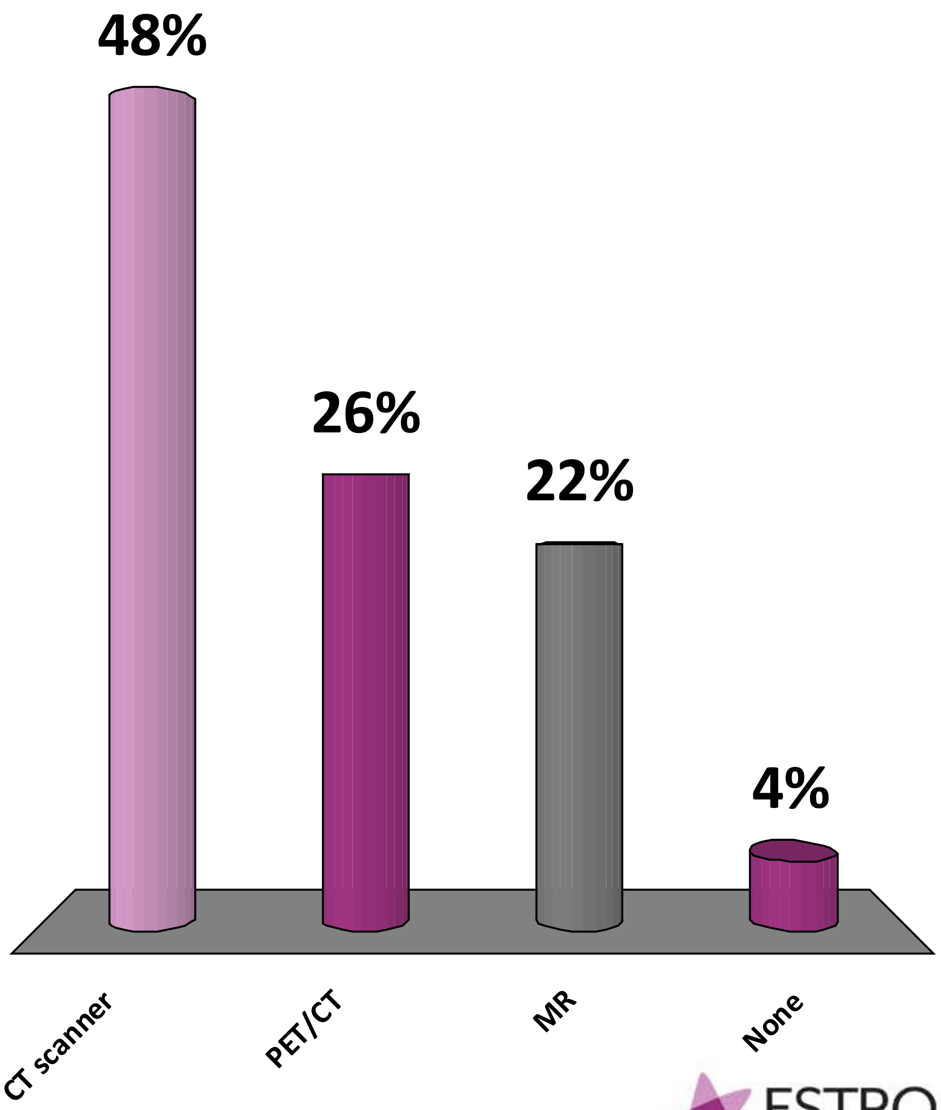
Imaging for radiotherapy planning

- CT: computed tomography
- PET: positron emission tomography
- MR: magnetic resonance

Do you have experience with

A. CT scanner
B. PET/CT
C. MR
D. None

Multiple answers possible!



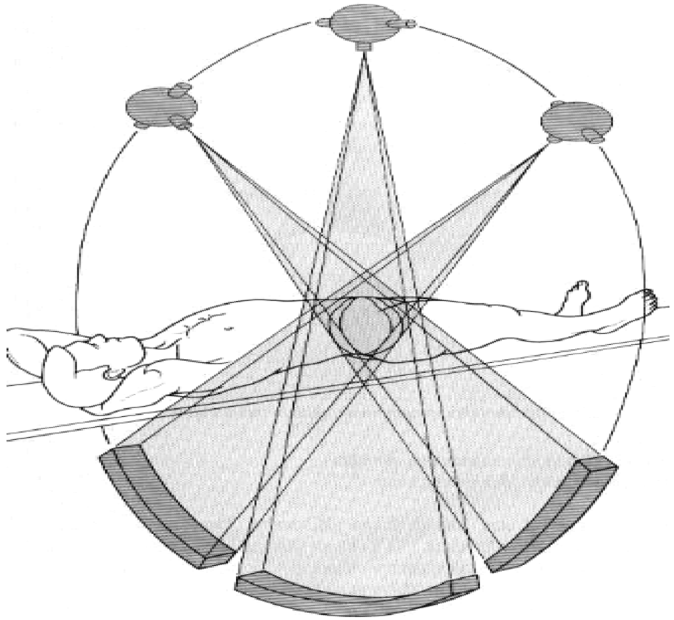
What is a CT scanner

Gantry

Couch

X-ray tube

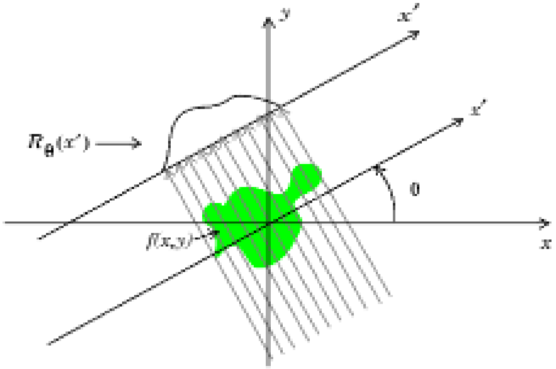
Detectors



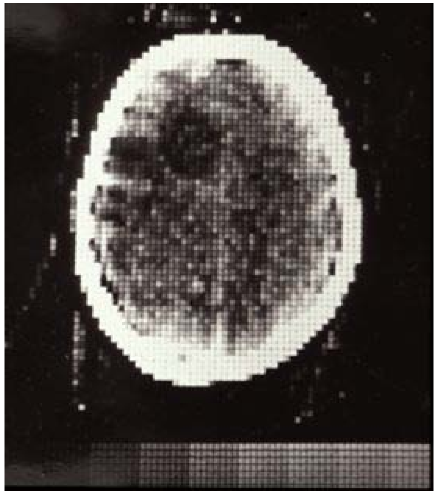
- X-ray tube rotates around the longitudinal axis in the gantry
- Simultaneous data collection from a detector, centred in the x-ray tube's focus point
- It takes a 360° for en complete data collection

Chronology

- 1917 mathematical grounds for CT reconstruction



- 1971 first clinical CT
- 1991 dual slice
- 2003 32-slice
- Today volume-scanning
  dual source, dual energy



80x80 matrix
5 min rotation time

1024x1024 matrix
< 0.3 s rotation time

Data collection

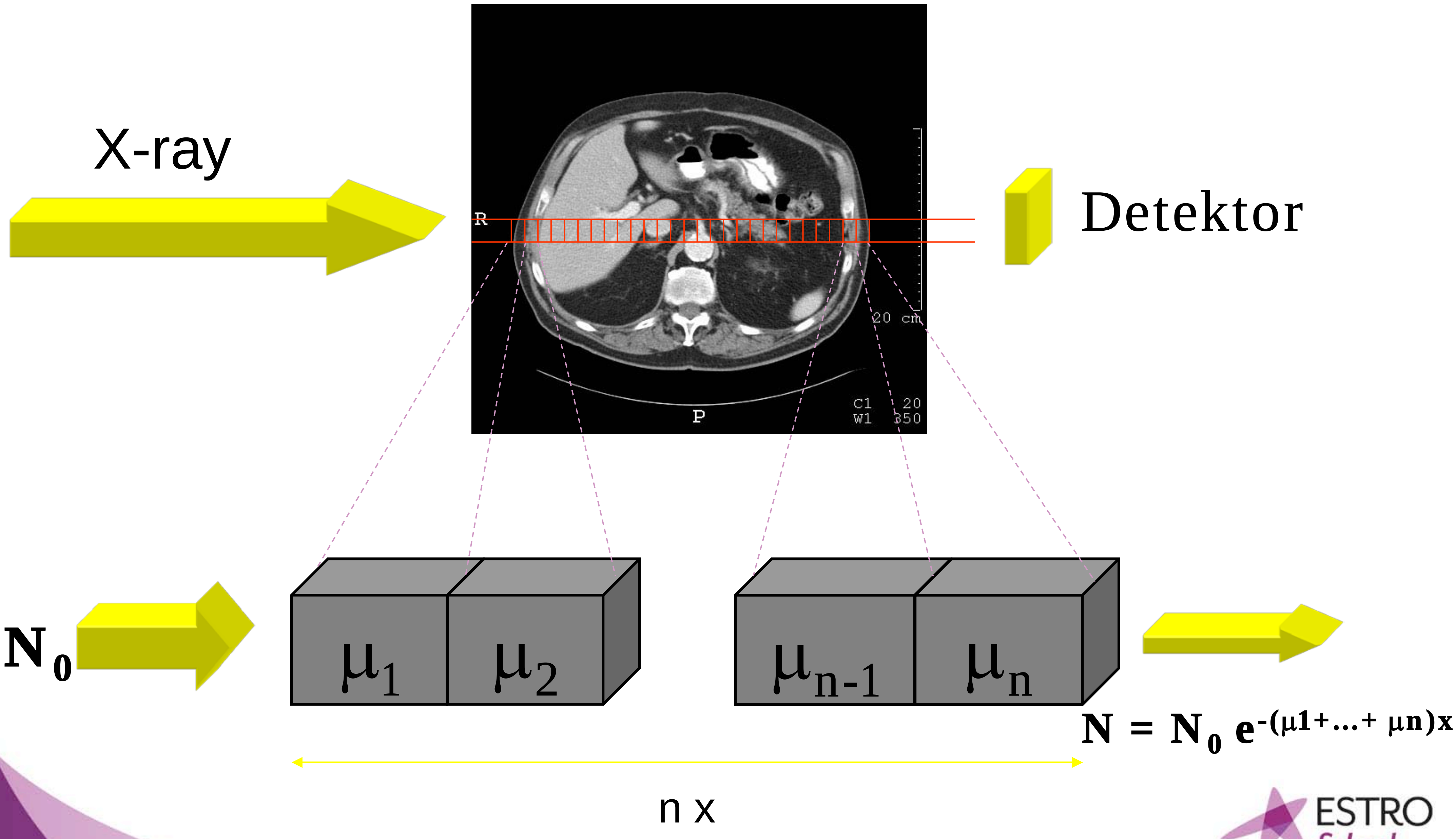
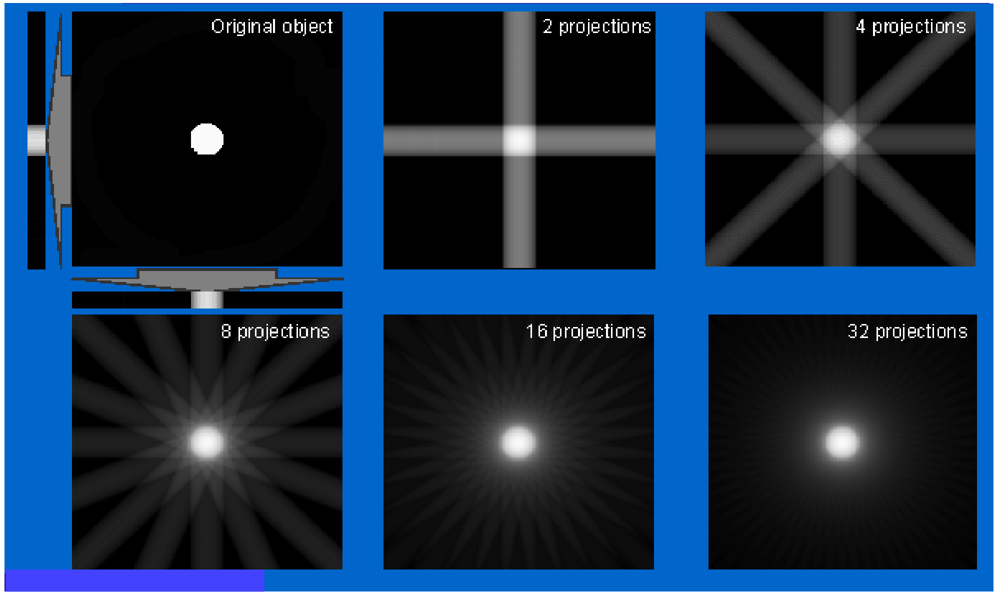


Image reconstruction

Back projection:

Reconstruction of the image from its projections



Filtered back projection:
Projections are filtered prior to the reconstruction

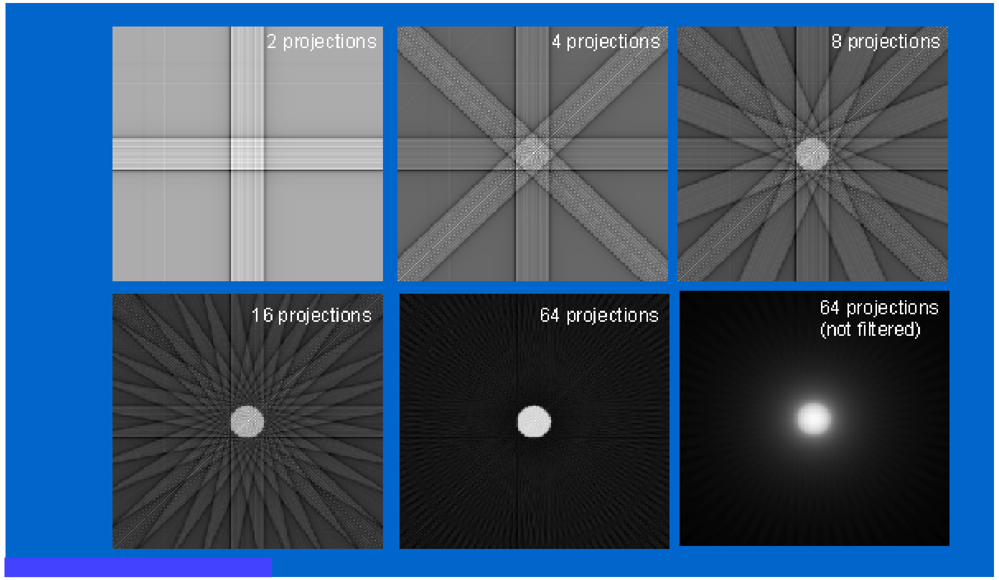


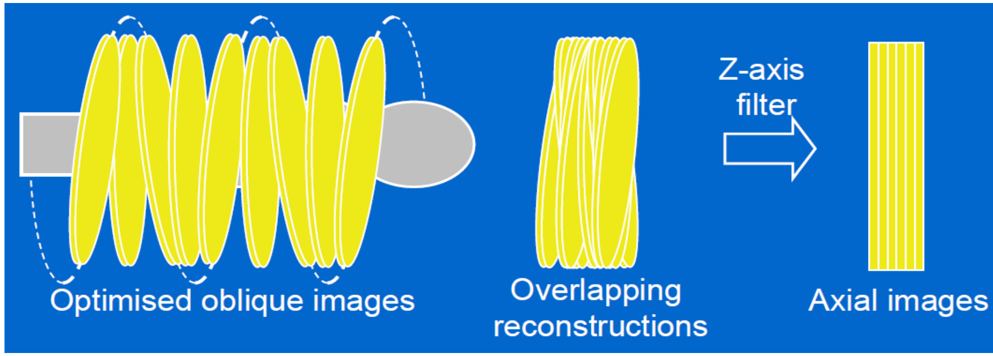
Image reconstruction

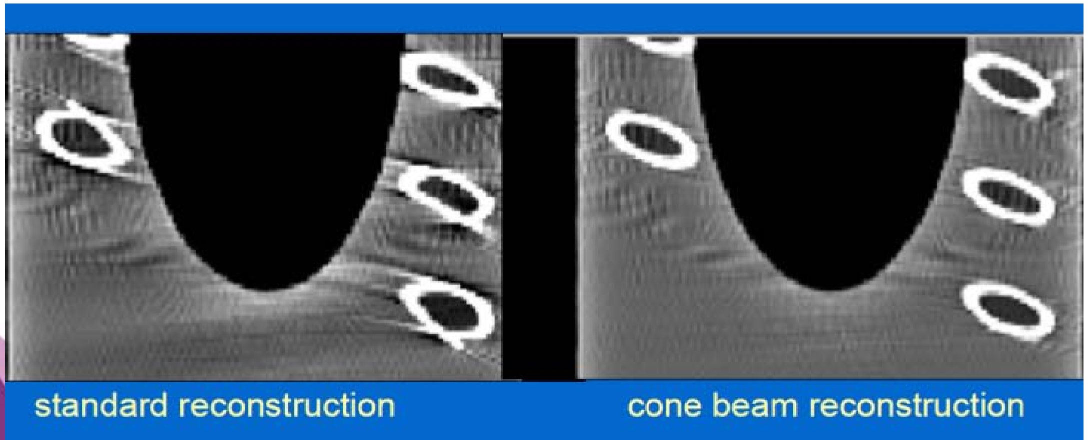
Advanced algorithms – necessity when beam is diverging, especially at the “edge” slices

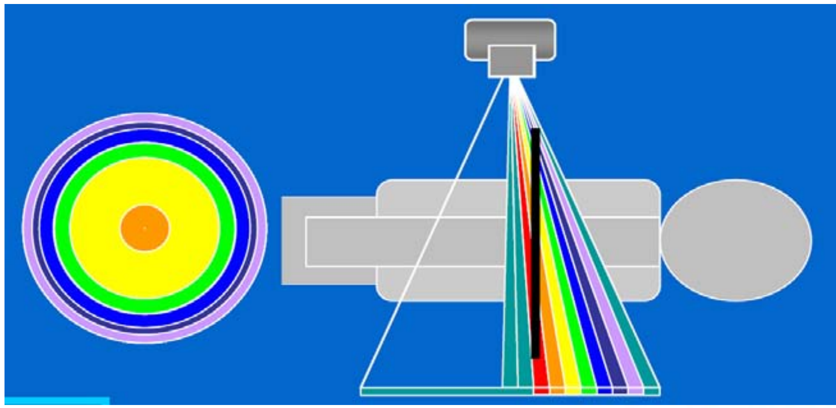
(back projection assumes non-diverging beam)

- Back projection in oblique planes

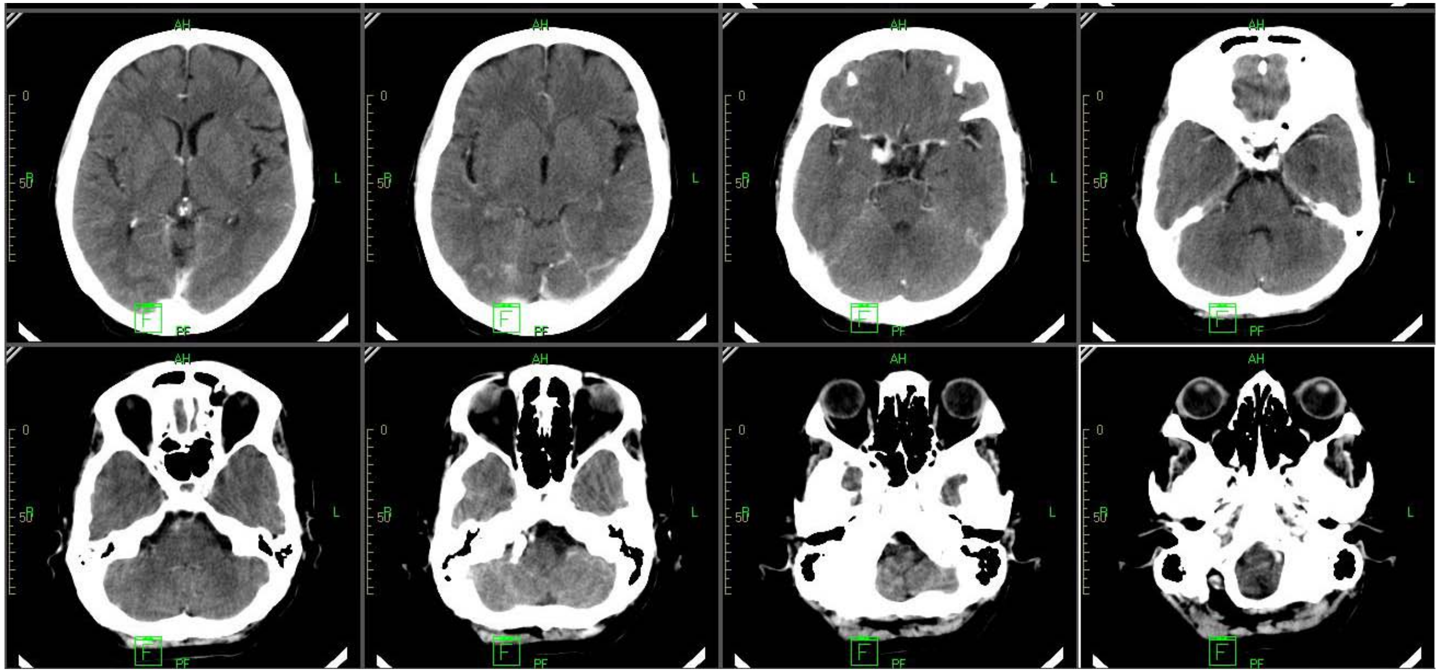
  re-filtering

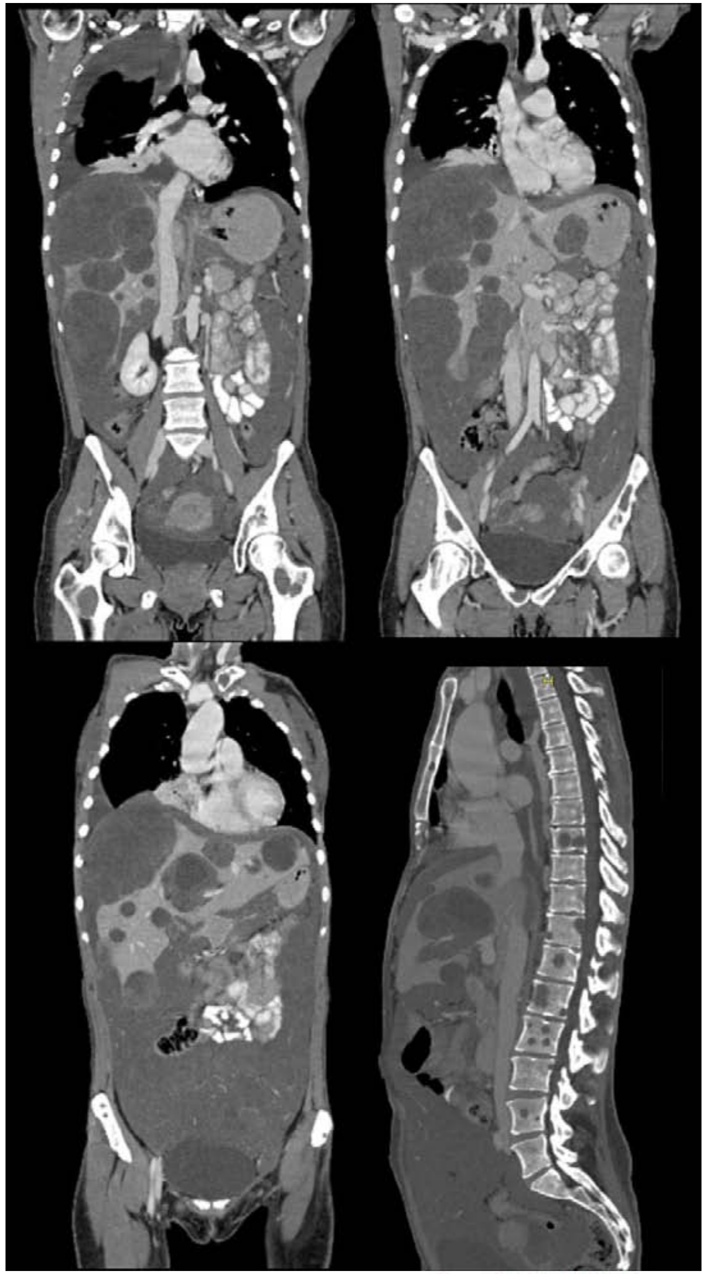






CT images

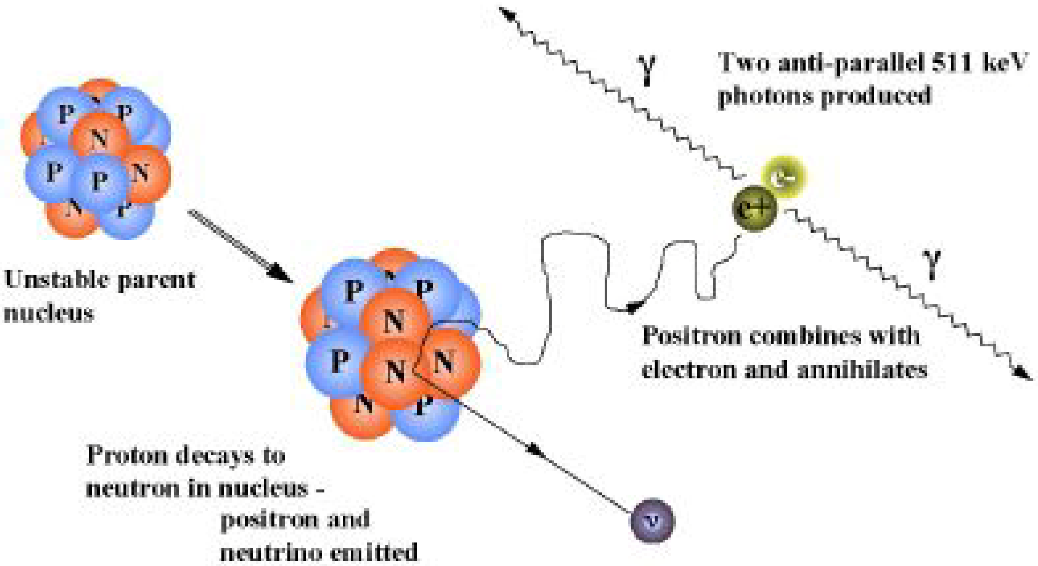


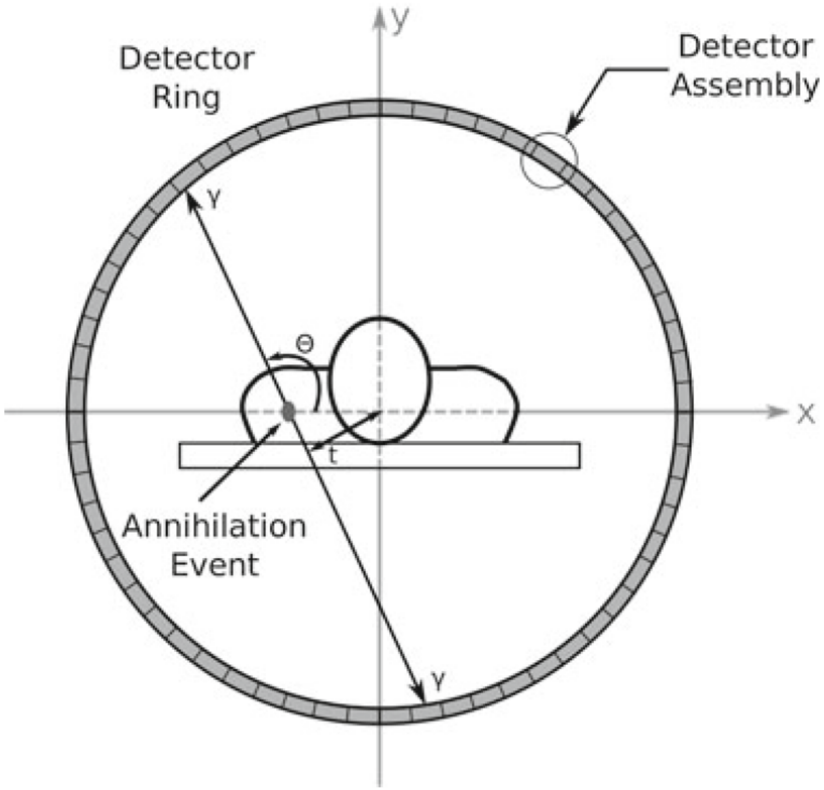


PET = Positron Emission Tomography

Radioactive tracers

- [^{18}F]FDG – FluoroDeoxyGlucose, with positron emitting fluorine 18





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SUV = Standard Uptake Value

- a semiquantitative metric

- $$\text{SUV} = \frac{\text{tissue radioactivity concentration}}{\text{injected activity / body weight}}$$

BUT…

- SUV depends on tumour metabolism, time after injection, plasma glucose, body composition…
- in small tumours the true activity is underestimated
- tumours are heterogeneous

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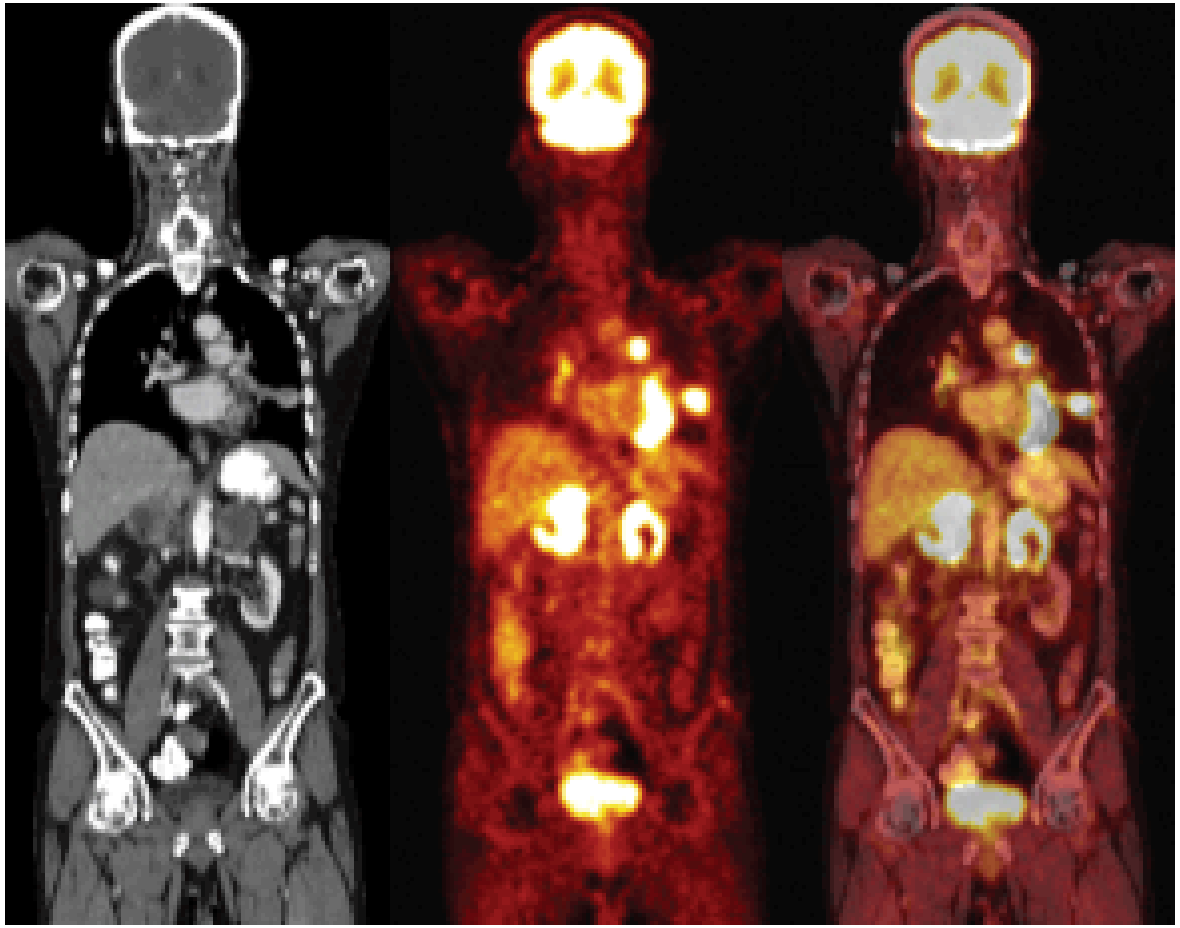
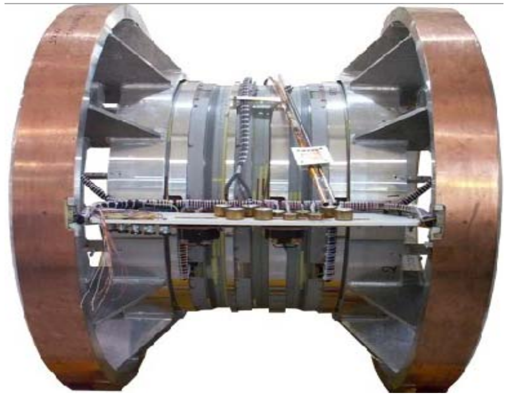
PET/CT images



What is a MR scanner

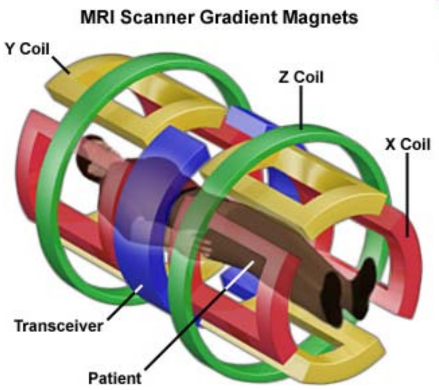
- Magnet



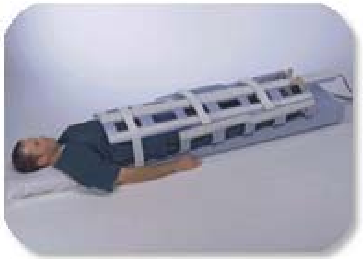
MR = magnetic resonance

NO ionising RADIATION!

- Gradients



- Coils



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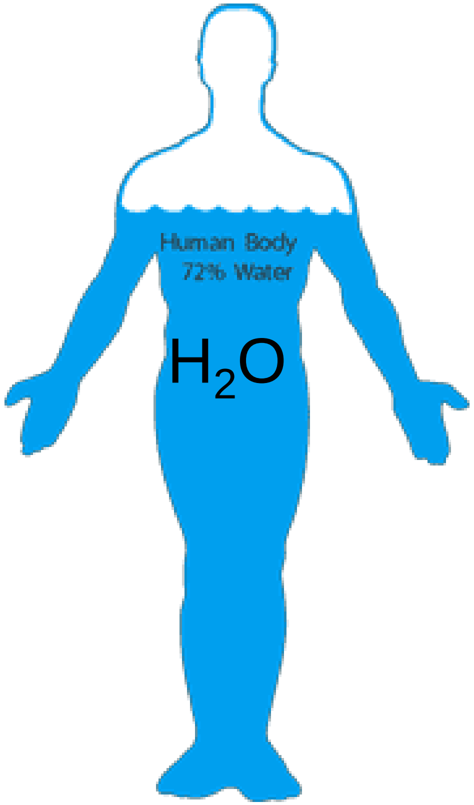
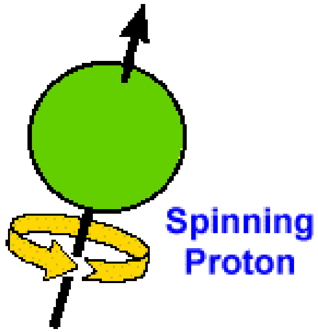
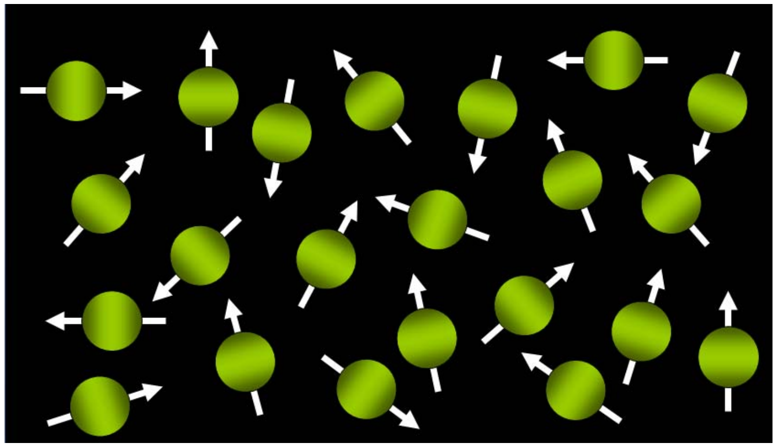
(some) MR basics



Hydrogen = proton





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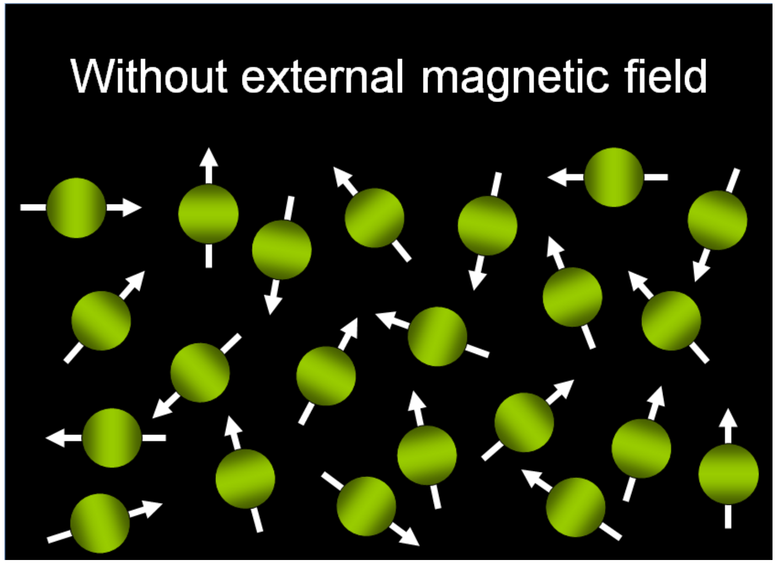
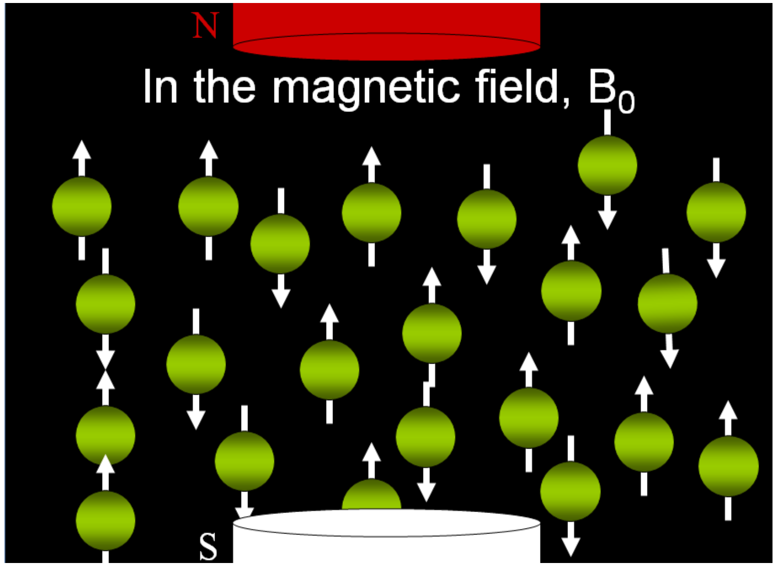
(some) MR basics

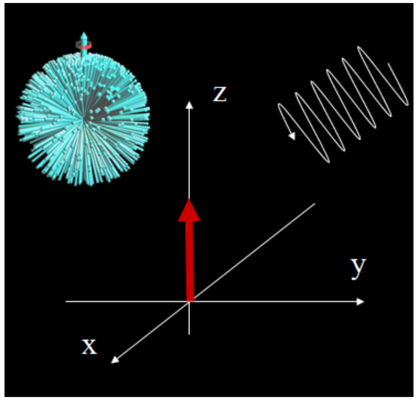


Net magnetisation = 0

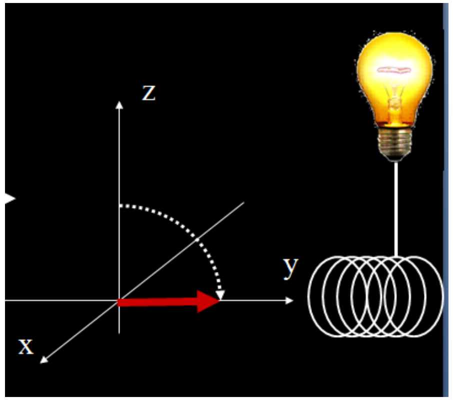


Net magnetisation ≠ 0

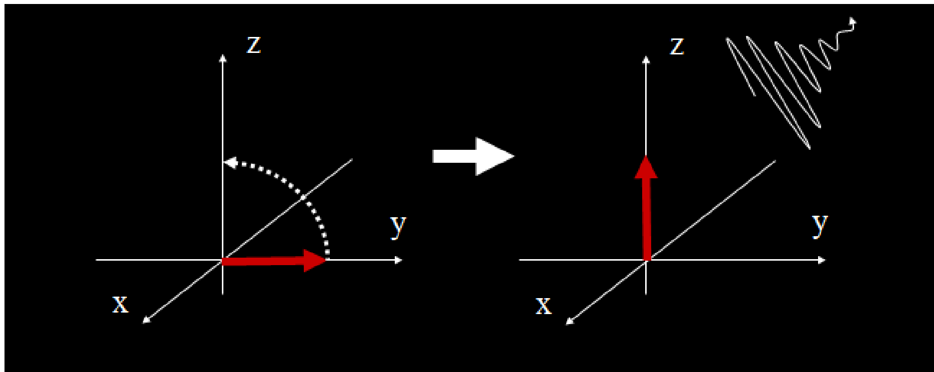
(some) MR basics

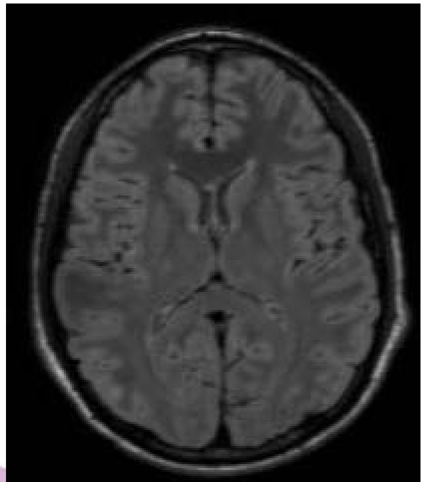


radiofrequency
waves ON



radiofrequency
waves OFF

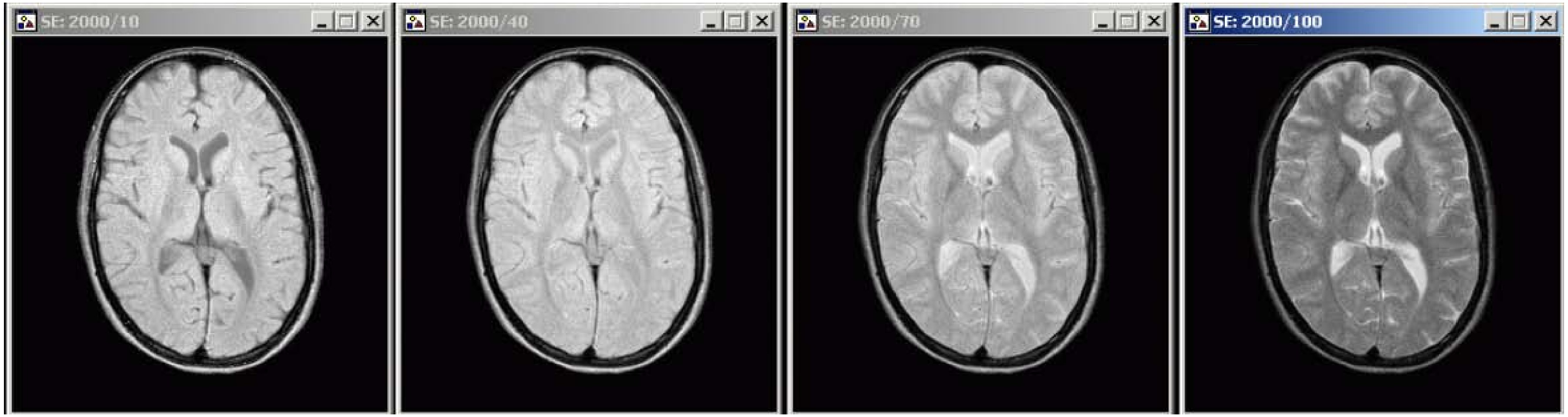




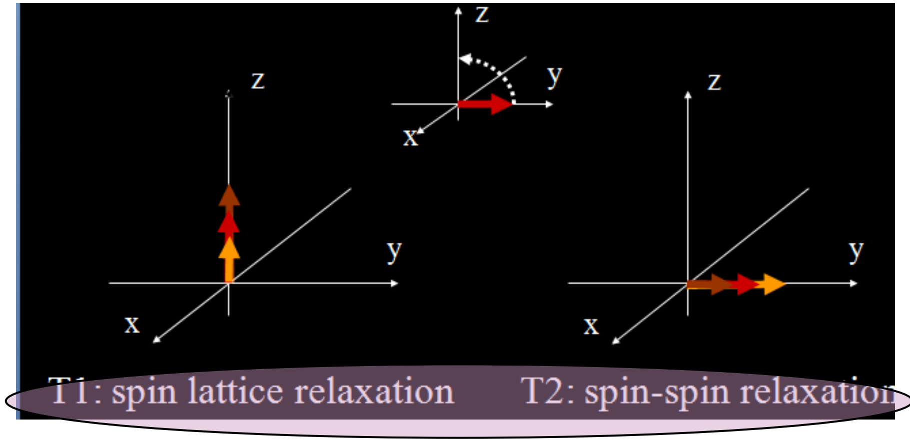
MR signal manipulation

aka the MR times…

- TR – Repetitiontime
  - ➢ The time between the successive RF pulses
- TE – Eccotime
  - ➢ The time after the RF puls, when the signal is captured



MR signal manipulation

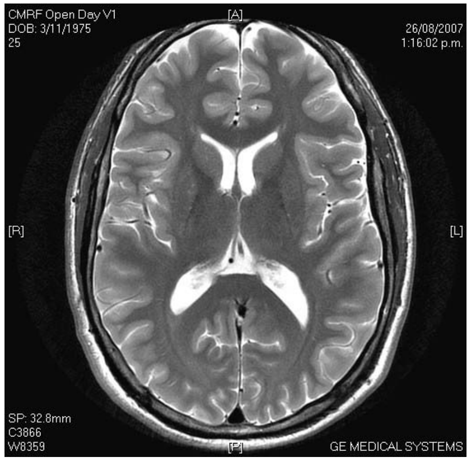


aka the MR times...

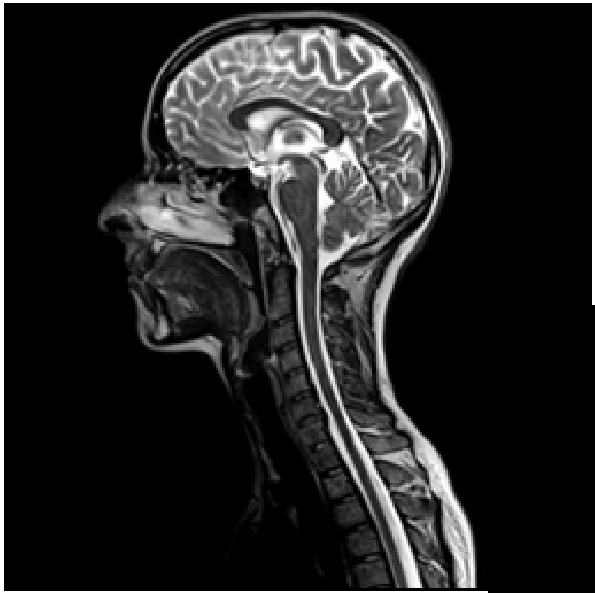
- T1
  - Short TR and short TE
- T2
  - Long TR and long TE

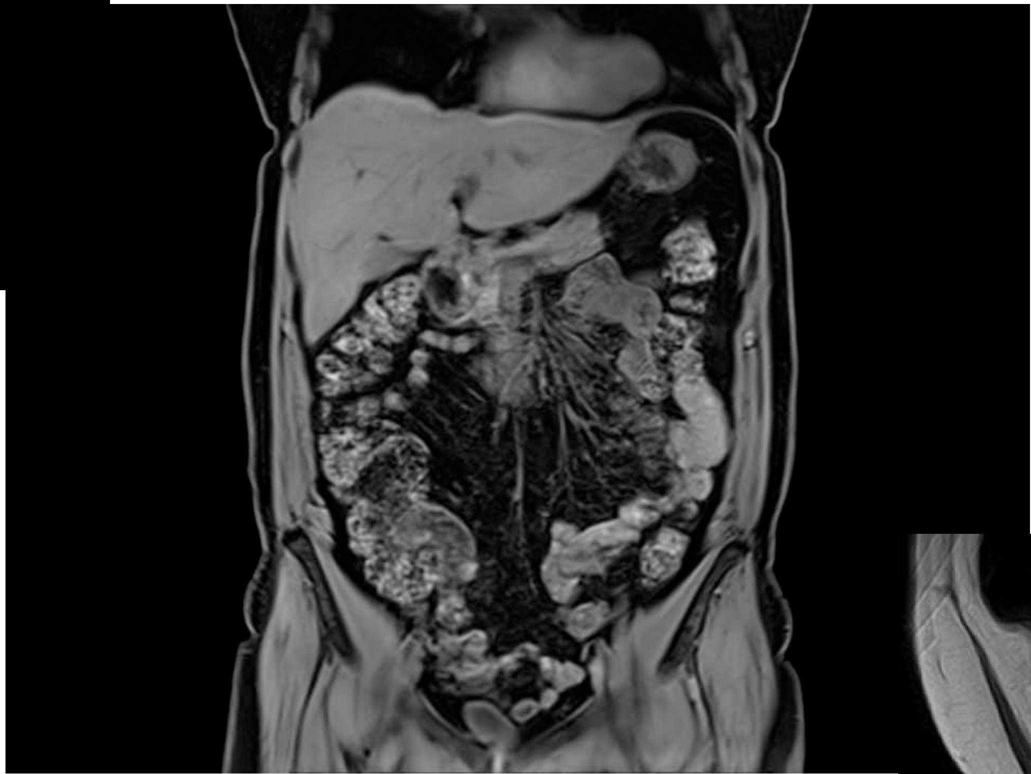
T1

T2

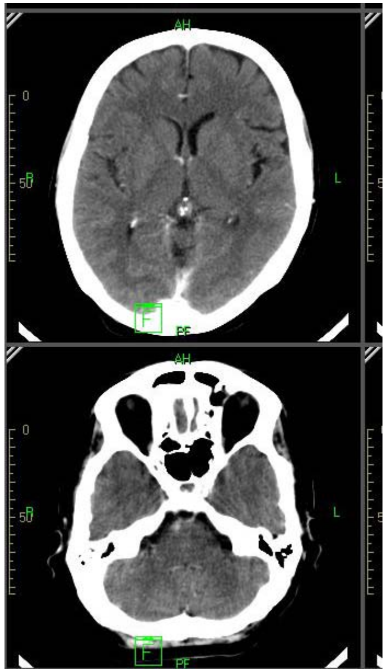


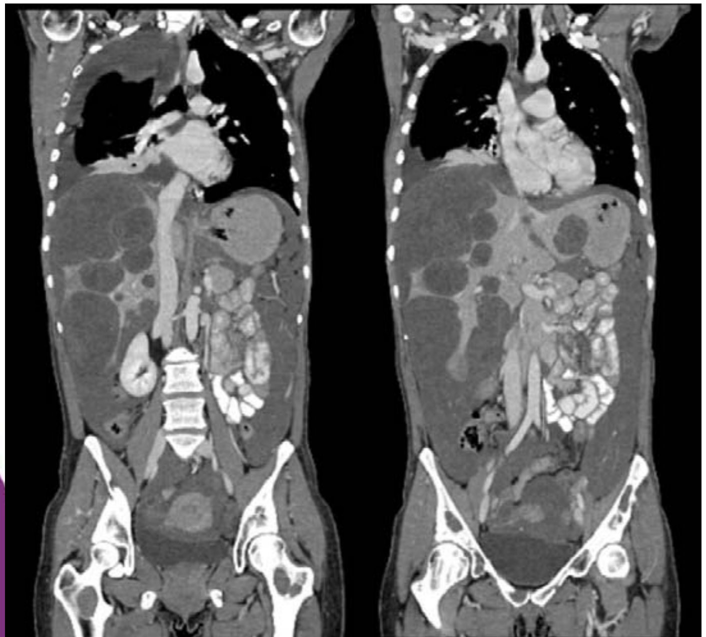
MR images

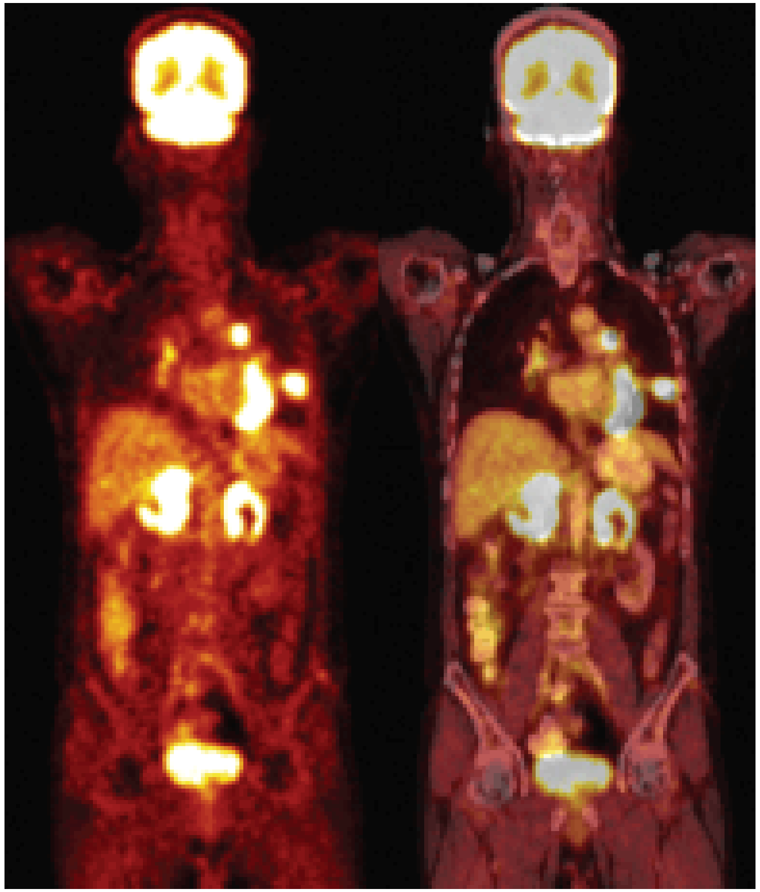


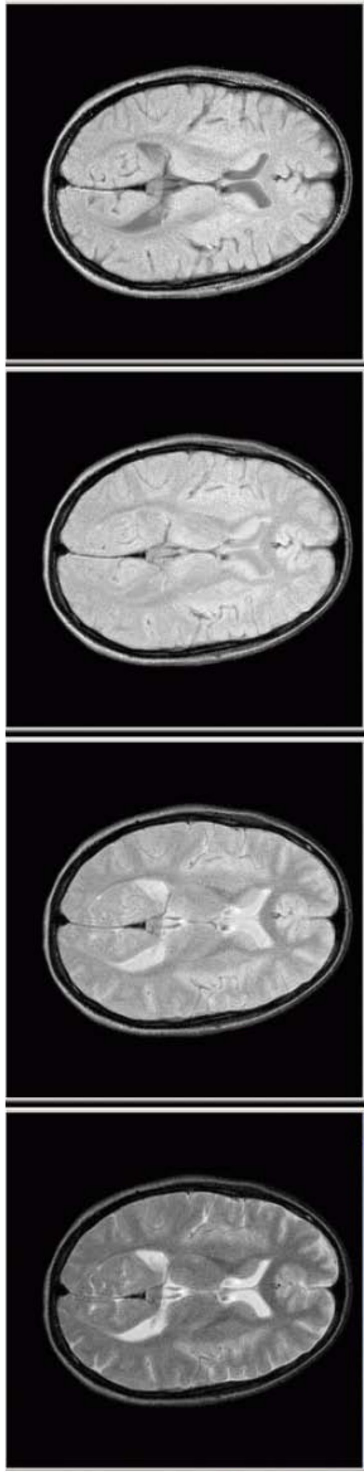


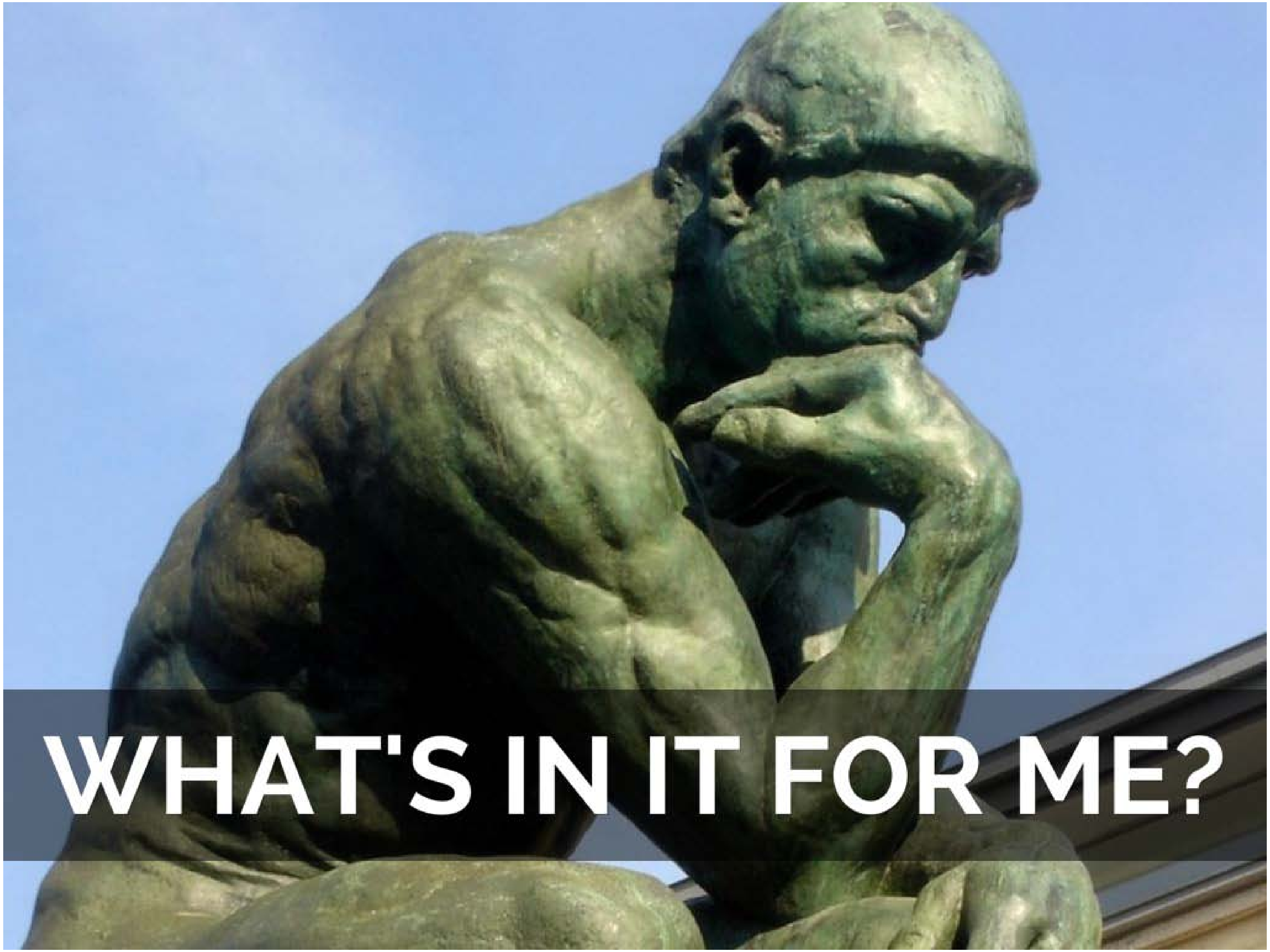
CT vs. PT vs. MR





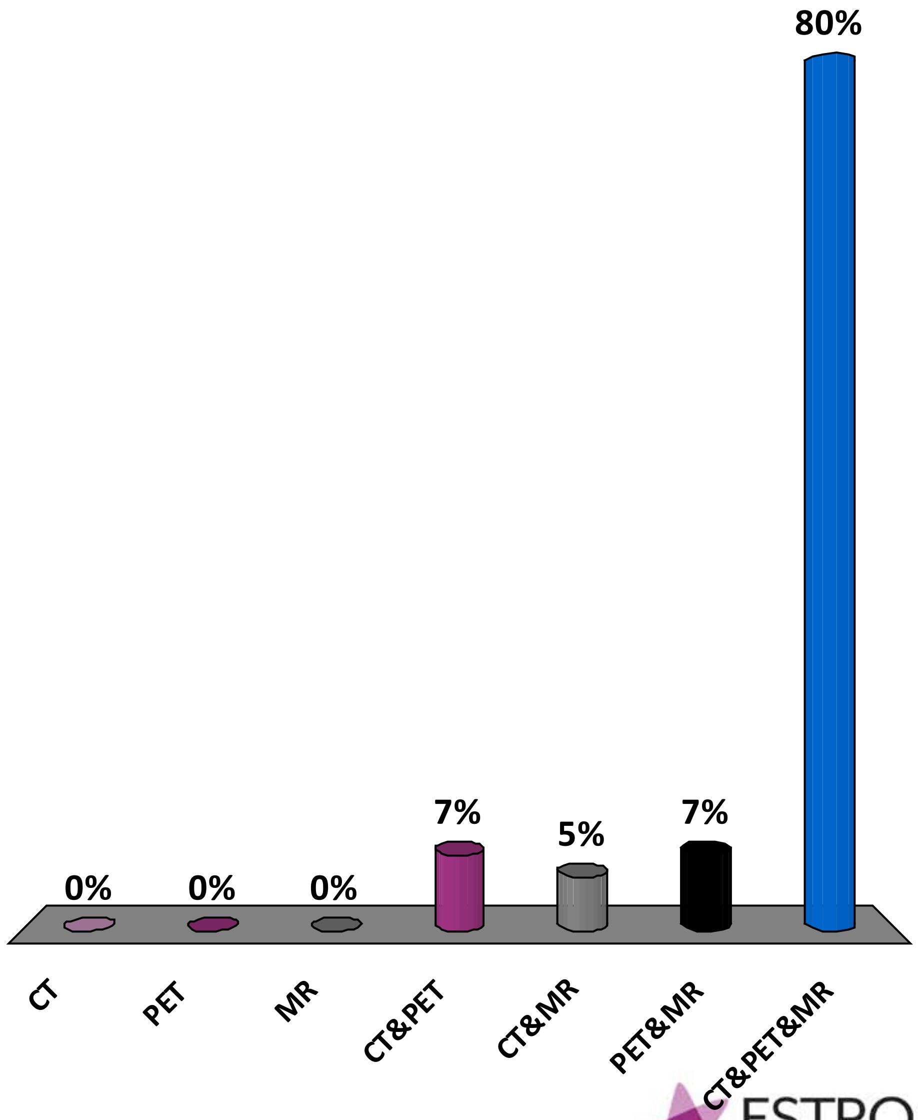





WHAT'S IN IT FOR ME?

Which imaging modalities do we need for modern state of the art radiotherapy?

A. CT
B. PET
C. MR
D. CT&PET
E. CT&MR
F. PET&MR
G. CT&PET&MR



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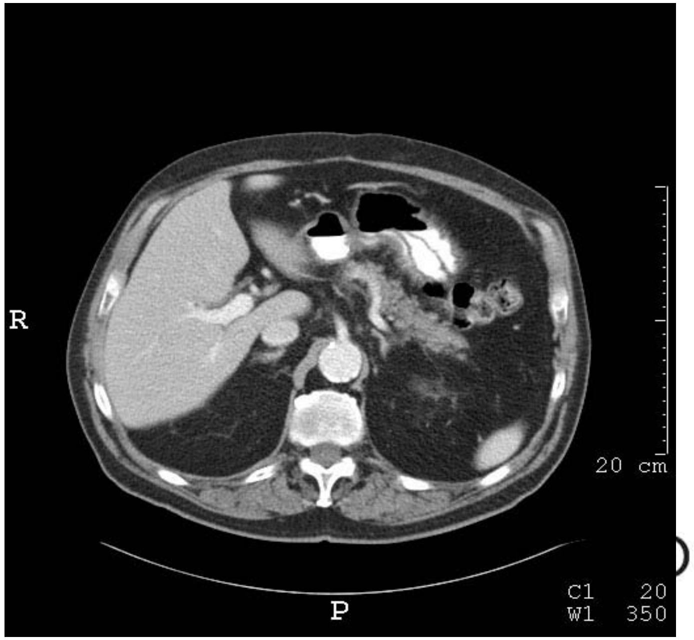
CT numbers = Hounsfield units

The grey tones on the CT image represent the attenuation in every pixel/voxel

The grey tones are expressed in Hounsfield units (HU)

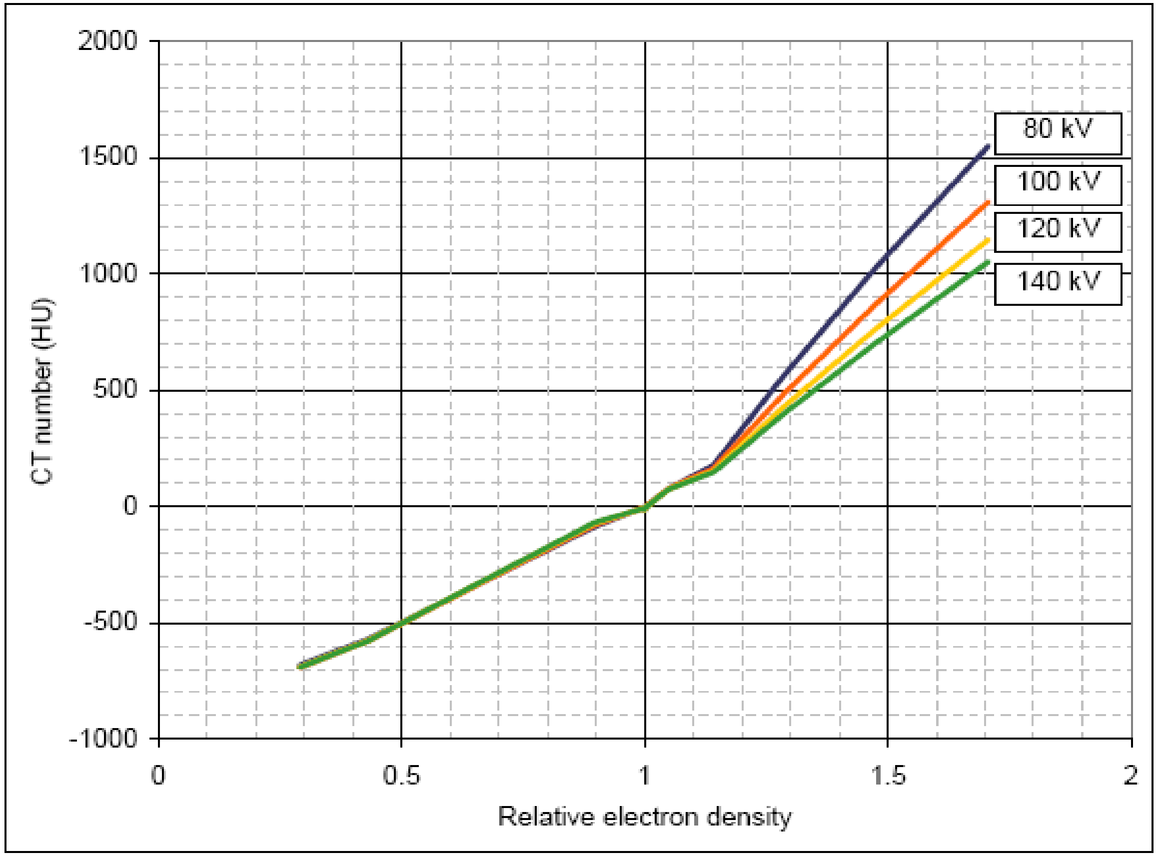
– CT numbers:

$$HU = \frac{\mu_{obj} - \mu_{water}}{\mu_{water}} \times 1000$$



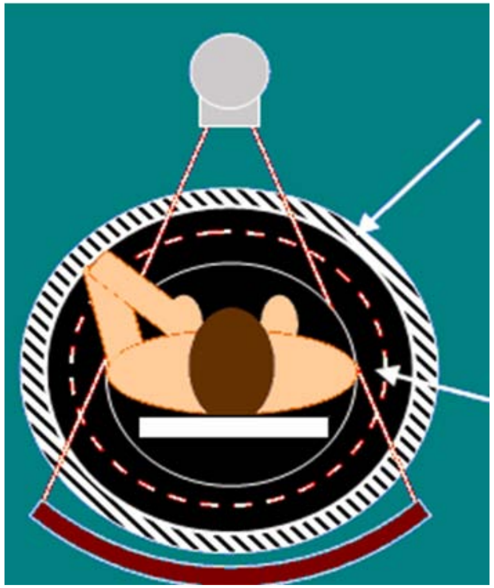
Hounsfield units → electron density

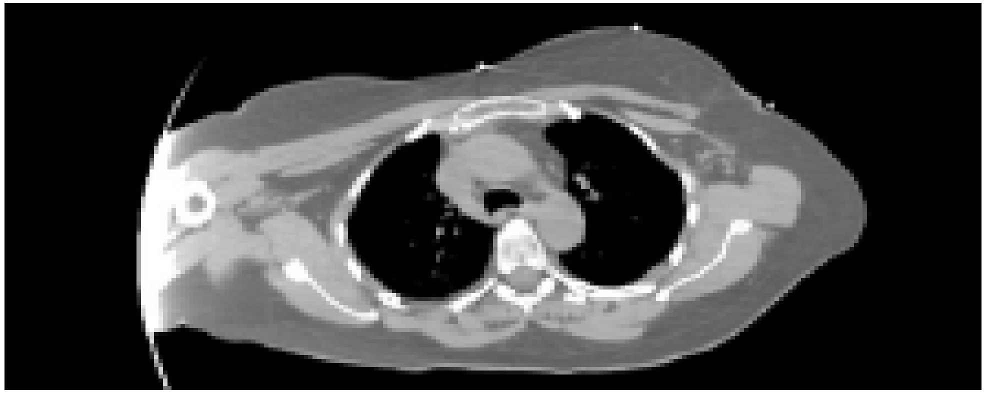
Figure 4. CT number against electron density at a range of kVs



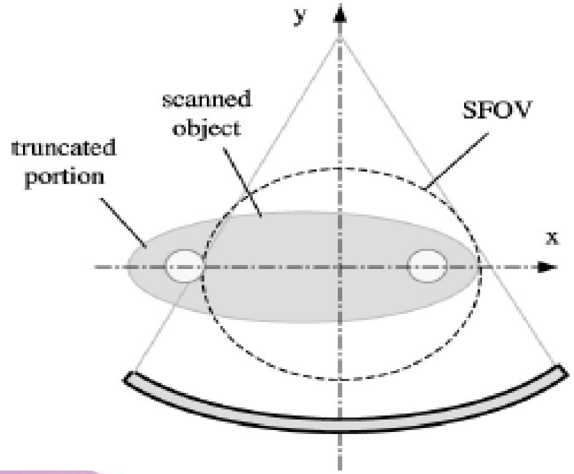
Enables dose calculation!

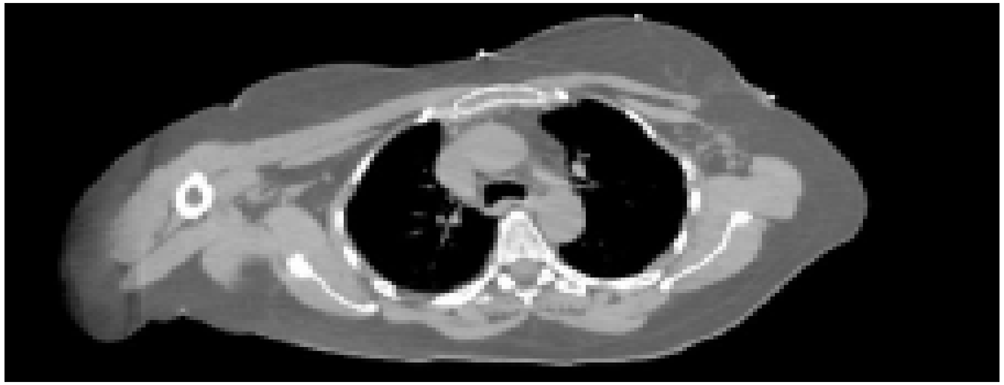
Challenges….





Scanned field of view





Reconstructed field of view

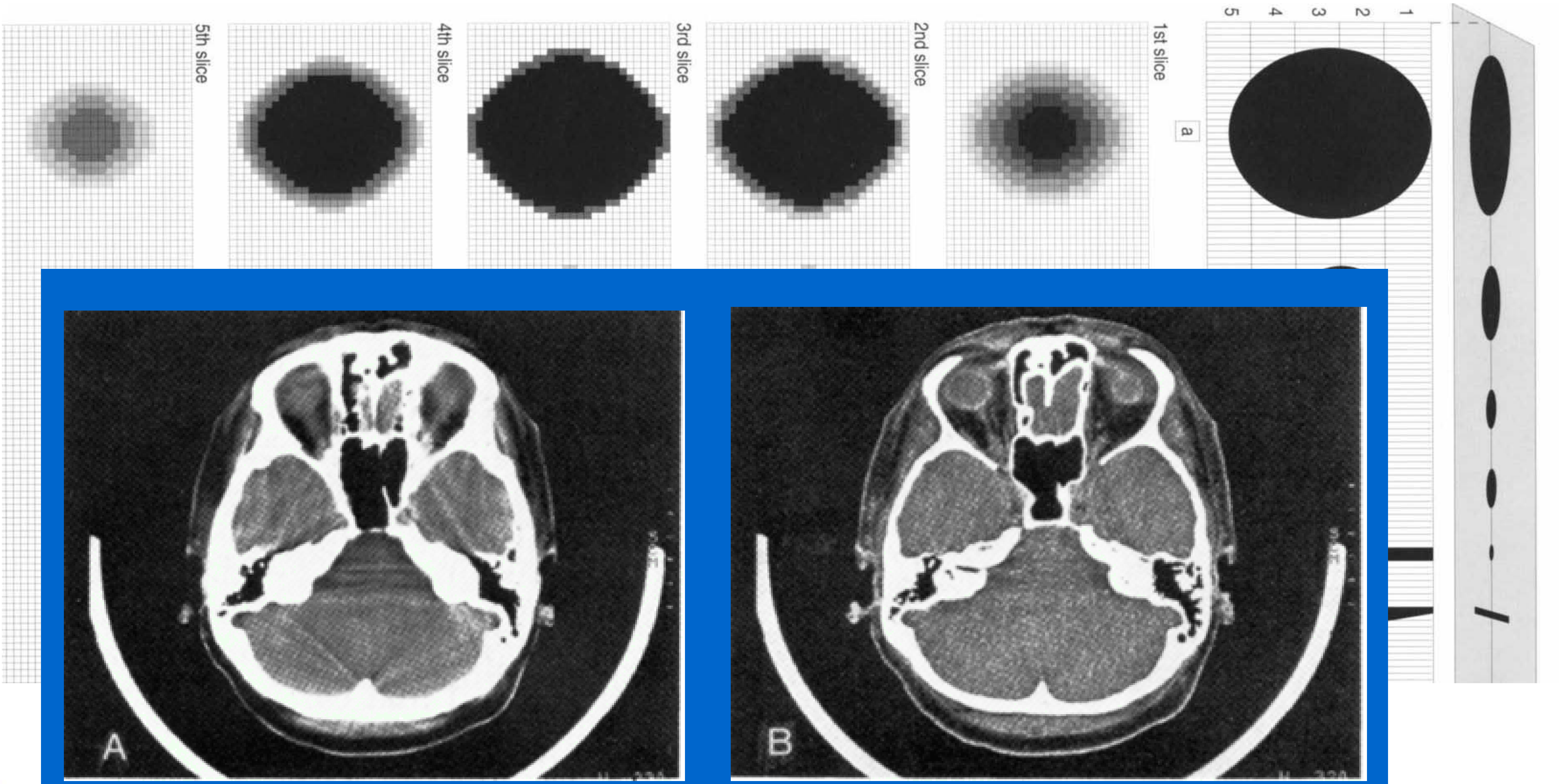
Image artefacts

Definition :

Systematic deviation between the HU in the reconstructed image and the objects correct attenuation’s coefficient

- **Partial volume artefacts**
- **Streak artefacts**
- Ring artefacts
- Motion artefacts
- Noise

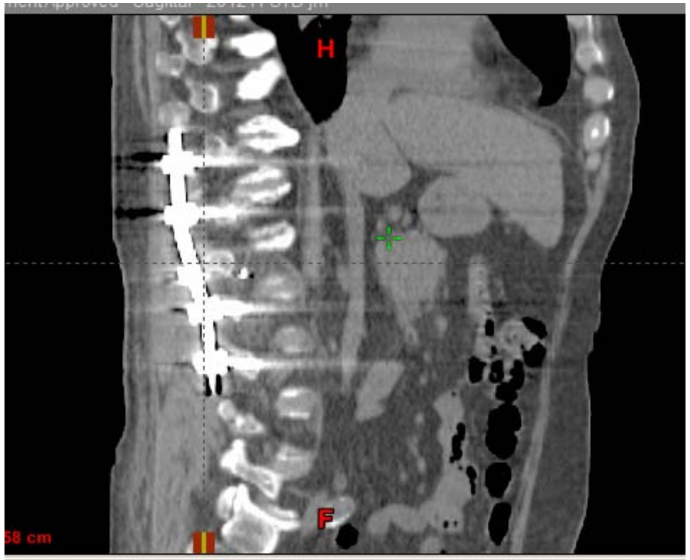
Partial Volume artefacts

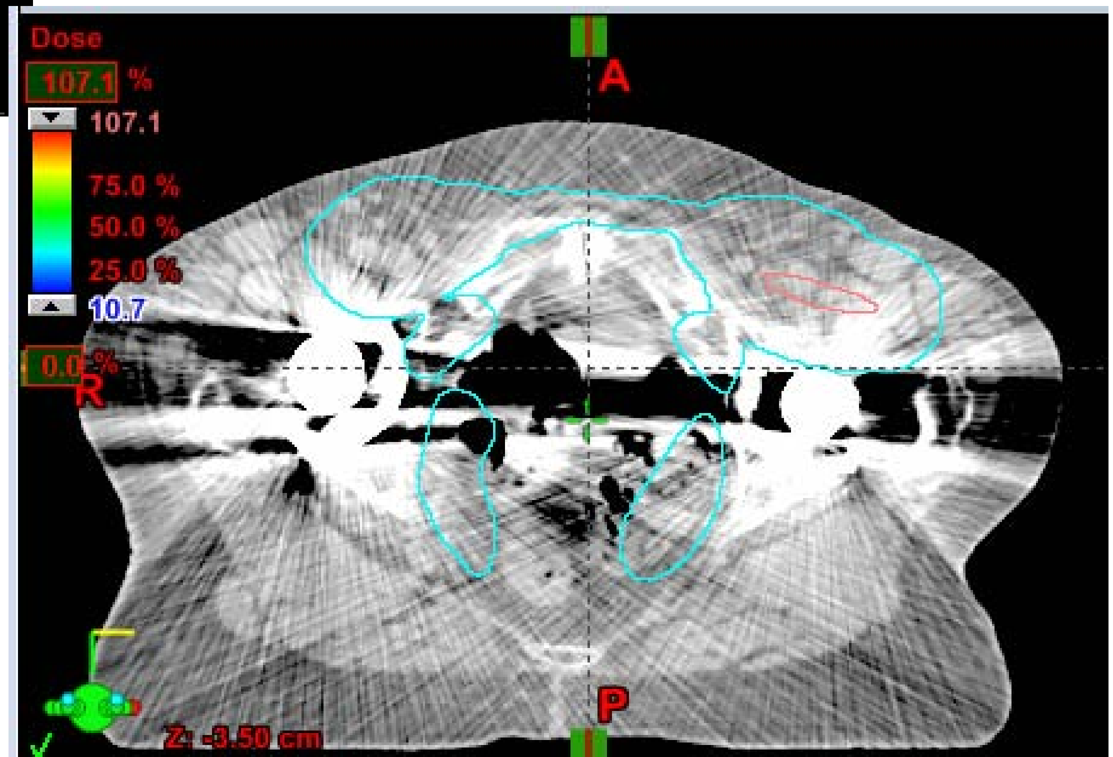


Thick slice

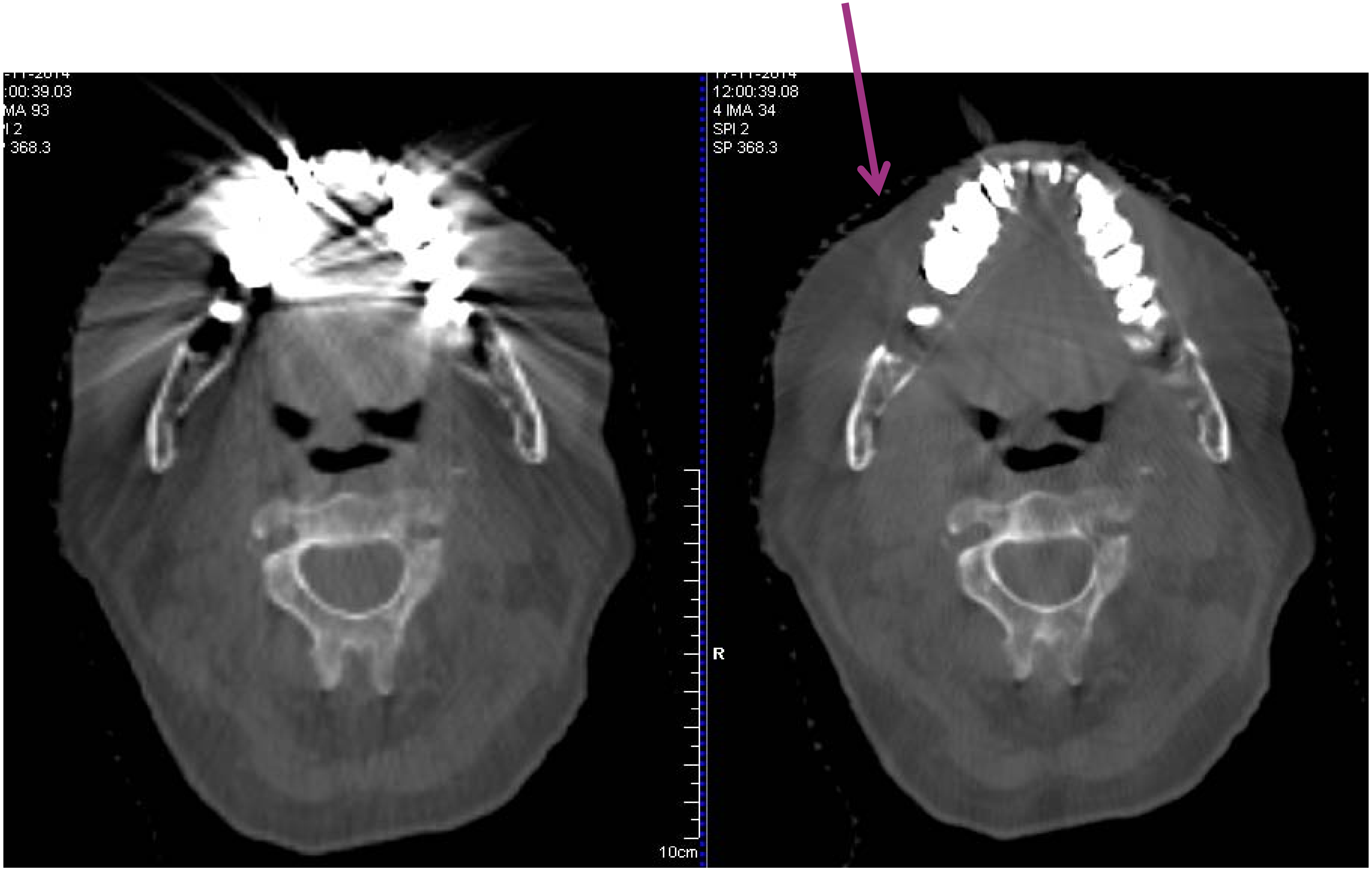
Thin slice

Streak artefacts





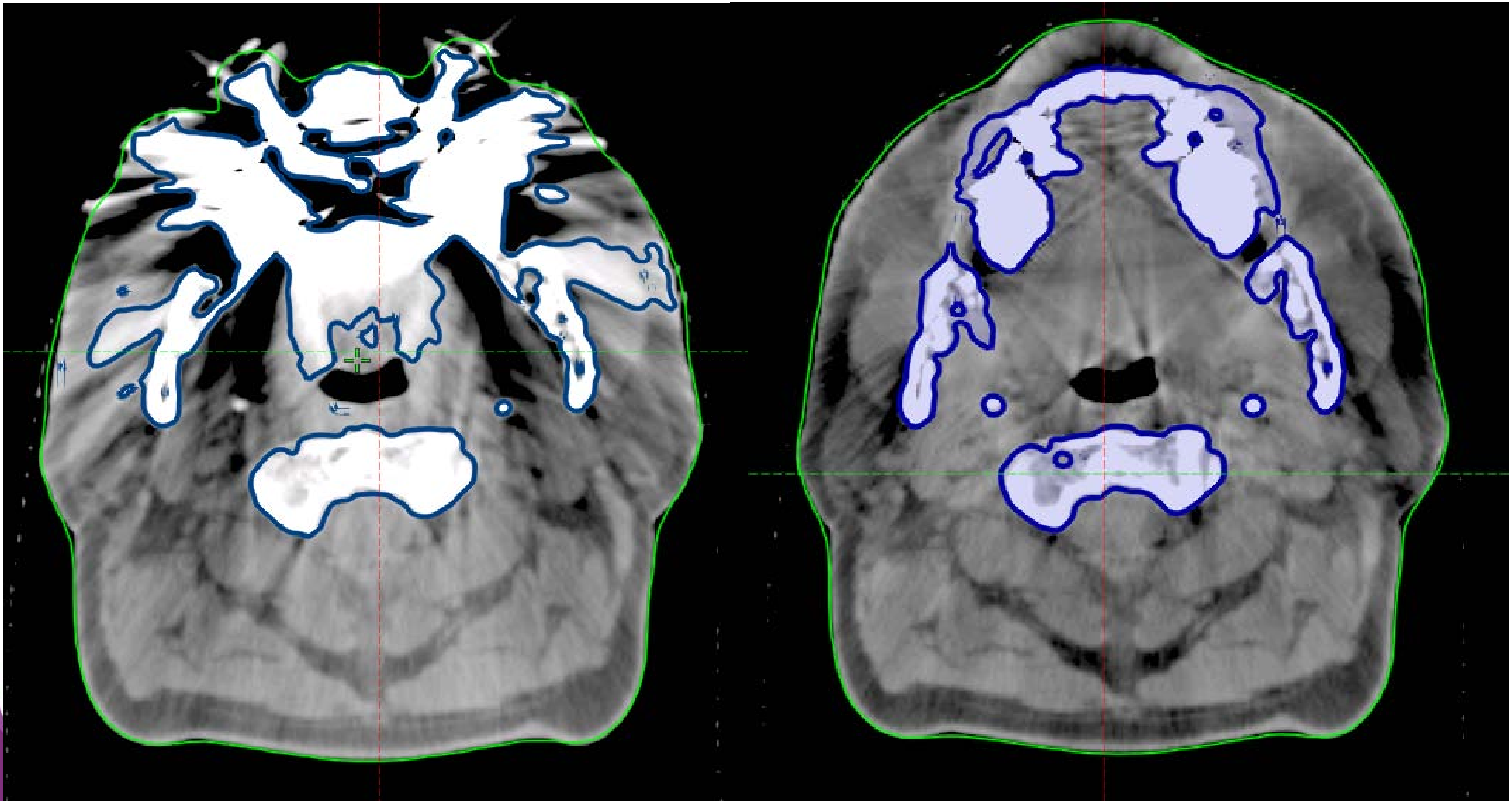
Metal artefact reduction sw



Images courtesy of Laura Rechner, Rigshospitalet

Impact on contouring

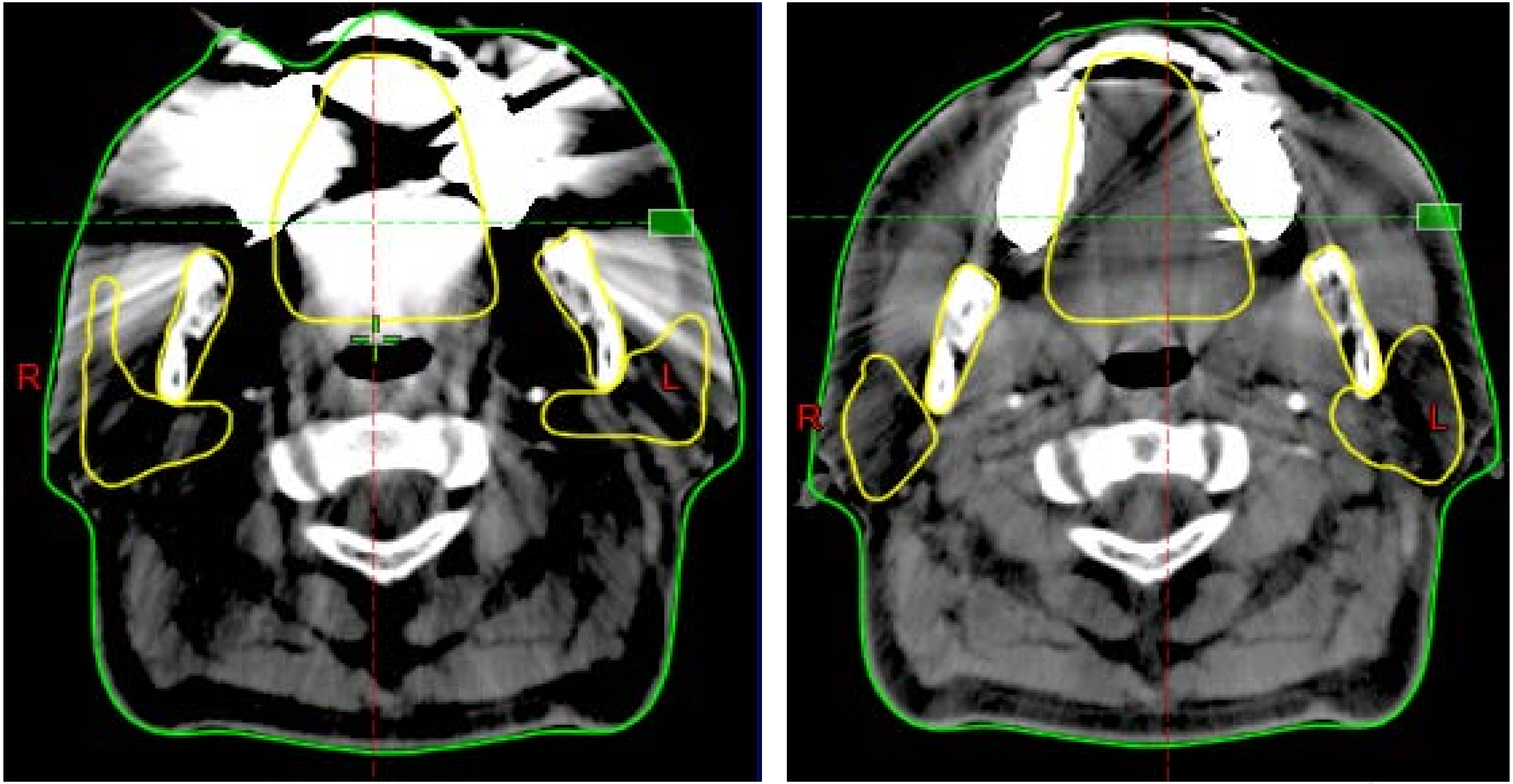
- Body and bone auto contour



Images courtesy of Laura Rechner, Rigshospitalet

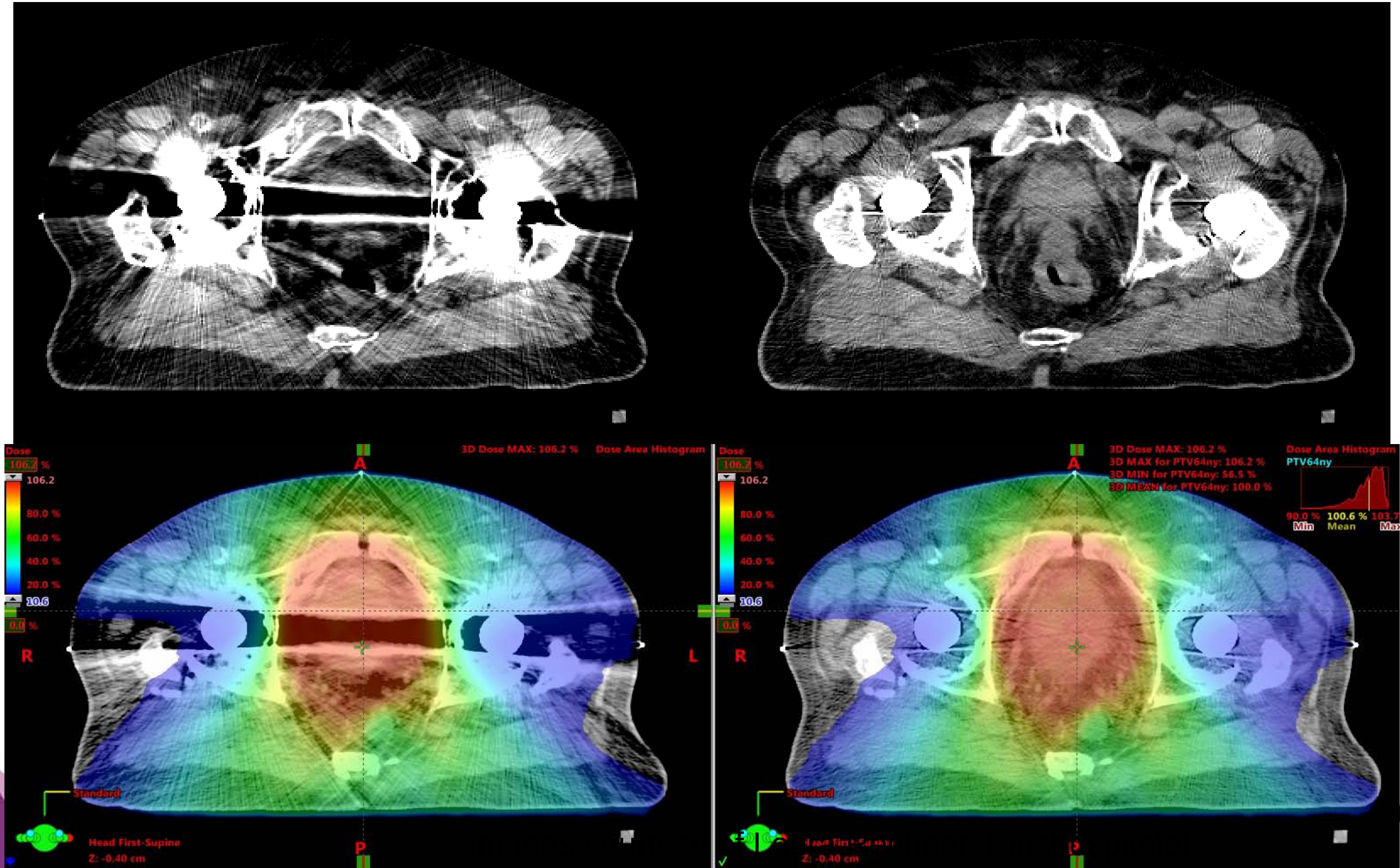
Impact on contouring

- Head and neck contouring by a radiation oncologist



Images courtesy of Jeppe Friborg, Rigshospitalet

Impact on dose planning



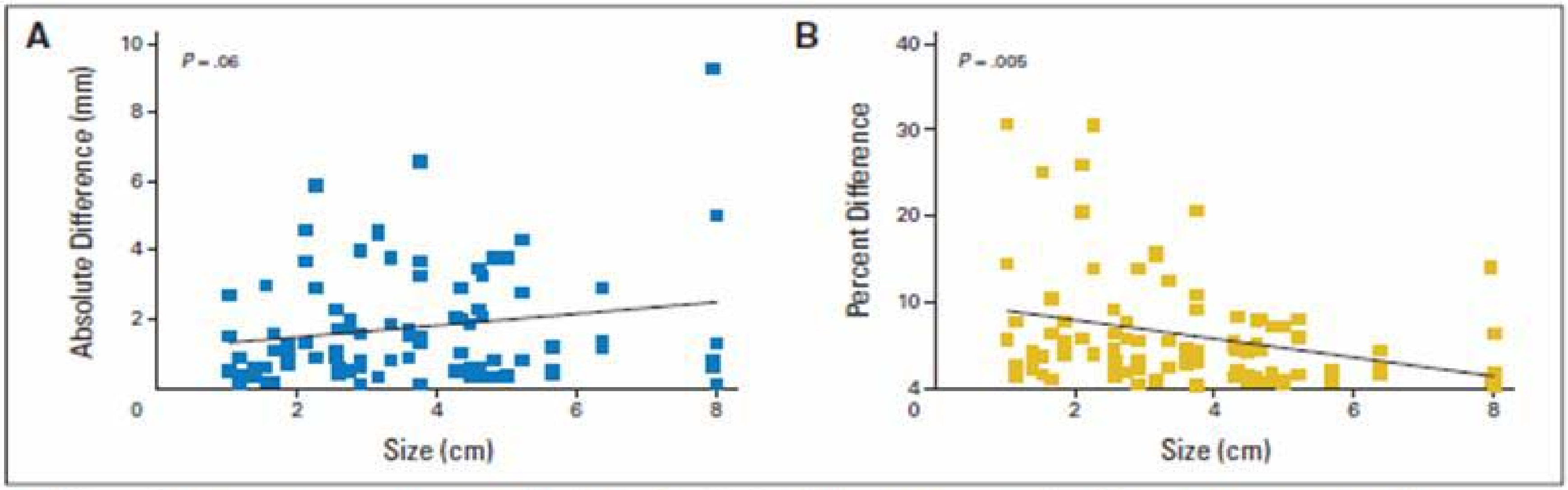
Oxnard et al. JCO 2011

Variability of Lung Tumor Measurements on Repeat Computed Tomography Scans Taken Within 15 Minutes

Table 3. Differences in Measurement Variability Depending on Lesion Size, As Calculated From Repeat CT Scans Performed Within 15 Minutes of Each Other

		Example Tumor		
Size of Tumor (cm)	Standard Deviation (mm)	Size (cm)	Range As a Result of Variability (cm)*	% Change As a Result of Variability
1-3	2.0	2	1.6-2.4	± 20
3-5	2.3	4	3.5-4.5	± 12
5-8	3.3	7	6.3-7.7	± 9

For a lesion measuring 4 cm,
CT variability can lead to measurements from 3.5 to 4.5 cm



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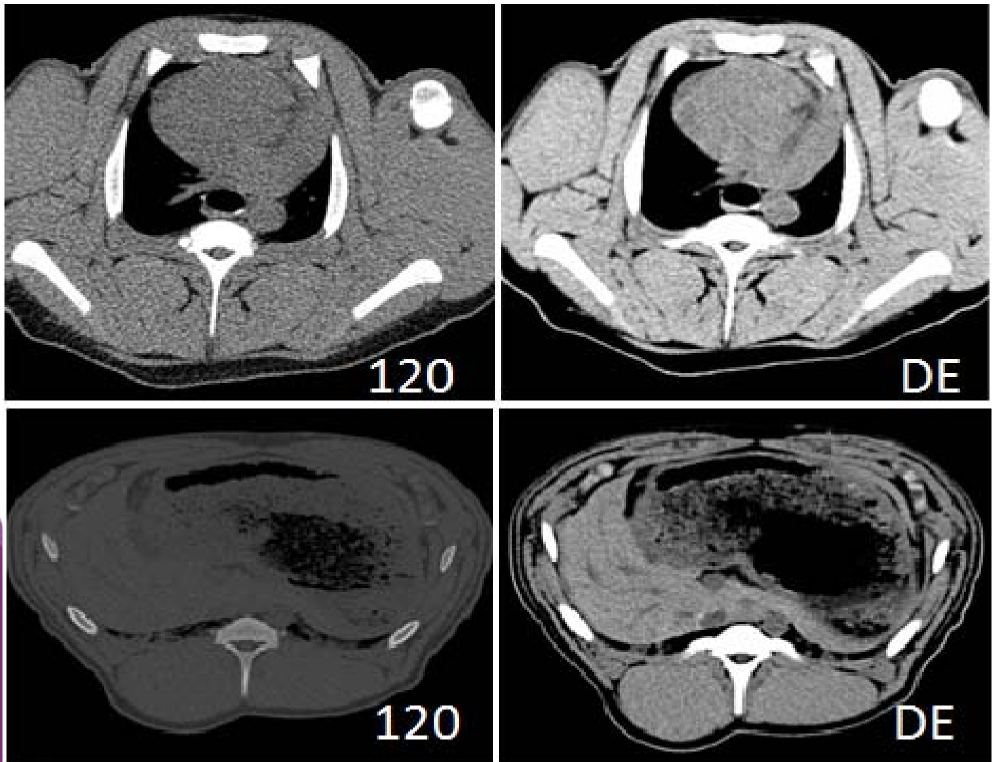
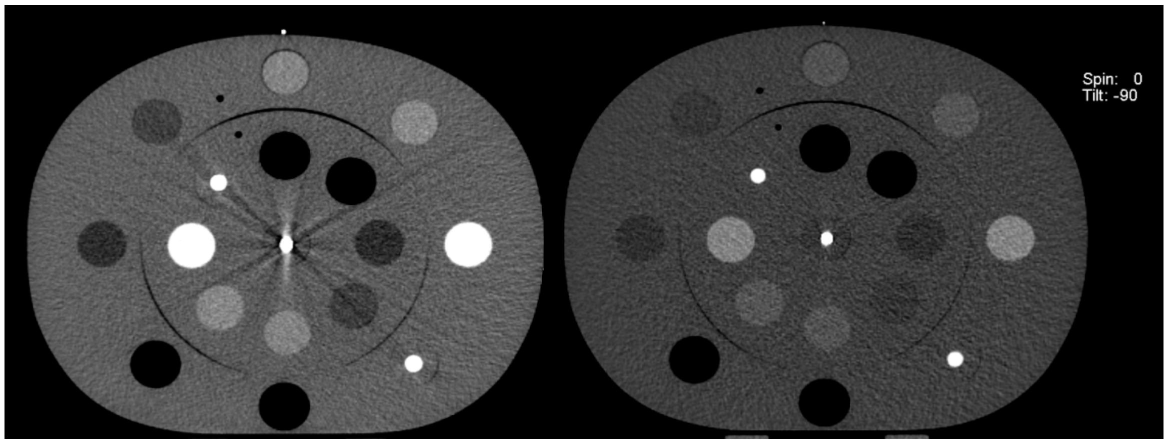
Dual energy CT

- Two energies used for scan: 80 kV + 140 kV
  - Gout, iodine mapping, kidney stones
  - Increased soft tissue contrast
  - Decreased metal artifacts





Imaging for RT planning

- Has to be precise
- Has to provide safe judgment of the extent of the disease

- CT images are base for treatment planning

BUT

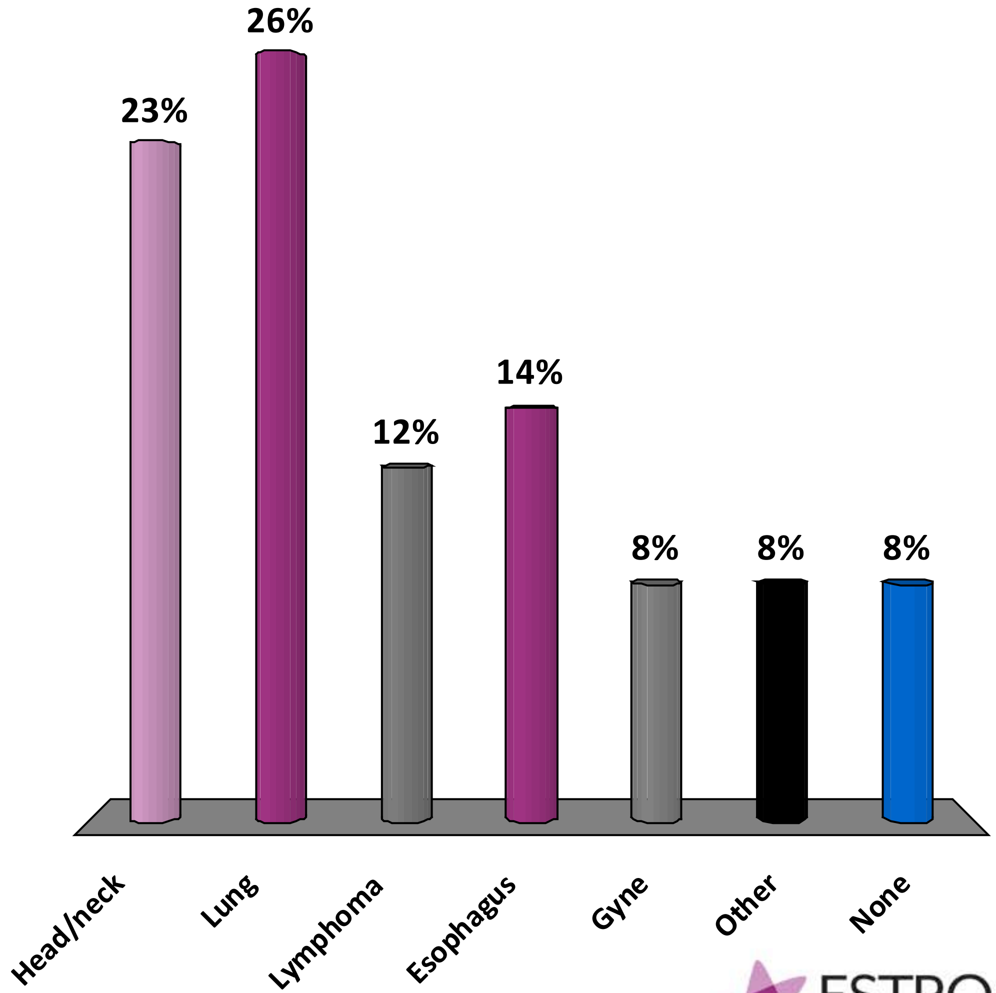
- On CT, it can be difficult to discriminate vital tumour tissue from scar tissue, oedema, atelectasis…

- CT can not stage correctly
  - ➢ detect small metastases
  - ➢ detect distant metastases

PET/CT for Radiotherapy

Which sites does your institution plan with PET/CT

A. Head/neck
B. Lung
C. Lymphoma
D. Esophagus
E. Gyne
F. Other
G. None



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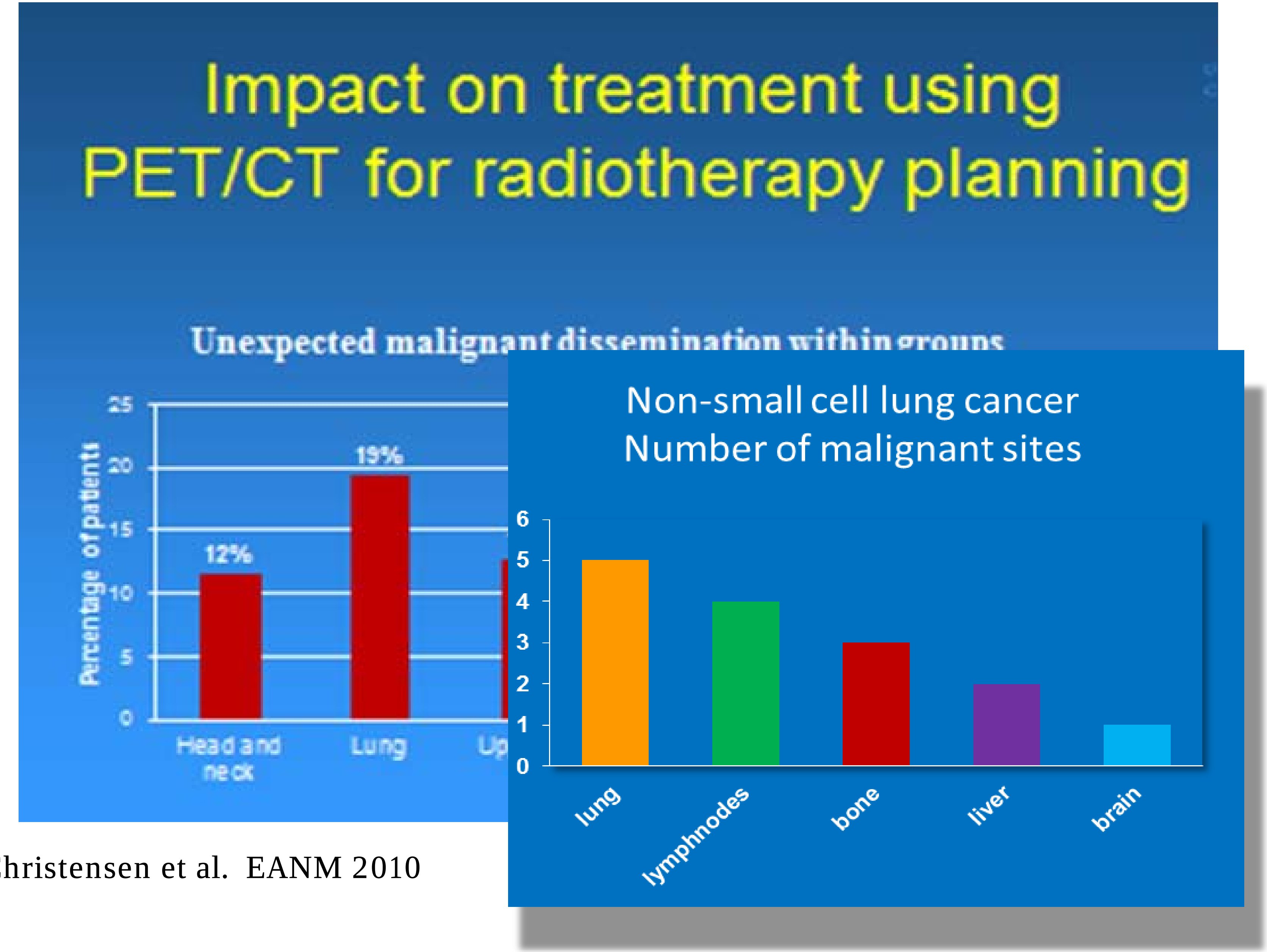
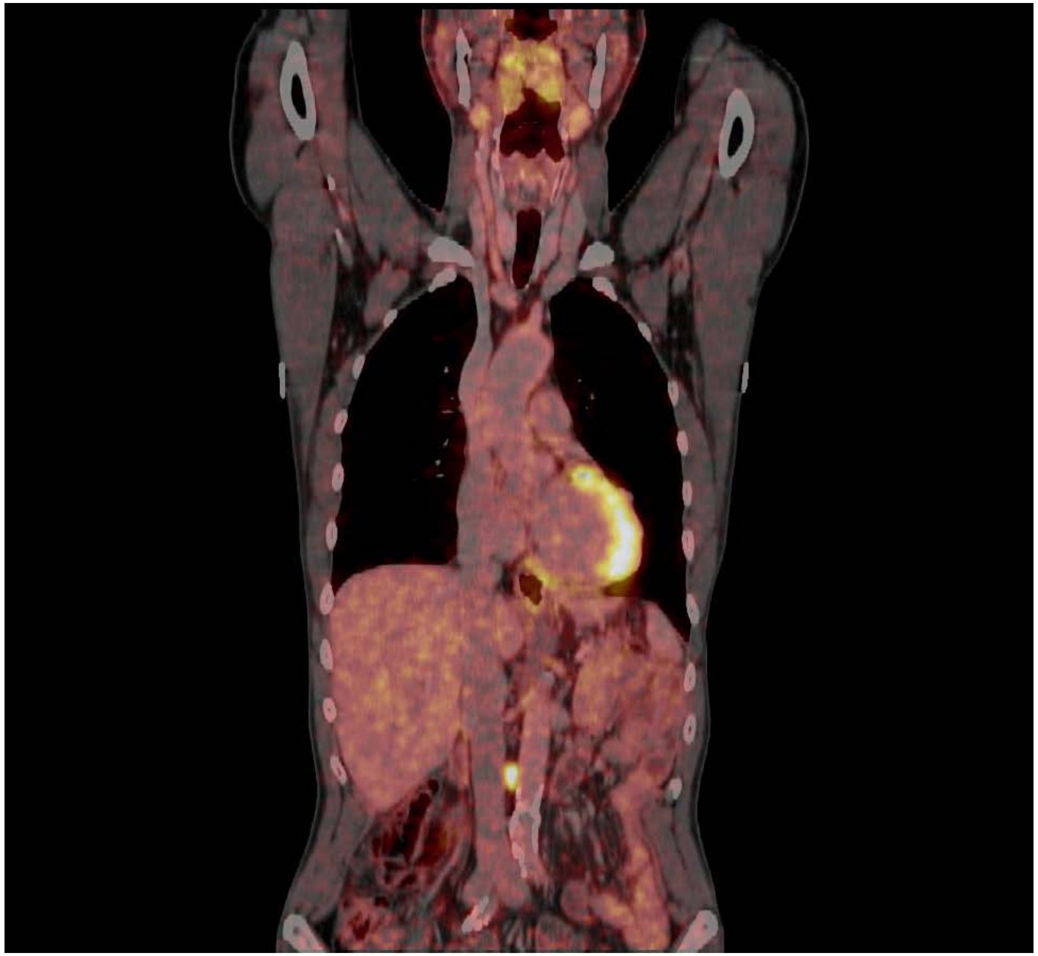
Always WB PET/CT at therapy scan.

Changing treatment strategy!



C.B.Christensen et al. EANM 2010

Change of treatment plan

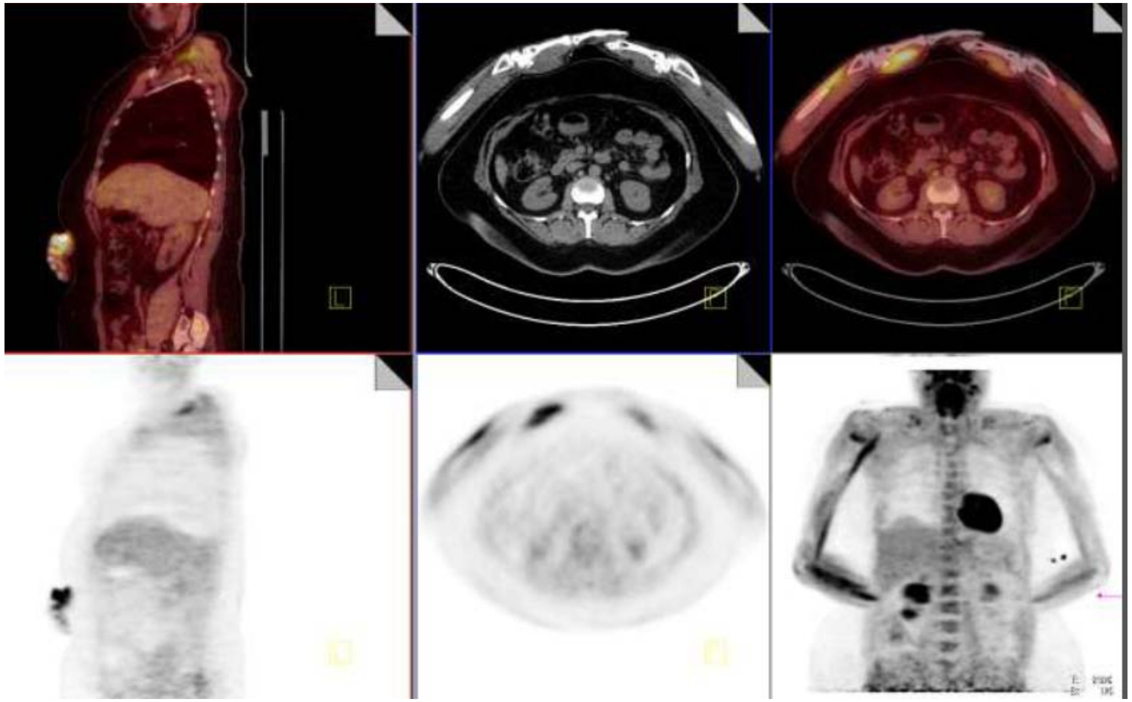


Radically operated oesophageal cancer with a small distant lymph node metastasis - radiotherapy was cancelled

Courtesy of AK Berthelsen

Pitfalls

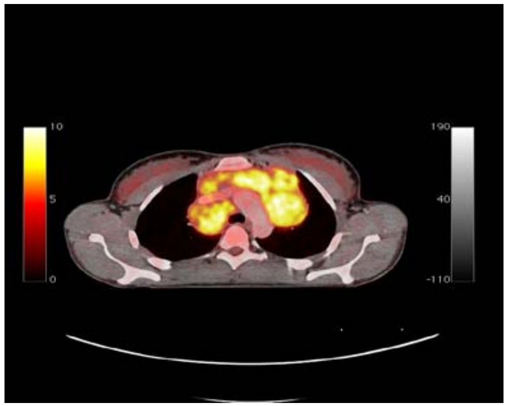
- FDG is not specific
  - ➢ Not all ”hot-spots” are malignant



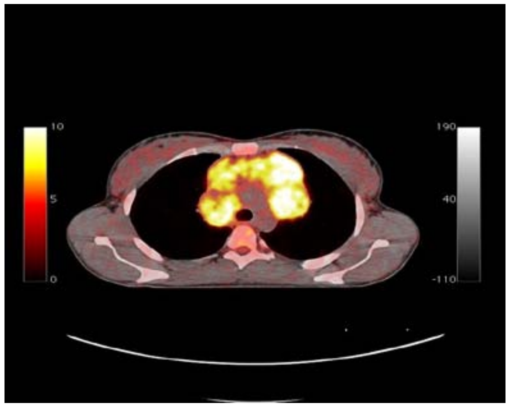
- Motion blurs the FDG uptake
  - ➢ Is it a small lesion, with high degree of motion and high SUV uptake?
  - ➢ Is it a large lesion, without motion and low SUV uptake?

Courtesy of TL Klausen

Free breathing



Breath hold



Courtesy of M Aznar

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PET imaging of brain tumours with FET

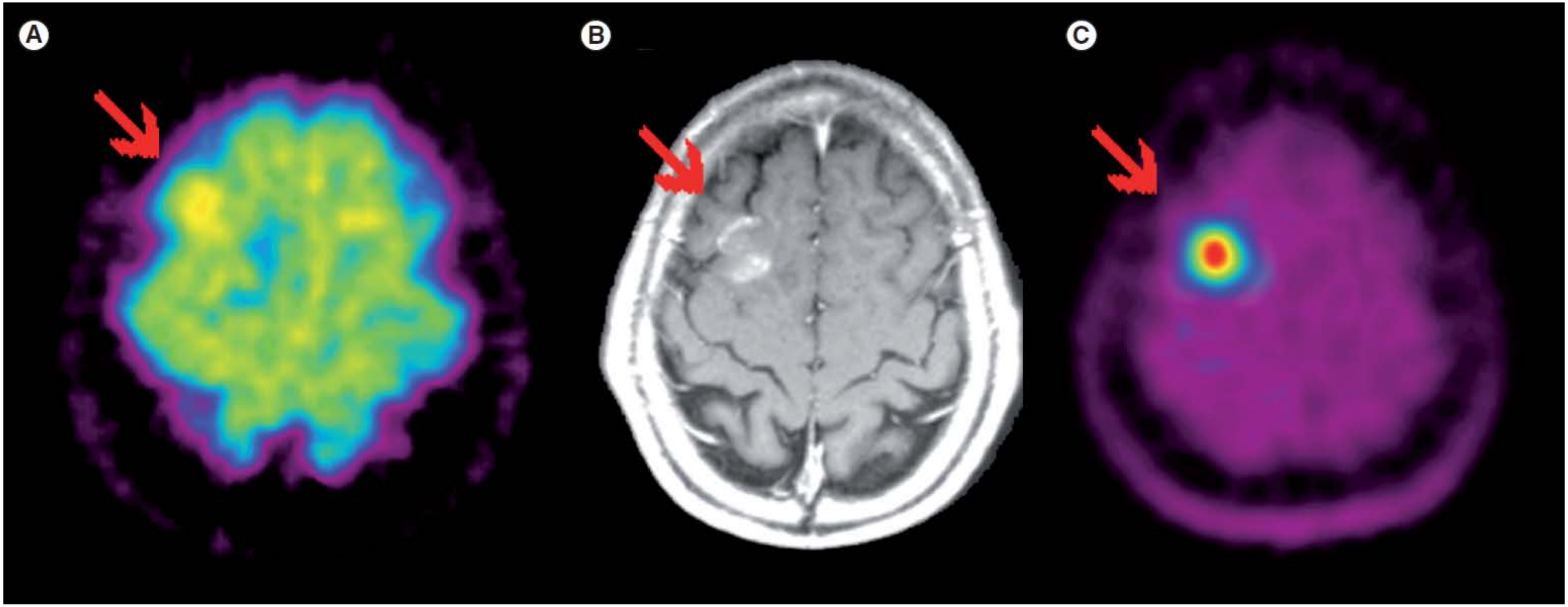

Figure 1. (A) ^{18}F-FDG; **(B)** contrast-enhanced MRI; **(C)** ^{11}C-MET PET. Glioblastoma in the right frontal lobe, which is hard to delineate in the ^{18}F-FDG PET. However, amino-acid PET with ^{11}C-MET clearly shows the lesion with excellent tumor to background contrast.

- Brain has high glucose metabolism
- 18F-Fluoro-Ethyl-Tyrosin (FET), aminoacid uptake

BD Kläsner et al. *Expert Rev. Anticancer Ther 2010*

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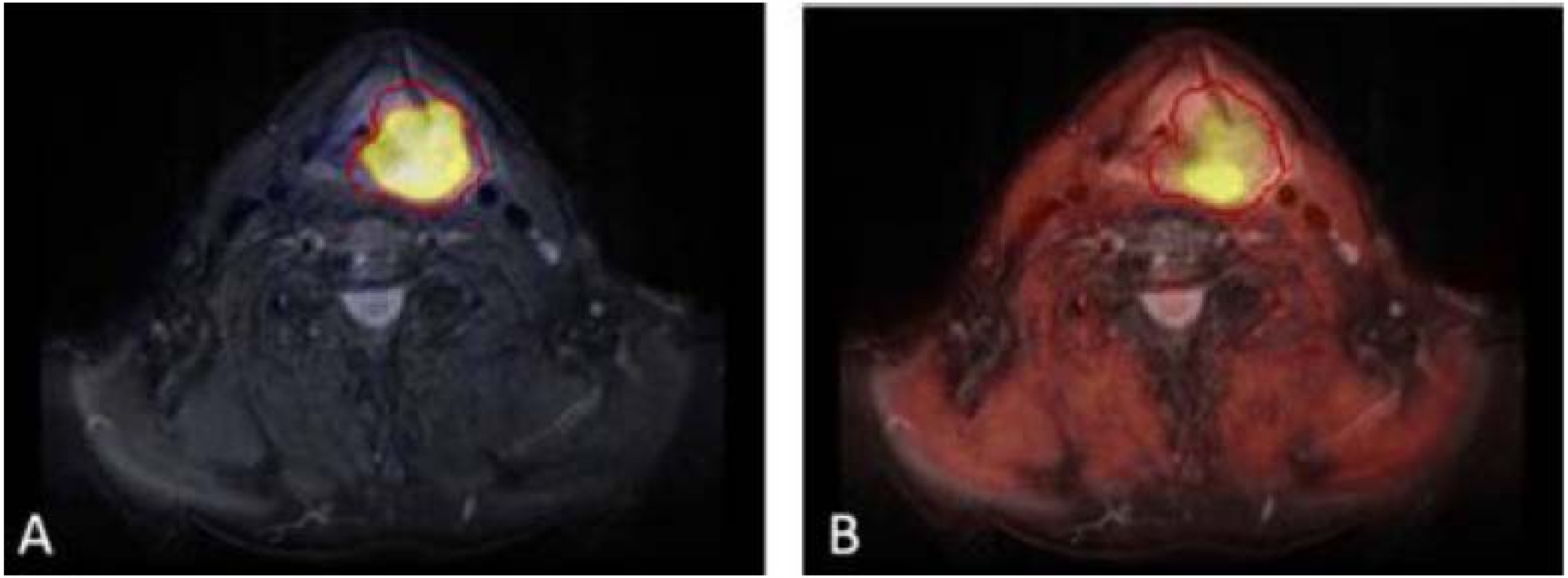
PET imaging of hypoxia with FMISO

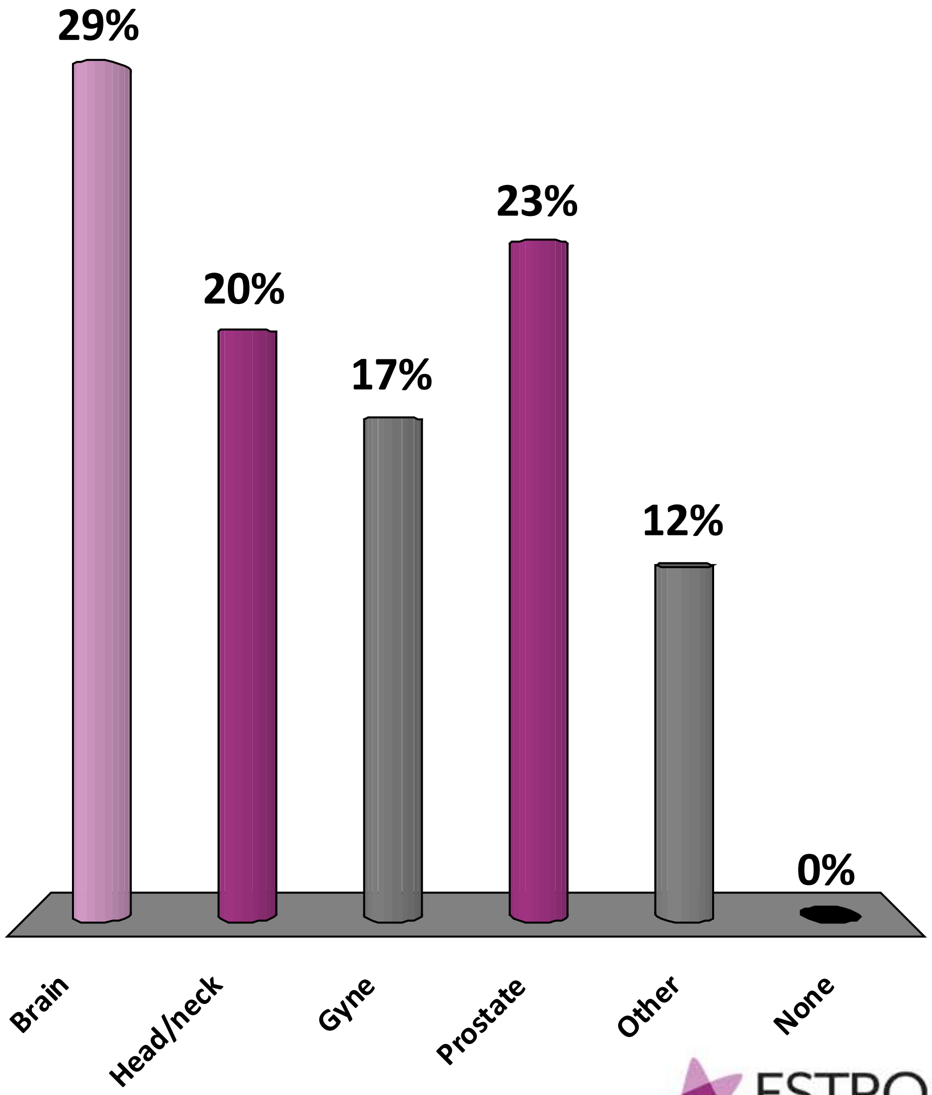


- Hypoxia area is associated with high risk of locoregional failure

Thorwarth BJR 2015

Which sites does your institution plan with MR?

A. Brain
B. Head/neck
C. Gyne
D. Prostate
E. Other
F. None



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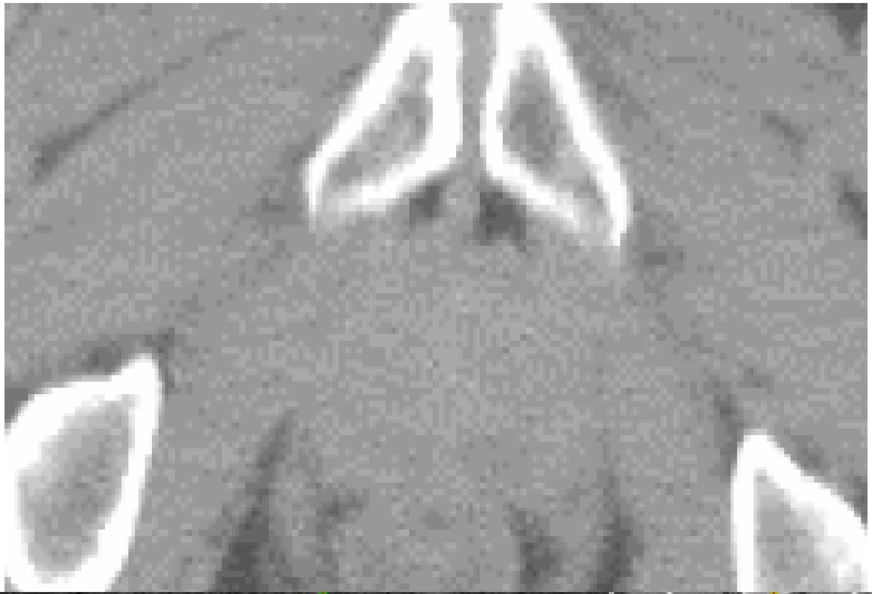
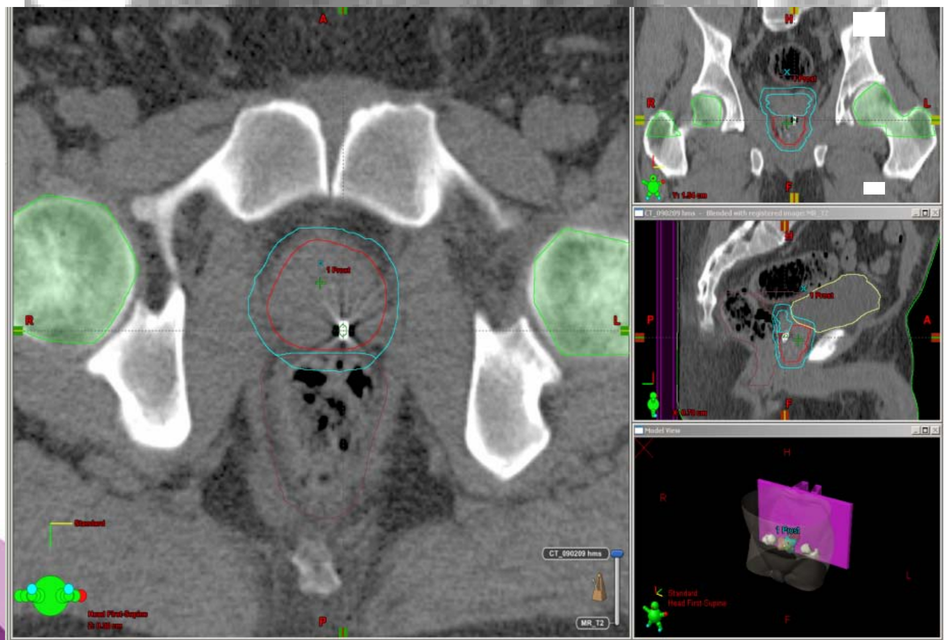
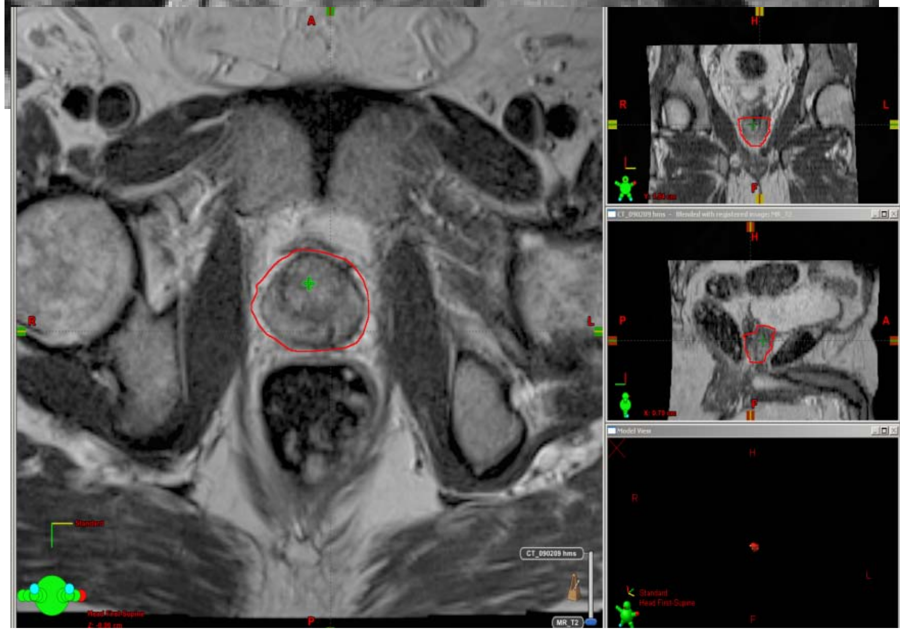
Prostate Cancer

CT



MR





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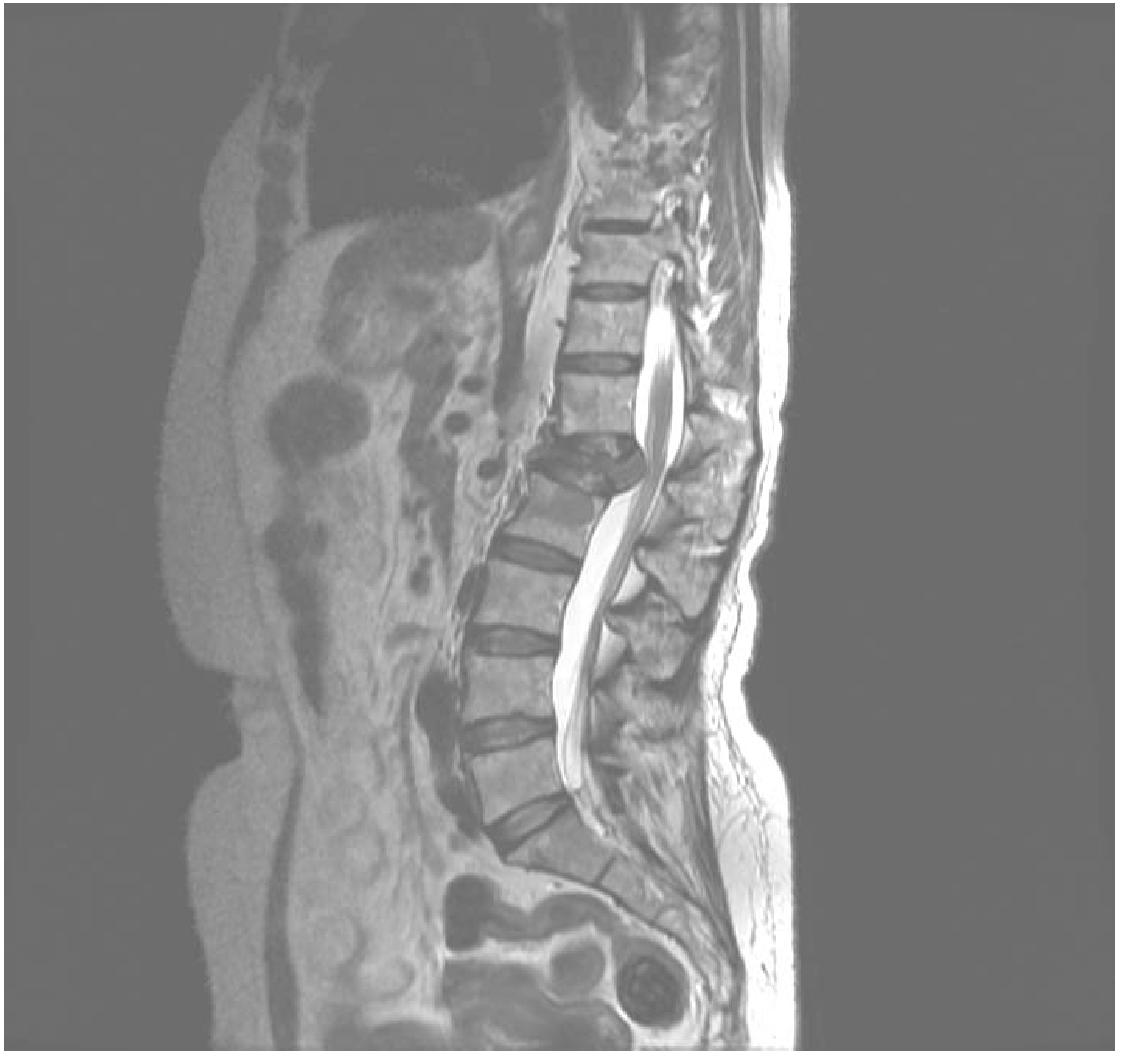
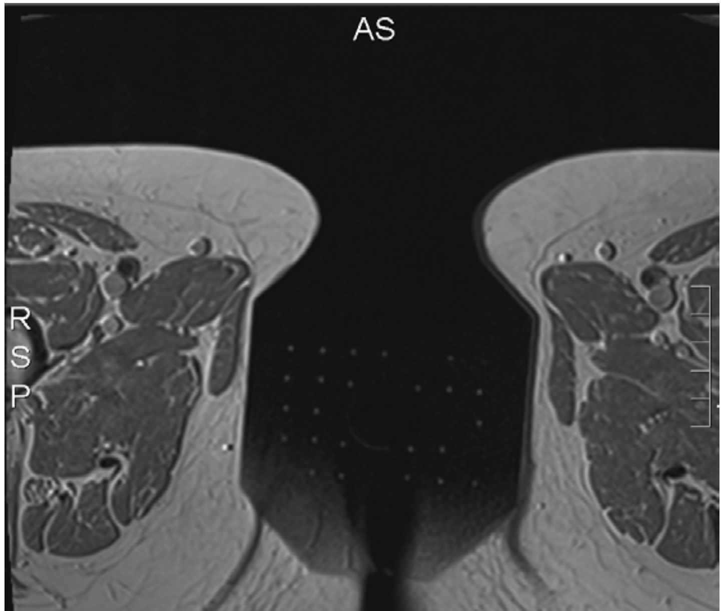
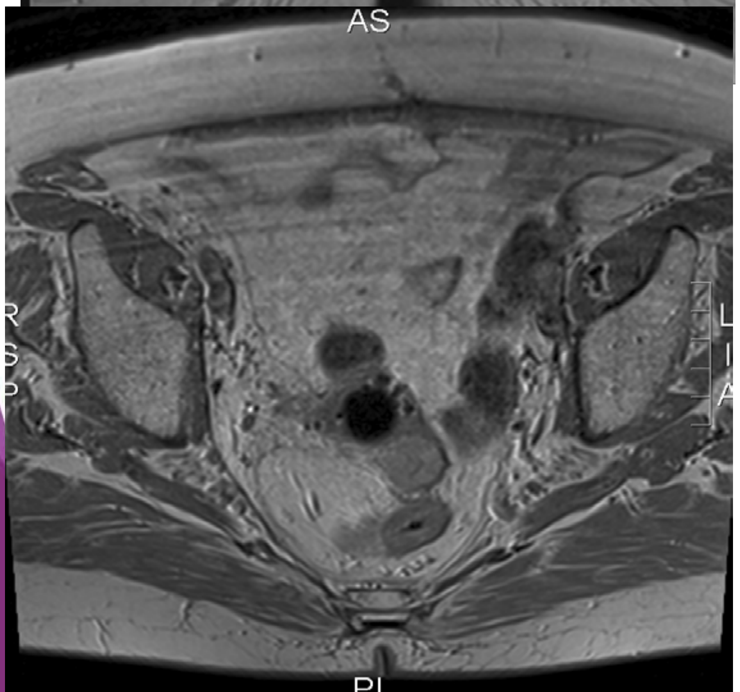
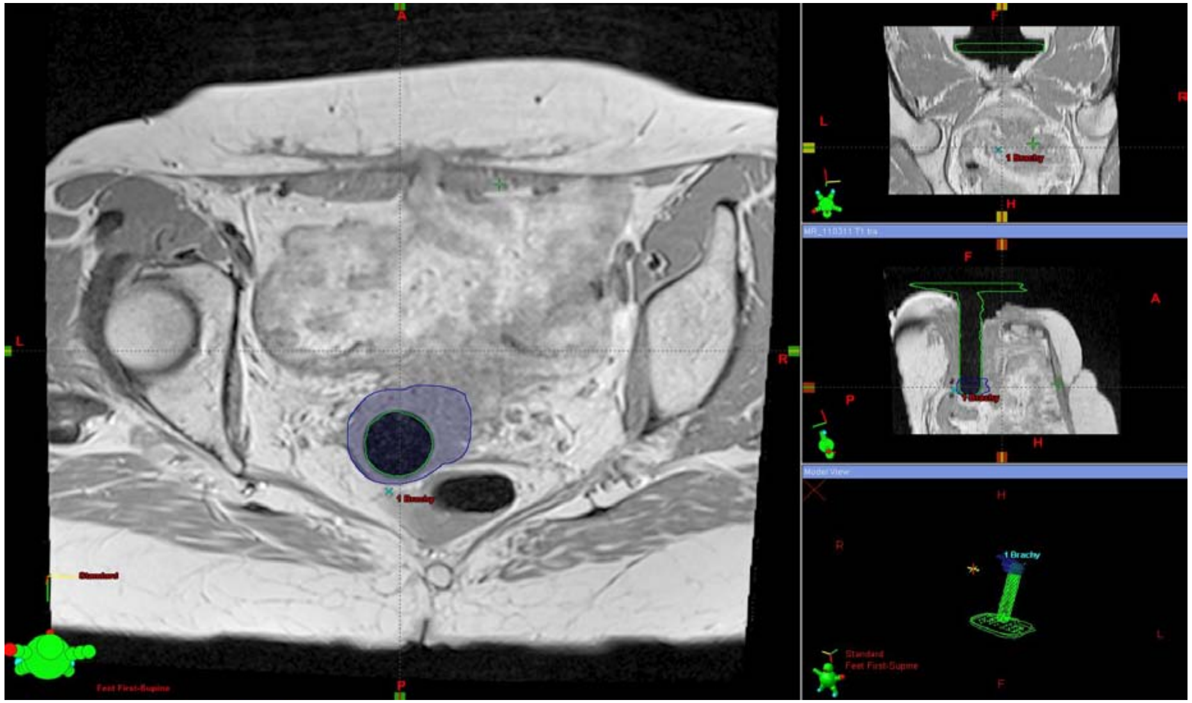
MR for spinal cord compression



MR – Cervical cancer
dummy template for interstitial brachytherapy







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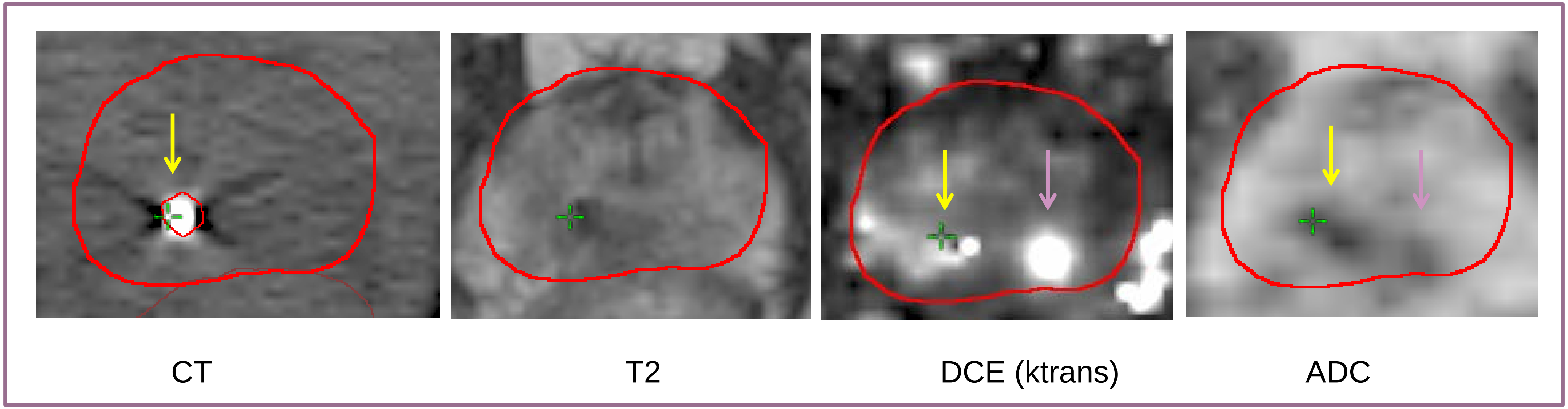
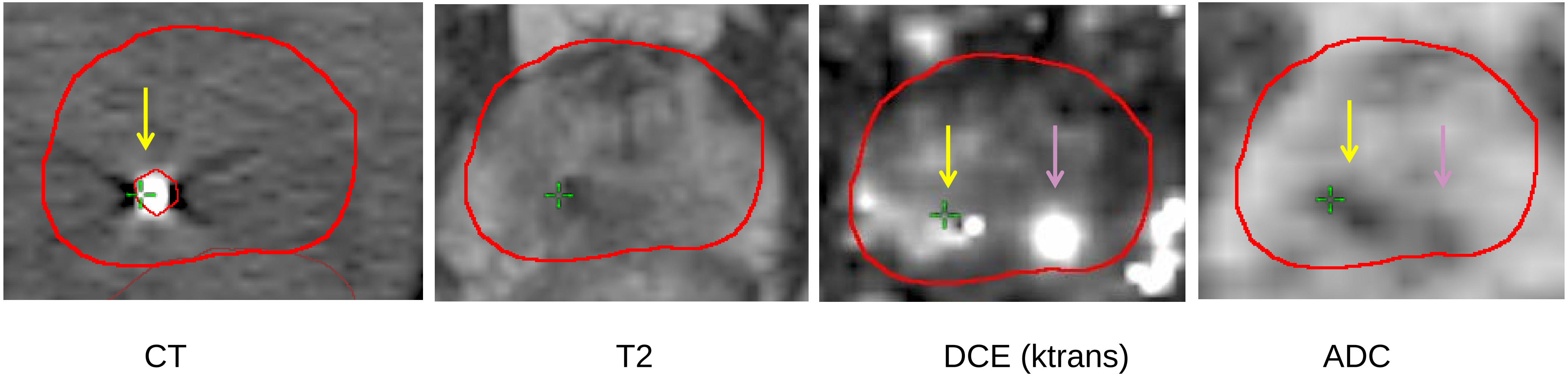
Functional imaging with MR



DCE = dynamic contrast enhanced
• high signal due to increase in capilar permeability
ADC = apparent diffusion coefficient
• lack of signal due to high cell density

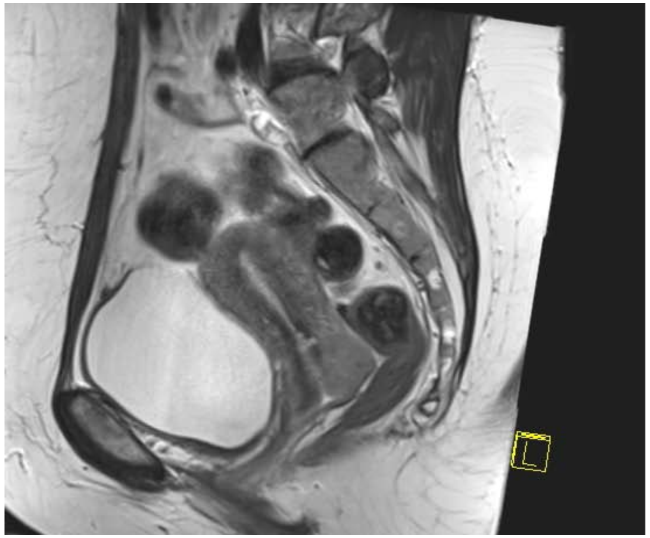
Functional imaging with MR



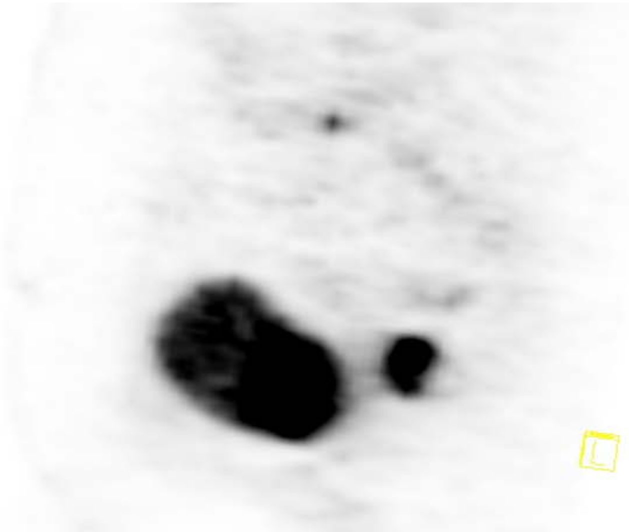
Potential biomarker for prostate cancer progression

- dose escalation
- no compromises in treatment plan

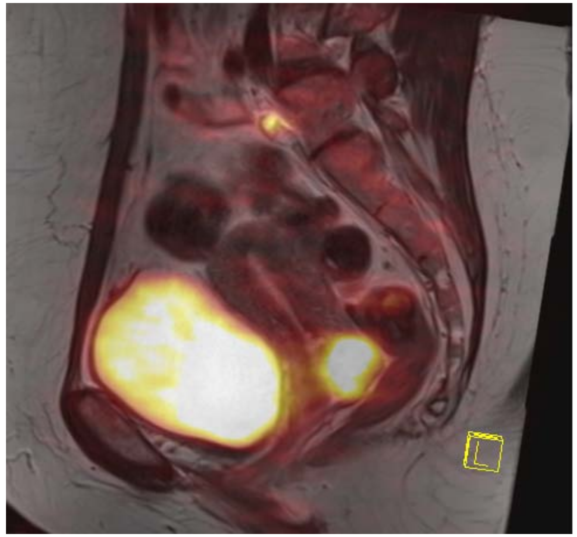
PET/MRI



T2 sag (MR)



FDG-PET



PET/MR

31 year old female with cervix cancer and involvement of a pelvic lymph node

Courtesy of AK Berthelsen

PET/MRI for RT?

ScienceDirect

Journals Books

PET MR radiotherapy | Author name | Journal or book title | Volume | Issu

Search results: 7,223 results found. See image results

European Journal of Radiology 84 (2015) 1285–1292

Conclusion: In conclusion, T2, TIRM, and contrast-enhanced T1 provide a high quality of lesion detectability and anatomical allocation of FDG-avid foci. Their performance is at least comparable to contrast-enhanced PET/CT. Non-enhanced T1 may be omitted and the necessity of DWI should be further investigated for specific questions, such as assessment of the liver.

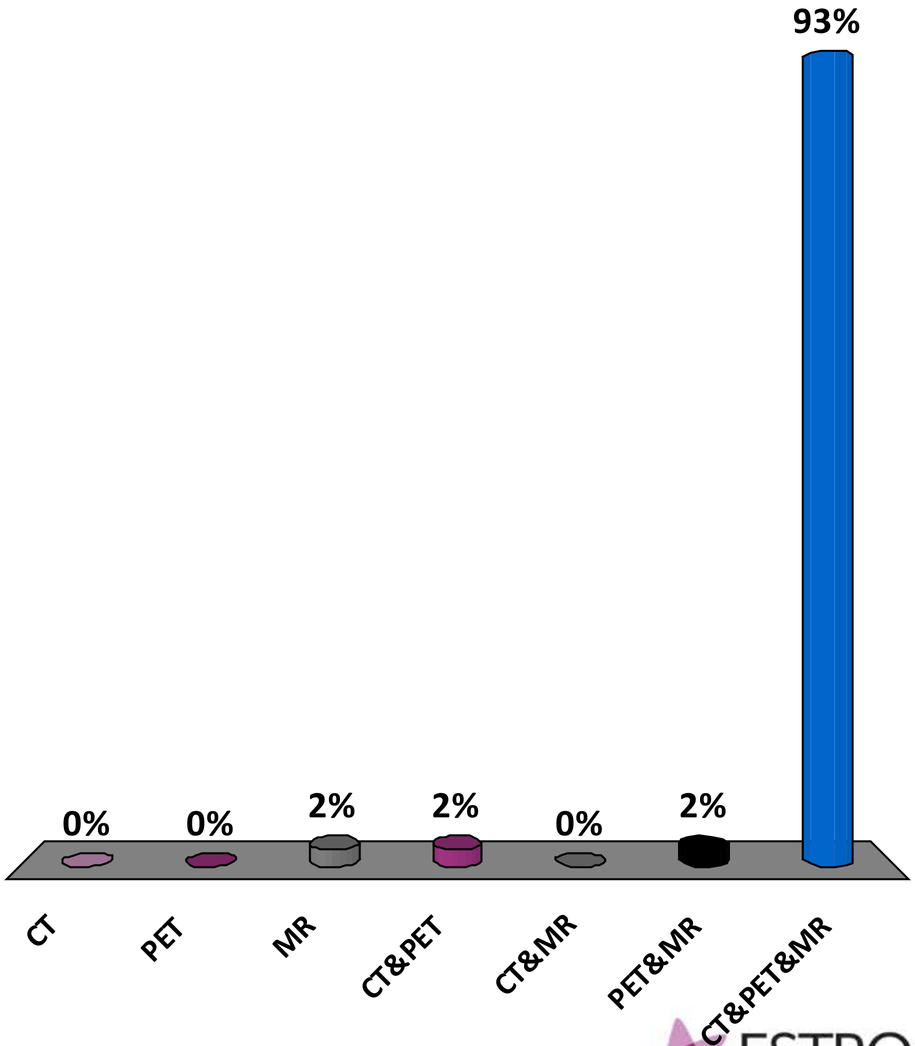
Oncological whole-body staging in integrated ^{18}F-FDG PET/MR: Value of different MR sequences for simultaneous PET and MR reading

CrossMark

Benedikt M. Schaarschmidt[a,b], Johannes Grueneisen[b], Philipp Heusch[a,*], Benedikt Gomez[c], Karsten Beiderwellen[b], Verena Ruhlmann[c], Lale Umutlu[b], Harald H. Quick[d,e], Gerald Antoch[a], Christian Buchbender[a]

Which imaging modalities do we need for modern state of the art radiotherapy?

A. CT
B. PET
C. MR
D. CT&PET
E. CT&MR
F. PET&MR
G. CT&PET&MR



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TARGET VOLUME DELINEATION

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Sofia Rivera, M.D.
Radiation Oncology Department
Gustave Roussy
Villejuif, France

GUSTAVE ROUSSY
CANCER CAMPUS
GRAND PARIS

Advanced skills for modern radiotherapy
June 2015

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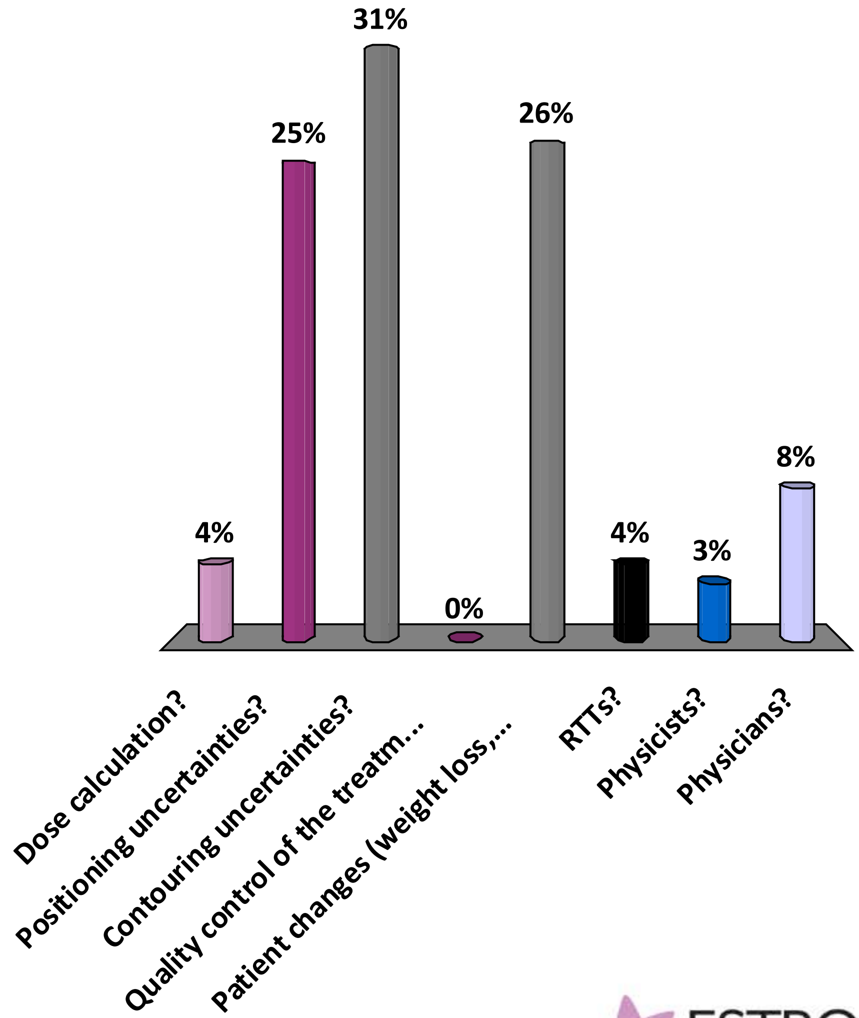
Which is the weakest point in our modern radiotherapy treatment chain?

A. Dose calculation?
B. Positioning uncertainties?
C. Contouring uncertainties?
D. Quality control of the treatment machine?
E. Patient changes (weight loss, movements…)?
F. RTTs?
G. Physicists?
H. Physicians?



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Learning outcomes

- Understand why heterogeneity in contouring is a major weak point in modern radiotherapy
- Discuss the challenges in contouring target volumes
- Identify skills required to delineate target volumes
- Identify tools for improving teaching in delineation
- Identify adequate imaging modalities according to the target to delineate
- Discuss the impact of inaccurate delineation of target volumes

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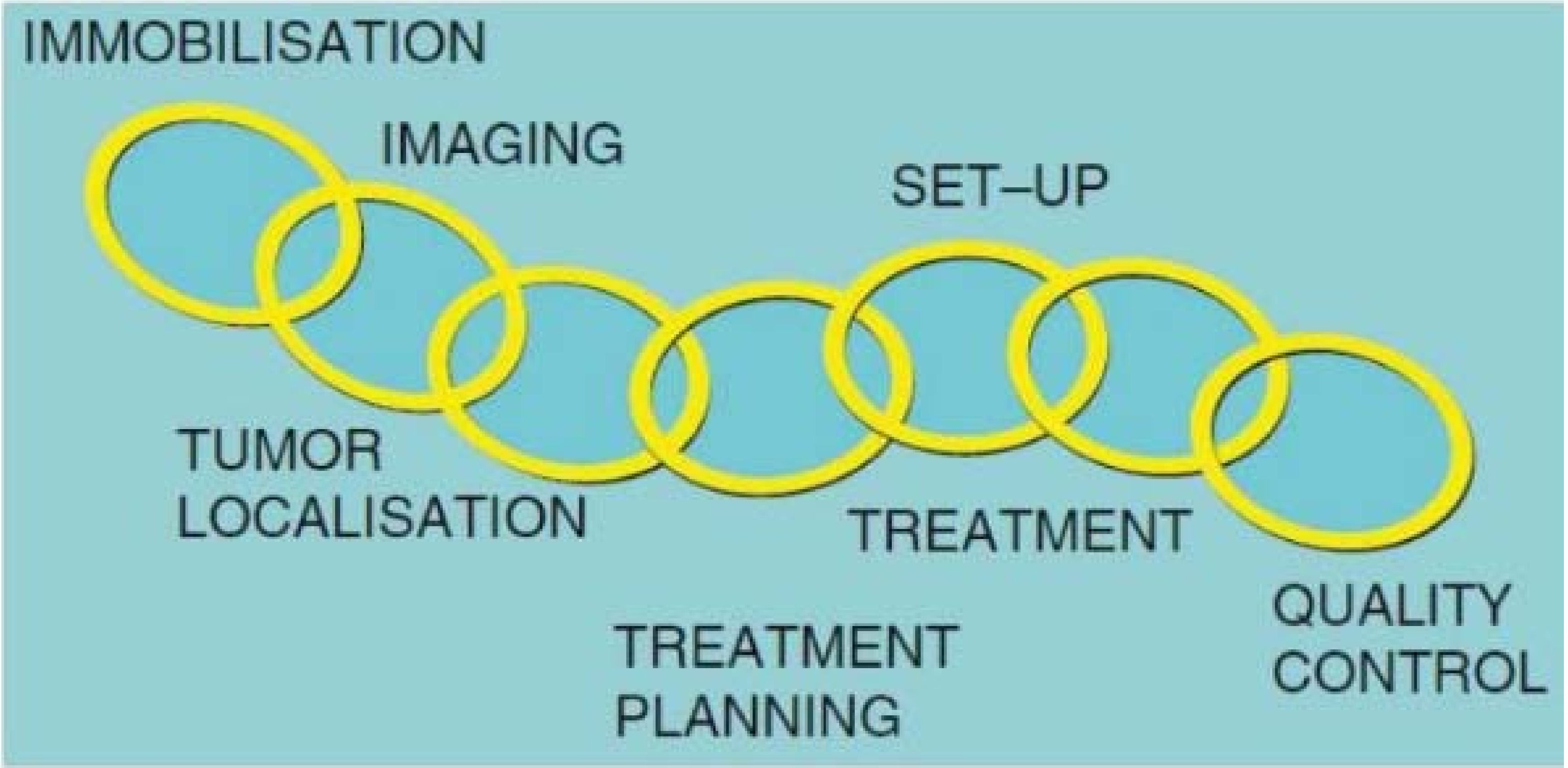
Delineation: one of the links in the treatment chain



Why is delineation important?

- Radiotherapy planning is nowadays mostly based on CT scans
- Constraints for dose distribution are used
- DVH are calculated based on the contours
- Field arrangements are becoming more complex
- An error in contouring will therefore translate in a **systematic error** all along the treatment and may have consequences:
  - ➢ Jeopardizing treatment efficacy
  - ➢ Impacting treatment toxicity

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Do we need to improve?

NIH Public Access
Author Manuscript
Radiother Oncol. Author manuscript; available in PMC 2013 June 27.

Published in final edited form as:
Radiother Oncol. 2012 April ; 103(1): 92–98. doi:10.1016/j.radonc.2012.02.010.

Heterogeneity in head and neck IMRT target design and clinical practice

Theodore S. Hong[a], Wolfgang A. Tomé[b,c,d], and Paul M. Harari[b,*]

Abstract

Purpose—To assess patterns of H&N IMRT practice with particular emphasis on elective target delineation.

Materials and methods—Twenty institutions with established H&N IMRT expertise were solicited to design clinical target volumes for the identical H&N cancer case. To limit contouring variability, a primary tonsil GTV and ipsilateral level II node were pre-contoured. Participants were asked to accept this GTV, and contour their recommended CTV and PTV. Dose prescriptions, contouring time, and recommendations regarding chemotherapy were solicited.

Results—All 20 institutions responded. Remarkable heterogeneity in H&N IMRT design and practice was identified. Seventeen of 20 centers recommended treatment of bilateral necks whereas 3/20 recommended treatment of the ipsilateral neck only. The average CTV volume was 250 cm^3 (range 37–676 cm^3). Although there was high concordance in coverage of ipsilateral neck levels II and III, substantial variation was identified for levels I, V, and the contralateral neck. Average CTV expansion was 4.1 mm (range 0–15 mm). Eight of 20 centers recommended chemotherapy (cisplatin), whereas 12/20 recommended radiation alone. Responders prescribed on average 69 and 68 Gy to the tumor and metastatic node GTV, respectively. Average H&N target volume contouring time was 102.5 min (range 60–210 min).

Conclusion—This study identifies substantial heterogeneity in H&N IMRT target definition, prescription, neck treatment, and use of chemotherapy among practitioners with established H&N IMRT expertise. These data suggest that continued efforts to standardize and simplify the H&N IMRT process are desirable for the safe and effective global advancement of H&N IMRT practice.

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How can we answer that need ?

- Adequate imaging, training and use of contouring recommendations are main strategies to minimize delineation uncertainties (Petrič et al 2013)

- Establishing and using consensus and guidelines have shown to reduce heterogeneity in contouring

Table III. Mean and ranges of DSC before and after consensus.

Volume	Consensus volume (ml)	Mean DSC (range) Before consensus	Mean DSC (range) After consensus
Breast	1247	0.93 (0.89–0.96)	0.95 (0.93–0.96)
Boost	40	NA	0.75 (0.60–0.89)
Internal mammary LN	15	0.59 (0.32–0.72)	0.71 (0.63–0.81)
Axillary LN level I	108	0.65 (0.59–0.75)	0.70 (0.60–0.77)
Axillary LN level II	32	0.56 (0.35–0.69)	0.76 (0.67–0.84)
Axillary LN level III	17	0.56 (0.39–0.73)	0.74 (0.66–0.82)
Periclavicular LN	47	0.41 (0.34–0.56)	0.56 (0.43–0.73)
Interpectoral LN	33	0.54 (NA)	0.66 (0.55–0.78)
Heart	731	0.91 (0.88–0.94)	0.94 (0.90–0.96)

DSC, Dice similarity coefficient; NA, not available.

NIELSEN et al 2013

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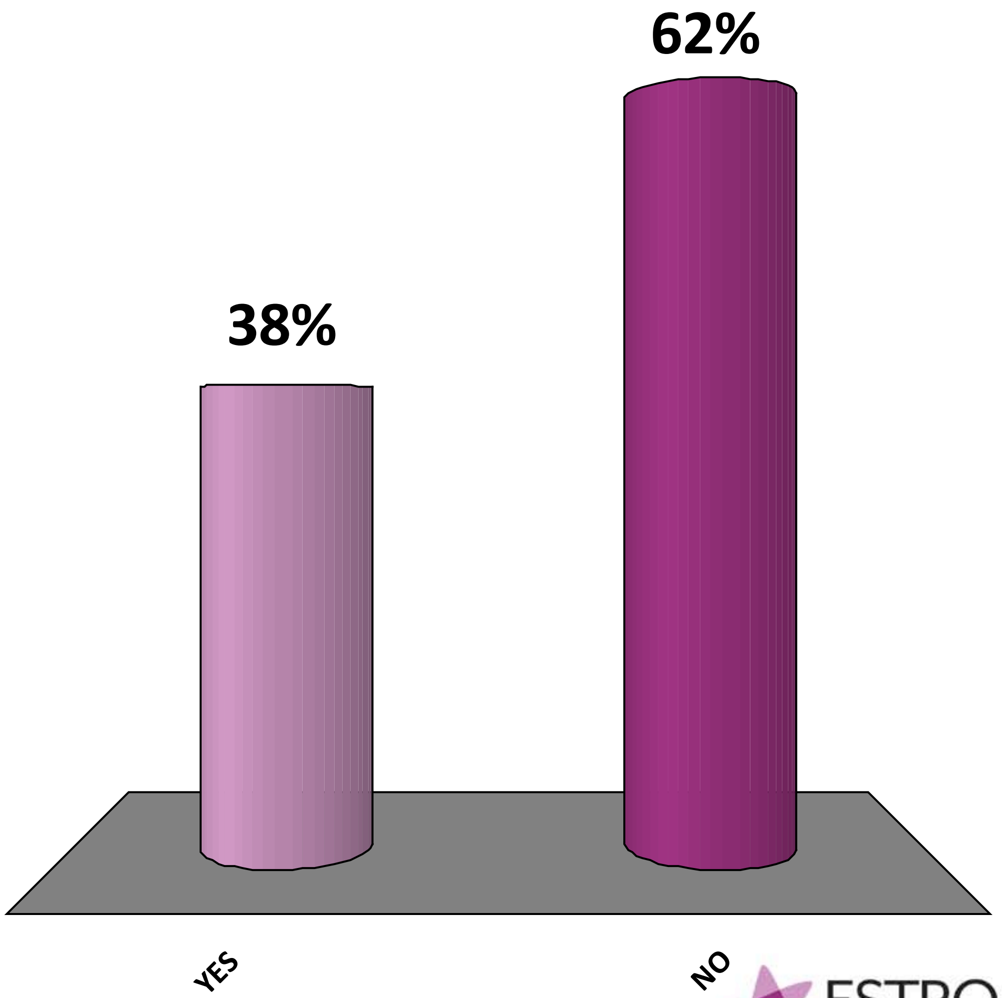
Do you know ESTRO provides a platform for hands on exercises on contouring?

A. YES

B. NO



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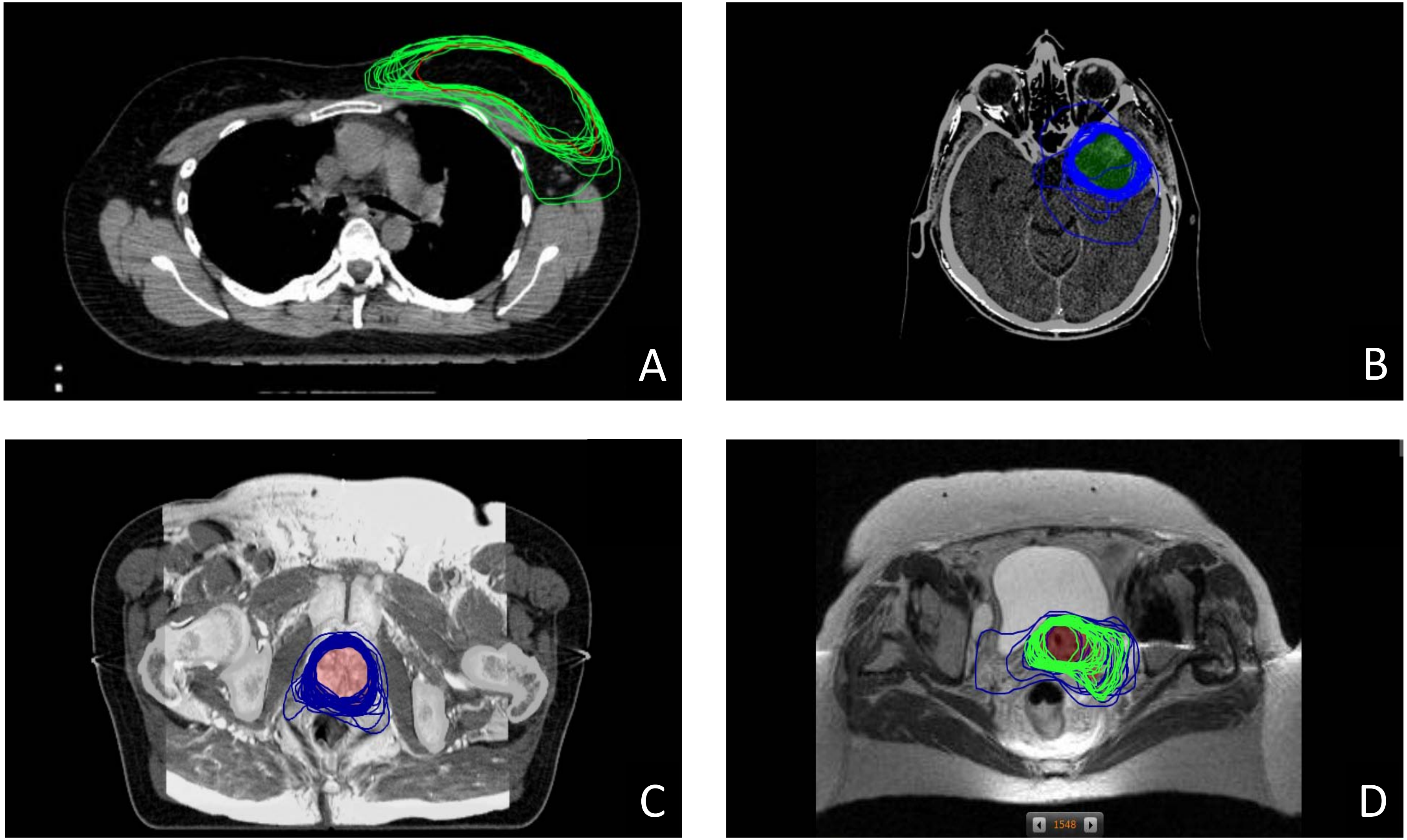
Inter-observer variability in contouring

Examples of participant contours from ESTRO FALCON workshops.
A: CTV breast, B: GTV Brain tumour, C: CTV prostate and D: GTV cervix cancer



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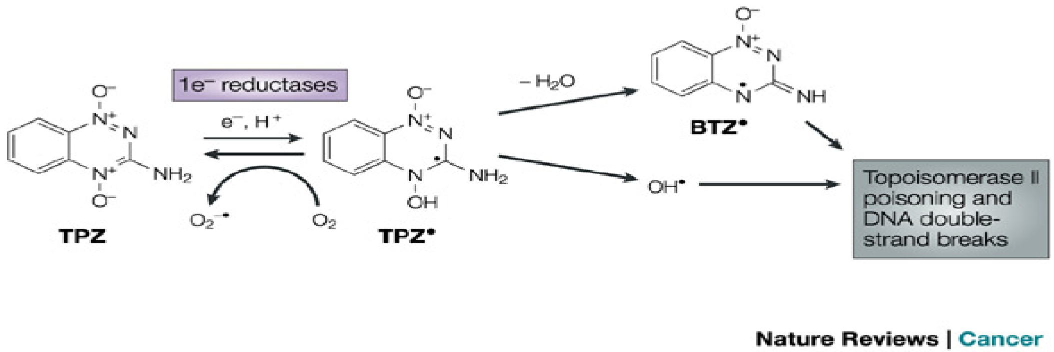
Does heterogeneity in RT matters?

- Bioreductive agent
- Radiosensitizer in hypoxia

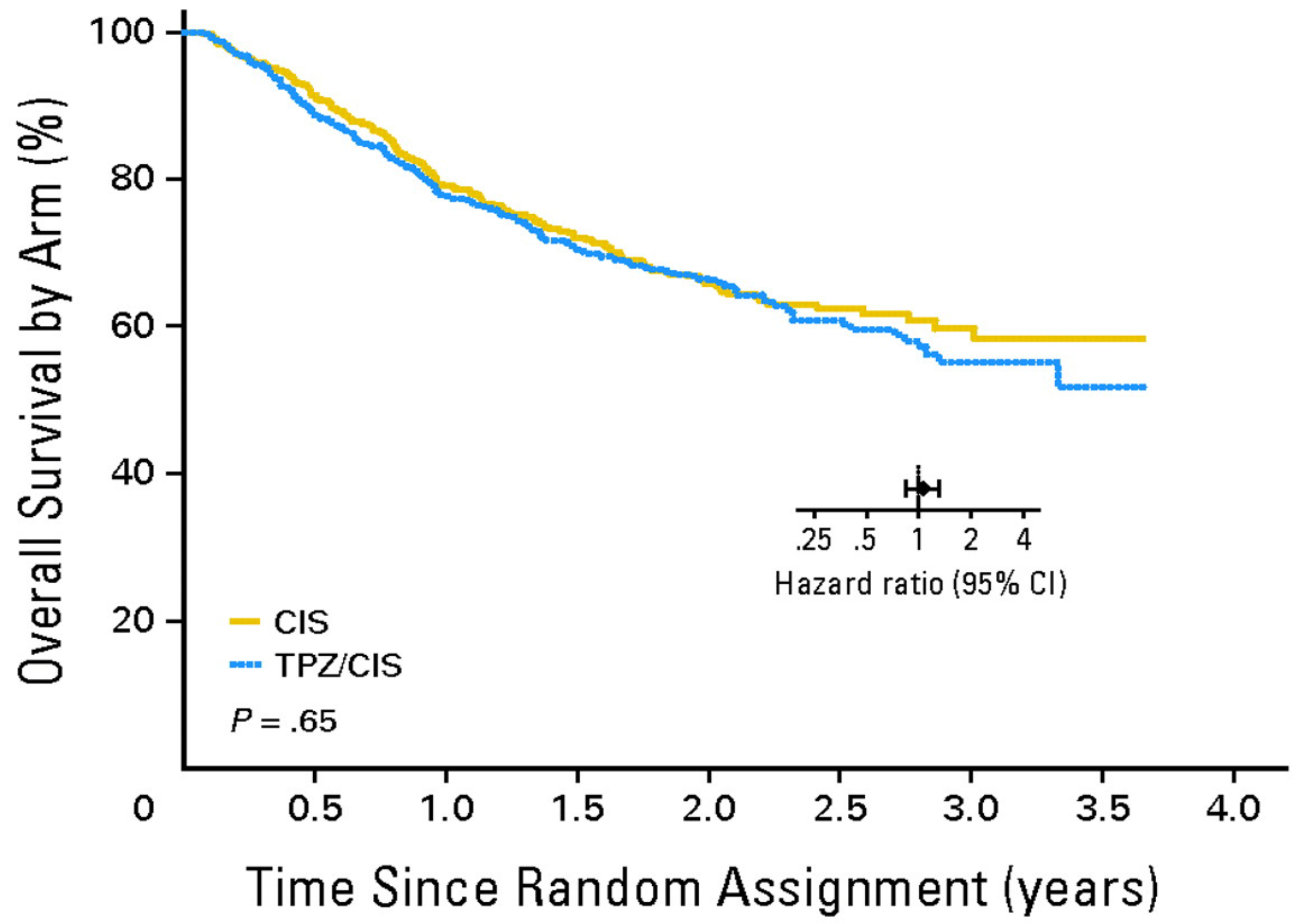


Multicentric international
Randomized phase III
853 locally advanced
H&N patients

RT + CDDP

RT + CDDP
+ Tyrapazamine

No benefit in overall survival



No. at risk									
CIS	428	389	332	294	248	91	45	6	0
TPZ/CIS	425	374	326	291	252	98	42	7	0

Rischin D et al. JCO 2010;28:2989-2995

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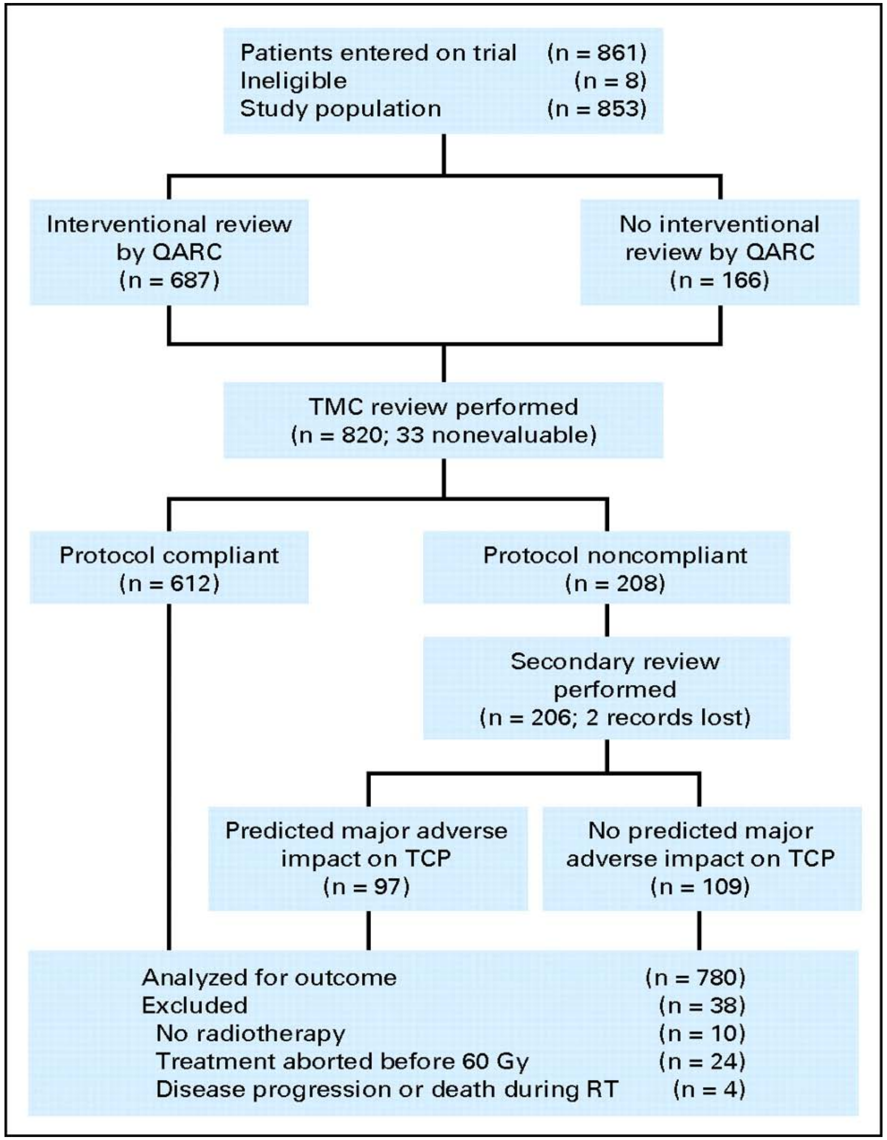
But… Trial quality control



Peters L J et al. JCO 2010;28:2996-3001

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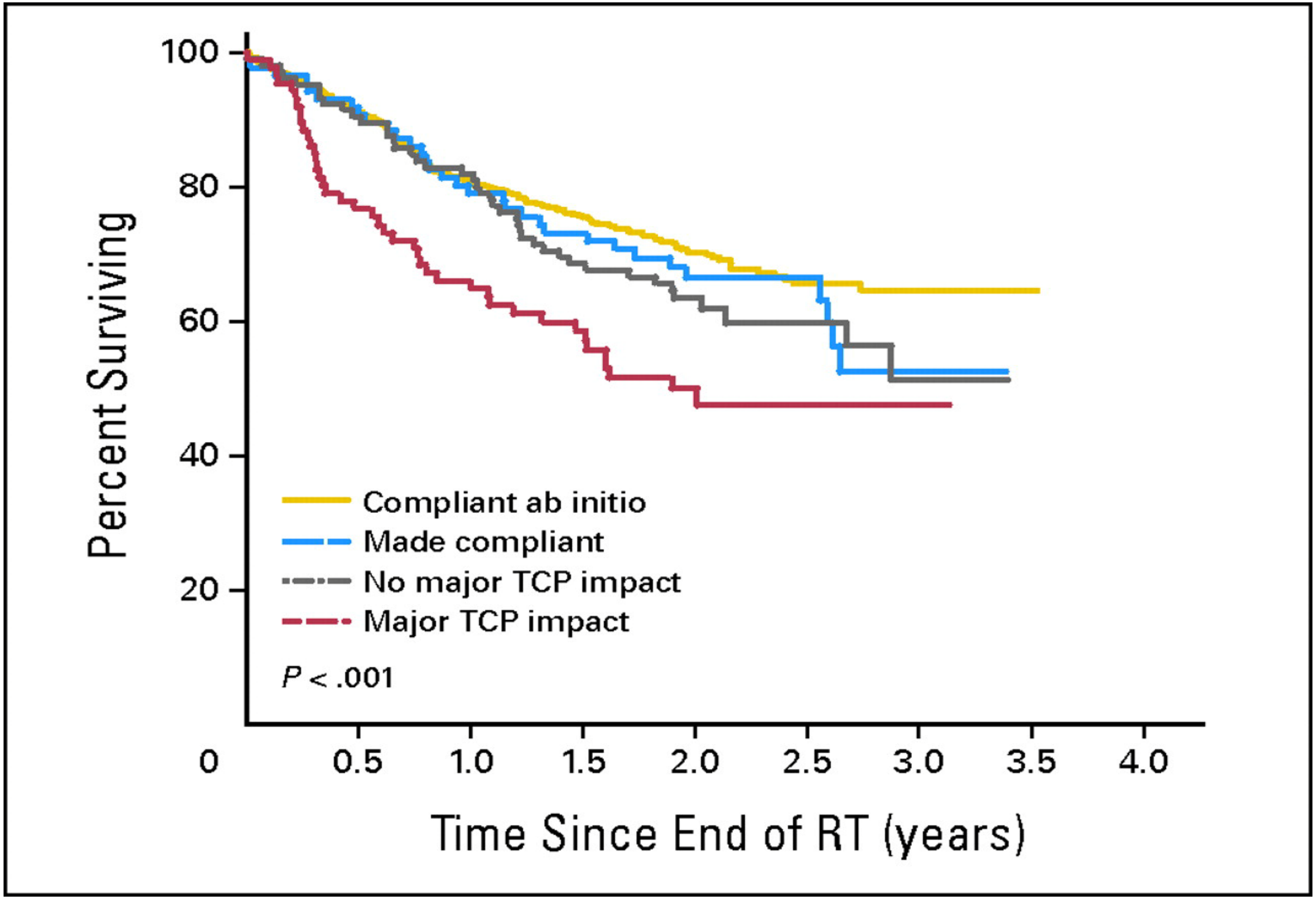
Impact of radiotherapy quality



Peters L J et al. JCO 2010;28:2996-3001

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How to improve?

- Need for a common language: ICRU
- Need for delineation guidelines and anatomical knowledge
- No absolute truth so need to specify according to which guidelines we contour
- Heterogeneity in understanding/interpreting the guidelines
- Need for teaching in contouring
- Need for evaluation in contouring

ICRU Guidelines (ICRU50): volume definition

- Volumes defined prior/ during treatment planning:
  - Gross Tumor Volume (GTV)
  - Clinical Target Volume (CTV)
  - Planning Target Volume (PTV)

  - Organs At Risk (OAR)

  - Treated Volume
  - Irradiated Volume

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Tumor Gross Volume: GTV

- Macroscopic tumor volume visible or palpable

- Includes:
  - Primary tumor
  - Macroscopically involved lymph nodes
  - Metastases

- When tumor has been surgically removed there is no GTV

Tumor Gross Volume: GTV

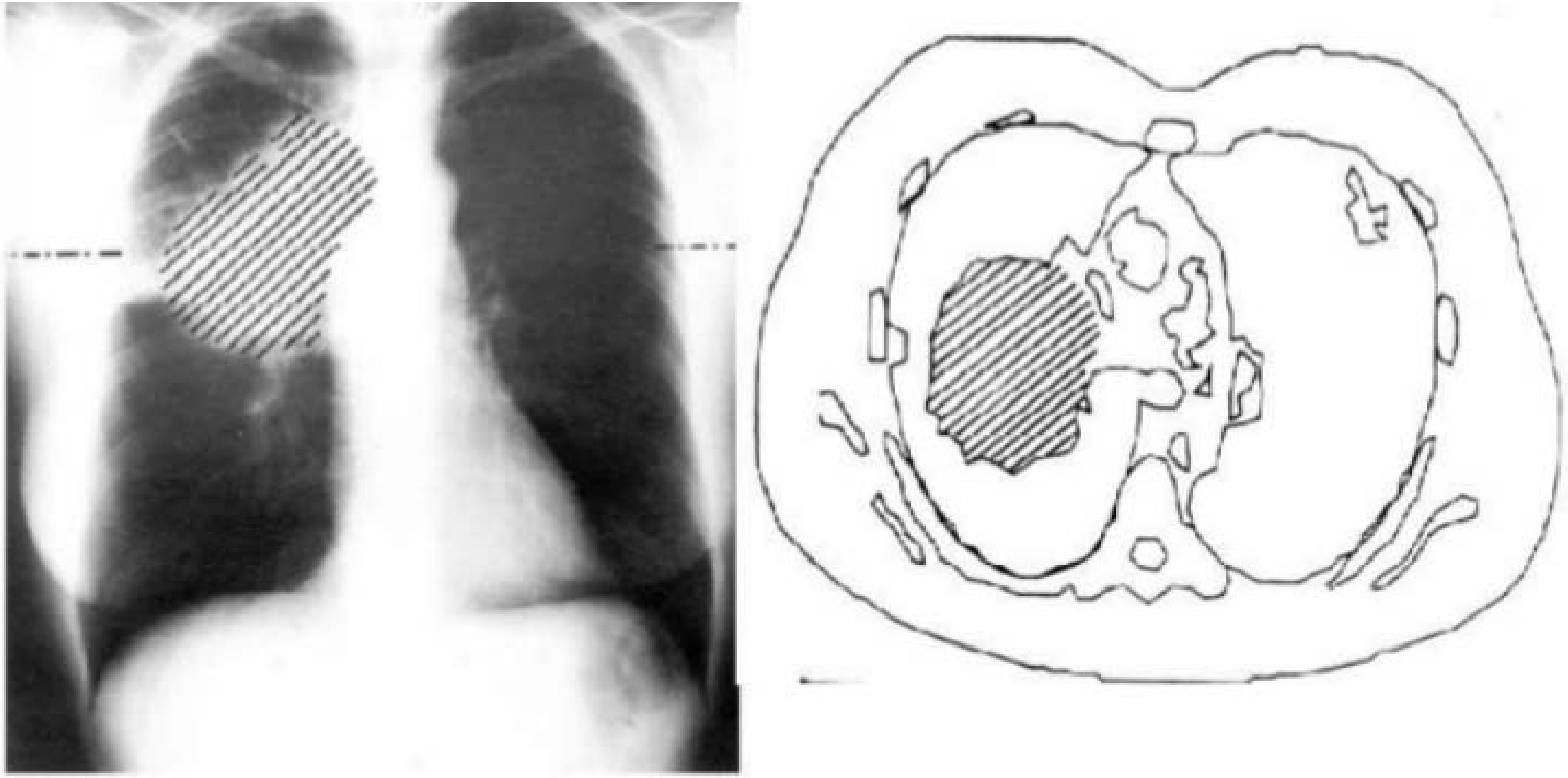
- GTV is defined based on clinical data (inspection, palpation) and imaging (CT, MR, US, PET depending on it's relevance for the tumor site)

- Definition of the GTV allows for TNM classification of the disease

- Definition of the GTV allows for tumor response assessment

- Adequate dose to GTV is therefore crucial for tumor control

Tumor Gross Volume: GTV



PET scans in delineation of lung cancer

Contents lists available at ScienceDirect

Radiotherapy and Oncology 101 (2011) 284–290

Contents lists available at ScienceDirect

- FDG-PET has an established role in contouring NSCLC
- Changes the tumor GTV in about 30–60% of patients
- Changes the nodal GTV in 9–39% of patients mainly through detection of occult metastases not seen on CT, lowering the risk of nodal recurrences

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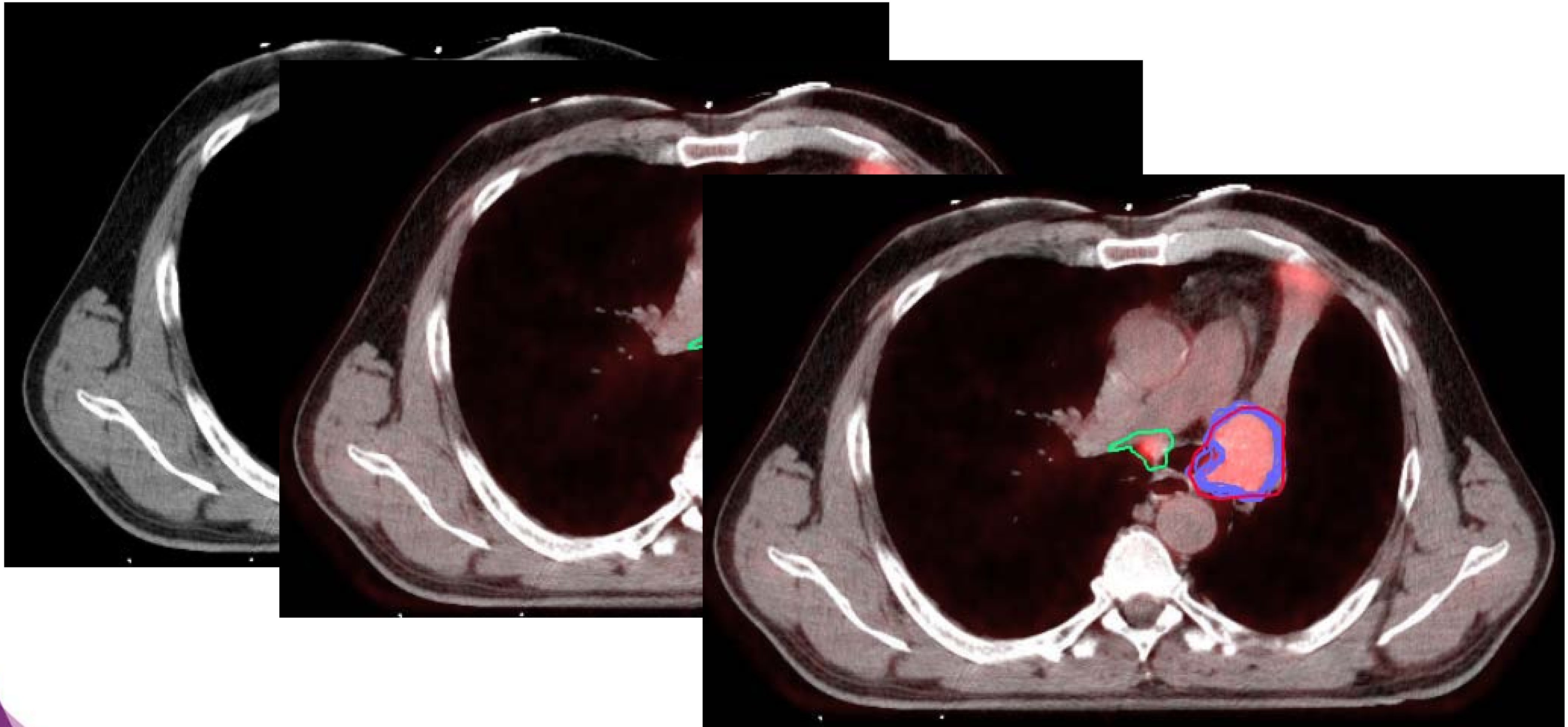
Tumor Gross Volume: GTV

- Adequate high quality imaging is a key point



Images from the FALCON platform; case Lung PET: Vienna 2013

Clinical Target Volume: CTV

- Includes GTV + microscopic extension of the tumor

- Volume to adequately cover to ensure treatment efficacy weather treatment is delivered with a curative or a palliative intent

- CTV delineation is based on local and loco regional capacity/probability of extension of the tumor

- Includes potential micromets surrounding the GTV

- Includes potential micromets in tumor’s drainage territory

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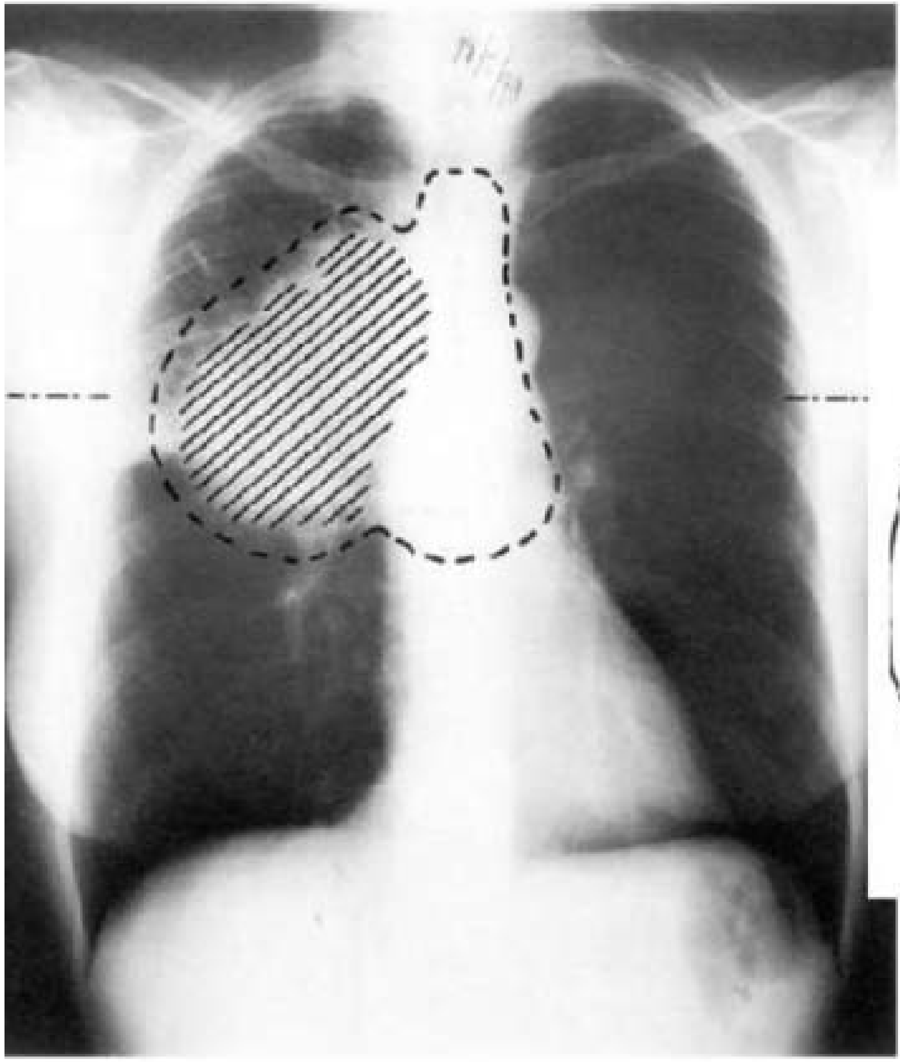
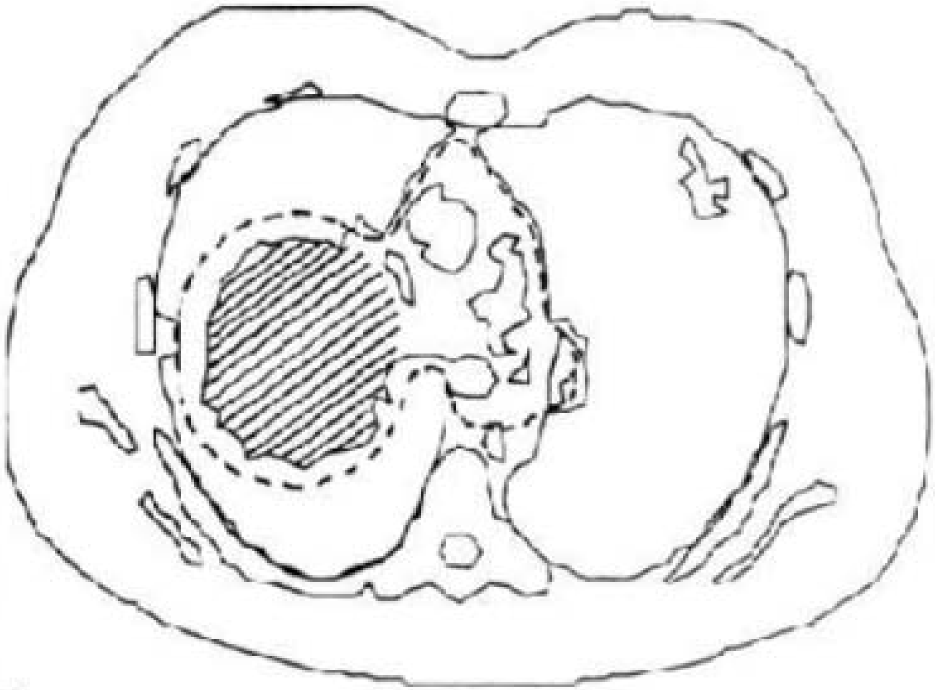
CTV





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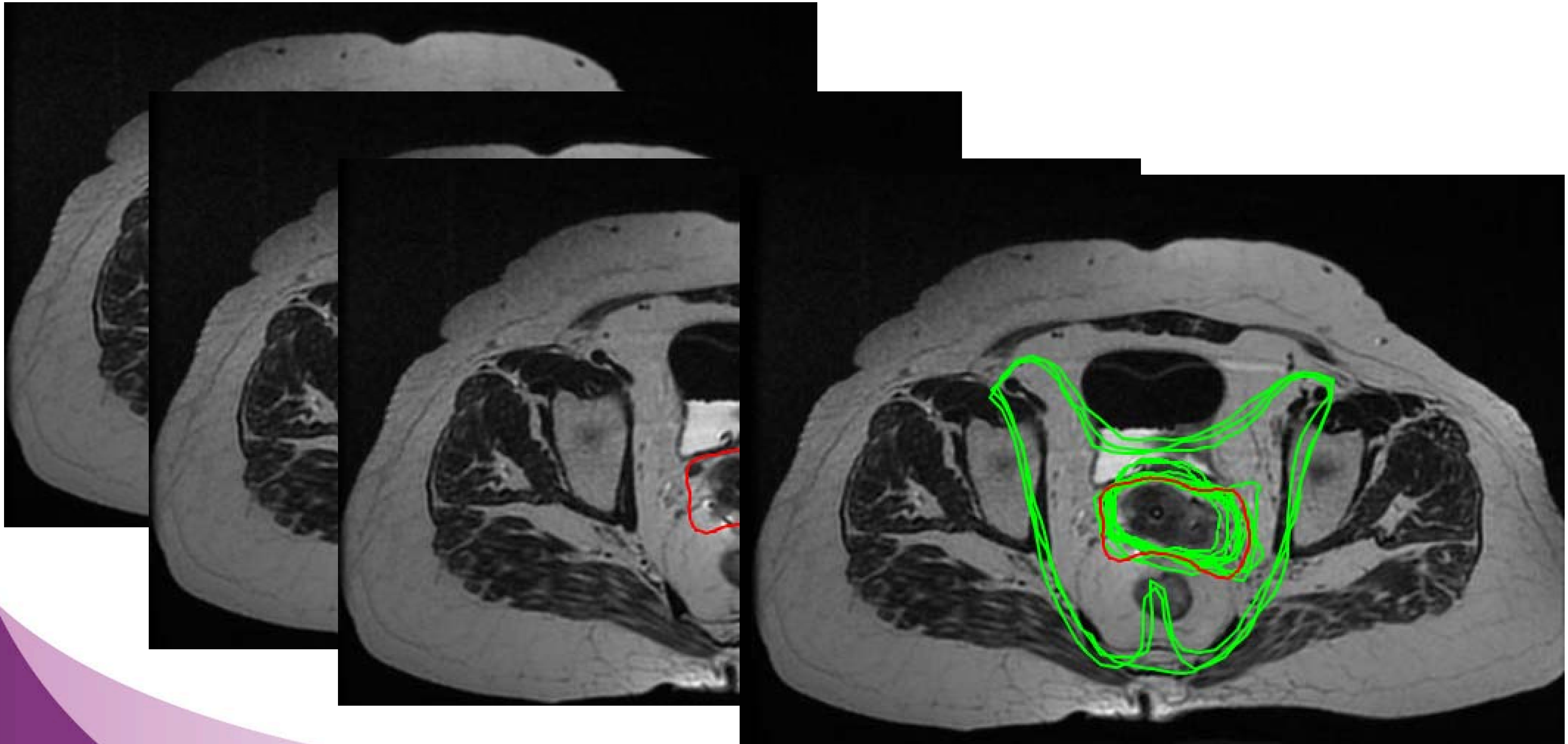
Clinical Target Volume: CTV

- High quality images are a key point for CTV delineation as well
- Margins adapted to anatomical boundaries



GTV and CTV

- Definition based on:
  - Anatomy
  - Morphology
  - Imaging
  - Biology
  - Natural history of each tumor site

- **But GTV and CTV delineation are independent of the technique used**

Planning Target Volume: PTV

- Geometric concept
- Meant to allow for an adequate coverage of the CTV what ever the technique, the movements, the set up uncertainties are
- Volume used for treatment planning
- Volume used for reporting

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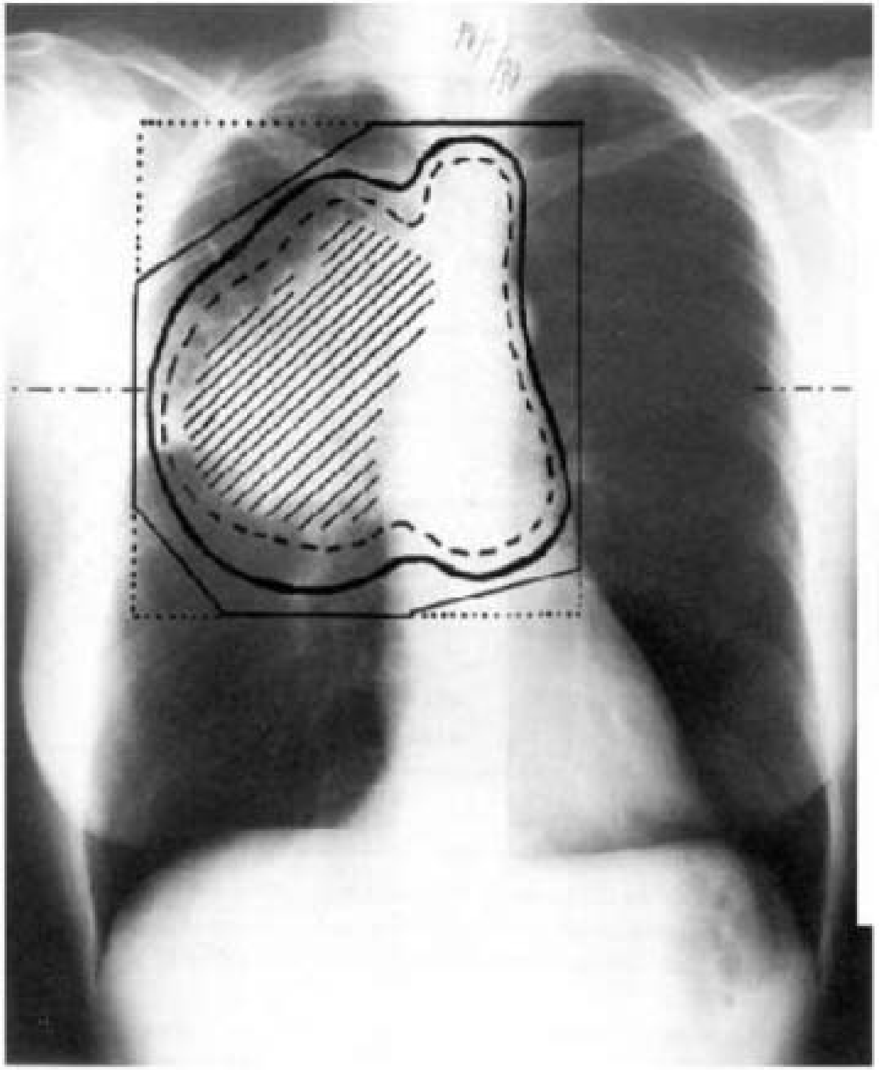
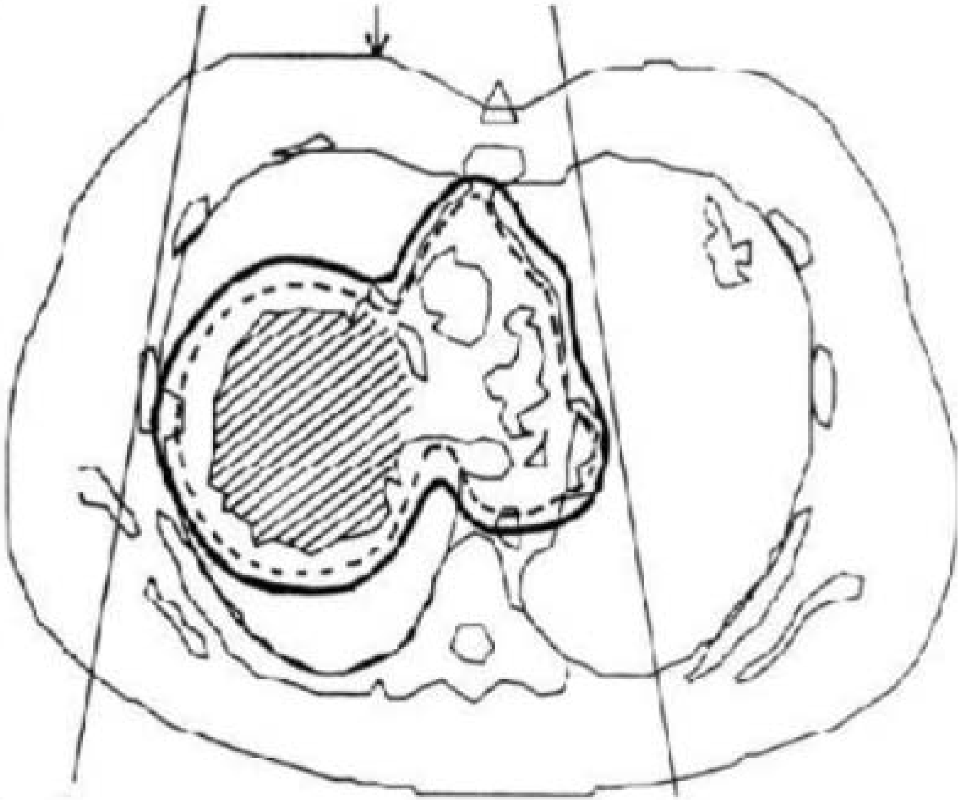
PTV





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Irradiated Volume and Treated Volume: IRV and TV

- IRV: Defined as the volume receiving a significant dose on surrounding normal tissues (Organs At Risk)
- Different from the treated volume which is meant to be treated
- Both depend on the technique used
- Both can be evaluated on the dosimetry but IRV evaluation is rather limited by most TPS
  - Ex: dose estimation outside of the treated field when using non coplanar beams

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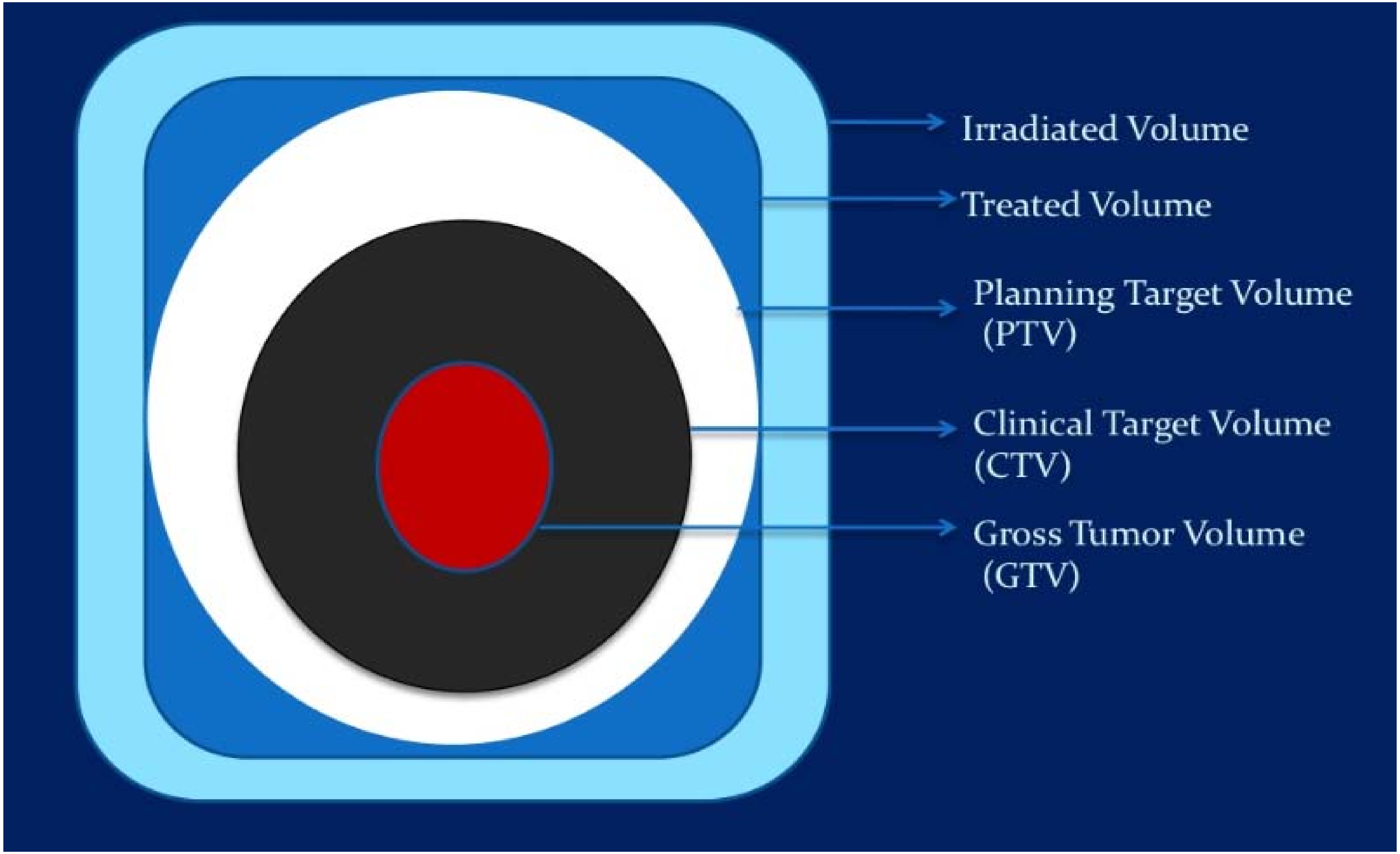
ICRU 50



Irradiated Volume
Treated Volume
Planning Target Volume (PTV)
Clinical Target Volume (CTV)
Gross Tumor Volume (GTV)

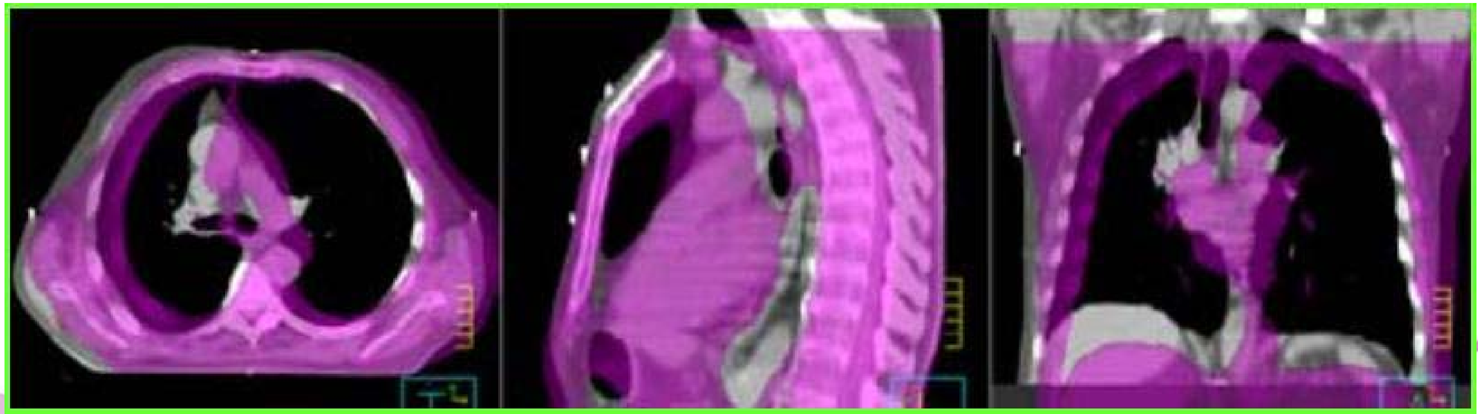
ICRU 62 (in addition to ICRU 50)

- Introduces the Conformity Index: **CI= treated volume/ PTV**

- Recommendations on anatomical and geometrical margins

- Internal Margins: **IM** are margins integrating physiological movements (breathing, bowel/ rectum/ bladder repletion, swallowing…)

- Internal Target Volume: **ITV** is defined as the volume taking into account Internal Margins



Set up Margin: SM

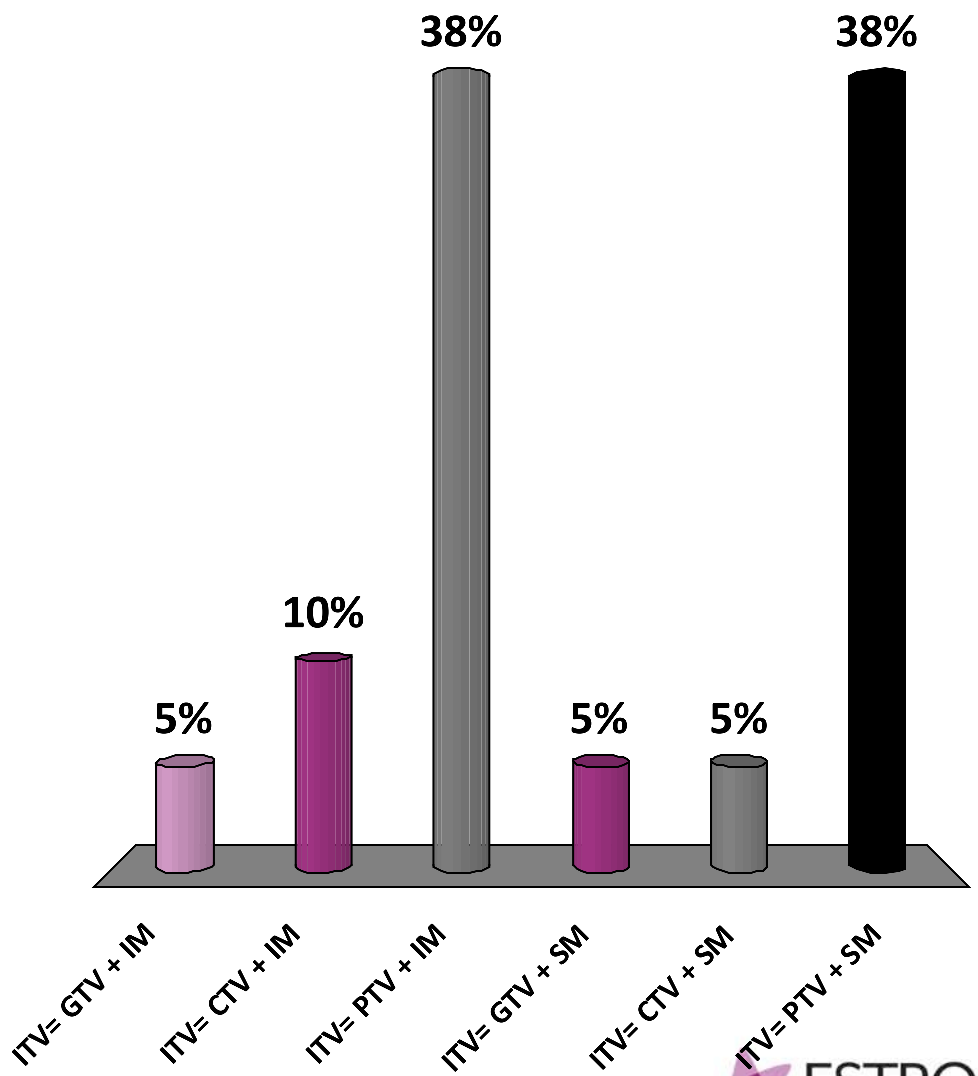
- Margins related to patient positioning:

  - ➢ Positioning uncertainties due to patient external movements
  - ➢ Positioning uncertainties due to body markers
  - ➢ Mechanical uncertainties due to immobilization device precision

- Depend on the technique (ex: tracking) and immobilization material and protocols (ex: thickness of painting markers or tattoos)

What is the definition of the ITV?

A. ITV= GTV + IM
B. ITV= CTV + IM
C. ITV= PTV + IM
D. ITV= GTV + SM
E. ITV= CTV + SM
F. ITV= PTV + SM



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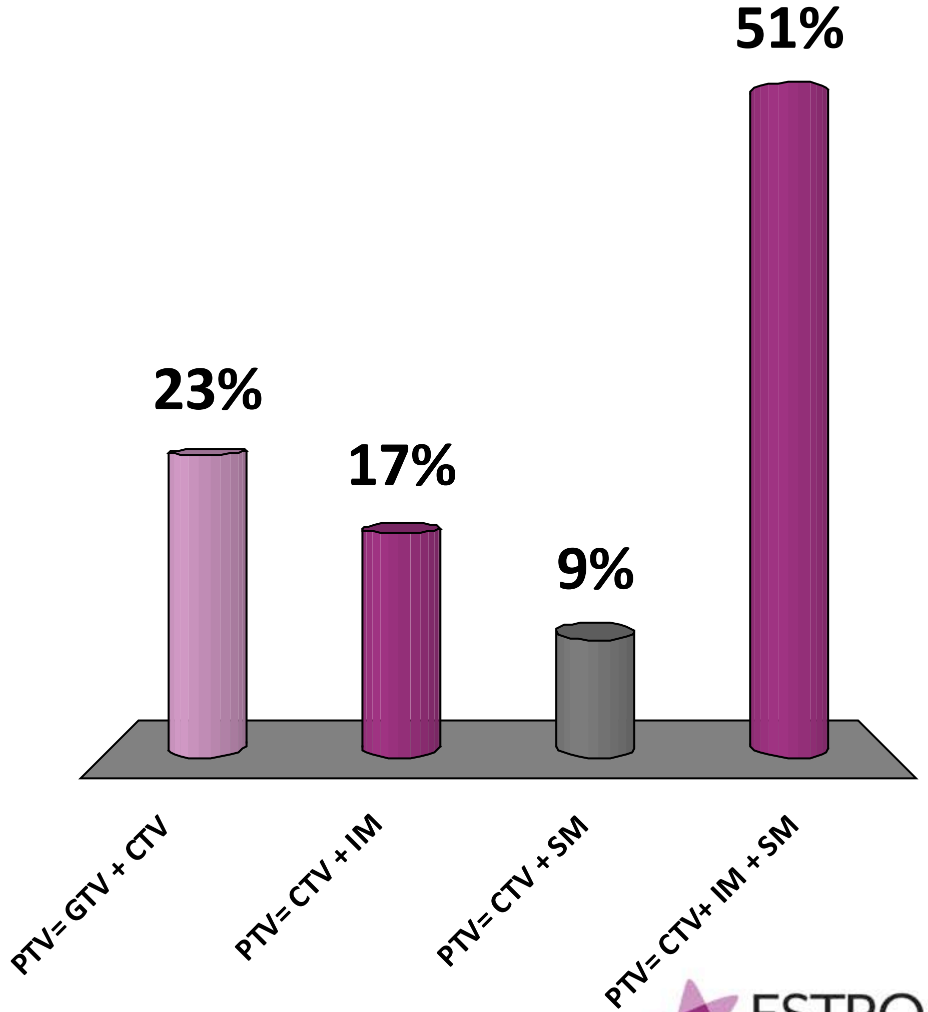
What is the definition of the PTV?

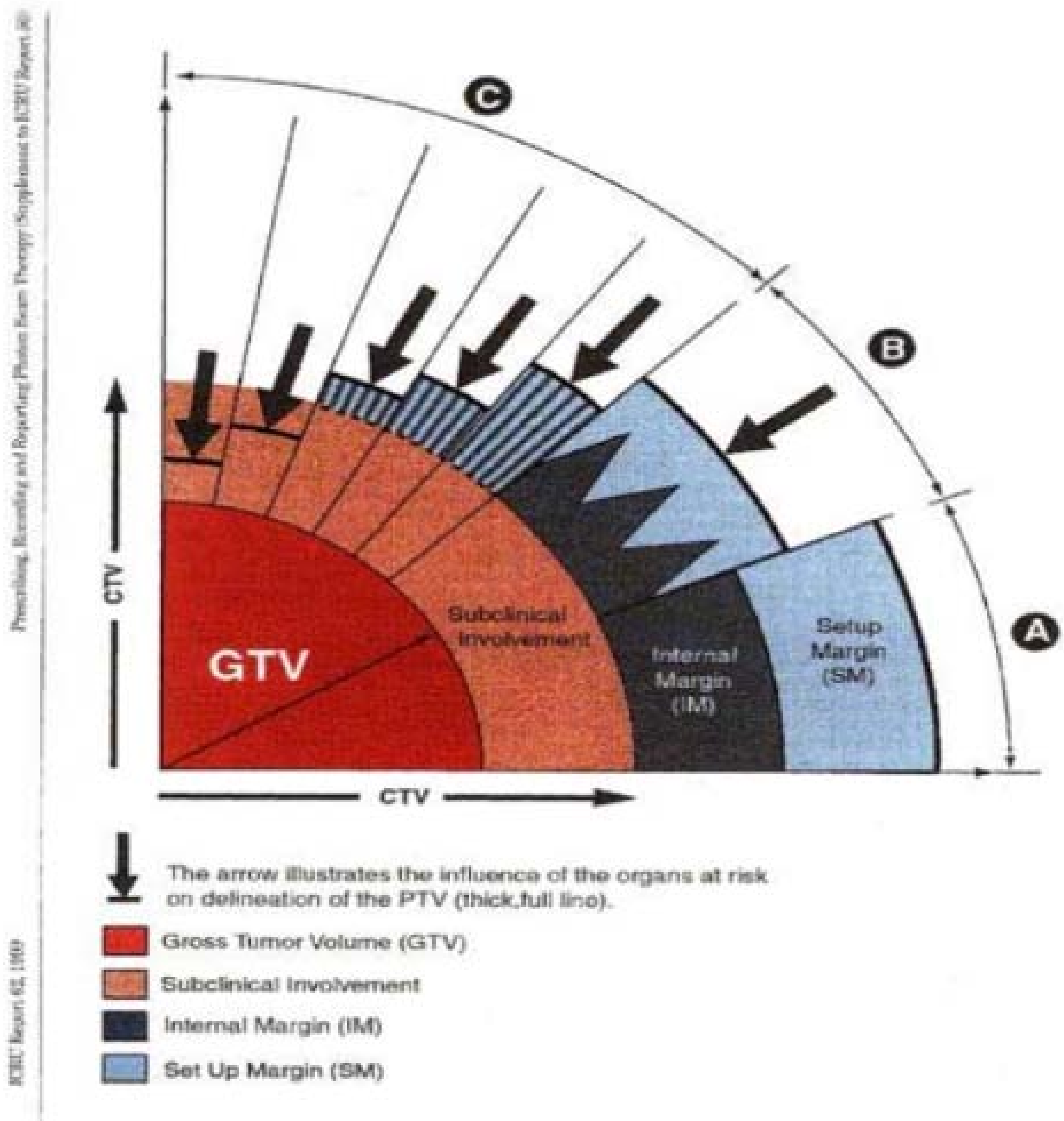
A. PTV= GTV + CTV

B. PTV= CTV + IM

C. PTV= CTV + SM

D. PTV= CTV+ IM + SM




C
B
A
CTV
CTV
GTV
Subclinical
Involvement
Internal
Margin
(IM)
Setup
Margin
(SM)
The arrow illustrates the influence of the organs at risk
on delineation of the PTV (thick,full line).
Gross Tumor Volume (GTV)
Subclinical Involvement
Internal Margin (IM)
Set Up Margin (SM)

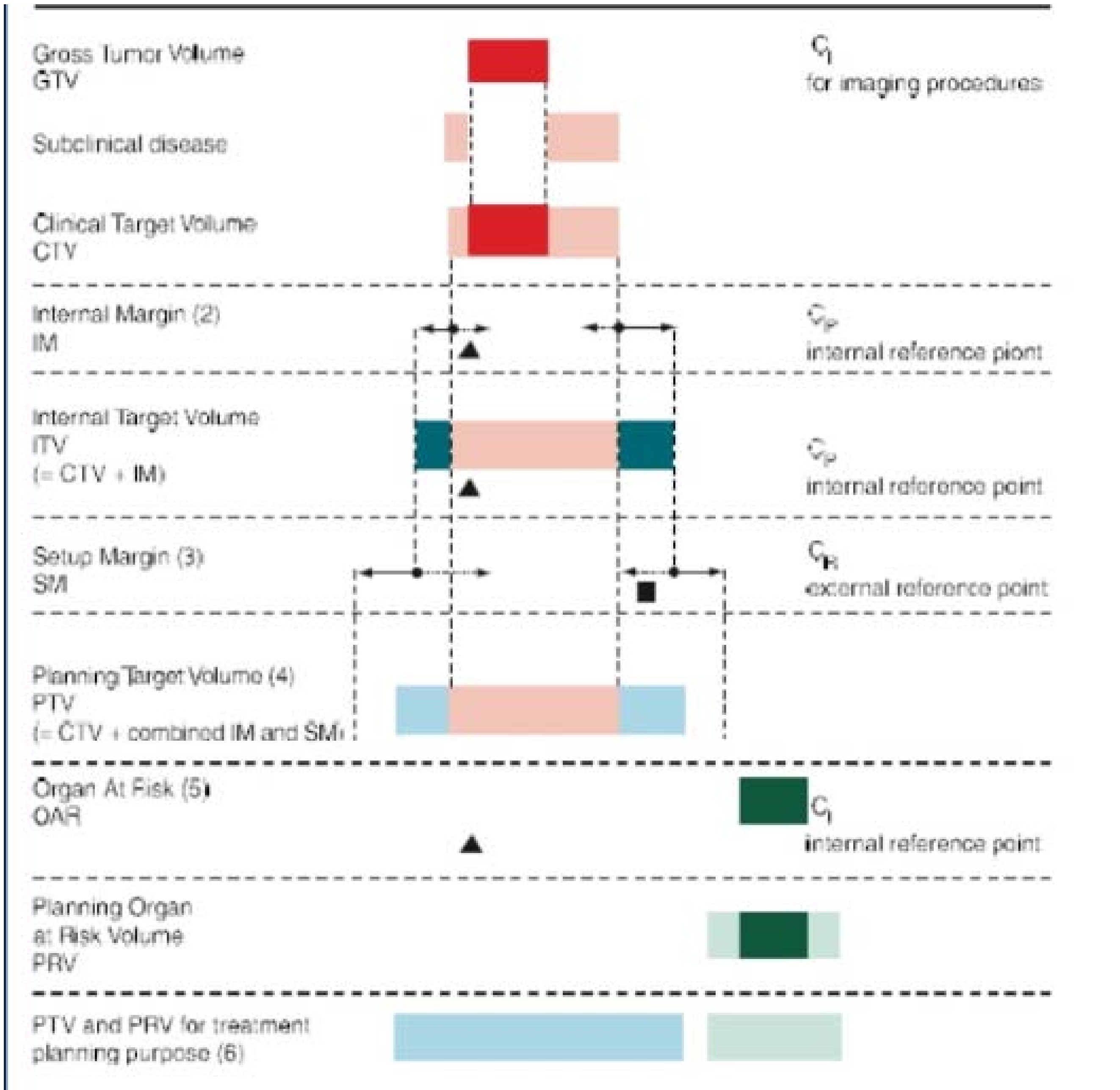


Fig. 3.21 Treatment volumes according to the ICRU-62 report

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Contouring Guidelines

- Ex: ESTRO breast guidelines

Radiotherapy and Oncology 114 (2015) 3–10

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

ESTRO consensus guidelines

ESTRO consensus guideline on target volume delineation for elective radiation therapy of early stage breast cancer

CrossMark

Birgitte V. Offersen [a,*], Liesbeth J. Boersma [b], Carine Kirkove [c], Sandra Hol [d], Marianne C. Aznar [e], Albert Biete Sola [f], Youlia M. Kirova [g], Jean-Philippe Pignol [h], Vincent Remouchamps [i], Karolien Verhoeven [j], Caroline Weltens [j], Meritxell Arenas [k], Dorota Gabrys [l], Neil Kopek [m], Mechthild Krause [n], Dan Lundstedt [o], Tanja Marinko [p], Angel Montero [q], John Yarnold [r], Philip Poortmans [s]

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Contouring Guidelines

Table 1
ESTRO delineation guidelines for the CTV of lymph node regions, breast and postmastectomy thoracic wall for elective irradiation in breast cancer (see figures).

Borders per region	Axilla level 1 CTVn_L1	Axilla level 2 CTVn_L2	Axilla level 3 CTVn_L3	Lymph node level 4 CTVn_L4	Internal mammary chain CTVn_IMN	Interpectoral nodes CTVn_interpectoralis	Residual breast CTVp_breast	Thoracic wall CTVp_thoracic wall
Cranial	Medial: 5 mm cranial to the axillary vein Lateral: max up to 1 cm below the edge of the humeral head, 5 mm around the axillary vein	Includes the cranial extent of the axillary artery (i.e. 5 mm cranial of axillary vein)	Includes the cranial extent of the subclavian artery (i.e. 5 mm cranial of subclavian vein)	Includes the cranial extent of the subclavian artery (i.e. 5 mm cranial of subclavian vein)	Caudal limit of CTVn_L4	Includes the cranial extent of the axillary artery (i.e. 5 mm cranial of axillary vein)	Upper border of palpable/ visible breast tissue; maximally up to the inferior edge of the sterno-clavicular joint	Guided by palpable/visible signs; if appropriate guided by the contralateral breast; maximally up to the inferior edge of the sterno-clavicular joint
Caudal	To the level of rib 4 – 5, taking also into account the visible effects of the sentinel lymph node biopsy	The caudal border of the minor pectoral muscle. If appropriate: top of surgical ALND	5 mm caudal to the subclavian vein. If appropriate: top of surgical ALND	Includes the subclavian vein with 5 mm margin, thus connecting to the cranial border of CTVn_IMN	Cranial side of the 4th rib (in selected cases 5th rib, see text)	Level 2's caudal limit	Most caudal CT slice with visible breast	Guided by palpable/visible signs; if appropriate guided by the contralateral breast

B.Offersen et al radiother oncol 2015

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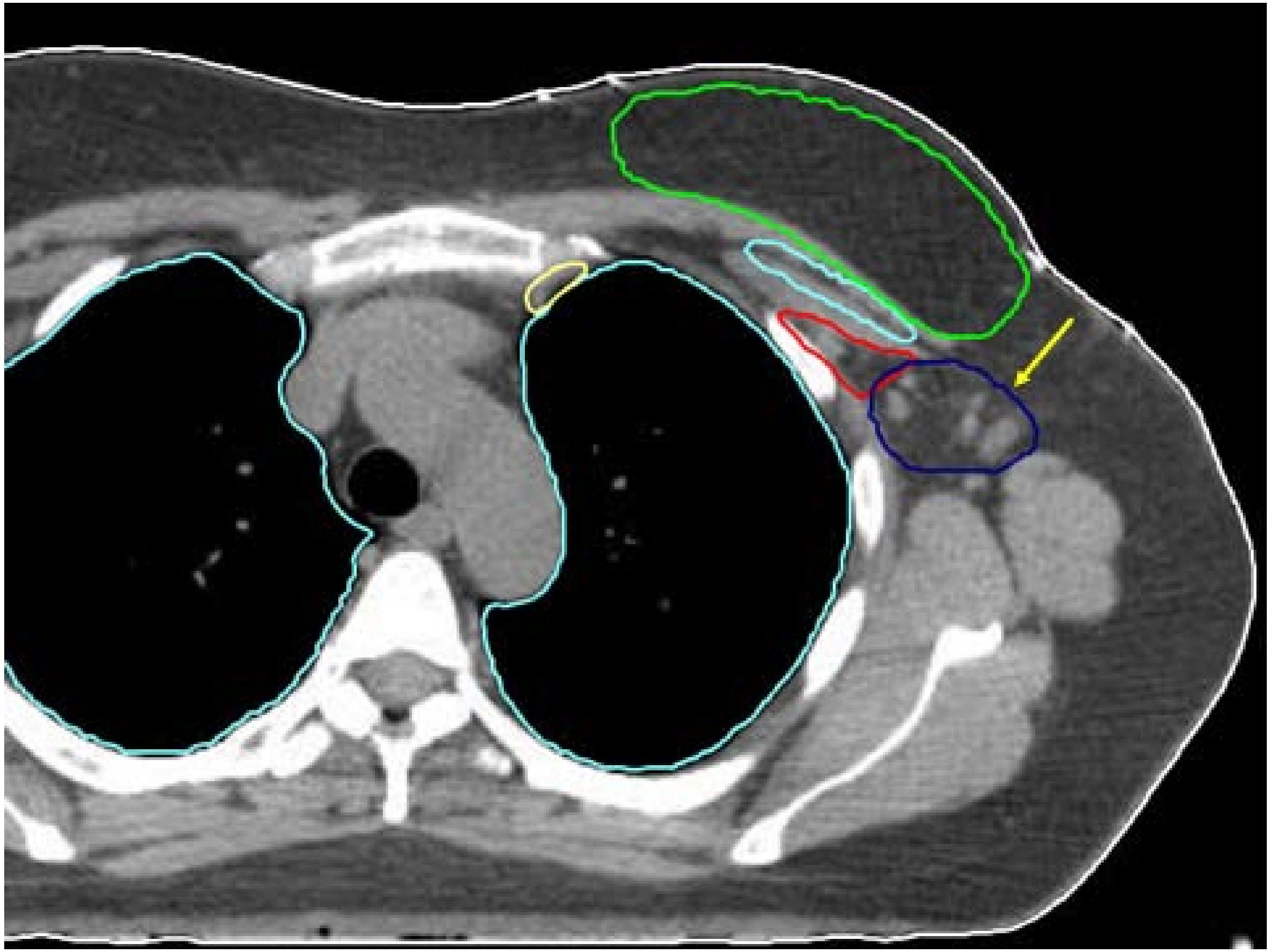
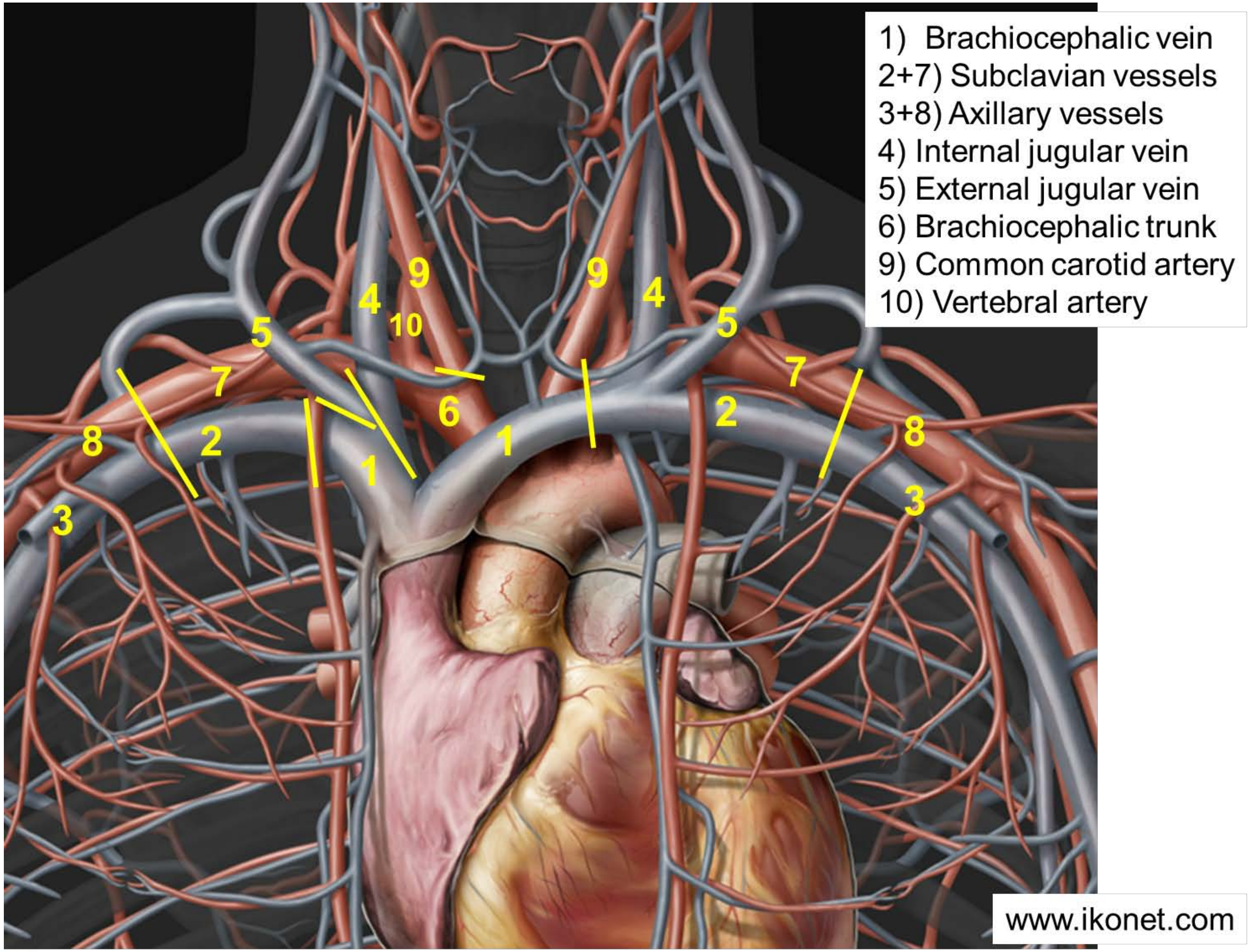
Contouring Guidelines

- Ex: ESTRO breast guidelines



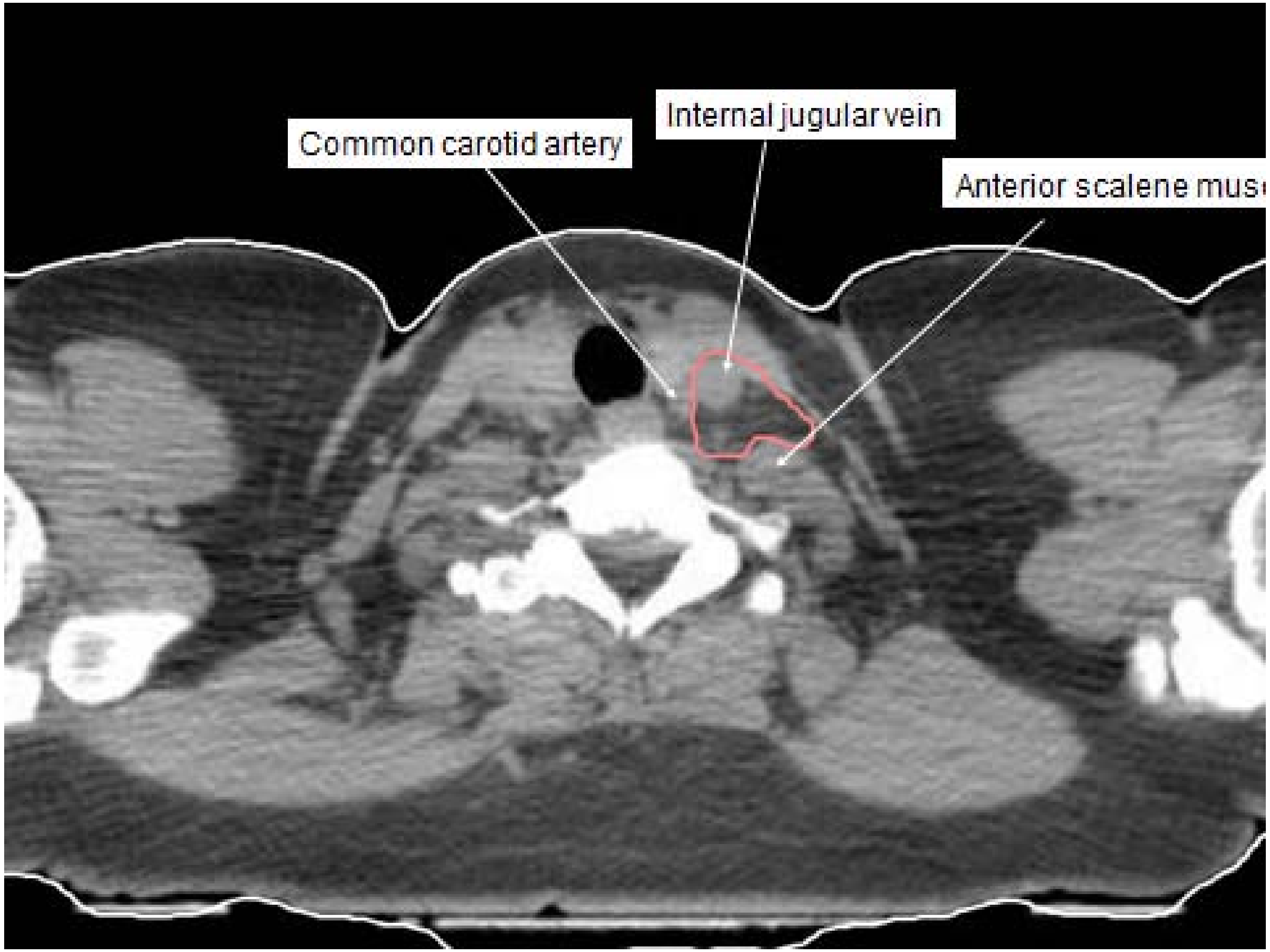
Contouring guidelines

- Anatomical basis are the key!



Contouring guidelines

- Anatomical basis are the key!



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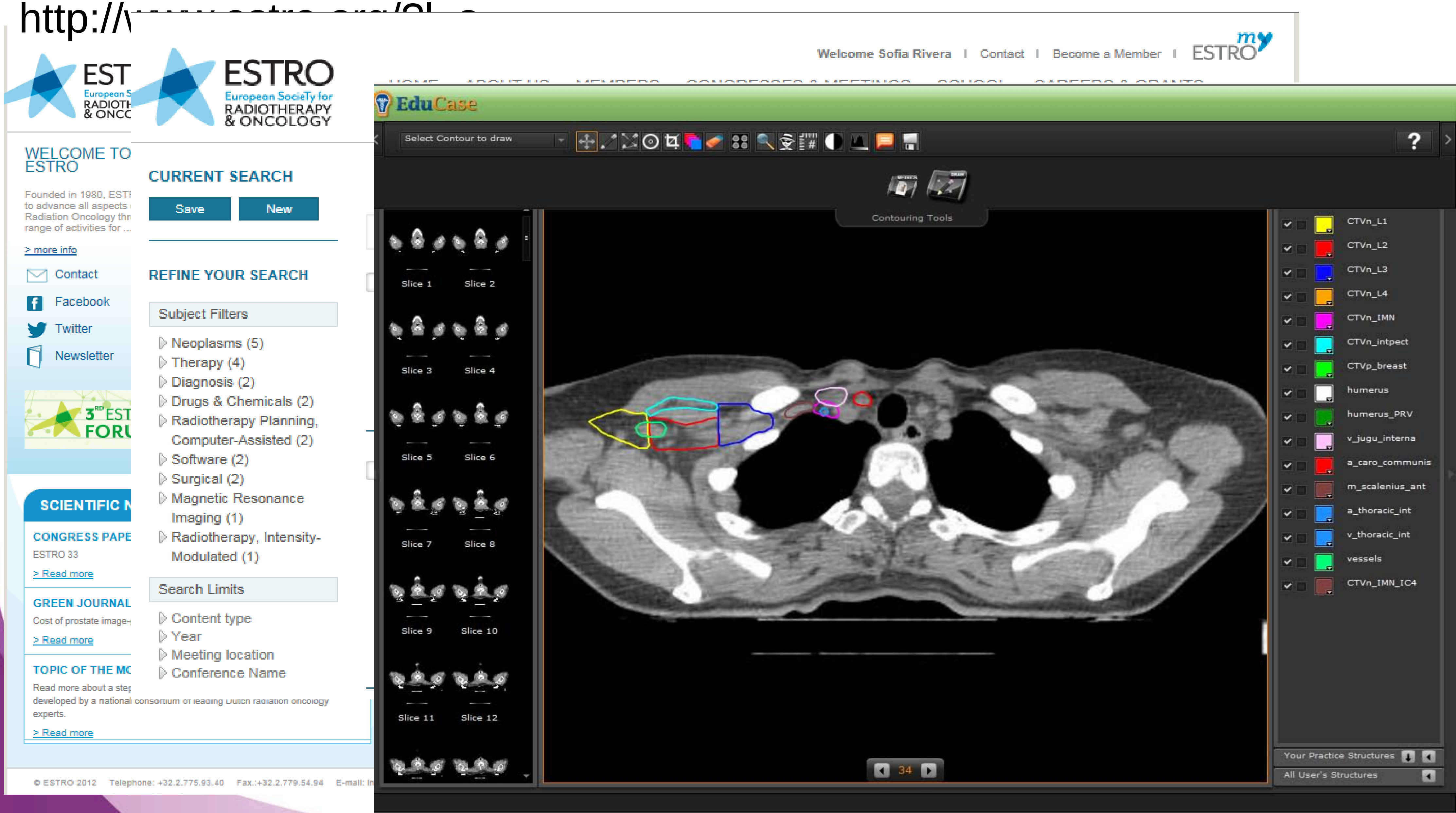
http://



Take home messages:

- Inter observer variability in contouring can translate in a systematic error

- Need for a common language: ICRU

- Need for delineation guidelines

- Need for teaching in contouring

Thank you for you attention

Any question?

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ORGANS AT RISK DELINEATION

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Discipline of Radiation Therapy
Trinity College Dublin

ARTT
Applied Radiation Therapy
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Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

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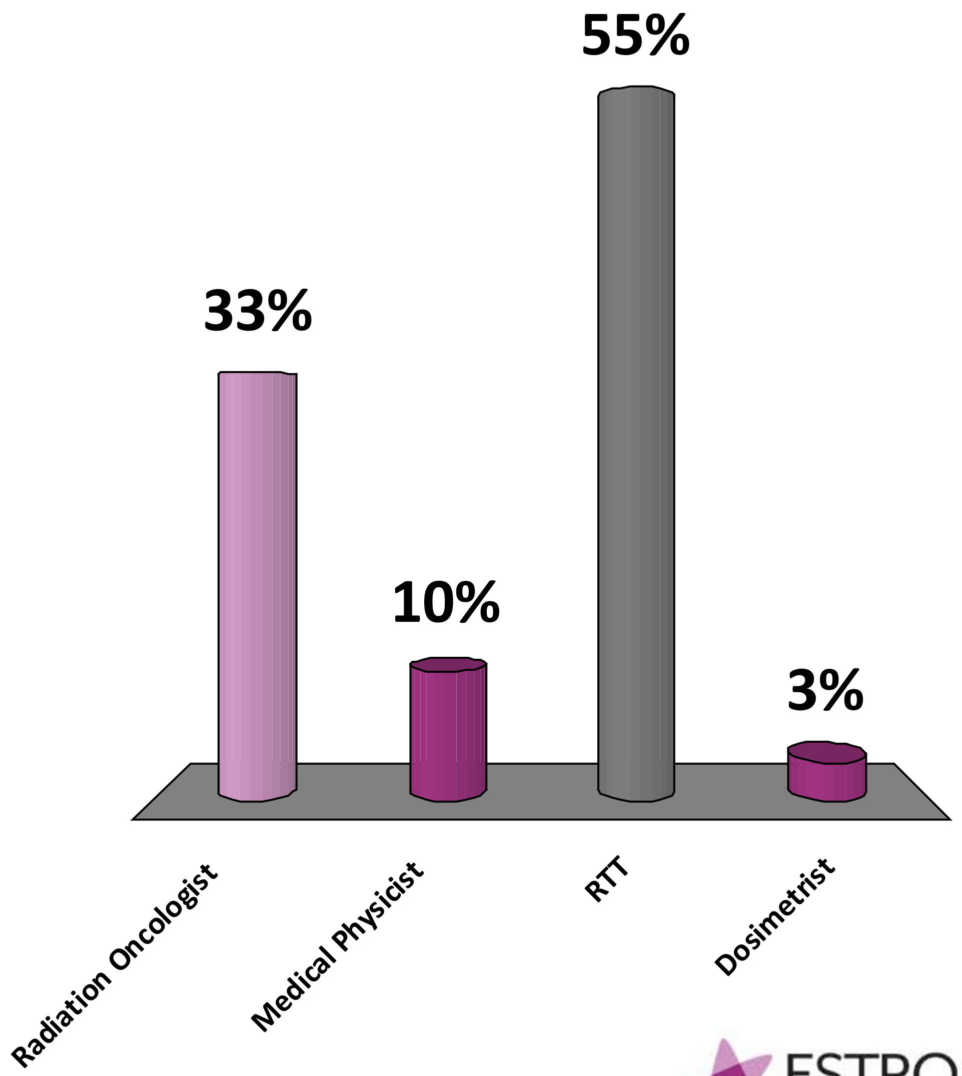
Learning Outcomes

- Discuss the changing roles and responsibilities of RTTs for Organ at Risk (OAR) delineation
- Identify skills required to delineate OARs
- Indentify tools for implementing RTT OAR delineation into your department
- Identify common OARs based on current clinical trials and evidence based consensus guidelines
- Discuss the impact of inaccurate OAR delineation on the evaluation of plan quality

Question Time!

In your department, OARs are contoured by:

A. Radiation Oncologist
B. Medical Physicist
C. RTT
D. Dosimetrist



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The New RTT!



"flexible inter professional boundaries" *Schick et al., 2011*



"The goal of a radiation therapist undertaking OAR delineation is logical role expansion." *(Schick et al 2011)*

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Tools for Implementation and Facilitating Change

- Education
  - ➢ Online courses
  - ➢ Support from national and international bodies

- Culture of the department
  - ➢ Clinical mentorship
  - ➢ Commitment to evidence based practice
  - ➢ Commitment to role development
  - ➢ Shared goals within the MDT
  - ➢ Open communication

↓ Intra and interobserver variability

Why Are OARs So Important?

- Do no harm culture of medicine
  - Decrease impact of radiation to our patients

- Requirement for inverse planning optimisation process
  - IMRT
  - VMAT

- Generates DVH information and assists in prediction of toxicity
  - Serial and Parallel structures
  - Assessment of clinical impact and disturbance on daily activities

Why Is *Accuracy* So Important?

- OAR delineation has significant impact on dose calculation and plan quality in dosimetry

- IMRT and VMAT are inverse planning techniques and as such are driven by volumes
  - Target and OAR relationship

- Accurate imaging ensures:
  - Decrease in interobserver variability
  - DVH calculation
  - Greater confidence in predicting toxicity
  - “reduction in inter- and intra-observer variability and therefore unambiguous reporting of possible dose-volume effect relationships” *(van der Water, 2009)*

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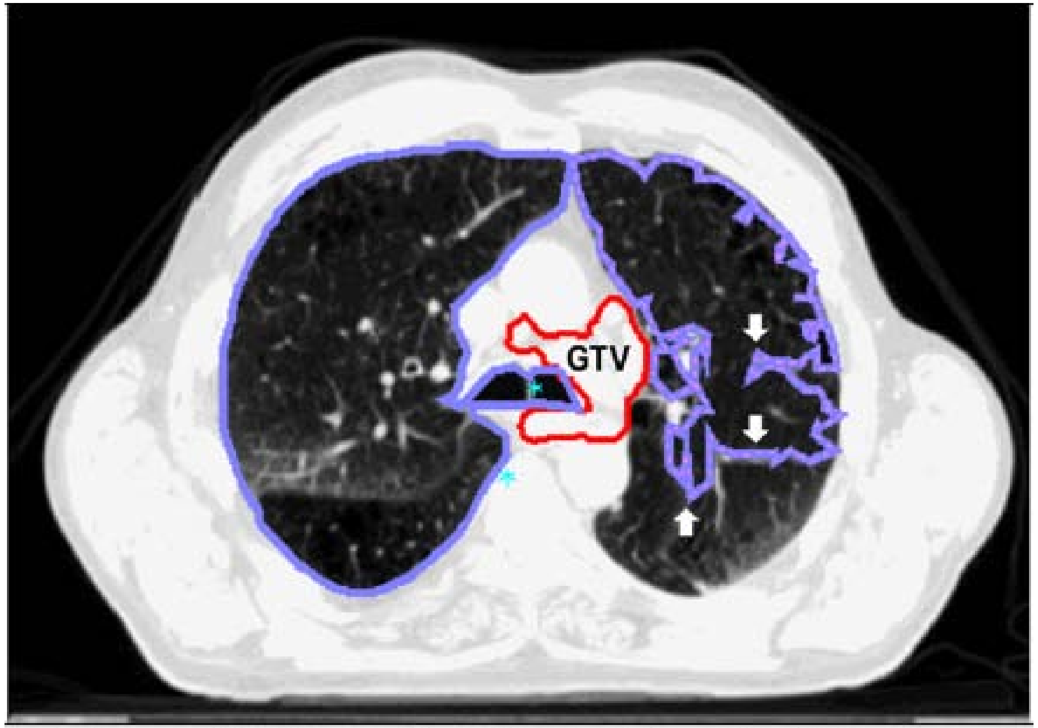
Why Is ***Accuracy*** So Important?

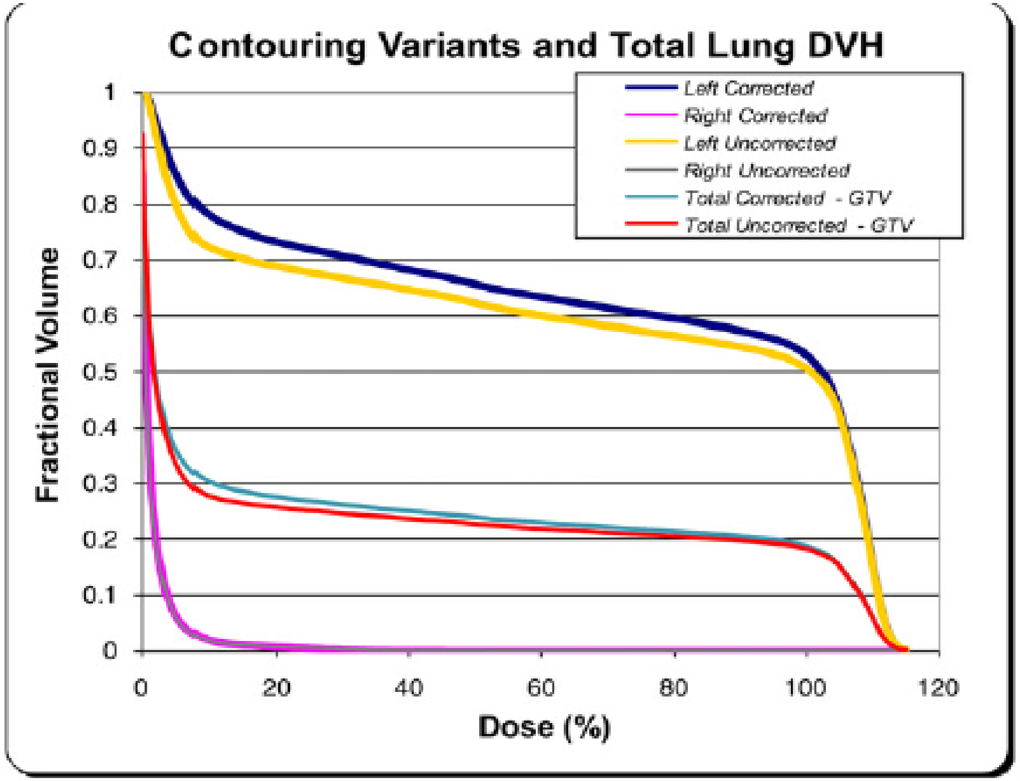
- Consistency and uniformity
  - Within the department
    - Prospective data collection
    - Analysis of local practice and impact on patients
  - Within the context of clinical trials
    - Compliance with trial specifications
    - Allows for collections of data and comparison of outcomes and toxicity at a larger international scale

Why is ***Accuracy*** So Important?



A: Lung Contour - Autotrack Failure (white arrows)

What is wrong in this picture?
What has caused this?
What impact would this have?



C: Lung DVH differences of contouring variants

Research

Open Access

Inter-observer variability in contouring the penile bulb on CT images for prostate cancer treatment planning

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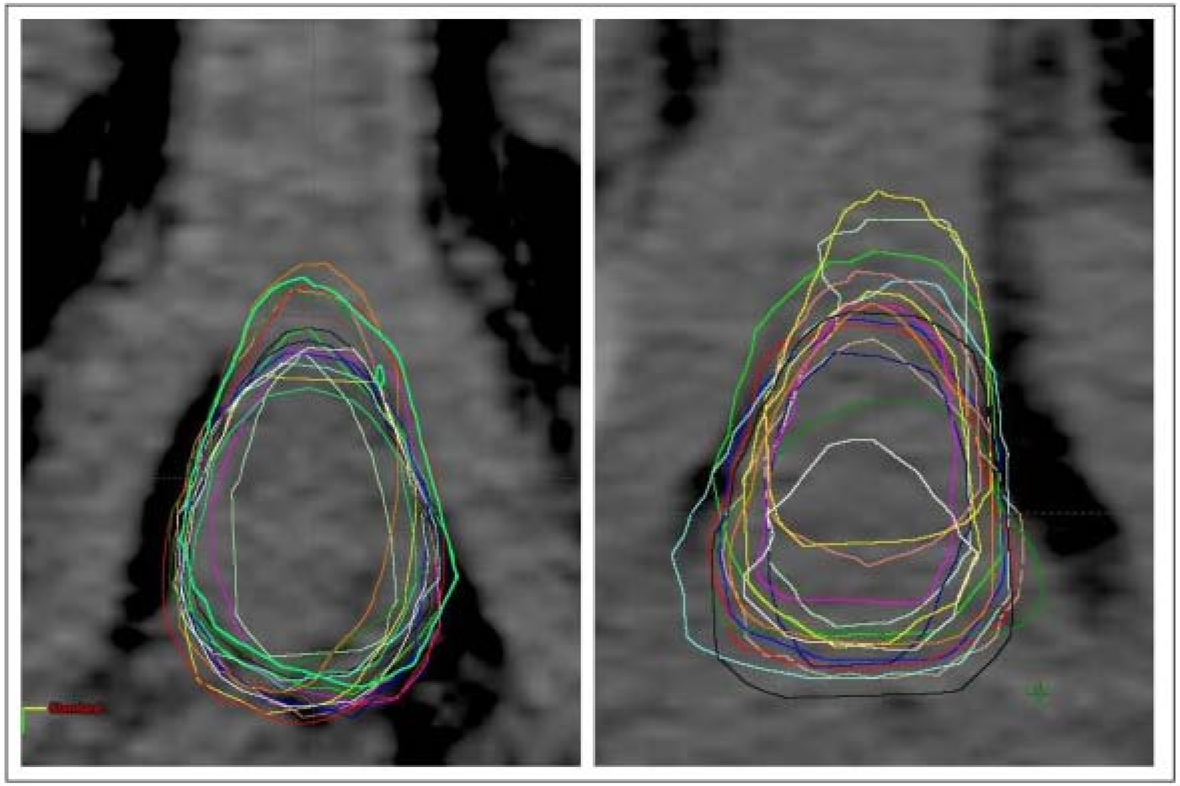
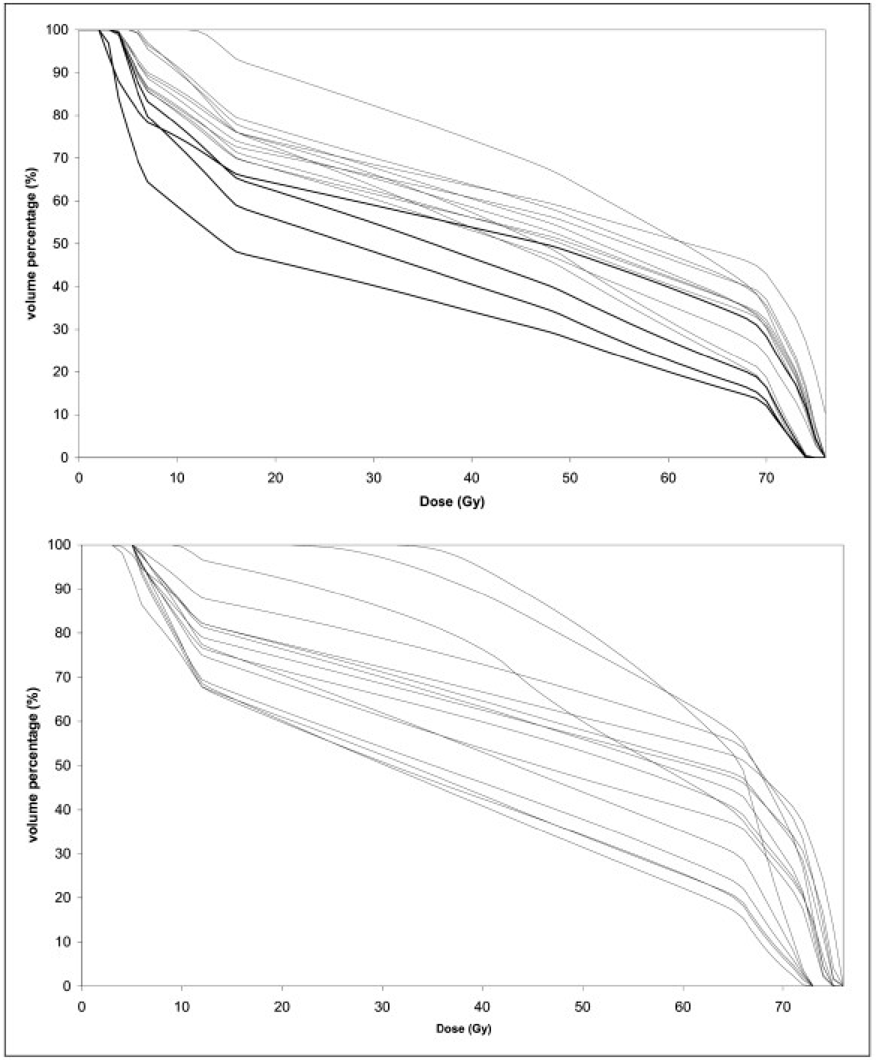


A plot of the central slice of PB contours drawn by all observers of two patients: one with the lowest inter-observer volume variation (left side) and one with the largest inter-observer volume variation (right side).

Perna *et al. Radiation Oncology* 2011 **6**:123 doi:10.1186/1748-717X-6-123



Graphs showing PB dose-volume histograms relative to the two patients in figure 5: the first (top of figure) with the lowest impact of inter-observer variation on DVH parameters, and the second (bottom of the figure) with the largest impact of inter-observer variation on DVH parameters.

Possible recommendations put forward by the authors:

- Contouring by a single user
- Introduction of MRI into practice
- Improving the agreement between observers (consensus)

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What Are Some of the Challenges in Delineation

- Windowing
- Length to contour
- Over reliance on auto-contouring
- Contrast
- Motion
- Exclusion of disease
- Patient positioning

Tools Available

- Windowing

Approximate Window Levels			
	Xio	**Eclipse**	**Pinnacle**
Brain	W200 / L70	W200 / L-70	W300 / L900
Bone	W1400 / L400	W1400 / L -400	W1400 / L800
Soft Tissue	W600 / L40	W600 / L-40	W500 / L850

- Interpolation
  - Can be attractive! But always be aware!
  - 1.25mm cuts through Head and Neck, rich in radiosensitive structures, potential dental artefacts
  - Contour daily rectal volume on CBCT

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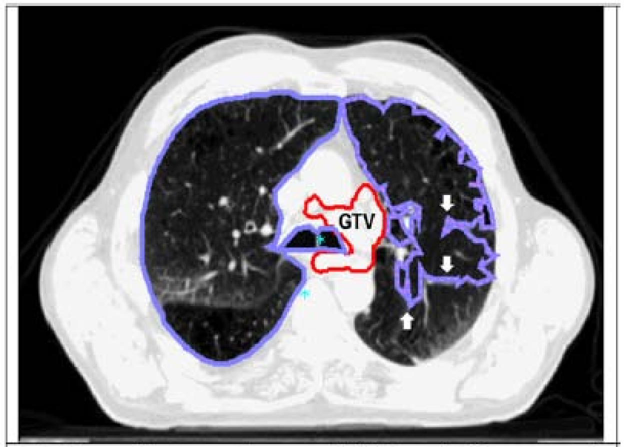
Tools Available

- Atlas based Auto segmentation
    - “atlas-based automatic segmentation tool … is timesaving but still necessitates review and corrections by an expert” *(Daisne and Blumhofer, 2013)*

- Auto segmentation
    - Spindle snake, Flood fill…
    - “Common errors include…using the auto-threshold contouring tools in the TPS and not editing the resulting errors” *(Gay et al., 2012)*



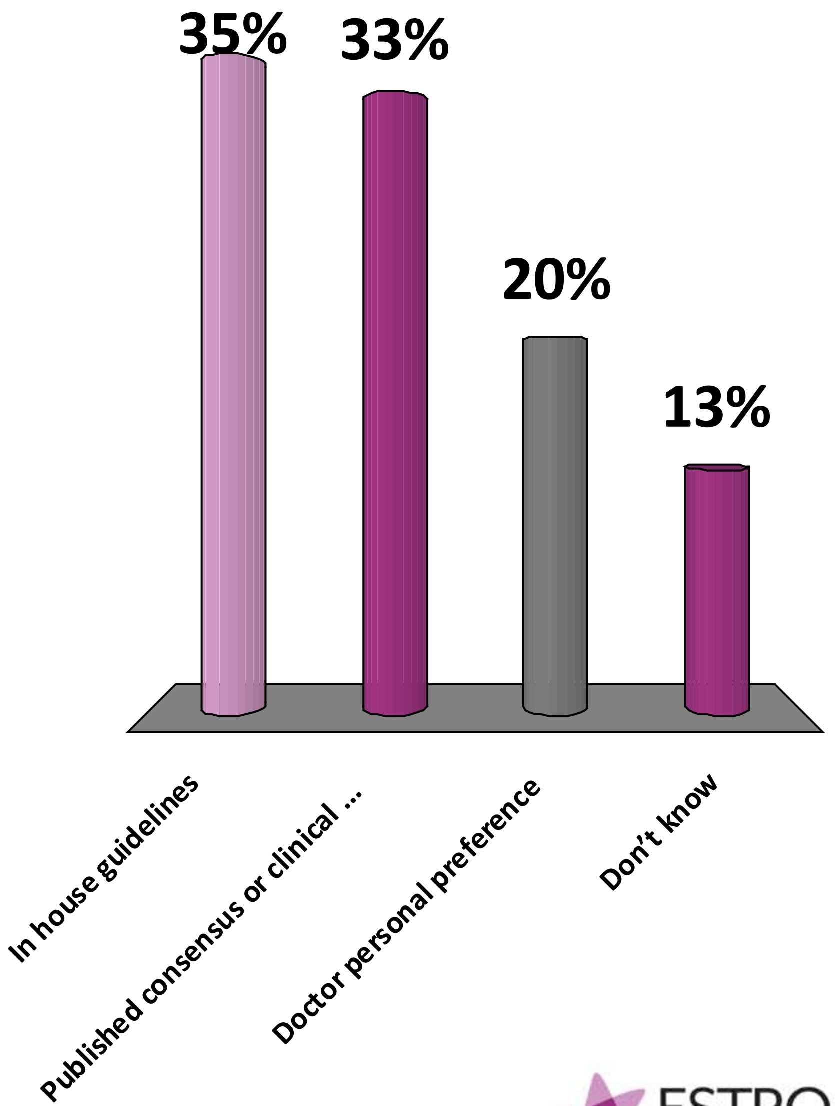
A: Lung Contour - Autotrack Failure (white arrows)

Trachea included and portion of lung missing

Question Time!

In your current practice, what defines how OARs are contoured?

A. In house guidelines
B. Published consensus or clinical trials
C. Doctor personal preference
D. Don’t know



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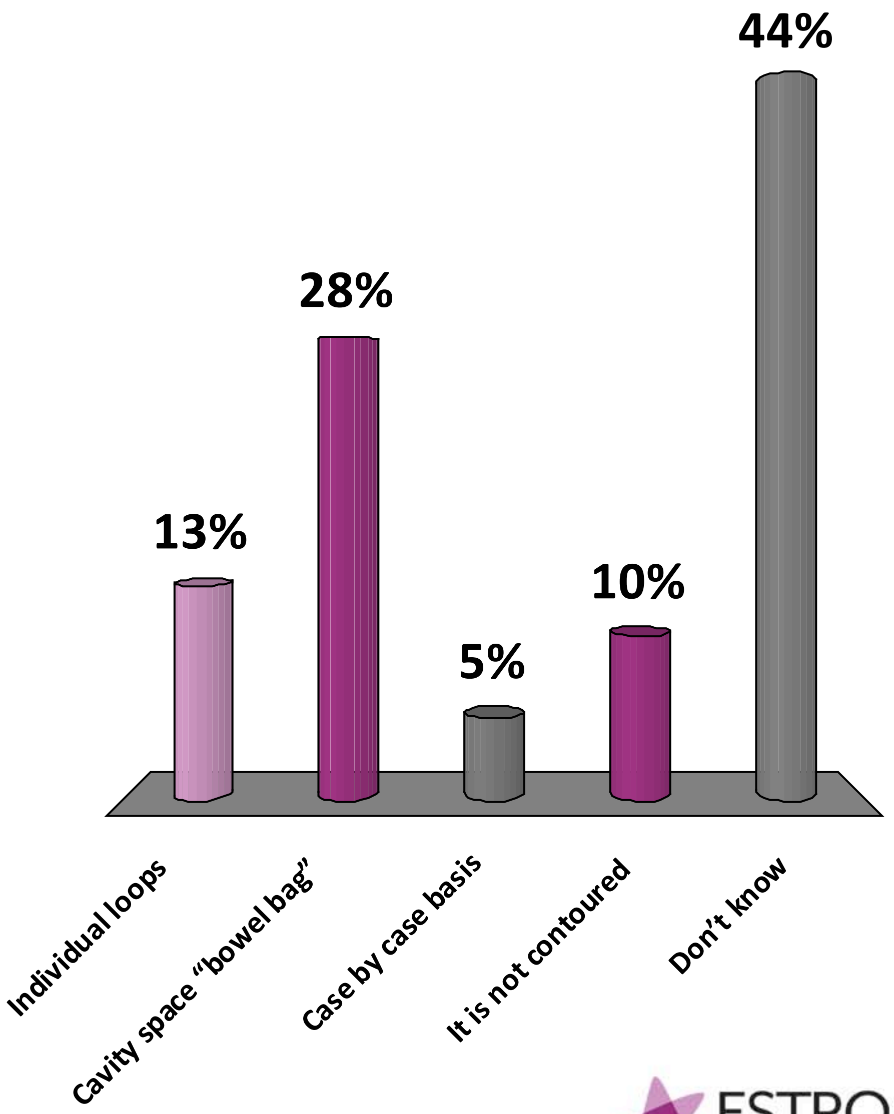
In your current practice how is the small bowel contoured?

A. Individual loops
B. Cavity space “bowel bag”
C. Case by case basis
D. It is not contoured
E. Don’t know



Is there Consensus?

eLearning Modules by Experts

QUANTEC

Contouring Atlases

Clinical Trials

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Let's Look at Some Common OARs in the

Pelvis

Rectum

Small Bowel

Urethra

Bladder

Sigmoid

Femoral heads

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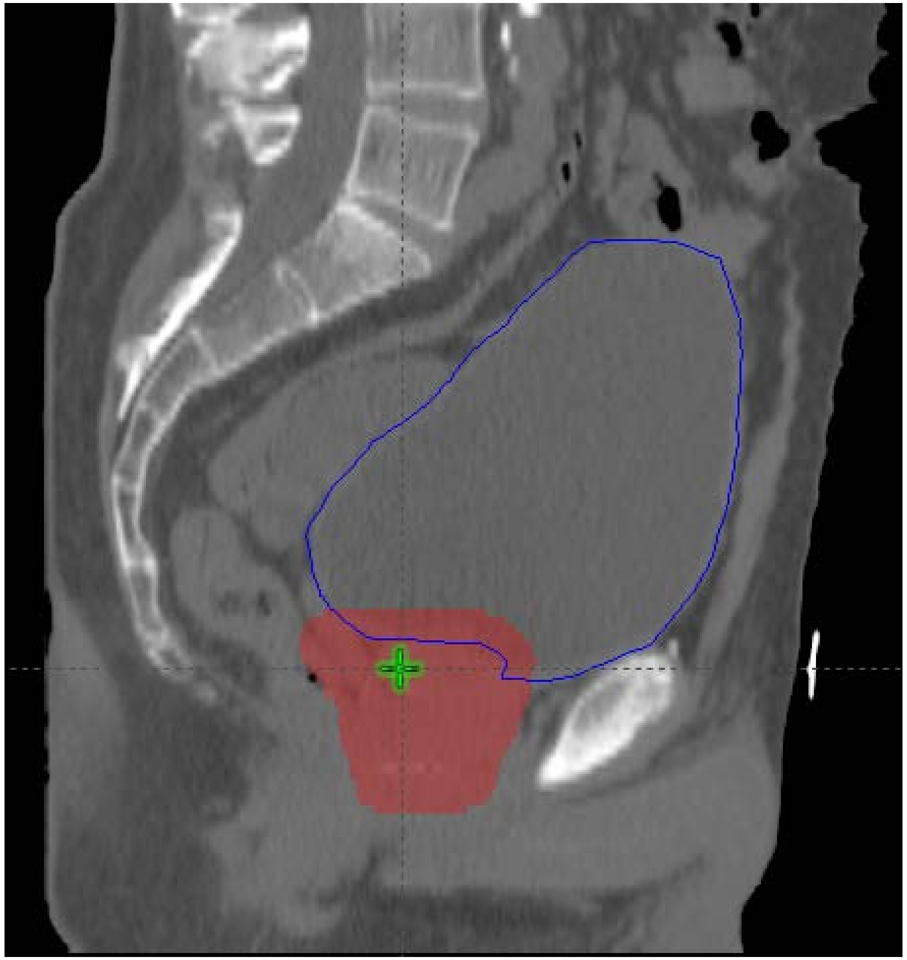
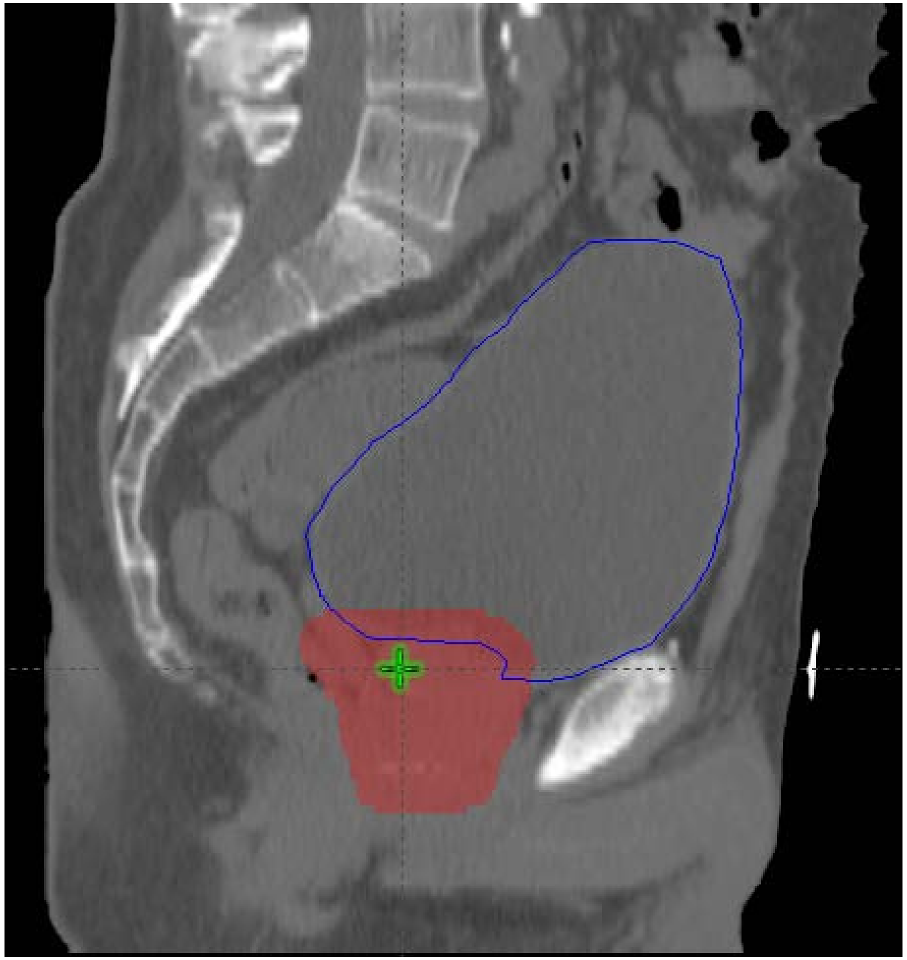
Bladder - Good or Bad?

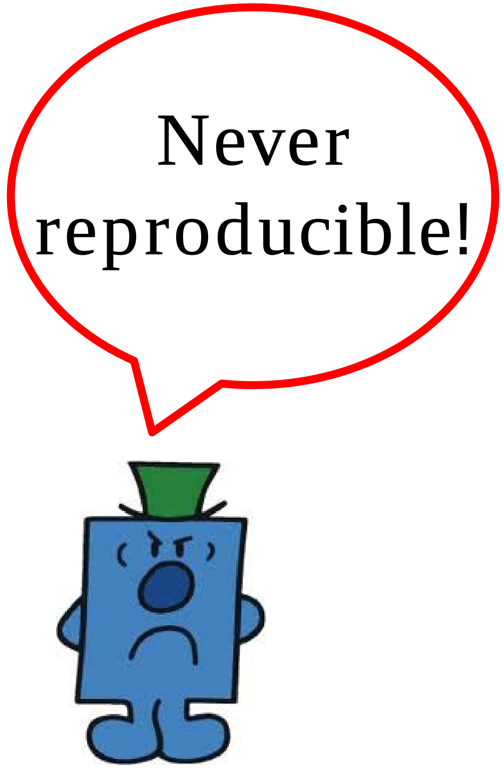


This bladder size is:

A. Good ☺
B. Bad ☹
C. Don’t know???

Bladder - Good or Bad?





What Do the Experts Say? - *Bladder*

- Uncertainties or variations in practice:
  - Bladder wall or solid contour including urine?
  - Whole structure or set length from PTV?
  - Contrast from post prostatectomy (defining the SUA)

  - Easy to define on planning CT but potential of high variation
    - Unrealistic DVH
    - Consider CBCT review and generate bladder DVH of the day

  - Does it impact on target position?
    - What are you treating?
    - Prostate
    - Prostate bed
    - Endometrial cancer

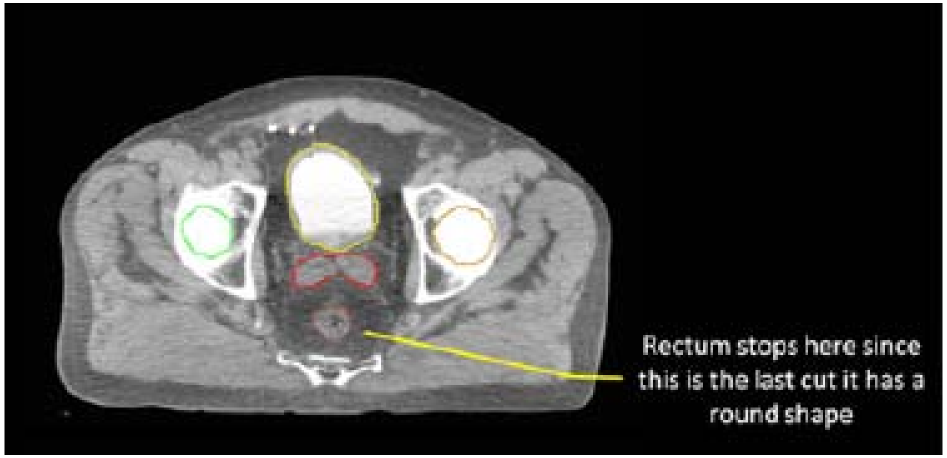
What Do the Experts Say? - *Rectum*

- Uncertainties or variations in practice:
  - ➢ Inferior limit – Anal verge or ischial tuberosities?
  - ➢ Rectal wall or solid including contents?
  - ➢ Set length defined by the PTV volume?

- Recommendations:

Organ segmentation

The rectum should be segmented from above the anal verge to the turn into the sigmoid colon, including the rectal contents. Although there can be variation in defining these landmarks, the superior limit is where the bowel moves anteriorly, close to the inferior level of the sacroiliac joints, and the inferior limit is commonly at the bottom of the ischial tuberosities. In prostate cancer therapy, an empty rectum at

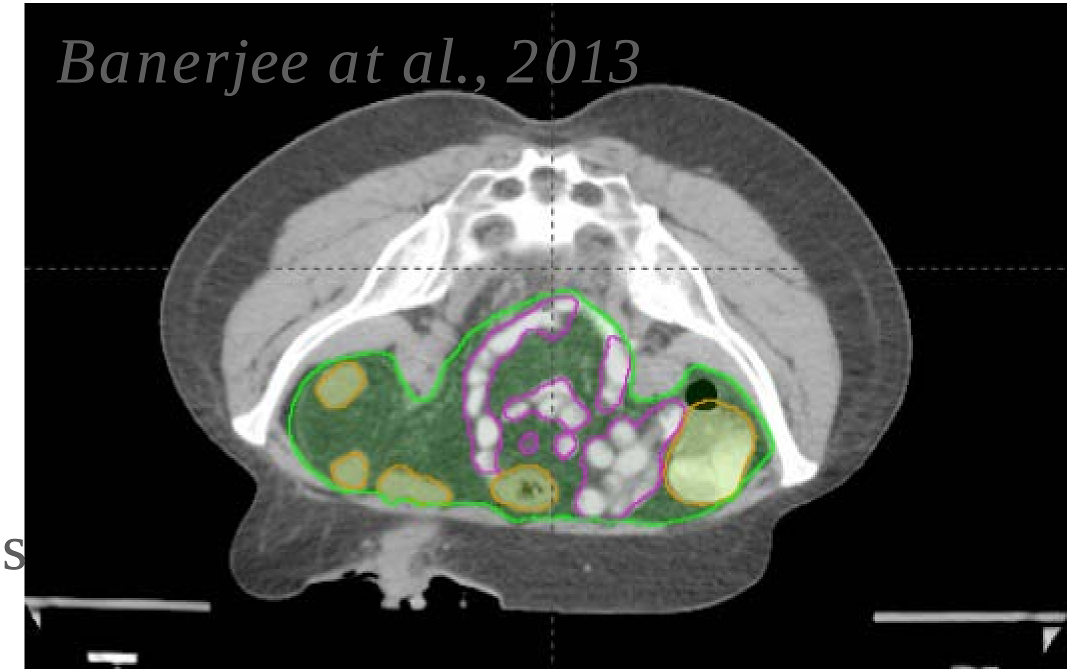


What Do the Experts Say? – *Small Bowel*

- Uncertainties or variations in practice
  - What is large bowel/vessels/nodes
  - Oral contrast results in artefact on planning scan and inappropriate HU
  - Small bowel position is variable during treatment
  - Individual loops vs. “Bowel bag”

- Recommendations:

The absolute volume of small bowel receiving ≥15 Gy should be held to <120 cc when possible to minimize severe acute toxicity, if delineating the contours of bowel loops themselves. Alternatively, if the entire volume of peritoneal space in which the small bowel can move is delineated, the volume receiving >45 Gy should be <195 cc when possible.



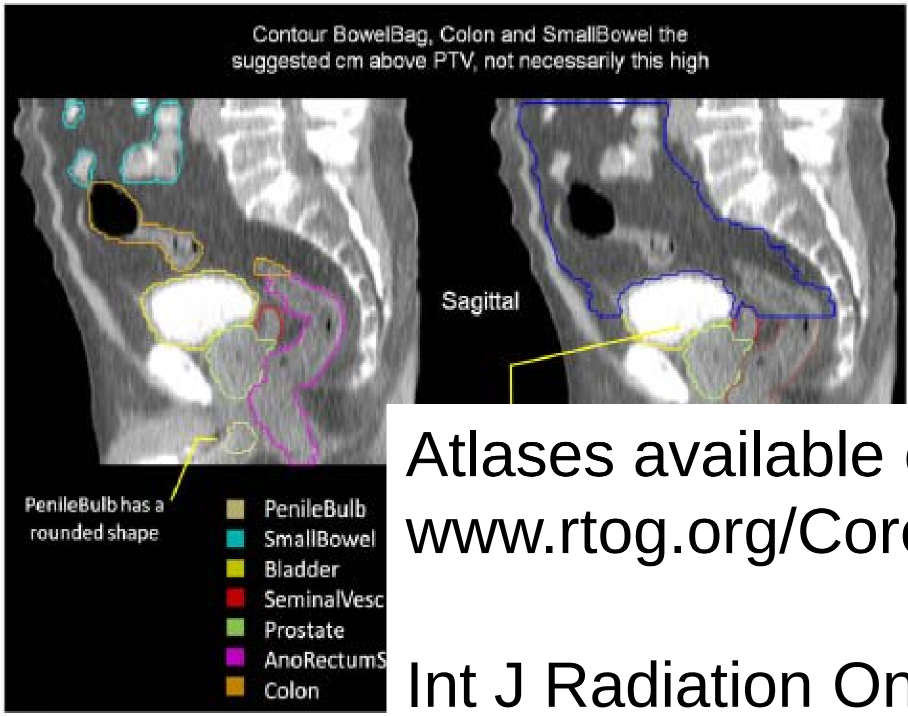
Orange = Large bowel

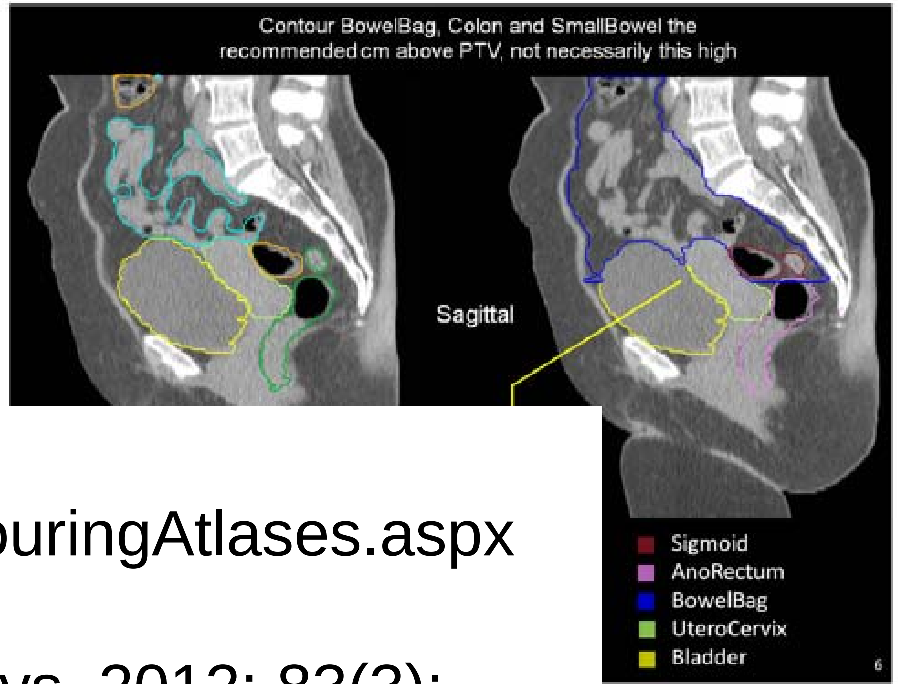
Pink = Small bowel loops

Green = Bowel bag

Male pelvis

Female Pelvis





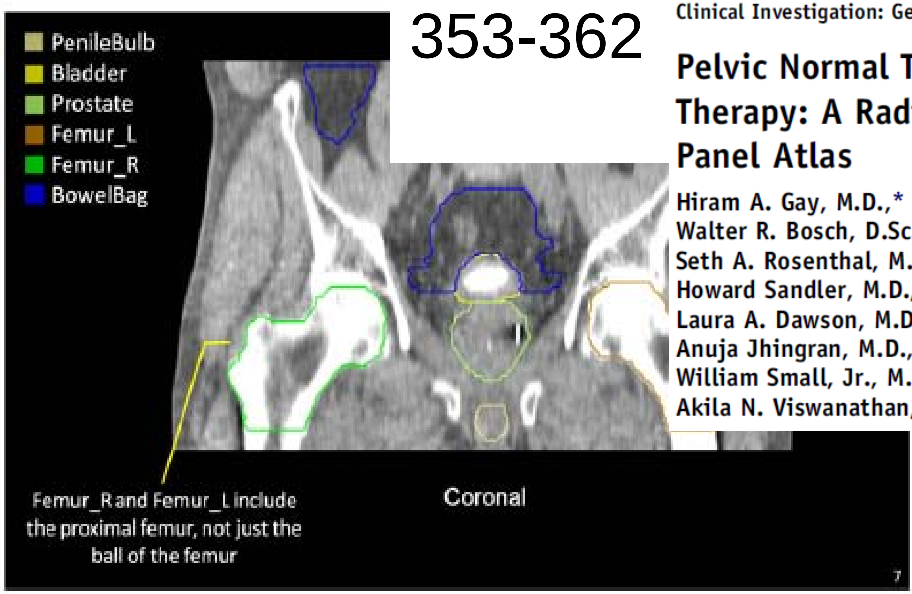
Atlases available online at:
www.rtog.org/CoreLab/ContouringAtlases.aspx

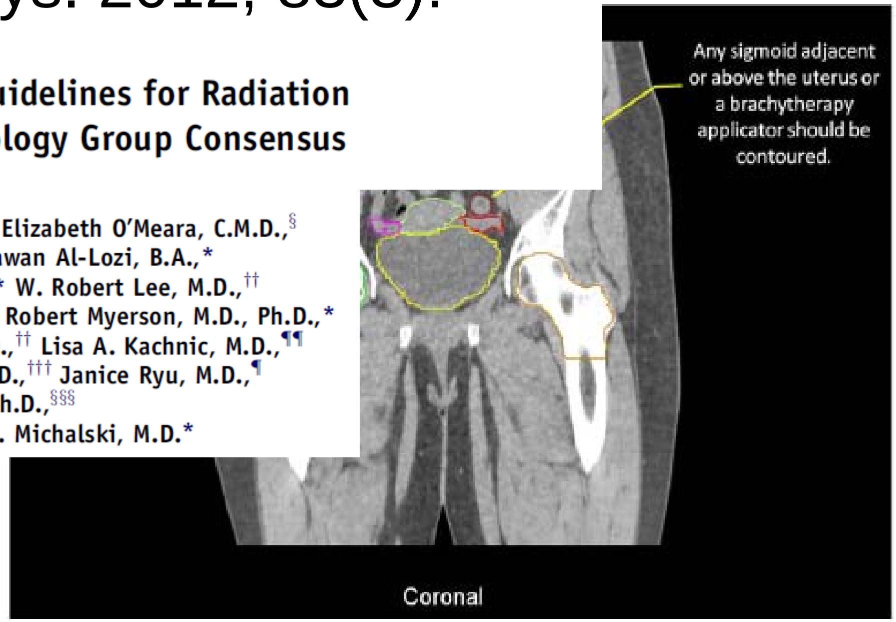
Int J Radiation Oncol Biol Phys. 2012; 83(3): 353-362

Clinical Investigation: Genitourinary Cancer

Pelvic Normal Tissue Contouring Guidelines for Radiation Therapy: A Radiation Therapy Oncology Group Consensus Panel Atlas

Hiram A. Gay, M.D.,* H. Joseph Barthold, M.D.,†,‡ Elizabeth O'Meara, C.M.D.,§ Walter R. Bosch, D.Sc.,* Issam El Naqa, Ph.D.,‖ Rawan Al-Lozi, B.A.,* Seth A. Rosenthal, M.D.,¶ Colleen Lawton, M.D.,** W. Robert Lee, M.D.,†† Howard Sandler, M.D.,‡‡ Anthony Zietman, M.D.,§§ Robert Myerson, M.D., Ph.D.,* Laura A. Dawson, M.D.,‖‖ Christopher Willett, M.D.,†† Lisa A. Kachnic, M.D.,¶¶ Anuja Jhingran, M.D.,*** Lorraine Portelance, M.D.,††† Janice Ryu, M.D.,¶ William Small, Jr., M.D.,‡‡‡ David Gaffney, M.D., Ph.D.,§§§ Akila N. Viswanathan, M.D., M.P.H.,‖‖‖ and Jeff M. Michalski, M.D.*





Let's Look at Some Common OARs in the ***Thorax***

Heart

Ribs

Lungs

Spinal Cord

Oesophagus

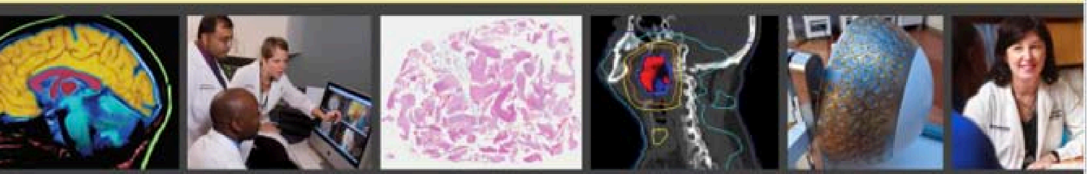
Main Bronchus

Brachial Plexus

RTOG Lung Atlas available from:

http://www.rtog.org/CoreLab/ContouringAtlases/LungAtlas.aspx

RTOG
RADIATION THERAPY ONCOLOGY GROUP



Atlases for Organs at Risk (OARs) in Thoracic Radiation Therapy

Feng-Ming (Spring) K
Leslie Quint
Mitchell Macht
Jeffrey Bradl

Int. J. Radiation Oncology Biol. Phys., Vol. 81, No. 5, pp. 1442–1457, 2011
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doi:10.1016/j.ijrobp.2010.07.1977

CLINICAL INVESTIGATION **Normal Tissue**

CONSIDERATION OF DOSE LIMITS FOR ORGANS AT RISK OF THORACIC RADIOTHERAPY: ATLAS FOR LUNG, PROXIMAL BRONCHIAL TREE, ESOPHAGUS, SPINAL CORD, RIBS, AND BRACHIAL PLEXUS

Feng-Ming (Spring) Kong, M.D., Ph.D.,* Timothy Ritter, Ph.D.,* Douglas J. Quint, M.D.,†
Suresh Senan, M.D.,‡ Laurie E. Gaspar, M.D.,§ Ritsuko U. Komaki, M.D.,¶
Coen
Jeffrey D. Bra

Int. J. Radiation Oncology Biol. Phys., Vol. 79, No. 1, pp. 10–18, 2011
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doi:10.1016/j.ijrobp.2009.10.058

CLINICAL INVESTIGATION **Breast**

DEVELOPMENT AND VALIDATION OF A HEART ATLAS TO STUDY CARDIAC EXPOSURE TO RADIATION FOLLOWING TREATMENT FOR BREAST CANCER

Mary Feng, M.D.,* Jean M. Moran, Ph.D.,* Todd Koelling, M.D.,† Aamer Chughtai, M.D.,‡
June L. Chan, M.D.,* Laura Freedman, M.D.,* James A. Hayman, M.D.,*
Reshma Jagsi, M.D., D. Phil.,* Shruti Jolly, M.D.,* Janice Larouere, M.D.,*
Julie Soriano, M.D.,* Robin Marsh, C.M.D.,* and Lori J. Pierce, M.D.*

What Do the Experts Say? - ***Lung***

Challenges

- Inappropriate window settings!
- Exclusion of disease from healthy lung?
- Inclusion of vessels?

Recommendations

- Air inflated lung only
  - Do not include fluid
- Contoured as single or combined structures
- Exclude lung GTV
- Exclude trachea/bronchus
- Exclude vessels <1cm
- Auto-segmentation is allowed combined with manual inspection
- Ensure appropriate windowing

What Do the Experts Say? – ***Spinal Cord***

Challenges

- Difficult to see true cord on CT
- Often not specifically covered in atlases
- Circumferential extend?
  - Contour cord or canal?
- Superior/Inferior extent
  - Entire length visible on planning scan or set distance from PTV?

Recommendations

- Use MRI fusion, if available
- Contour to the bony limits of the canal
- For lung cases, superior limit is the same as oesophagus (cricoid cartilage)
- Inferior limit is L2/L3 junction

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What Do the Experts Say? – *Heart*

Challenges

- Contour specific structures within the heart?
- Superior limit

Recommendations

- Superiorly: Just inferior to the left pulmonary artery, include the great vessels in a rounded contour
- Inferiorly: to diaphragm, include pericardium
- If contrast is used, contour SVC separately

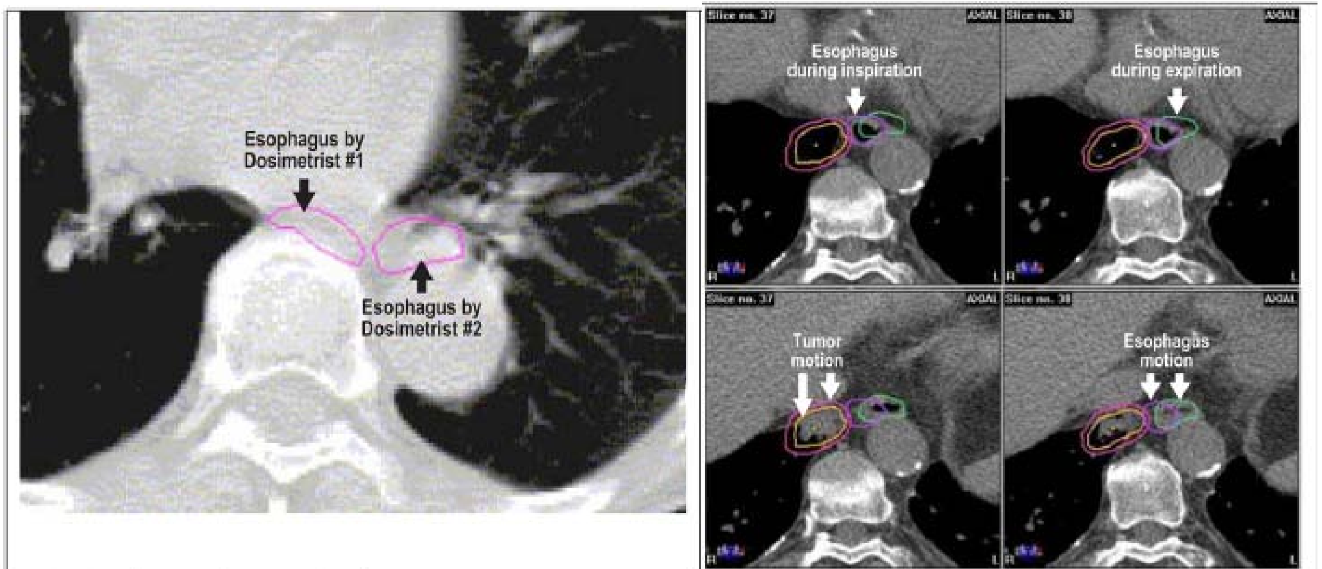
What Do the Experts Say? – ***Oesophagus***

Challenges

- Impact of windowing
- Impact of oral contrast
- Motion
- Inclusion of the muscular wall
- Length of contour

Recommendations

- Use mediastinal windowing level
- Contour from cricoid cartilage to gastro oesophageal junction
- Avoid oral contrast
  - Distorts shape and density



A: Esophagus Contour Variants | B: Esophagus Motion

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What about clinical trials?

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RTOG 0529

A Phase II Evaluation of Dose-Painted IMRT in Combination with 5-Fluorouracil and Mitomycin-C for Reduction of Acute Morbidity in Carcinoma of the Anal Canal

Critical Normal Structures: In addition, surrounding critical normal structures, including the femoral heads (right and left), bladder, external genitalia, iliac crest, small bowel, large bowel outside the CTVs, and perianal skin should be outlined. The normal tissues will be contoured and considered as solid organs. The tissue within the skin surface and outside all other critical normal structures and PTVs is designated as unspecified tissue.

Critical normal structures: DVHs must be generated for all critical normal structures.
NOTE: Effort should be made to achieve the listed dose constraints to normal tissues below. Failure to meet the 6.5.1.1 and 6.5.1.2 dose constraints will result in minor deviation. The dose constraints are listed in order from most to least important.

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AGITG – For Anus

International Journal of Radiation Oncology biology • physics

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Clinical Investigation: Gastrointestinal Cancer

Australasian Gastrointestinal Trials Group (AGITG) Contouring Atlas and Planning Guidelines for Intensity-Modulated Radiotherapy in Anal Cancer

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Received Jun 19, 2011, and in revised form Dec 13, 2011. Accepted for publication Dec 18, 2011

- Bladder
  - Entire outer wall
- Femoral Heads
  - Inferior – Cranial edge of the lesser trochanter
- Bowel
  - Small and large bowel
  - 15mm superior of PTV down to the rectosigmoid junction
- External Genitalia
  - Male – penis, scrotum, skin and fat anterior to the pubic symphysis
  - Female - clitoris, labia majora and minora, skin and fat anterior to pubic symphysis
- Bone Marrow
  - Iliac crests, both contoured and combined
  - Superior - top of the iliac crests
  - Inferior - superior part of the acetabulum

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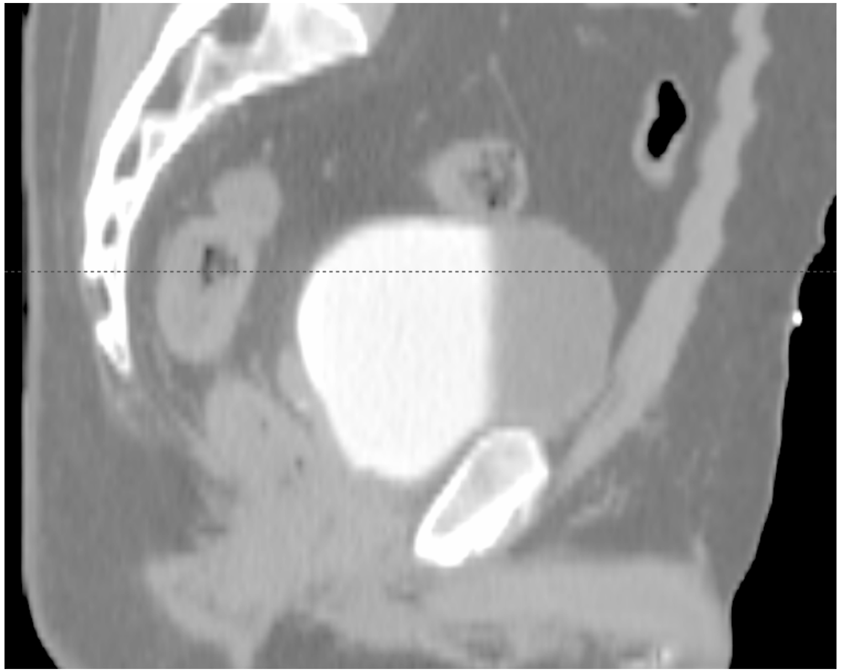
RAVES

- Femoral head:
  - Superior – acetabulum
  - Inferior – inferior edge of the treatment field
- Bladder:
  - Whole structure with bulk homogeneity correction for contrast
- Rectum:
  - Superior – rectosigmoid junction
  - Interior – 15mm inferior to the CTV



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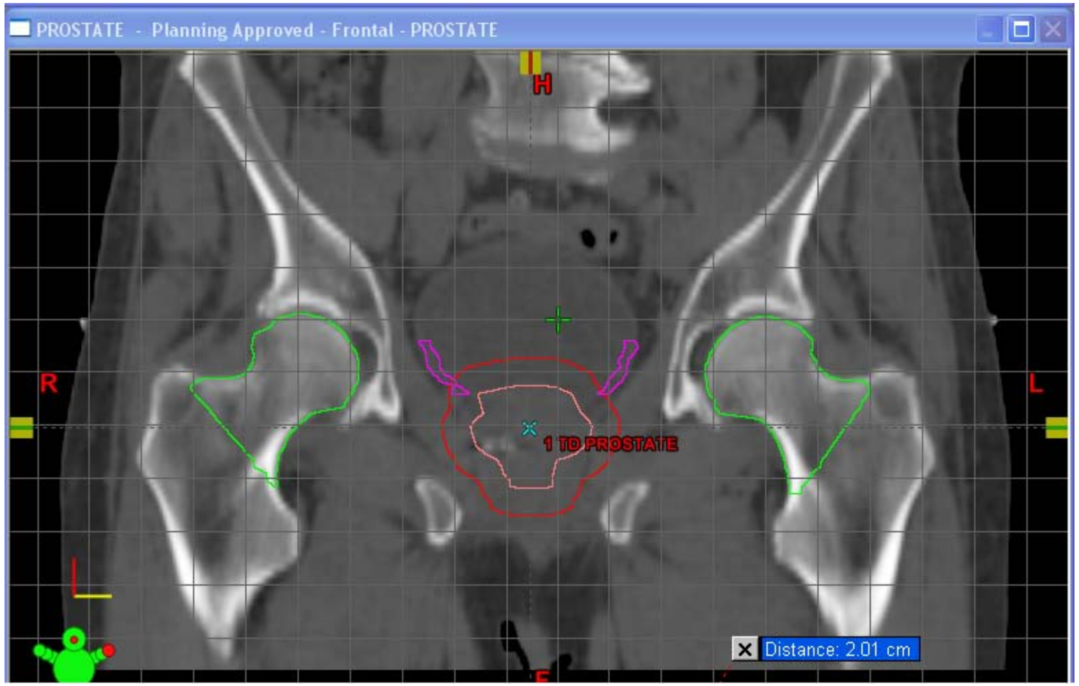
PROFIT Trial

- Rectal Wall
- Bladder Wall
- Femoral Head and Neck



Head and Neck

RADIATION THERAPY ONCOLOGY GROUP

RTOG 0615

A PHASE II STUDY OF CONCURRENT CHEMORADIOTHERAPY USING THREE-DIMENSIONAL CONFORMAL RADIOTHERAPY (3D-CRT) or INTENSITY-MODULATED RADIATION THERAPY (IMRT) + BEVACIZUMAB (BV) FOR LOCALLY OR REGIONALLY ADVANCED NASOPHARYNGEAL CANCER

NCI-supplied agent: Bevacizumab (NSC 704865; IND 79211)

A lot of contouring!

Critical Normal Structures

Surrounding critical normal structures, including the brainstem, spinal cord, optic nerves, chiasm, parotid glands, pituitary, temporo-mandibular (T-M) joints and middle and inner ears, skin (in the region of the target volumes), oral cavity, mandible, eyes, lens, temporal lobes, brachial plexus, esophagus (including postcricoid pharynx) and glottic larynx should be outlined.

Critical structures are ***critical***!

Planning Priorities

Critical normal structure constraints followed by the prescription goals are the most important planning priorities. The priorities in addressing the protocol aims and constraints will be in the following order:

1) Critical Normal Structure Constraints (Section 6.5);
2) Dose Specifications (Section 6.1);
3) Planning Goals: Salivary glands (Section 6.5.3);
4) Planning Goals: Other normal structures (Section 6.5.3).

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Head and Neck

- RTOG Atlases for H&N do not cover OARs!!!

- Where to turn to?
  - ➢ Published literature
  - ➢ Expert consensus

Radiotherapy and Oncology 93 (2009) 545–552

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Xerostomia

Delineation guidelines for organs at risk involved in radiation-induced salivary dysfunction and xerostomia

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Head and Neck

Radiation Oncology, Head and Neck, Organs at Risk (OAR)

ID: 001523 Approved:08 Aug 2013 Last Modified: 02 Oct 2013 Review Due:08 Se

Head and Neck Organs At Risk (OAR)

- Doses listed in the table below are based on radiation doses of 2Gy per fraction

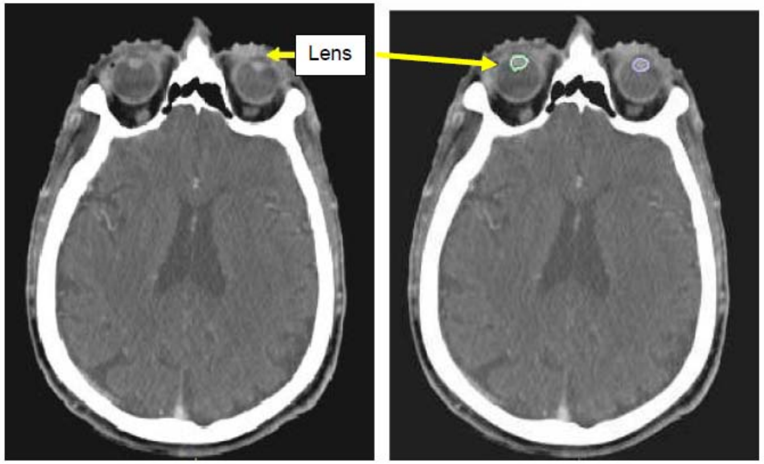
OAR Structure	Description based on RTOG 0920	True structure constraint (ideal)	Notes (Aim to keep doses as low as possible)
Brainstem	The inferior most portion of the brainstem is at the cranial-cervical junction where it meets the spinal cord. The superior most portion of the brainstem is approximately at the level of the top of the posterior clinoid. The brainstem shall be defined based on the treatment planning CT scan.	▪ Max dose $\leq$ 54Gy	Additional goals may include: ▪ $\leq$ 1% of PRV to exceed 60Gy ▪ small volumes (1-10cc) max dose $\leq$ 59Gy for fraction doses $\leq$ 2Gy [1]
Optic nerves		▪ Max dose $\leq$ 50Gy	Additional goals may include: ▪ $\leq$ 1% of PRV to exceed 60Gy ▪ To keep the risk of radiation induced optic neuropathy (RION) $\leq$ 3-7%, max dose 55-60Gy ▪ The risk of RION increases to 7-20% for doses > 60Gy in 1.8-2Gy fractions [2]
Optic Chiasm		▪ Max dose $\leq$ 54Gy	Additional goals may include: ▪ $\leq$ 1% of PRV to exceed 60Gy ▪ To keep risk of radiation induced optic neuropathy (RION) < 3-7%, max dose 55-60Gy ▪ The risk of RION increase to 7-20% for doses > 60Gy in 1.8-2Gy fractions [2]

Available from www.eviq.org.au

eviQ Head and Neck Critical Structures Atlas

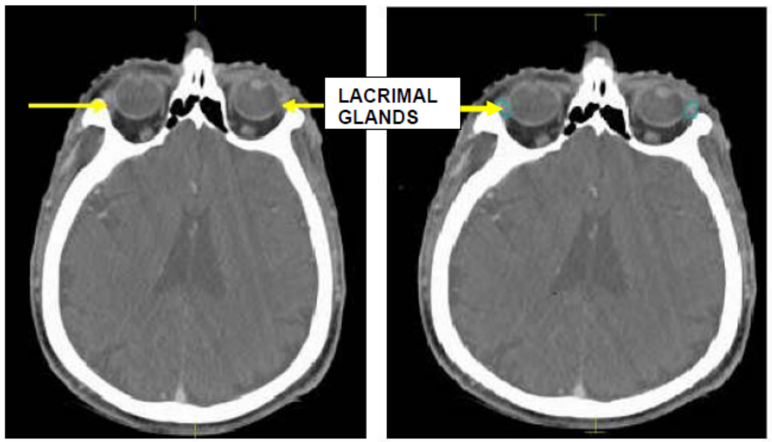
LENSES

Description: The lens is an anterior structure 5-8mm in length
Window level: W600/L40
Typical tolerance dose: 5Gy maximum



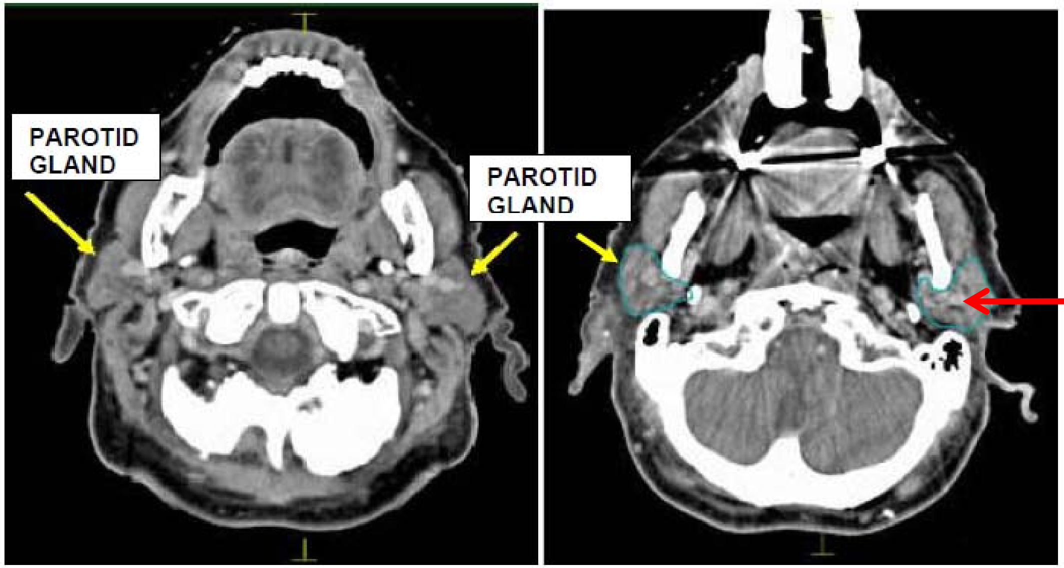
LACRIMAL GLAND

Location: Bilateral structure located supero-laterally to the orbits.
Length: Contoured extends approximately 10-15mm
Scroll through the images first to distinguish between muscle and the gland itself.
Window level: use approximately W270/L40 or W500/L60.
Typical Tolerance dose: <40Gy



- Shows adjacent images with and without contour
- Provides anatomical location, description, suggested window level and tolerance dose

eviQ Head and Neck Critical Structures Atlas



Note: degradation of image quality due to dental artefact

PAROTID GLAND

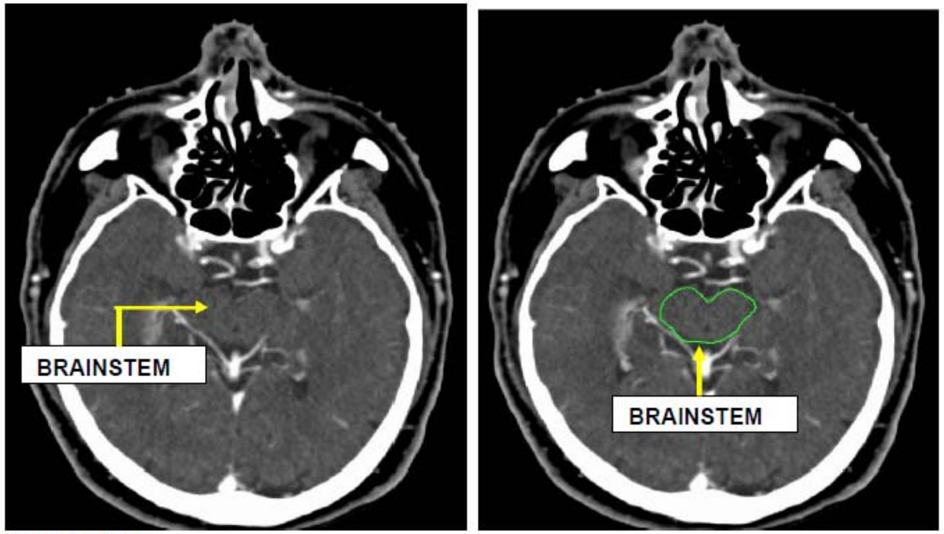
Location: The parotid gland is a bilateral glandular tissue lying anterior to the ear between the masseter muscle and the skin. It lies inferior to the zygomatic arch beneath the skin that covers the lateral and posterior surface of the mandible.
Length: approximately 50-60mm.
Borders: Medial Border is at the styloid process. Anteriorly hooks around the posterior aspect of anterior ramus of mandible.
Window level: use approximate window levels W290/L40 or W400/L80.
Typical tolerance doses: Mean parotid dose <26Gy (in at least one gland) or at least 50 % of one gland should receive <30Gy mean. (Doses to the parotid should be kept as low as reasonably achievable)

eviQ Head and Neck Critical Structures Atlas

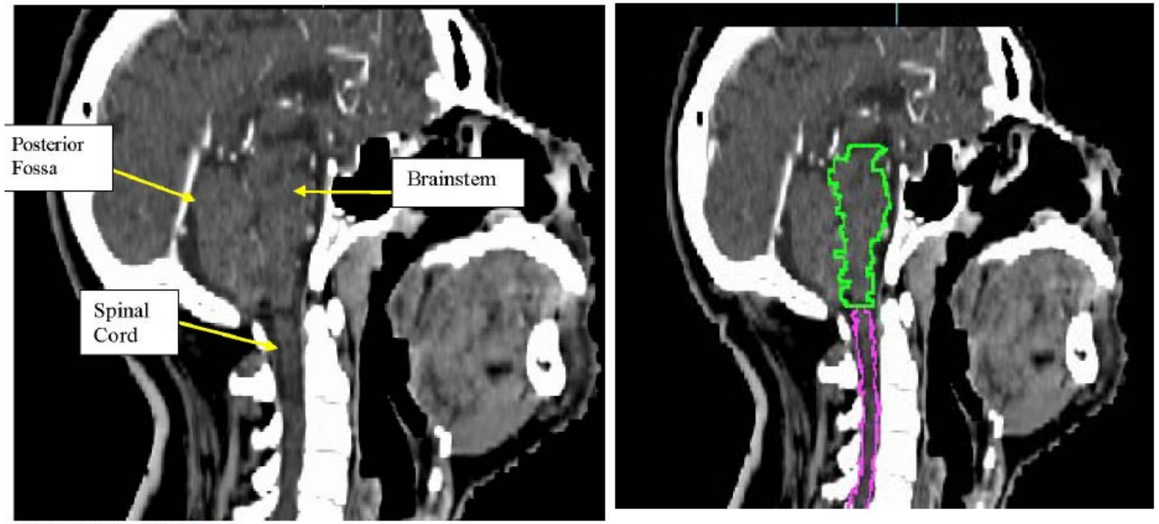
BRAINSTEM

Location: Superior to as well as a continuous structure from the proximal spinal cord, the brain stem is characterised by a sudden increase in width compared to the spinal cord above the level of the foramen magnum. The brain stem sits inferior to the optic chiasm. The brainstem is composed of the medulla, the pons and midbrain. It lies posterior to the bony clivus. Use sagittal view for ant/post definition; inferiorly it may be over contoured as spinal cord, due to tighter dose constraints.
Window level: Approximate window level of W200/L80.
Typical tolerance doses: <54Gy maximum.

Remember to view structures in all planes



Superior level



Brainstem sagittal view

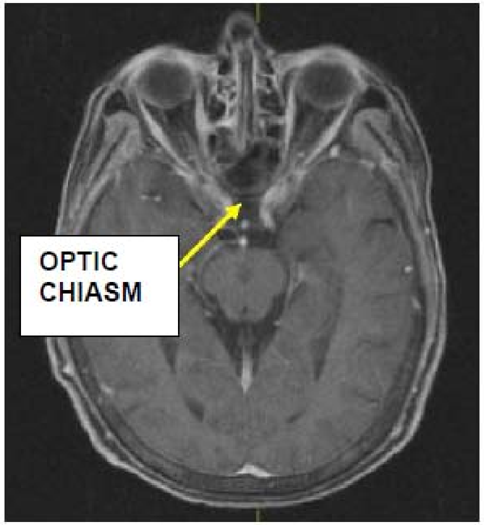
Note: It is important to avoid a gap between the brainstem and spinal cord contours as the emetic centre which controls nausea is located in this space. To avoid dose dumping in this region it is advised to overlap the contours by 1 CT slice to avoid a gap between these structures. (Monroe et al 2008 Radiother Oncol 87(2):188-194).

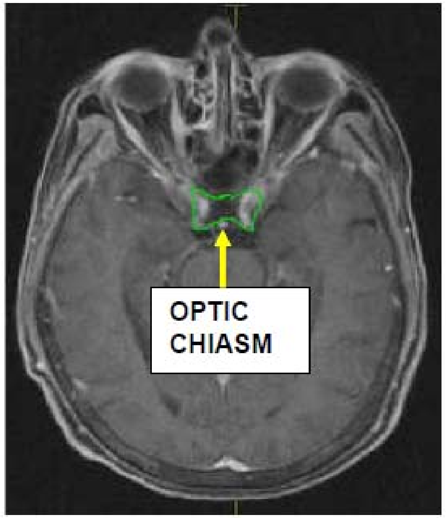
eviQ Head and Neck Critical Structures Atlas

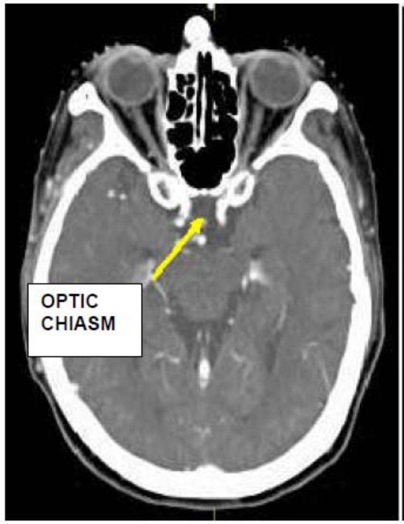
OPTIC CHIASM

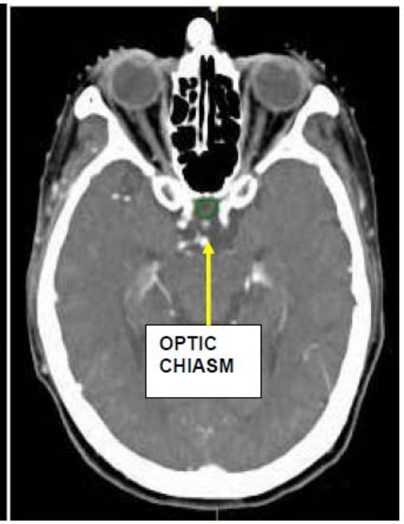
Location: A butterfly-shaped structure which sits directly above the pituitary fossa. To aid in contouring trace the optic nerves to the point of posterior intersection to help with identifying the optic chiasm.
Course: Anterior it begins directly posterior to the optic canal. Begin contouring at this position. At this area it lies medial to the carotid arteries (which enhance with contrast) but anterior to the pituitary stalk. The optic chiasm joins in front of the pituitary stalk and then divides again posteriorly to travel to the most superior/anterior part of the brainstem (ie gives position of the most superior limit of the brainstem). It should look butterfly shaped.
Length: Approximately 5-8mm, consider using an MRI study set if it is available for easier visualisation of the optic chiasm.
Window level: use approximate window level of W220/L70.
Typical Tolerance dose: Ideally <50Gy with a maximum of <54Gy

Remember to use all imaging available for that patient









Other Points to Consider

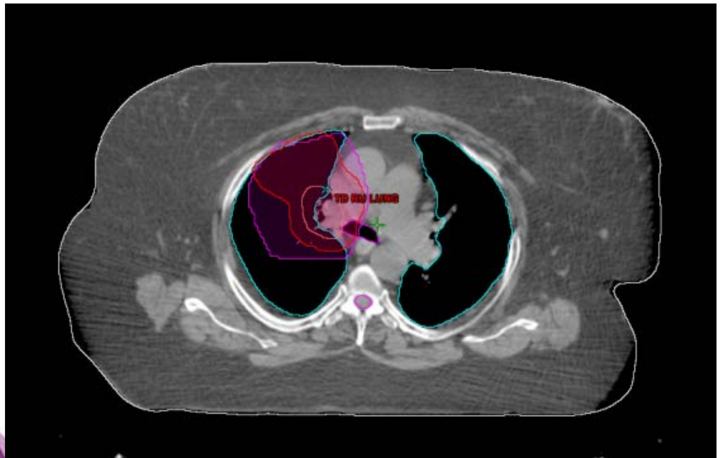
- Planning Risk Volume
  - Margin added to true structure
  - ICRU 83
  - RTOG H&N Trials

- Understand your potential errors
  - Recalculate plan with a error or shift induced to determine potential impact
    - Eg.   Shift isocentre 3mm posterior for Head and Neck patient and review DVH

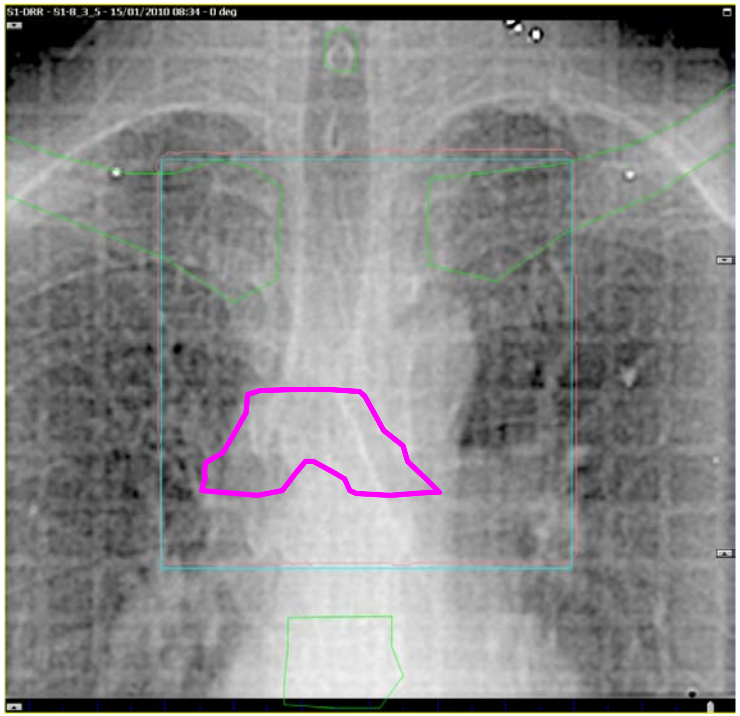
Other Structures for IGRT at the Linac

- What is the best surrogate for the target?
- What else can you see that might help you match?

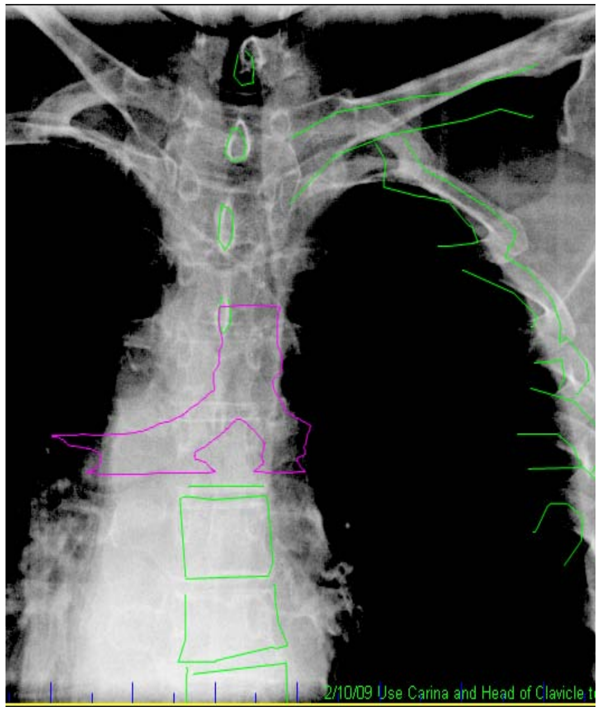
Planning CT



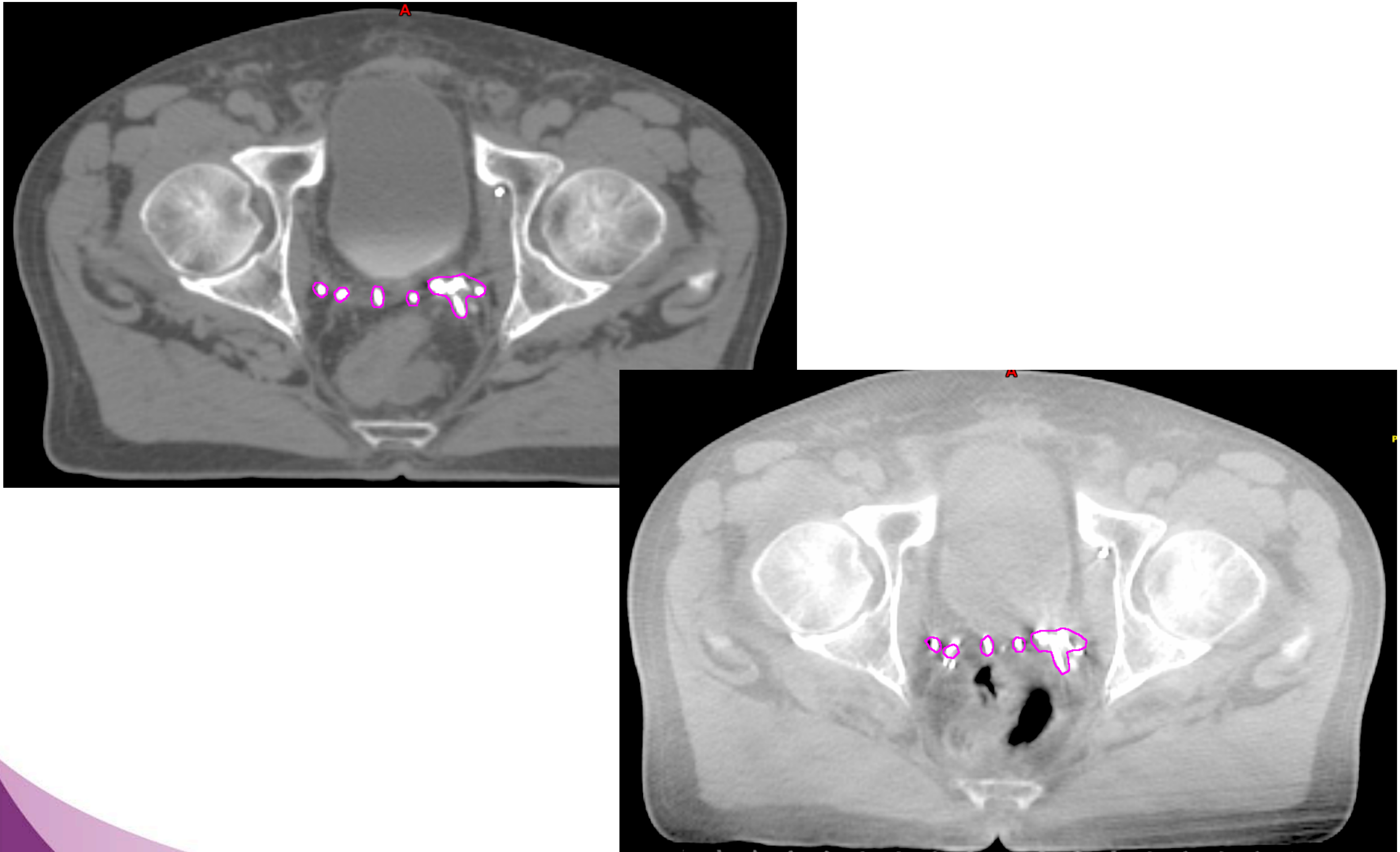
2D MV EPI



2D kV OBI



Other Structures for IGRT at the Linac



Take Home Message

- Quality assurance of organ delineation is vital regardless of who is responsible for OAR delineation

- "The accuracy of any autosegmenting tools should be carefully assessed" *(Marks et al., 2010)*

- Use all imaging modalities and viewing planes that you have available for that patient

- Think about the whole patient pathway
  - ➢ What will these contours impact on?

- Be consistent!
  - ➢ Preferably with international recommendations/consensus
  - ➢ At least at a local level

ESTRO School

"Inaccuracy and variation in defining critical volumes will affect everything downstream: treatment planning, dose–volume histogram analysis, and contour based visual guidance used in image-guided radiation therapy" *(Nelms et al., 2012)*

Geometrical uncertainties and margins

Peter Remeijer

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Introduction

- Geometrical uncertainties are unavoidable
- Many are patient related
- What types of errors do we get?
- How large a margin do we need?

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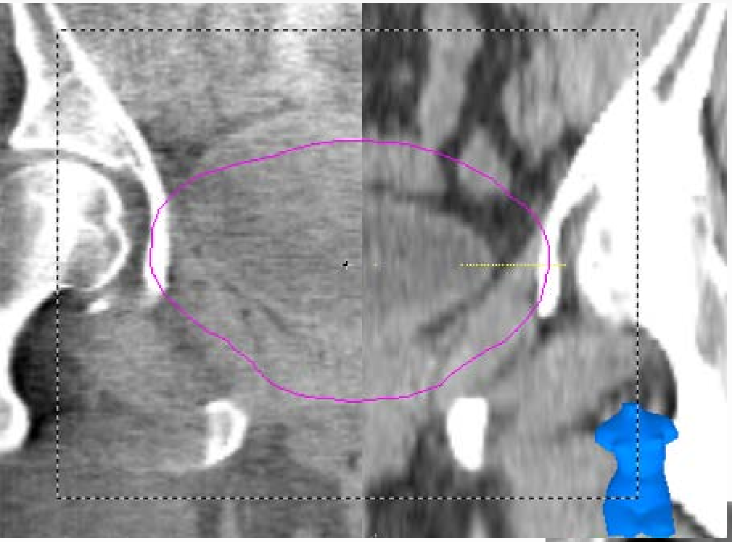
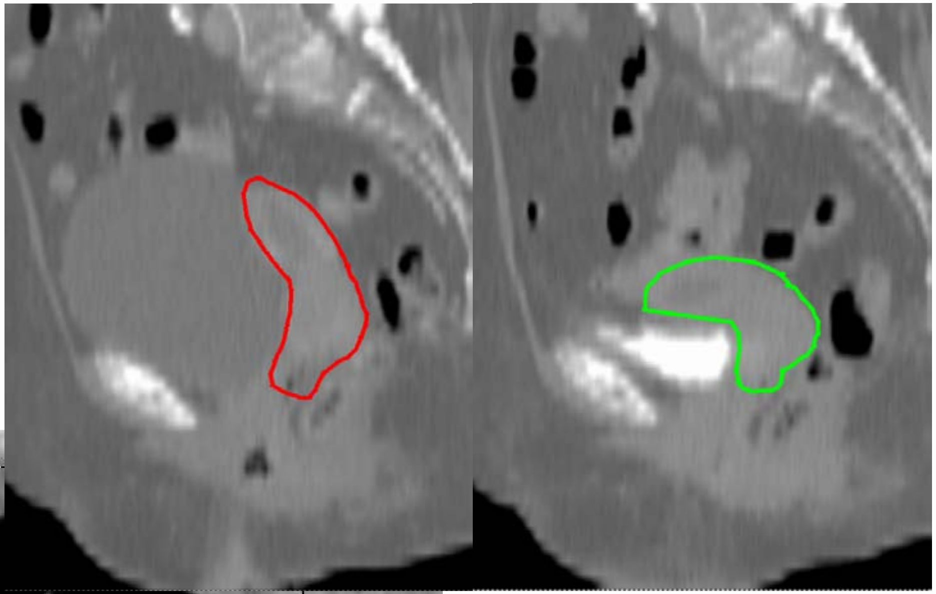
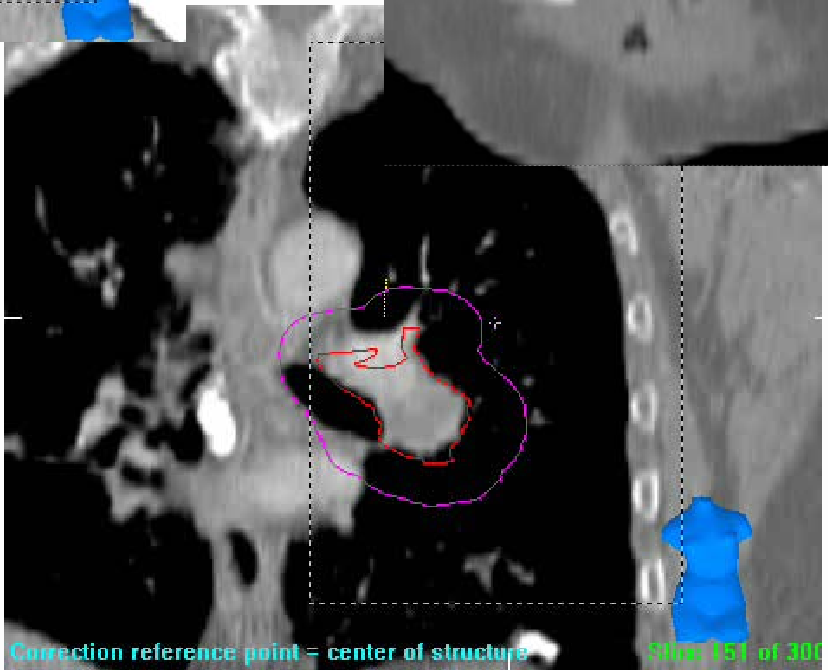
Some examples







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The basics

The radiotherapy chain

1 x

35 x

Patient

Patient

- CT room
- Lasers
- Skin markers
- Images
- Bone
- Tumor
- Delineation
- Margin
- Planned beam

- Treatment room
- Lasers
- Skin markers
- Bone
- Tumor
- Beam
- Accelerator
- Treatment room

Patient data

17 steps with a lot of room for errors

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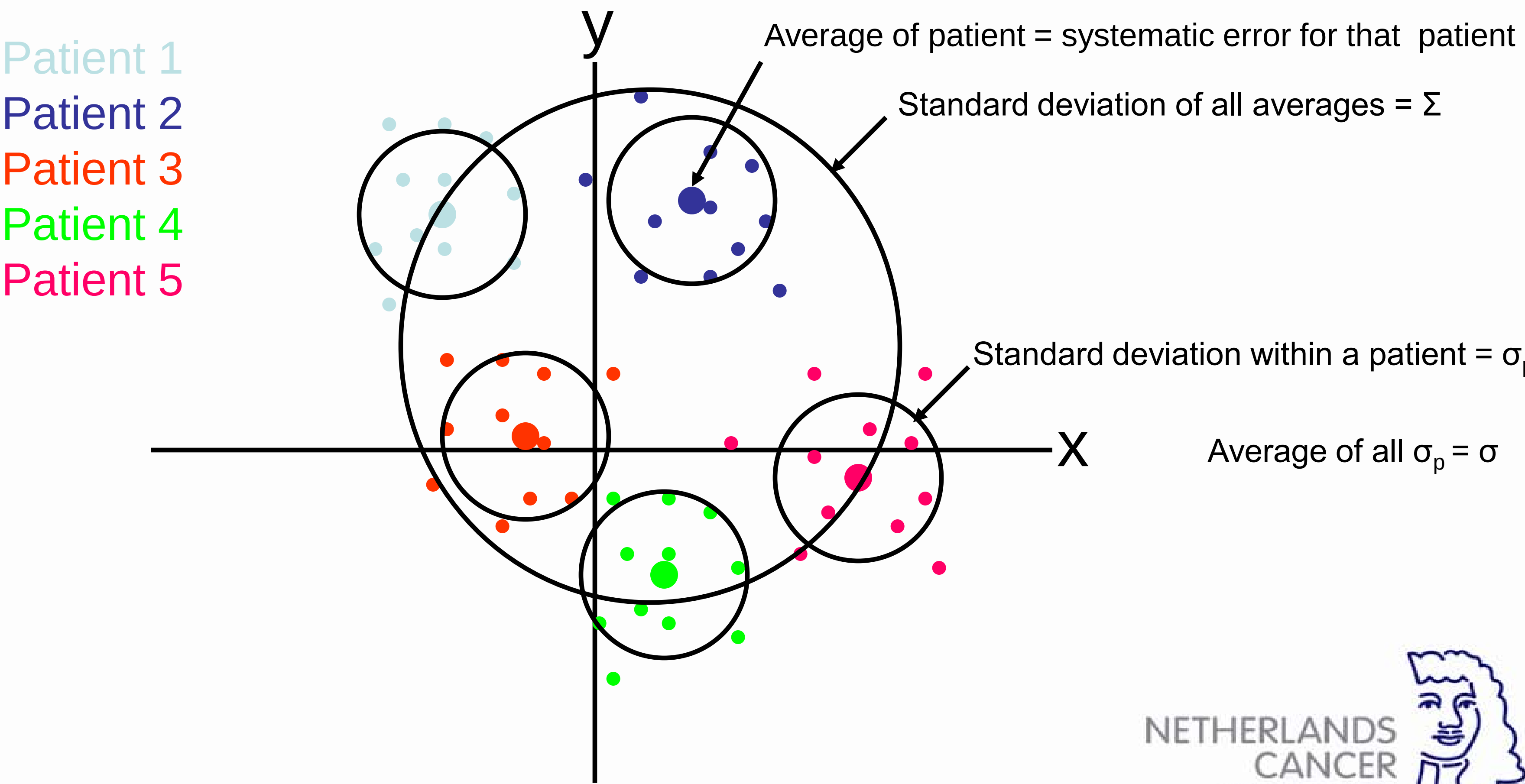
Geometrical uncertainties



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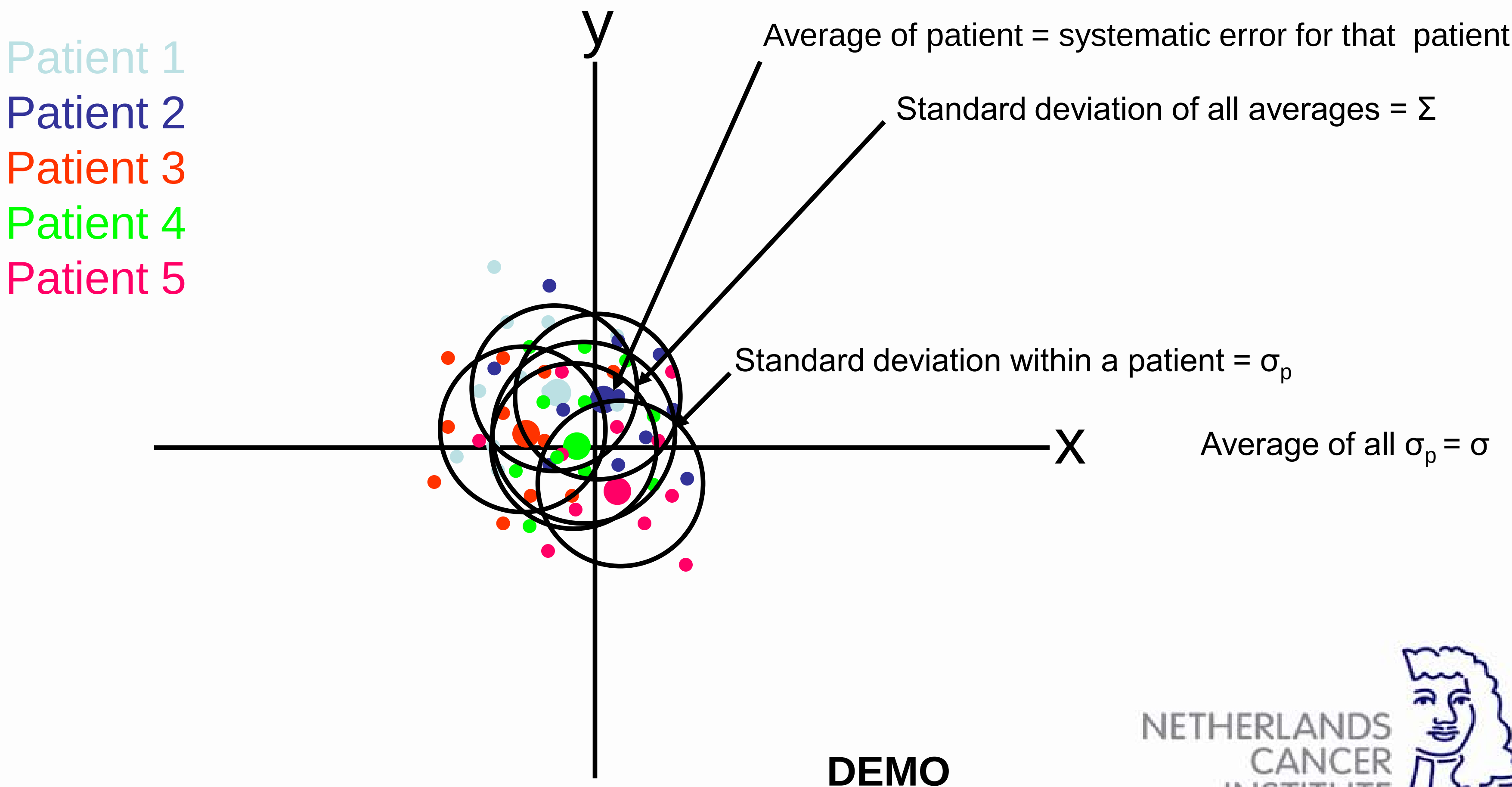
Geometrical uncertainties



DEMO

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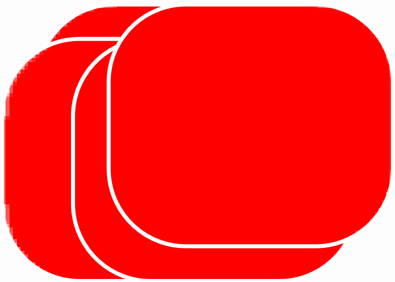
Effect of geometrical errors

Random errors (σ) blur the cumulative dose distribution



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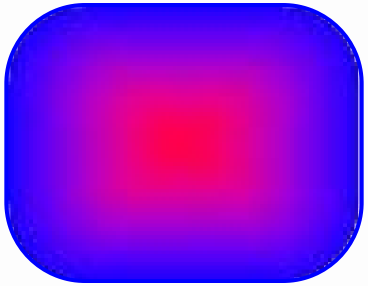
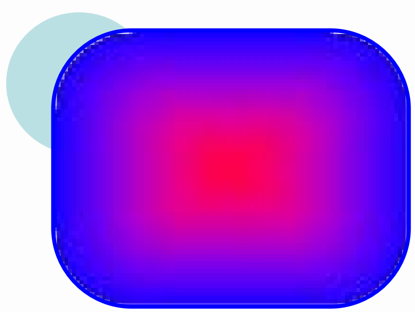


Systematic errors (Σ) shift the cumulative dose distribution

CTV



Dose distribution

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Geometrical uncertainties

- Systematic
  - Same for whole treatment
  - Shifts the dose distribution
  - May be different for each patient but the same for one patient
  - Quantified with standard deviation Σ

- Random
  - Different every day
  - Some patients may have larger variations from day to day than others
  - Blurs the dose distribution
  - Quantified with standard deviation σ

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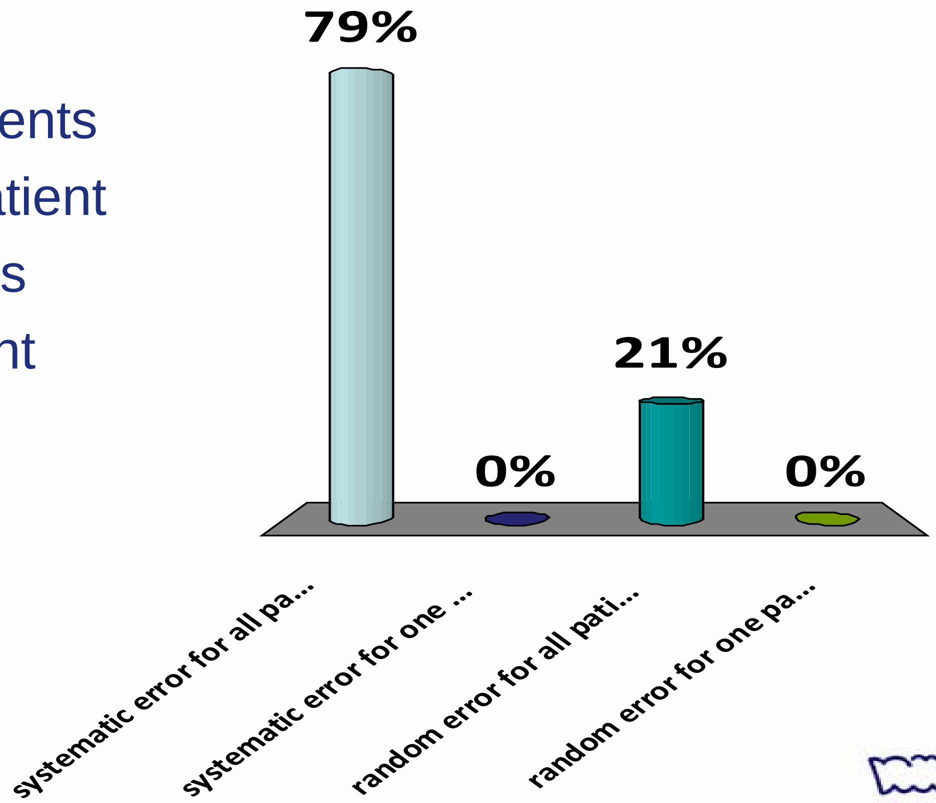
The lasers are misaligned. This will result in a ..

A. systematic error for all patients
B. systematic error for one patient
C. random error for all patients
D. random error for one patient



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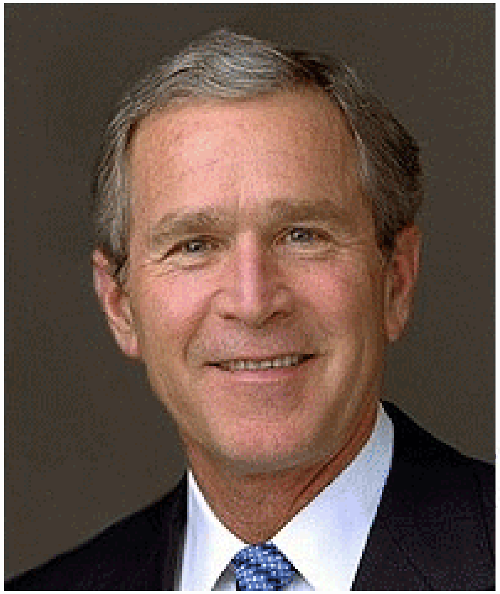
Many varieties

- Translational errors
- Rotational errors
- Shape changes



But also different sources!

Source	Systematic	Random	Solution
Delineation example	1-?? mm	-	Multiple modalities
Setup	1-5 mm	1-5 mm	Portal imaging
Organ motion	<1-50 mm	<1-50mm	Markers Repeat CT

And all come as translations / rotations / deformations!

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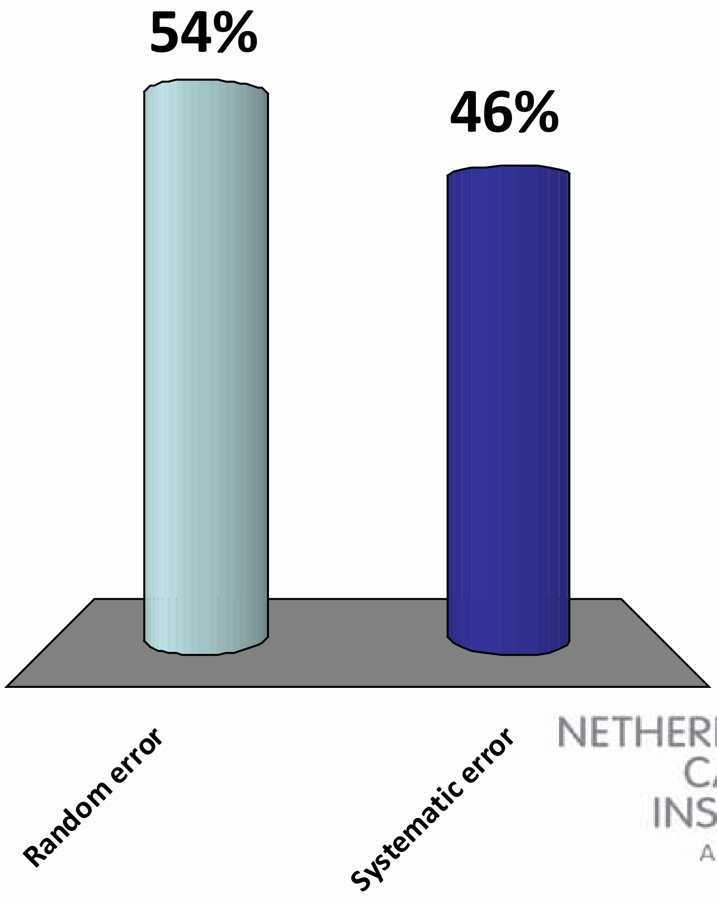
Examples of geometrical uncertainties

Prostate

- Large amount of air in rectum during planning scan
- Not present during treatment

What kind of error does this introduce?

A. Random error
B. Systematic error



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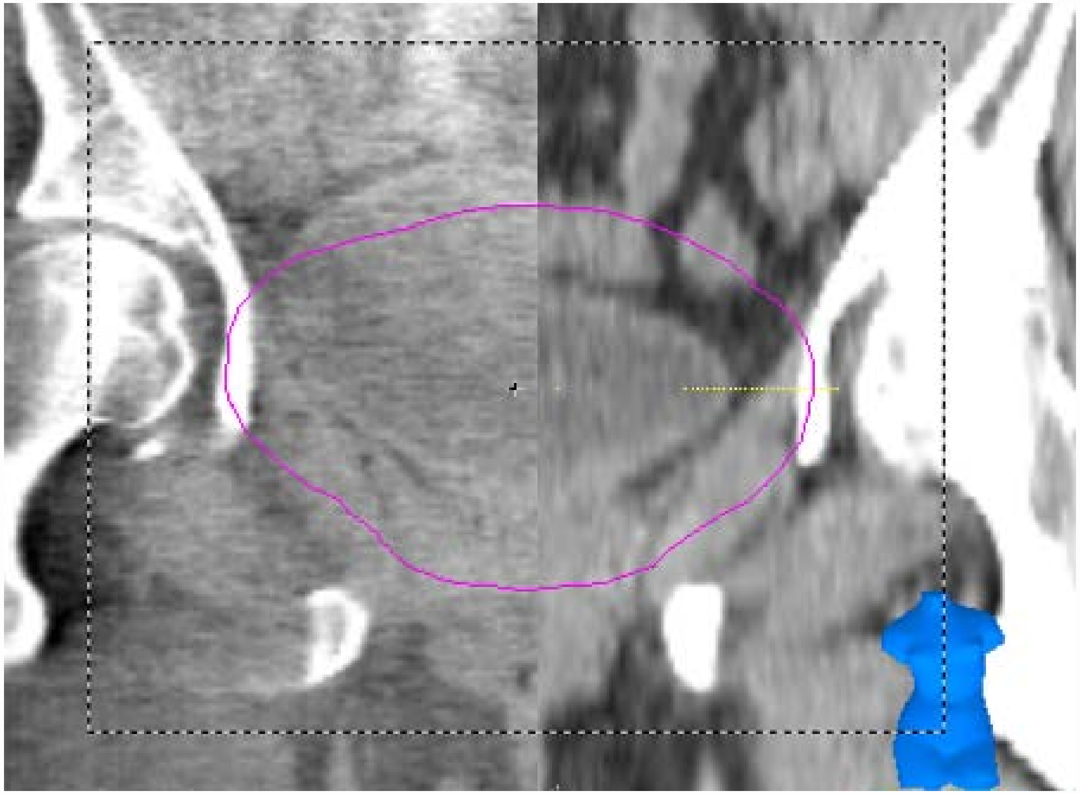
Bladder

- Bladder volume is larger in the CBCT scan than in the planning scan



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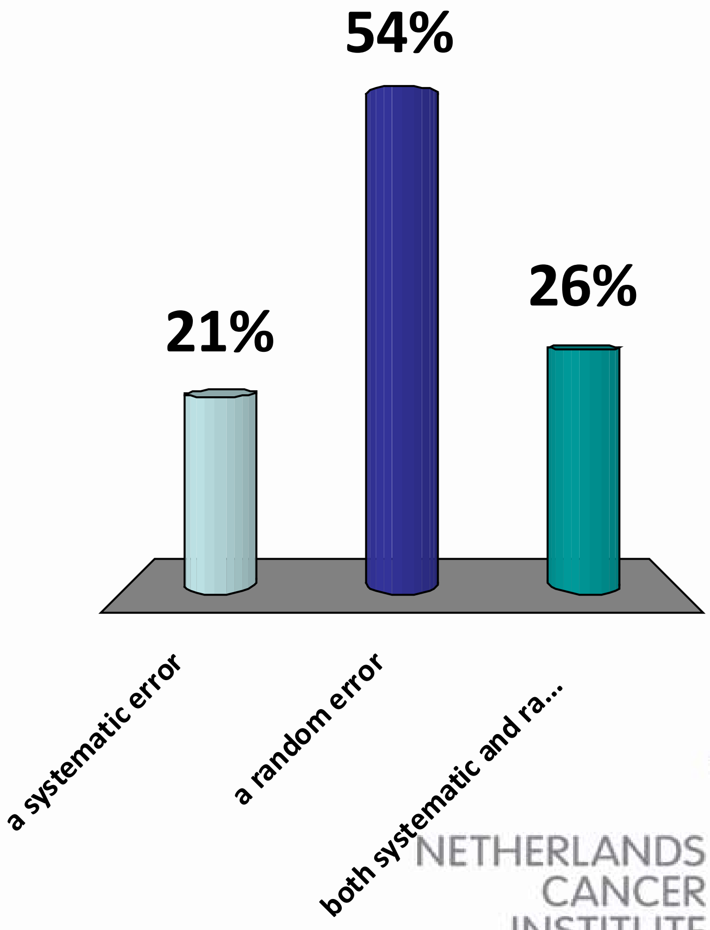
This introduces

A. a systematic error
B. a random error
C. both systematic and random errors



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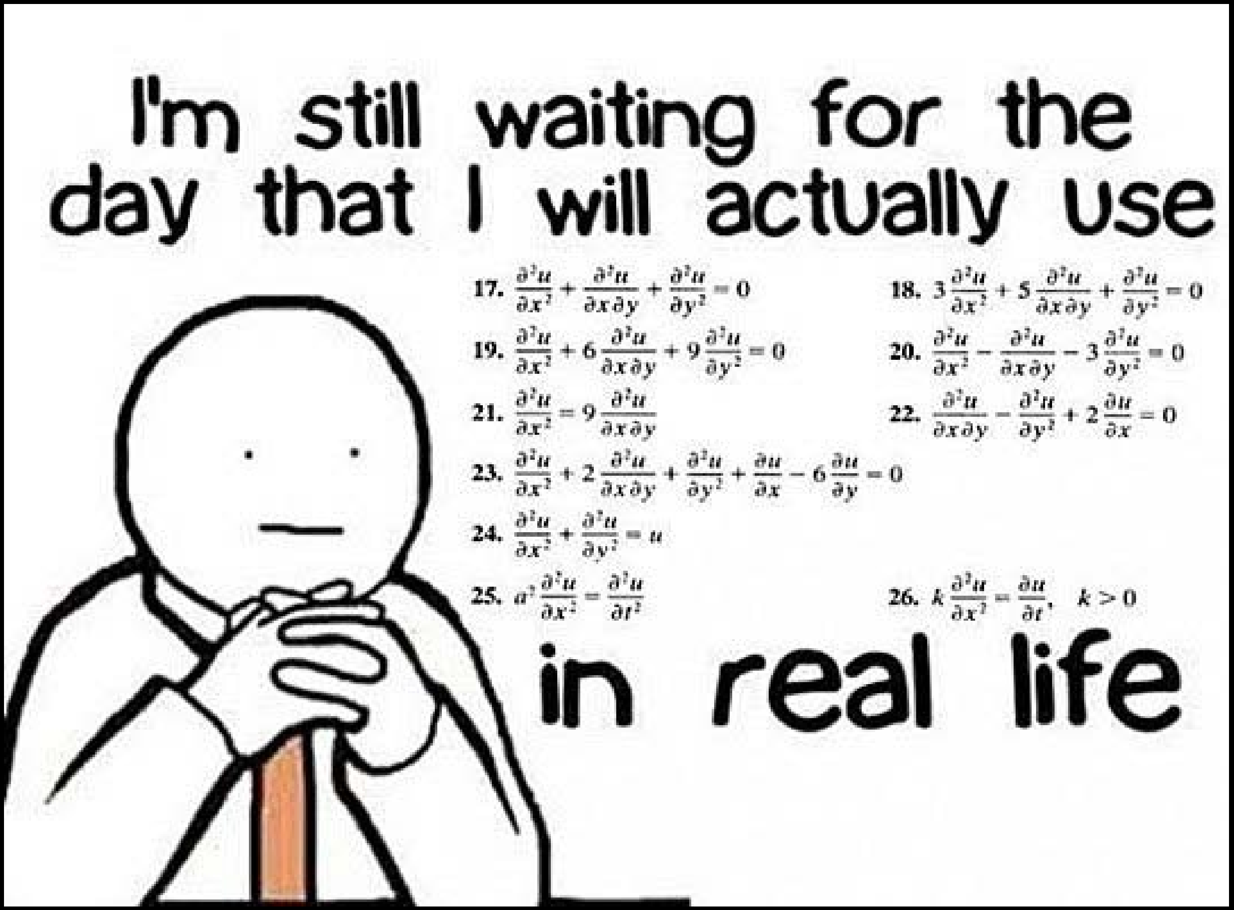
So how do we determine these errors?



Determining the uncertainties

- Imaging!

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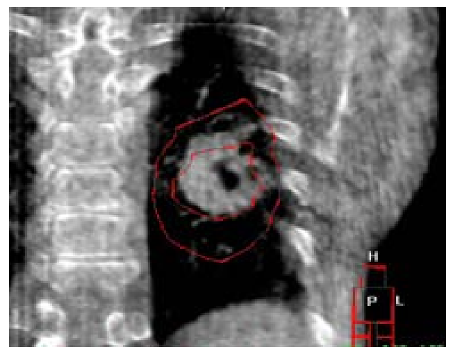
Determining the uncertainties

- Image guided radiotherapy (IGRT):
  → Determine positioning errors of target volume during treatment



- Image tumor
- Use surrogates
  – Fiducials

  – Bony anatomy (margin for organ motion!)

Determining the uncertainties

- Register bony anatomy → Setup error
- Register tumor position → Organ motion
- Analyse re-delineation → Delineation variability

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Example for setup errors

- Workshop!

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Margins

How do we determine the margin?

- Effect of random and systematic errors on the dose distribution is different

→ We need a separate approach!

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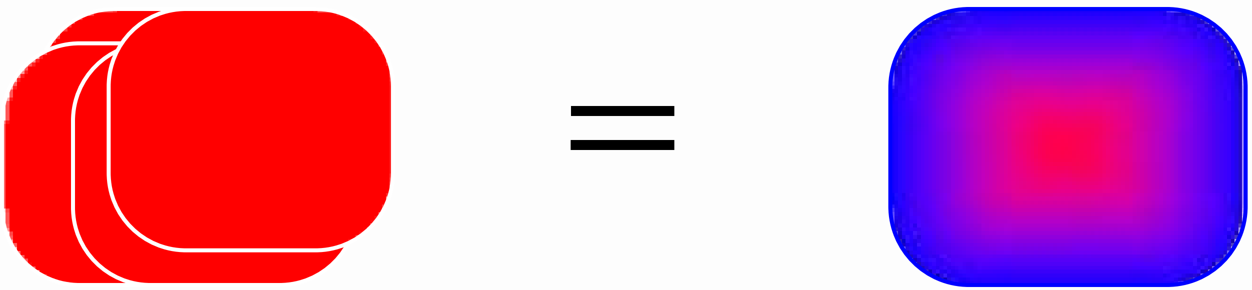
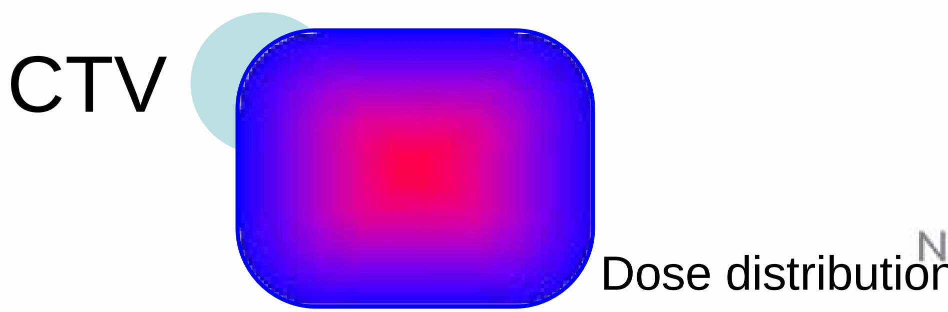
Effect of geometrical errors

Random errors (σ) blur the cumulative dose distribution



Systematic errors (Σ) shift the cumulative dose distribution



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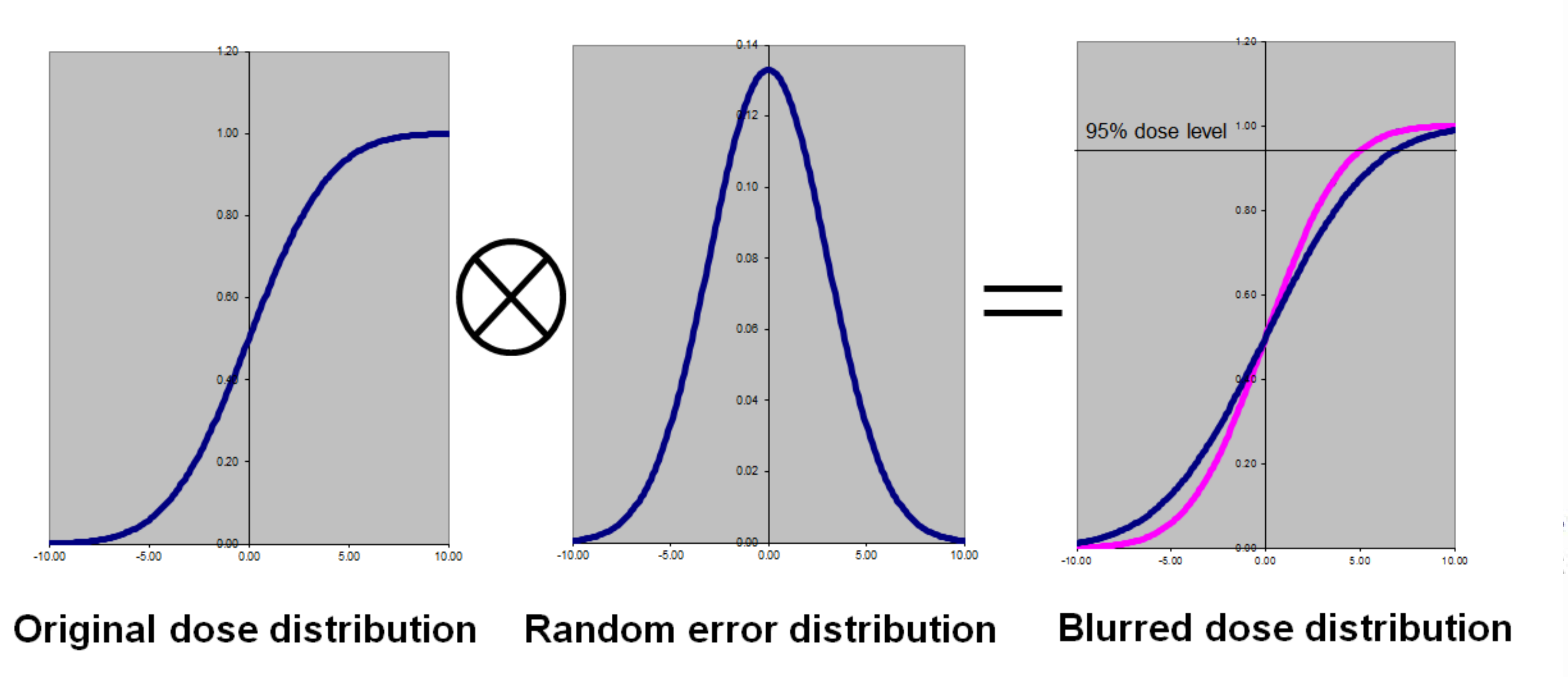
Margins for random errors

- Random errors blur the dose distribution
  - Translations : Convolution dose with error distribution
  - Rotations : Convolution dose with error distribution (Bel)



Margins for random errors

- Margin for random errors:

→Difference at 95 % dose level (i.e. the dose level of interest) before/after convolution

- Example

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Margins for random errors

Dose level	PTV margin	PTV margin* (ψ = 3.2 mm)
80%	$0.84 \sqrt{(\sigma^2 + \psi^2)} - 0.84\,\psi$	$0.4\,\sigma$
85%	$1.03 \sqrt{(\sigma^2 + \psi^2)} - 1.03\,\psi$	$0.5\,\sigma$
90%	$1.28 \sqrt{(\sigma^2 + \psi^2)} - 1.28\,\psi$	$0.6\,\sigma$
95%	$1.64 \sqrt{(\sigma^2 + \psi^2)} - 1.64\,\psi$	$0.7\,\sigma$

σ = SD of execution/random errors,

ψ = σ of Gaussian penumbra

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*linear approximation

Margins for systematic errors

- Systematic errors <u>shift</u> the dose distribution
  - But we don’t know in advance in which direction!

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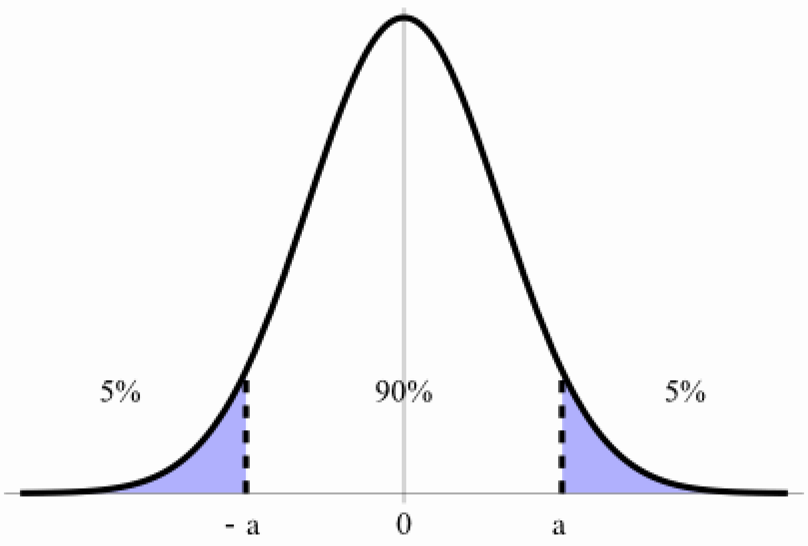
Margins for systematic errors

- Systematic errors shift the dose distribution
  - But we can say something about the “target area’ if we know the distribution of the errors, i.e. the standard deviation



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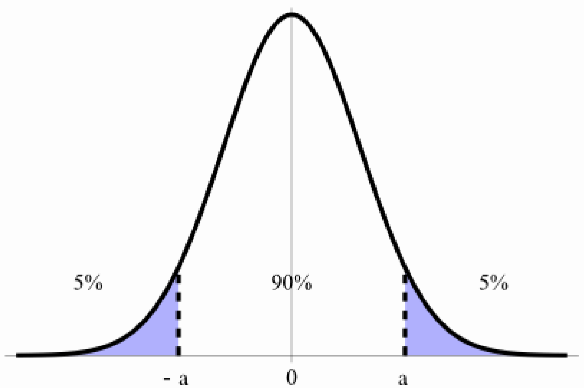
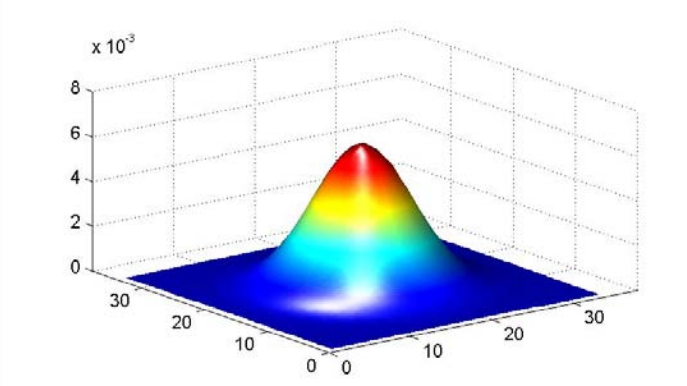
PTV for systematic translations

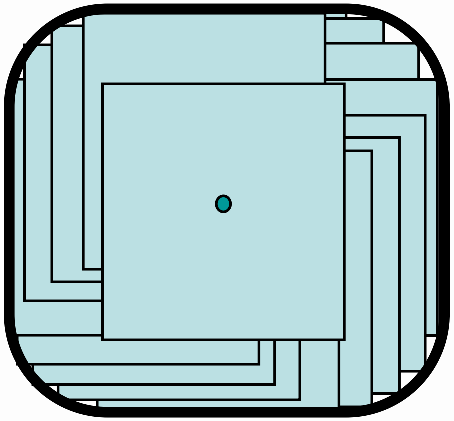
- 90 % Confidence interval
  - 1-D : ±1.64 Σ
  - 2-D : Ellipse with radii 2.15 $\Sigma_{x,y}$
  - 3-D : Ellipsoid with radii 2.50 $\Sigma_{x,y,z}$

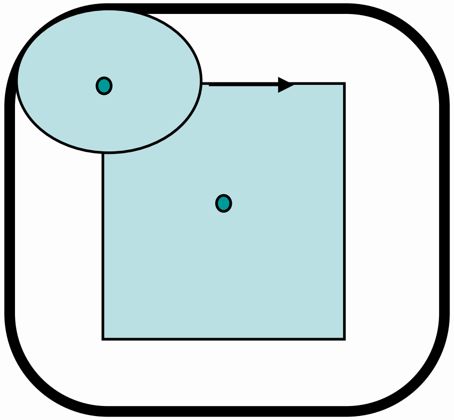




Margins for systematic translations

- Select point in (square shaped) CTV
- Determine CI = Ellipse with radii $\alpha\Sigma_{x,y}$ mm *
- Determine envelope of all CTVs in CI





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*90% 2D CI: α=2.15

Margin for systematic errors

Confidence level	1-D errors	2-D errors	3-D errors
80%	1.28 Σ	1.79 Σ	2.16 Σ
85%	1.44 Σ	1.95 Σ	2.31 Σ
90%	1.64 Σ	2.15 Σ	2.50 Σ
95%	1.96 Σ	2.45 Σ	2.79 Σ

Σ = SD of preparation/systematic errors

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Margin recipe

- To cover 90% of the patients with the 95% isodose level:

Margin = 2.5 * Σ + 0.7 * σ

Where

$$\Sigma = \sqrt{\Sigma_{organmotion}^2 + \Sigma_{setup}^2 + \Sigma_{delineation}^2}$$

$$\sigma = \sqrt{\sigma_{organmotion}^2 + \sigma_{setup}^2}$$

IJROBP 47 (4), 2000, 1121–1135

THE PROBABILITY OF CORRECT TARGET DOSAGE: DOSE-POPULATION HISTOGRAMS FOR DERIVING TREATMENT MARGINS IN RADIOTHERAPY

MARCEL VAN HERK, PH.D., PETER REMEIJER, PH.D., COEN RASCH, M.D., AND JOOS V. LEBESQUE, M.D., PH.D.

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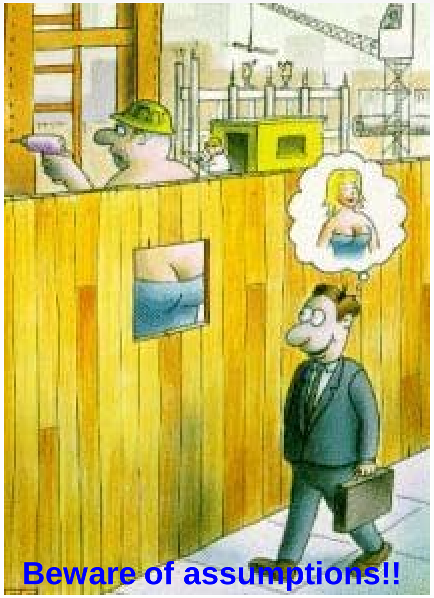
Keeping things in perspective

- Margin recipe assumptions
  - Perfectly conformal dose distribution
  - Large and smooth (compared to penumbra size) CTV
  - Translational errors only
  - Homogeneous dose distribution
  - Large number of fractions (for the 0.7 part)



- Real life
  - Not conformal, i.e. margin will depend on shape of dose distribution
  - Not smooth
  - Lots of changes → translations, rotations, shape changes…
  - Inhomogeneous dose distributions
  - Any number of fractions (or very few!)

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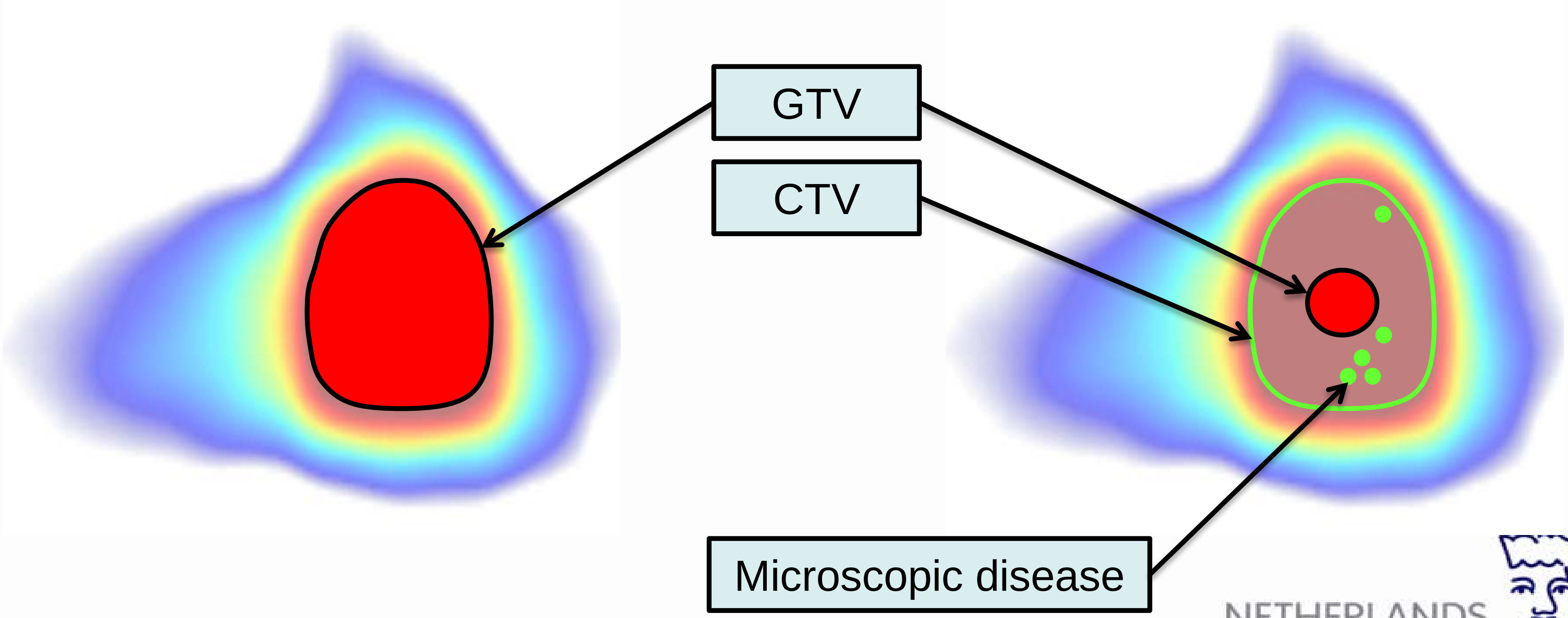
GTV versus CTV underdosage

GTV: Whole volume tumor

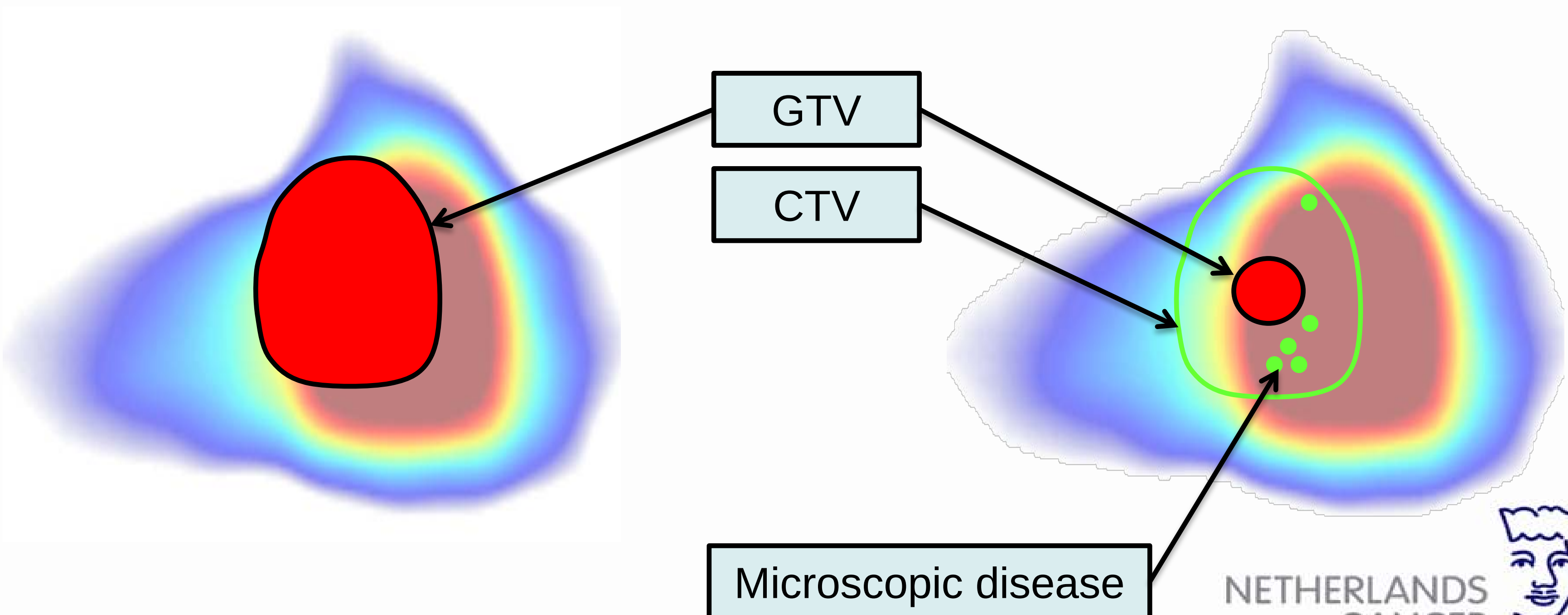
CTV: Probability of tumor



GTV versus CTV underdosage

Underdosage of GTV will always lead to underdosage of tumor cells

Underdosage of CTV will **not** always lead to underdosage of tumor cells



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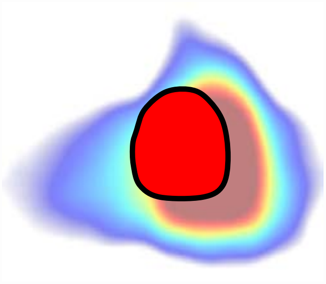
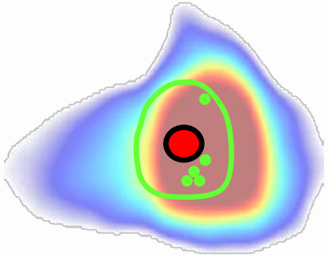
Keeping things in perspective

- GTV → PTV margin
  - All cells in the GTV are considered to be tumor
  - $P_{underdosage} = P_{geometrical\ miss}$
  - Use margin prescription



- CTV → PTV margin
  - In the CTV there is a <u>probability</u> of tumor cells
  - $P_{underdosage} = P_{geometrical\ miss} \times P_{presence\ of\ tumor\ cells}$
  - Margin can probably be smaller



- Caveat: Tumor cell probability is needed

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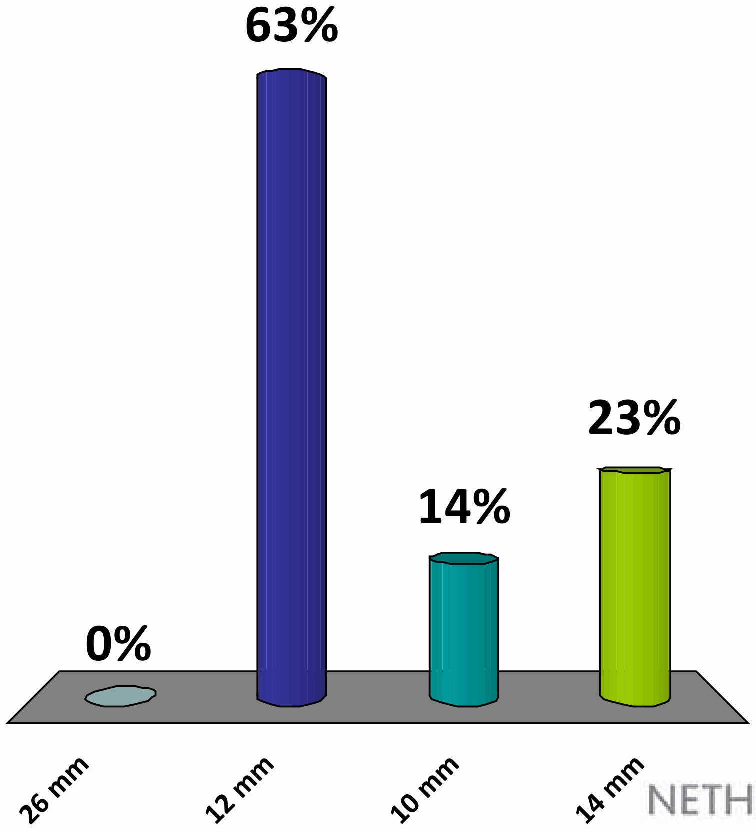
σ= 10 mm and Σ=2mm. What should the margin be?

A. 26 mm
B. 12 mm
C. 10 mm
D. 14 mm



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Keeping things in perspective

- Margin recipe assumptions
  - Perfectly conformal dose distribution
  - Large and smooth (compared to penumbra size) CTV
  - Translational errors only
  - Large number of fractions (for the 0.7 part)

- Real life
  - Not conformal, i.e. margin will depend on shape of dose distr.
  - Not smooth
  - Lots of changes → translations, rotations, shape changes, delineation errors…
  - Any number of fractions (or very few!)

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Keeping things in perspective

- GTV → PTV margin
  - No underdosage allowed
  - Use margin prescription

- CTV → PTV margin
  - In the CTV there is a <u>probability</u> of tumor cells
  - Not clear what PTV margin to use → probabilistic approach
  - Margin prescription probably too large
  - CTV sometimes based on 'anatomical' borders (e.g. bone) → Margin prescription does not apply, or applies to the border

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Conclusions

- Systematic errors have different dose effects than random errors
- A margin is always necessary. Without the proper margin underdosage will occur
- To determine margins it is important to now the statistics of the geometrical errors

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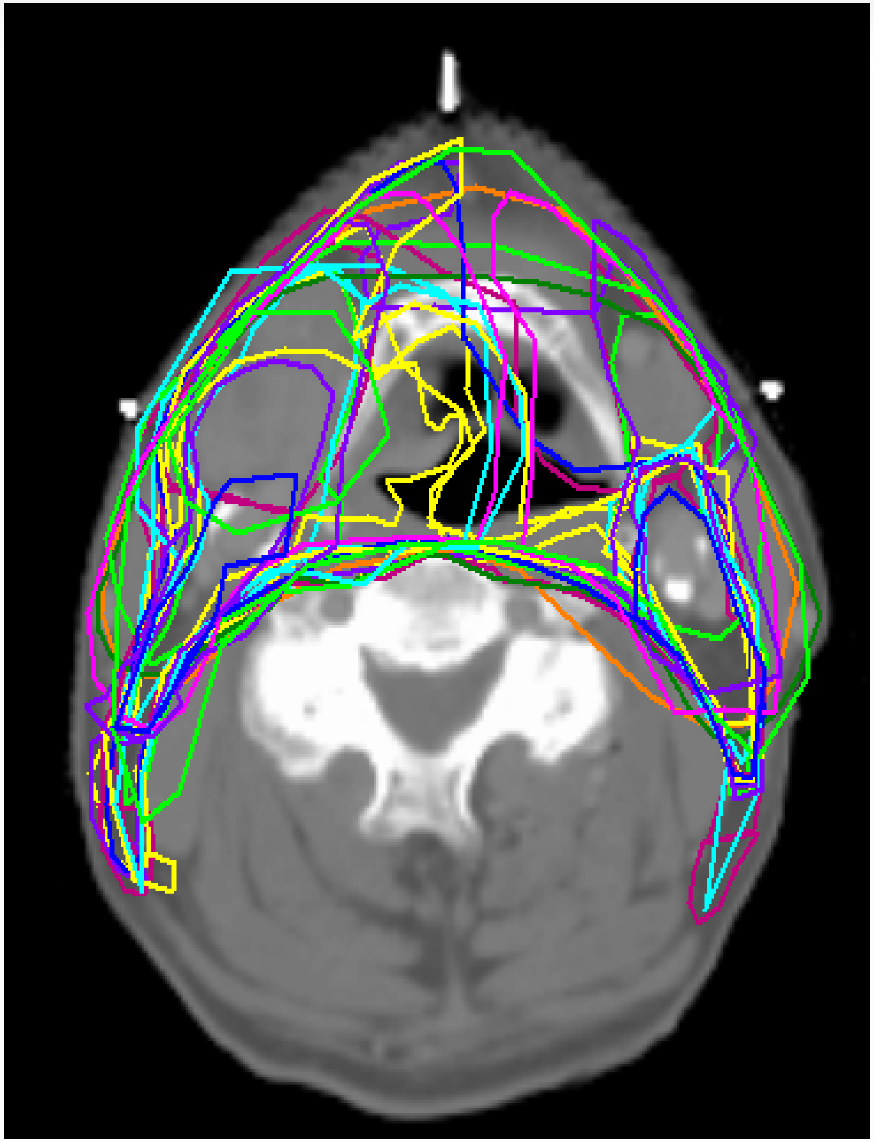
Delineation variation



back

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Image registration

Mirjana Josipovic
Dept. of Radiation Oncology
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Copenhagen, DK

Peter Remeijer

NKI-AVL
Amsterdam, NL

Advanced skills in modern radiotherapy
June 2015

Image registration

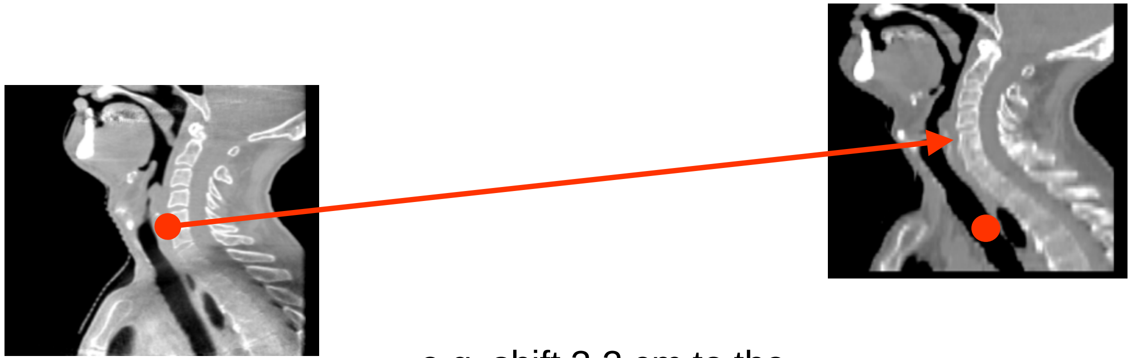
You may also call it

- Image fusion
- Image matching
- Image warping

= process of aligning two (or more) images

Image registration

- Determine the transformation between two scans

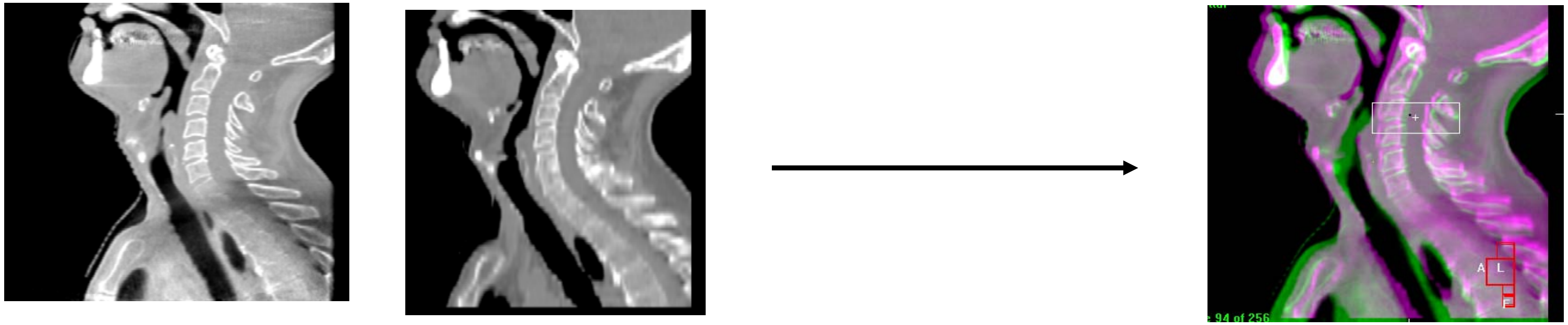


e.g. shift 3.2 cm to the right and 4.1 cm up

- Allows comparison of scans on a pixel-by-pixel basis

Image fusion

- Combine the information of two scans



- Allows viewing and validation of registration result

3D image registration & fusion in radiotherapy

- Include other modalities than CT in the treatment planning process
  - MRI
  - PET
  - SPECT

- Quantify organ motion
- Detect patient anatomy changes during treatment
- Image guided radiotherapy

3D image registration for follow up

- Measure tumor response
- Measure normal tissue damage
- Investigate causes of local failure
- Investigate possibility of re-irradiation

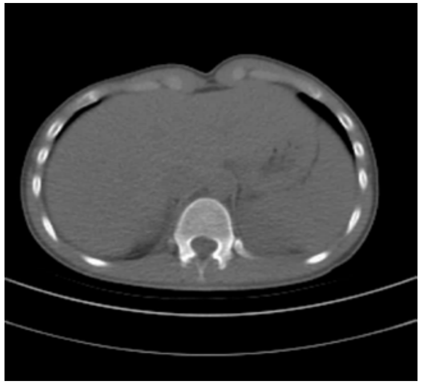
Manual image registration

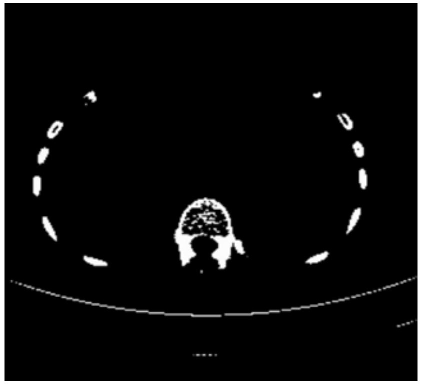
- Simple ‘algorithm’
- Good for gross alignment

- Difficult in 3-D
- Not very precise

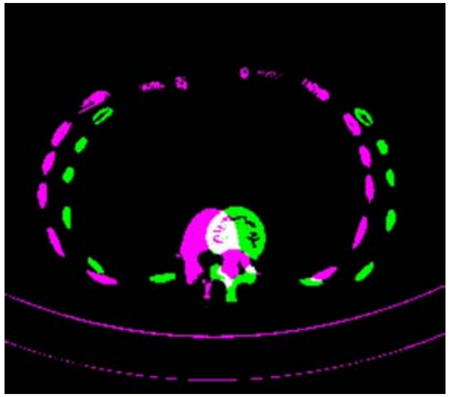
Chamfer matching

1. Segment the features in both scans





2. Minimize the distance between the features



- Good for high density structures
- Relatively fast & robust algorithm

Used on Elekta

Grey value registration

- Uses gray values in all pixel values
  - <u>Inside the regions of interest</u>
- Values are compared through different cost functions
  - Mutual information
  - Root mean square of difference
  - Correlation ratio
  - Product
- Slower than chamfer matching
  - But getting faster with more computing power ☺

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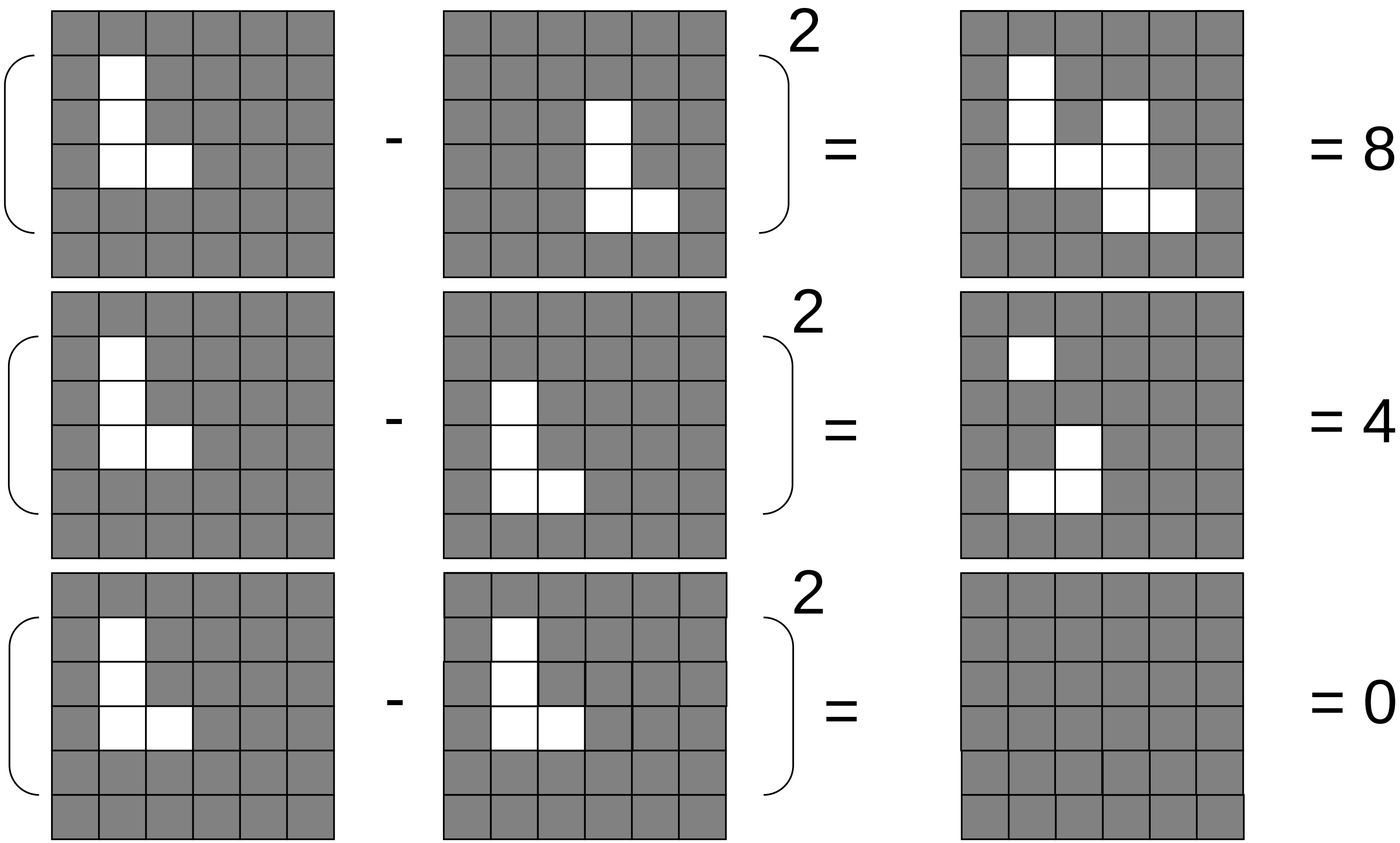
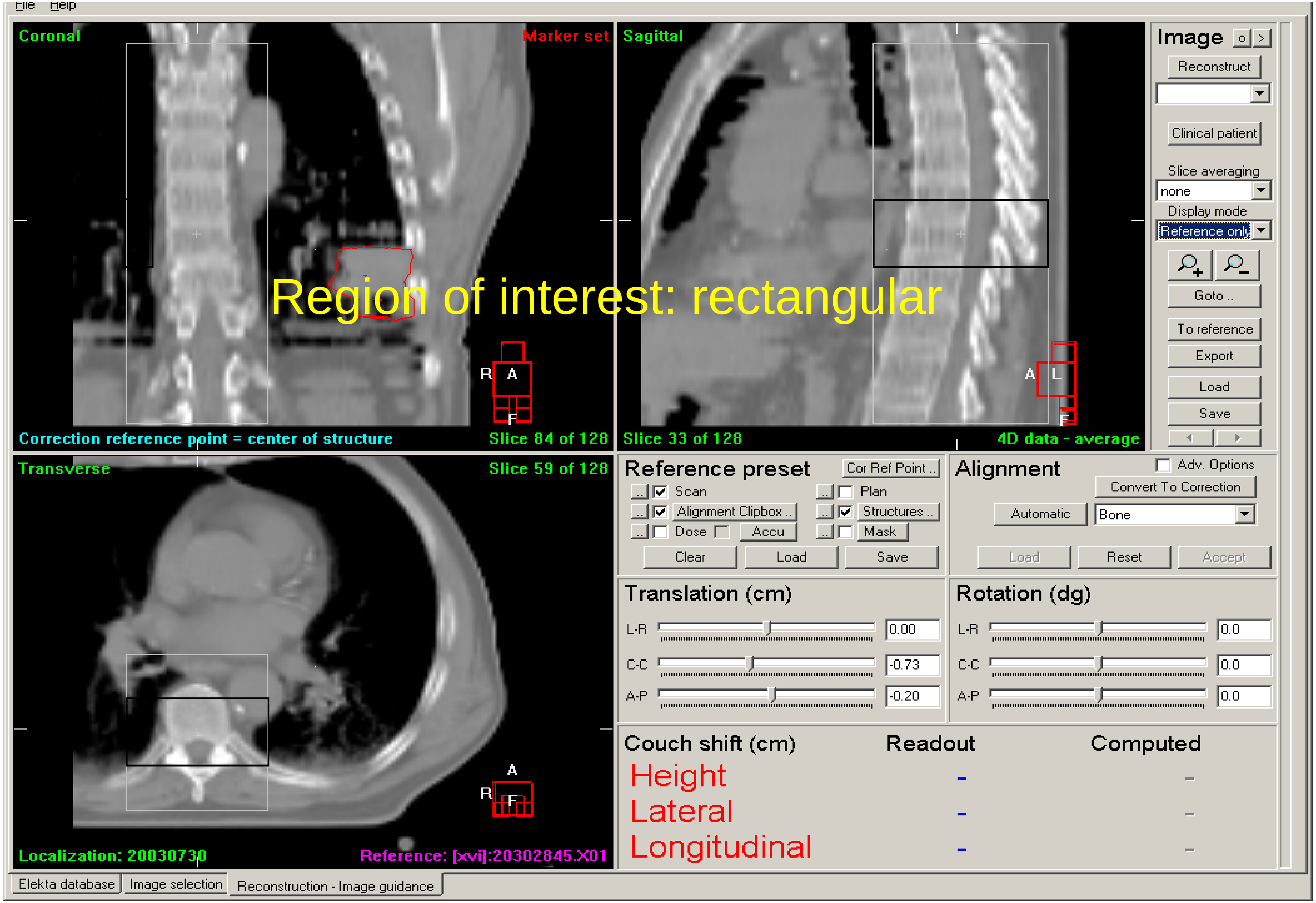
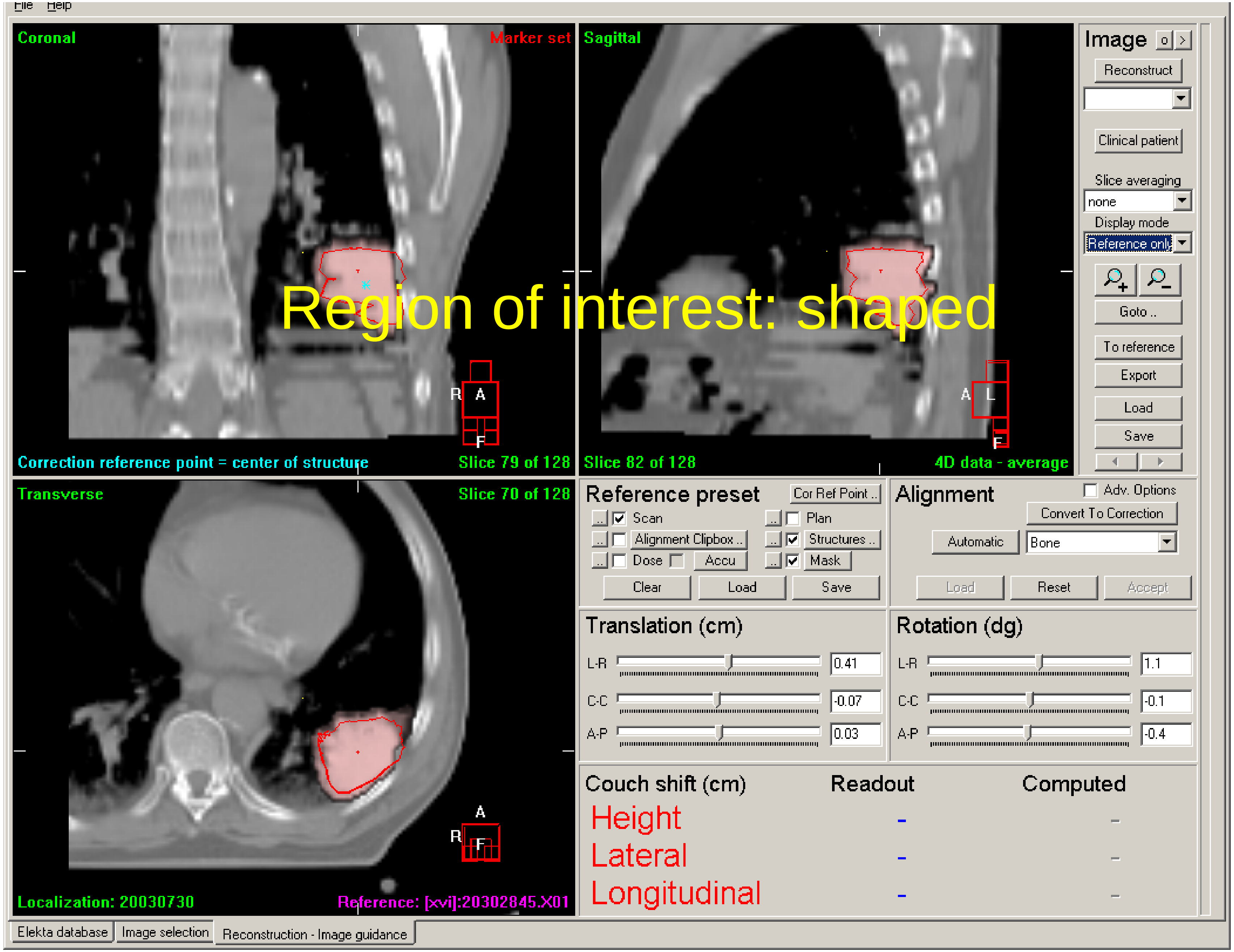
Grey value registration example





Elekta

Easily defined: well suited for ‘easy’ registration (e.g., bone)



Define by expanding delineation

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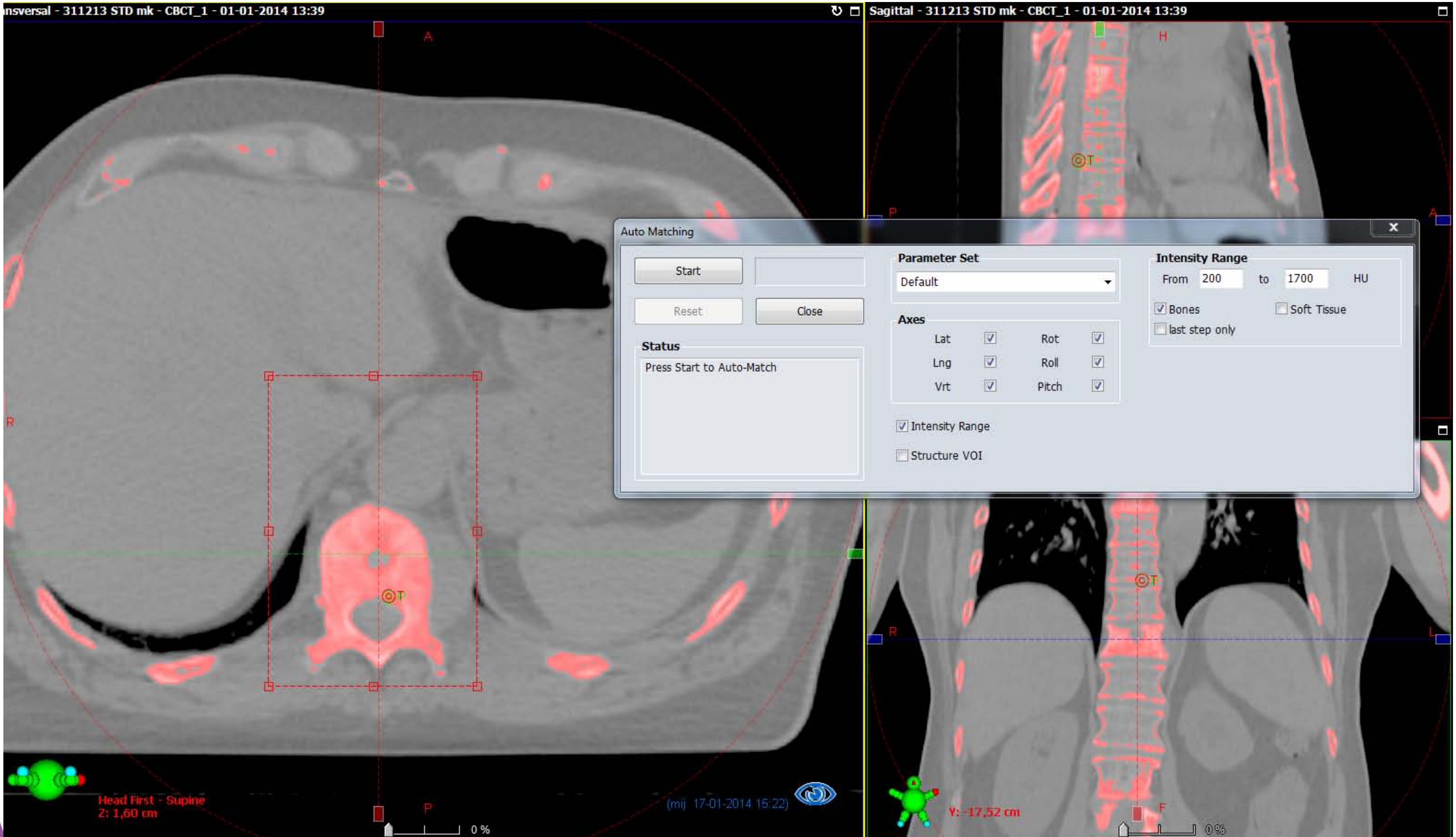

Varian

BONE gray values

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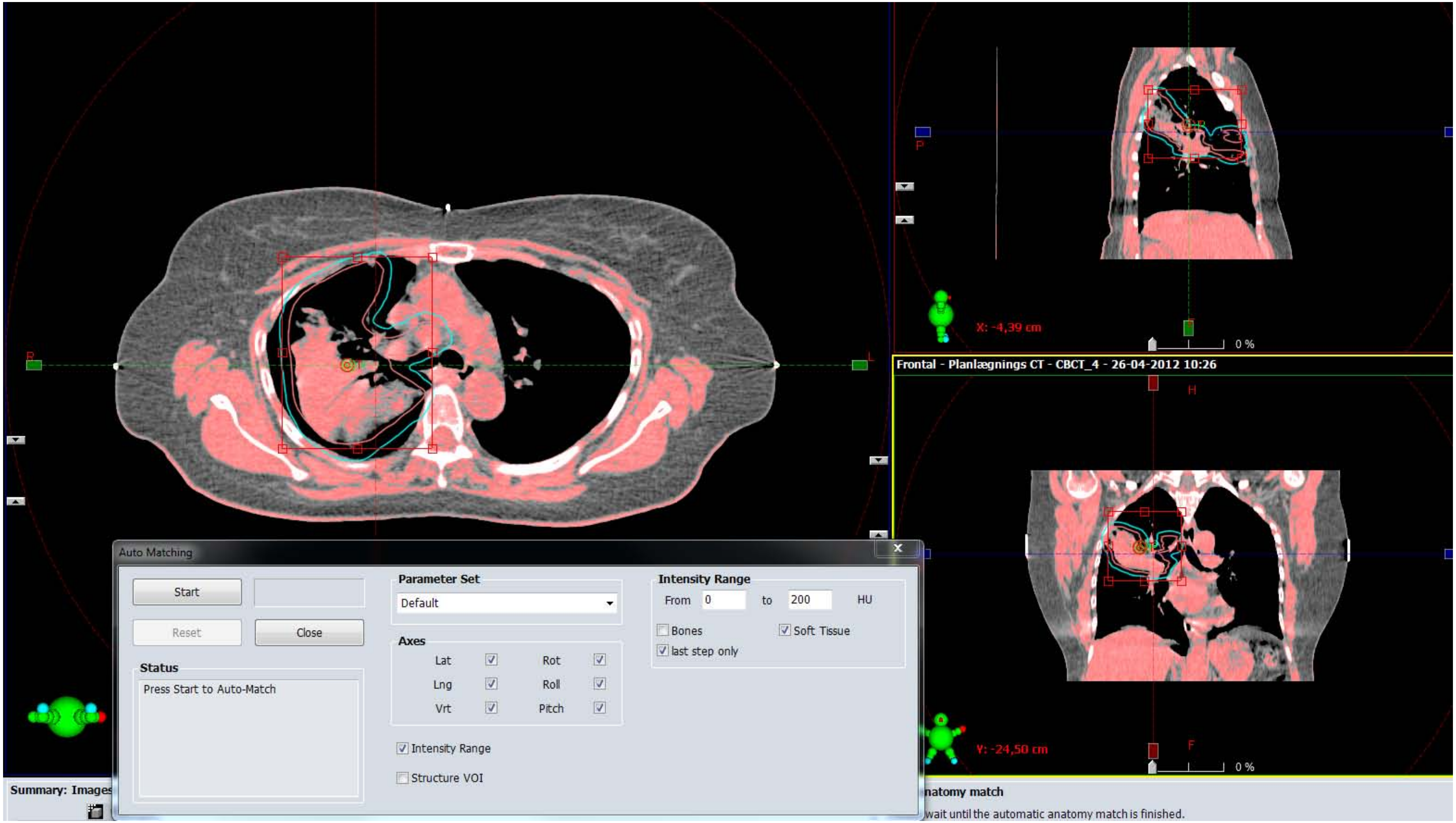
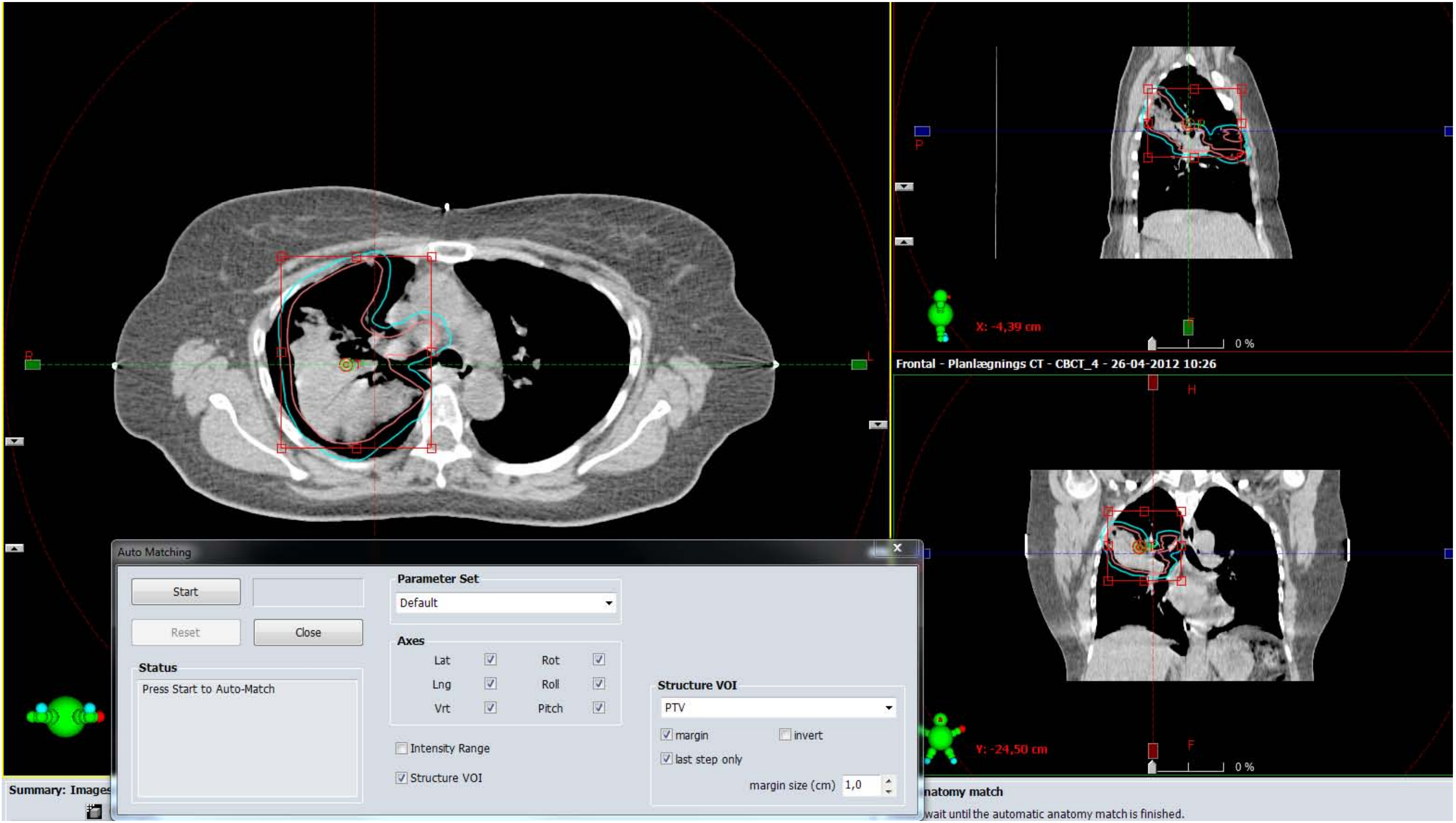


Varian

Soft tissue gray values



gray values in a defined region of interest (ROI)

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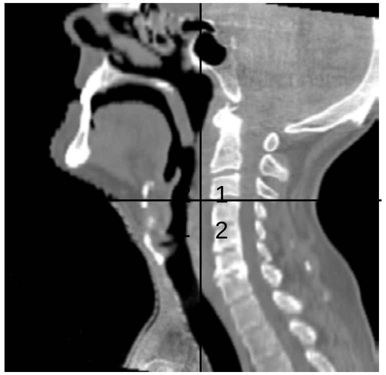
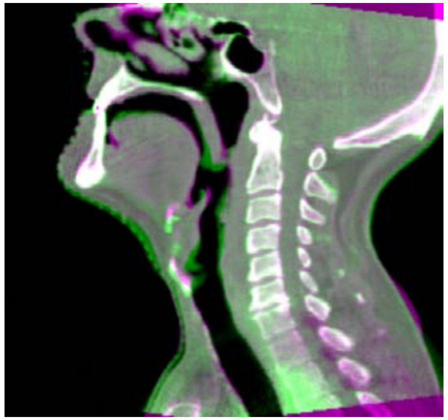
Image fusion

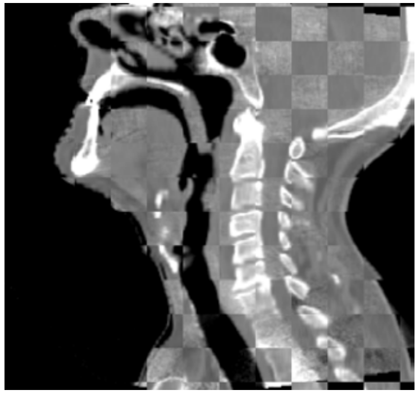
- Viewing & validation



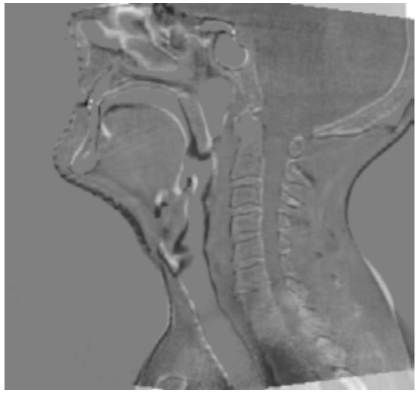
Sliding window



Overlay



Checker



Substract

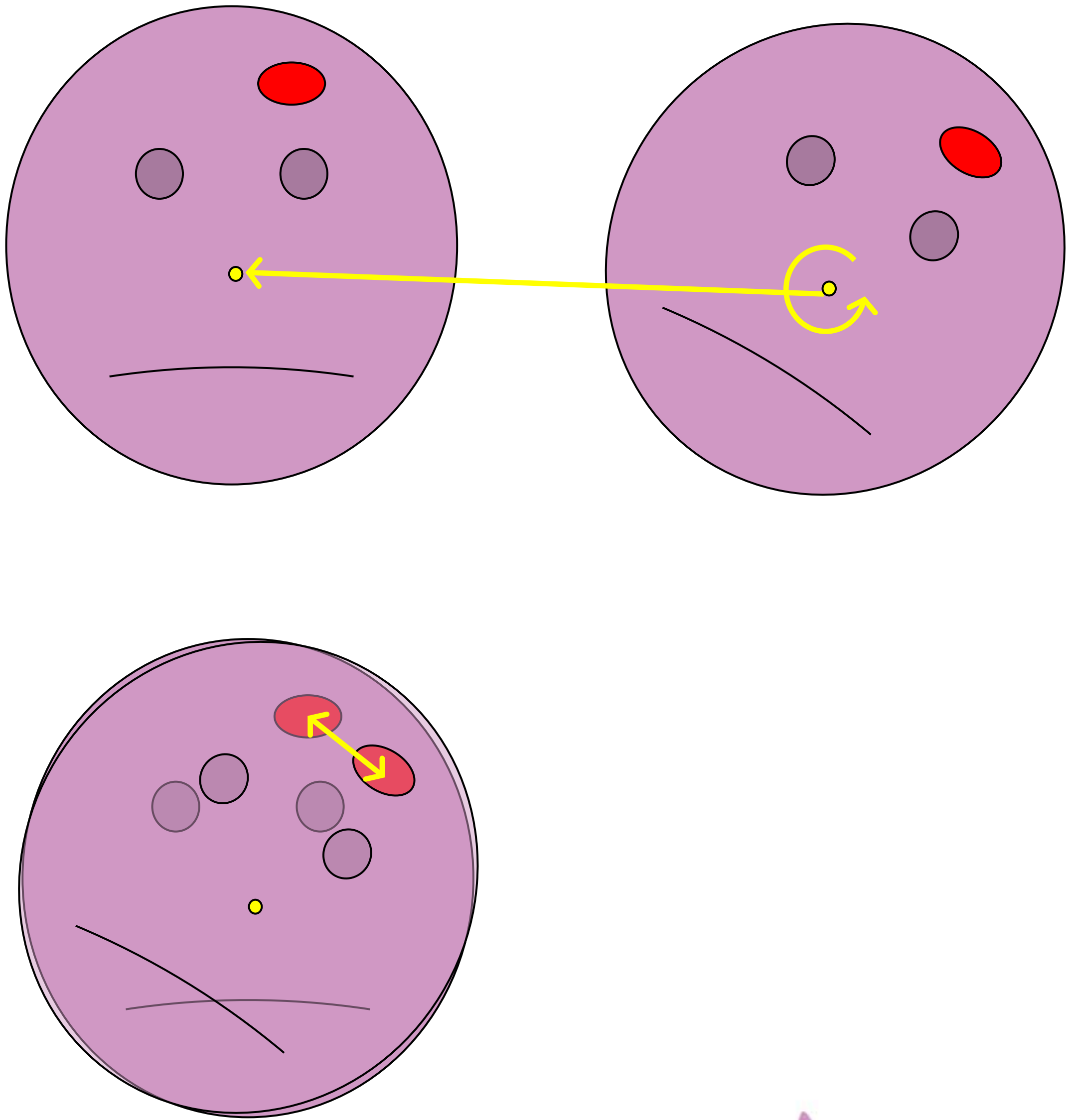
Image registration for treatment guidance

- Determine tumor position at the time of treatment
- Use the information for on- or offline corrections

Corrections without rotations

- Registration
  - Bony anatomy
  - Translations and rotations
  - Very accurate

- Correction
  - Only translations
  - Potentially large errors



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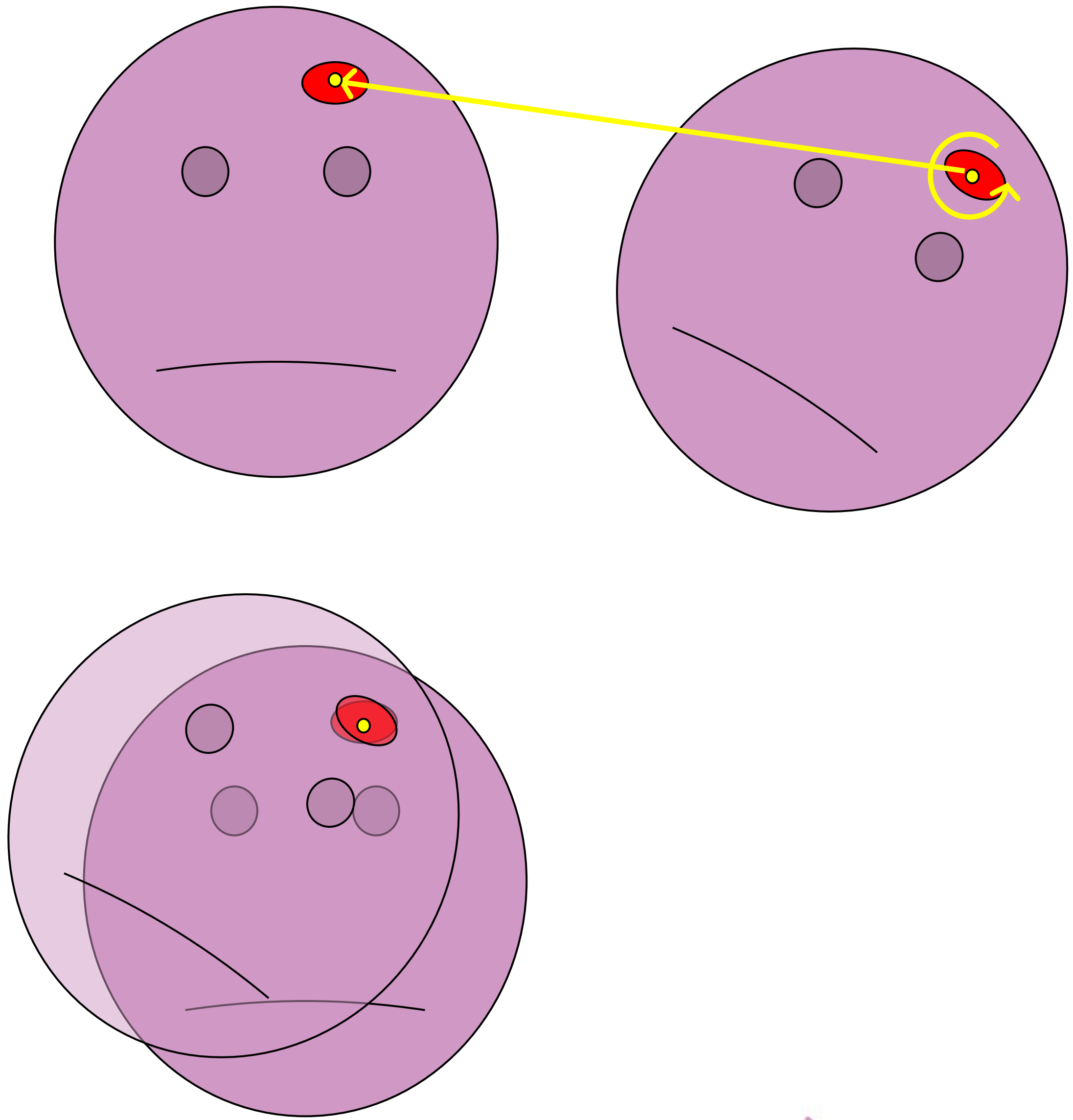
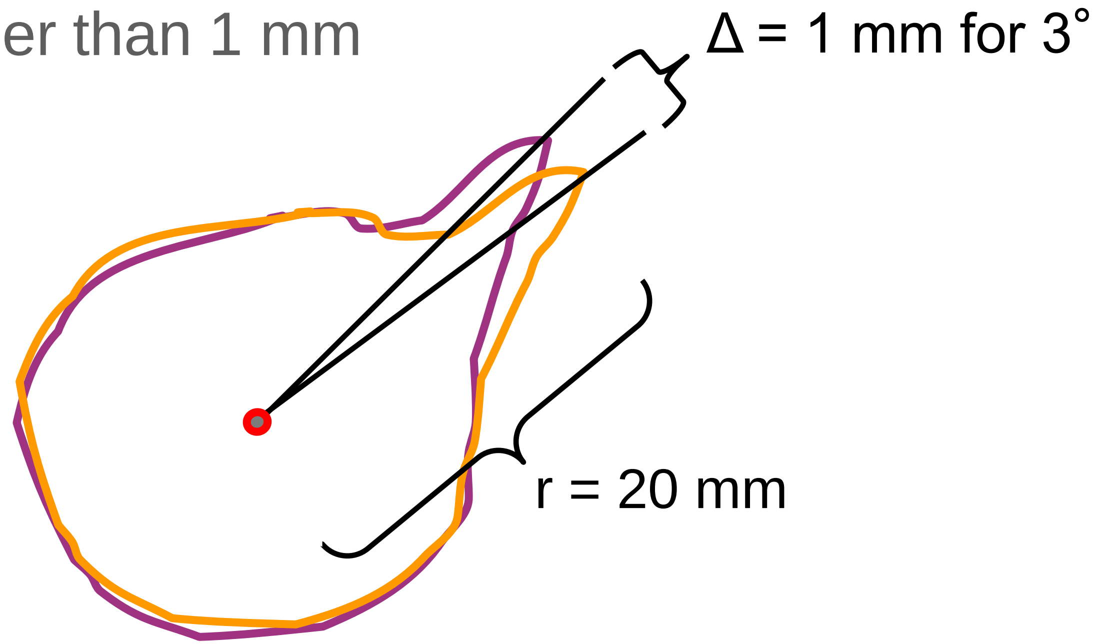
Corrections without rotations

- Registration
  - Redefine match volume
- Correction
  - Only translations
  - Rotational errors are small close to rotation center



Corrections without rotations

- If rotation is 3 degrees (SD 1 degree)
- And CTV diameter is 40 mm
- And rotation centre is in CTV
- Errors to CTV will be smaller than 1 mm



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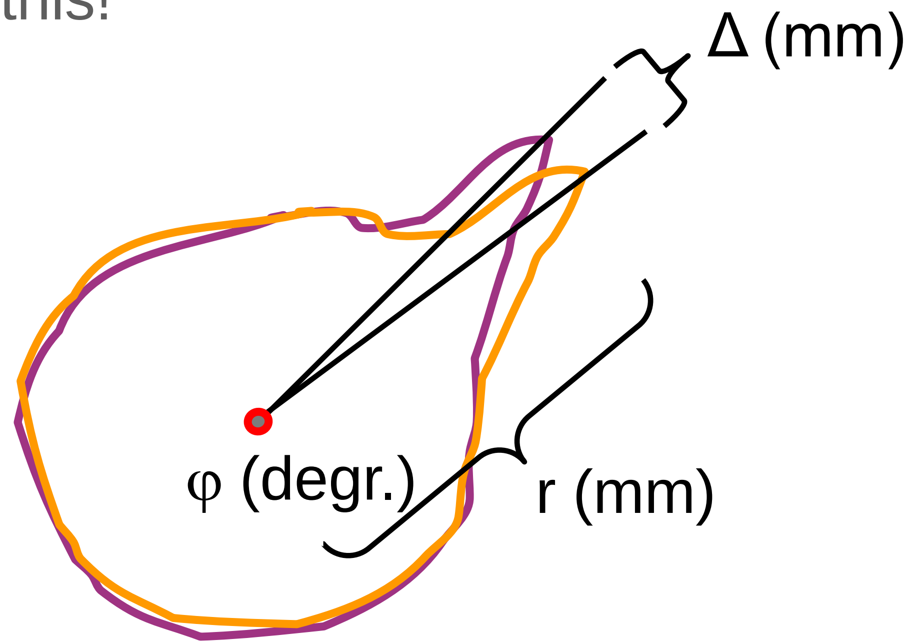
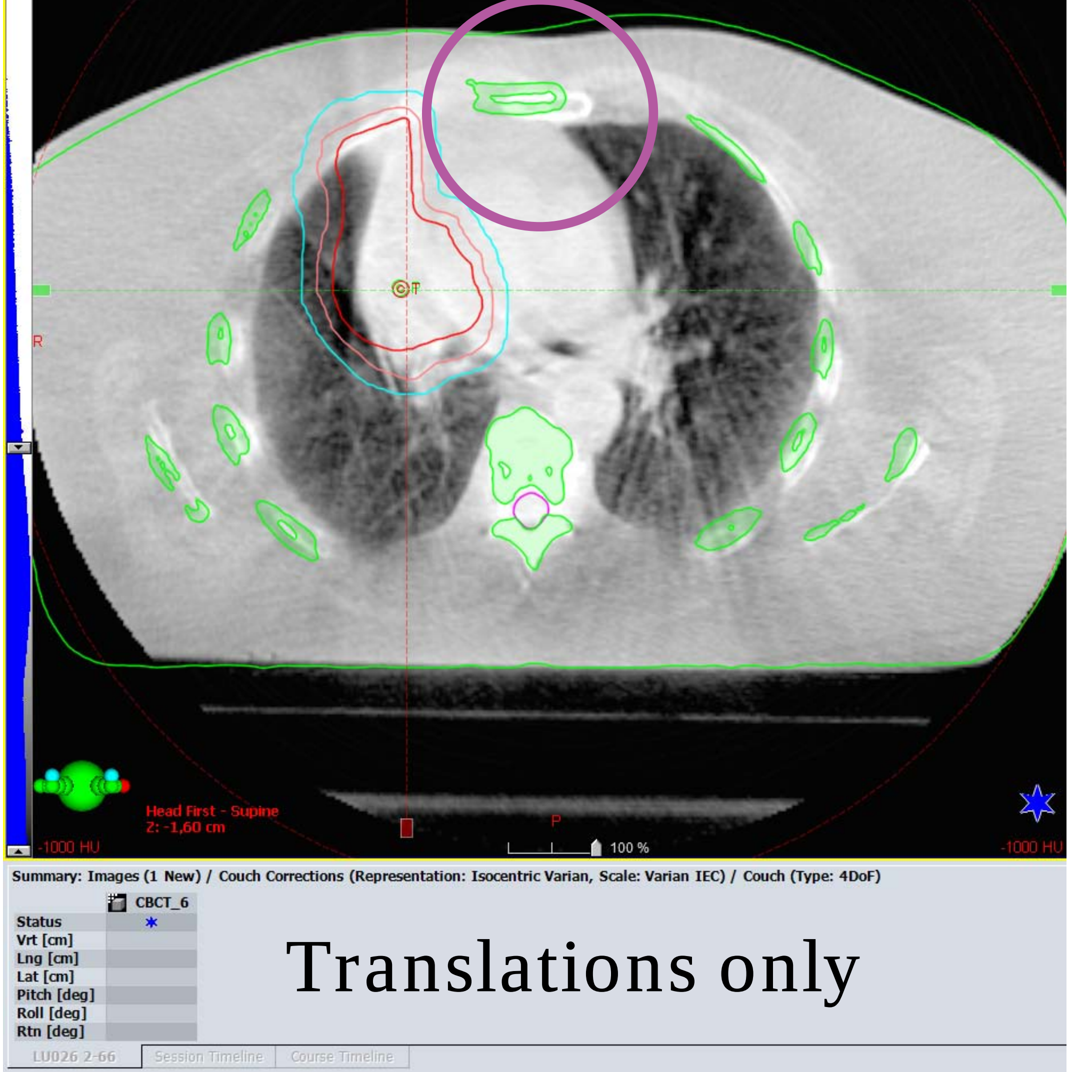
Corrections without rotations

- Problem for structures far from rotation center
- Rule of thumb: $\Delta = 0.02 \times \varphi \times r$ (mm)

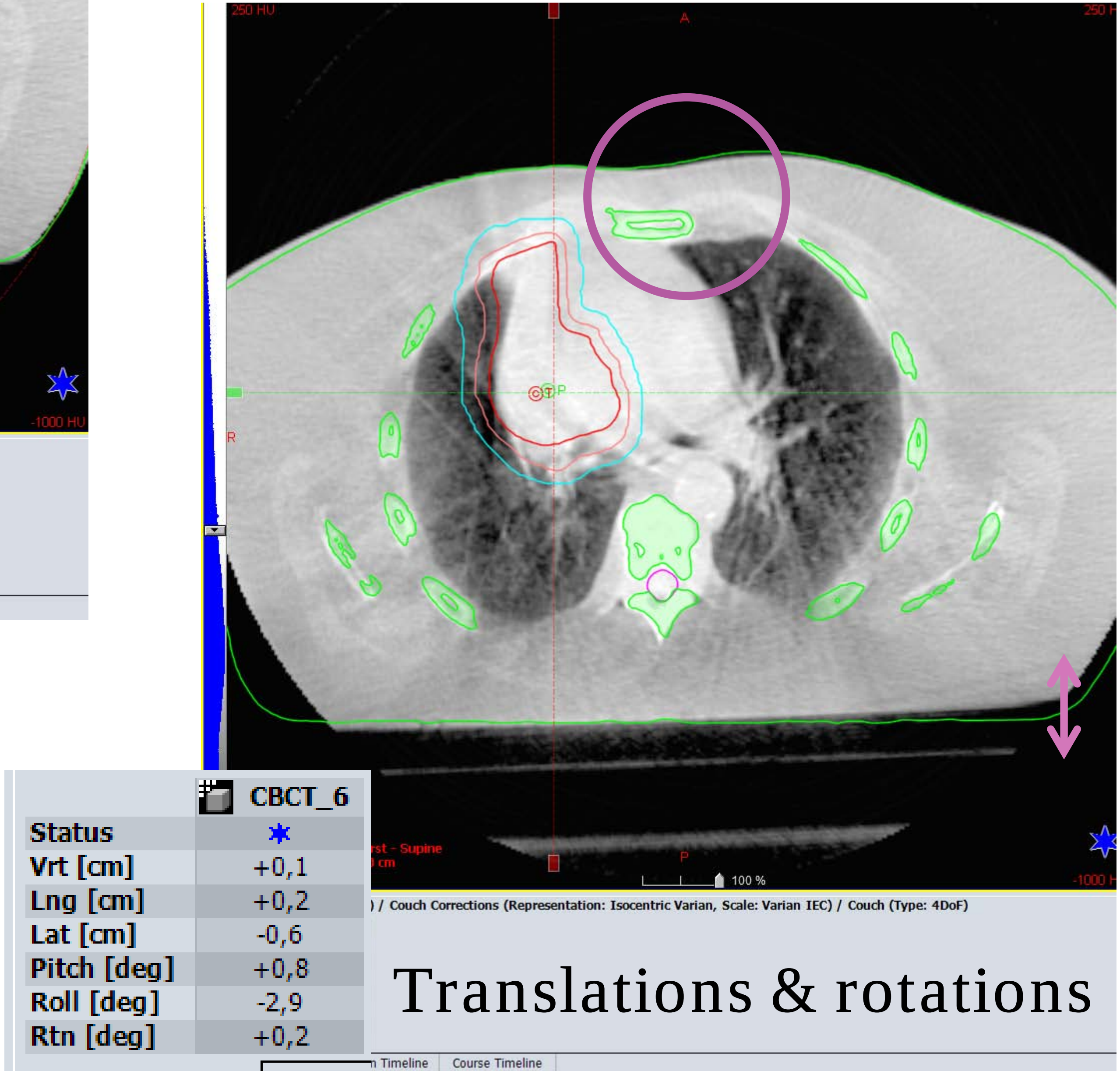
(So 3° will yield a 6 mm shift at 10 cm distance)

$\Rightarrow$ Plan should allow for this!





Translations only



	CBCT_6
Status	*
Vrt [cm]	+0,1
Lng [cm]	+0,2
Lat [cm]	-0,6
Pitch [deg]	+0,8
Roll [deg]	-2,9
Rtn [deg]	+0,2

Translations & rotations

Lung SBRT

Table II. Residual positioning error when correcting for three degrees of freedom compared to six degrees of freedom, i.e. when rotational errors are not corrected for.

	AP [mm]	CC [mm]	LR [mm]	pitch [°]	roll [°]	rot [°]
M	−0.1	0.1	−0.1	0.31	−0.06	−0.56
Σ	1.3	1.0	0.8	1.20	1.23	1.42
σ	1.5	1.0	1.1	0.79	1.33	0.85

AP, anterior-posterior; CC, cranio-caudal; LR, left-right.

Josipovic et al, Acta Oncol 2012

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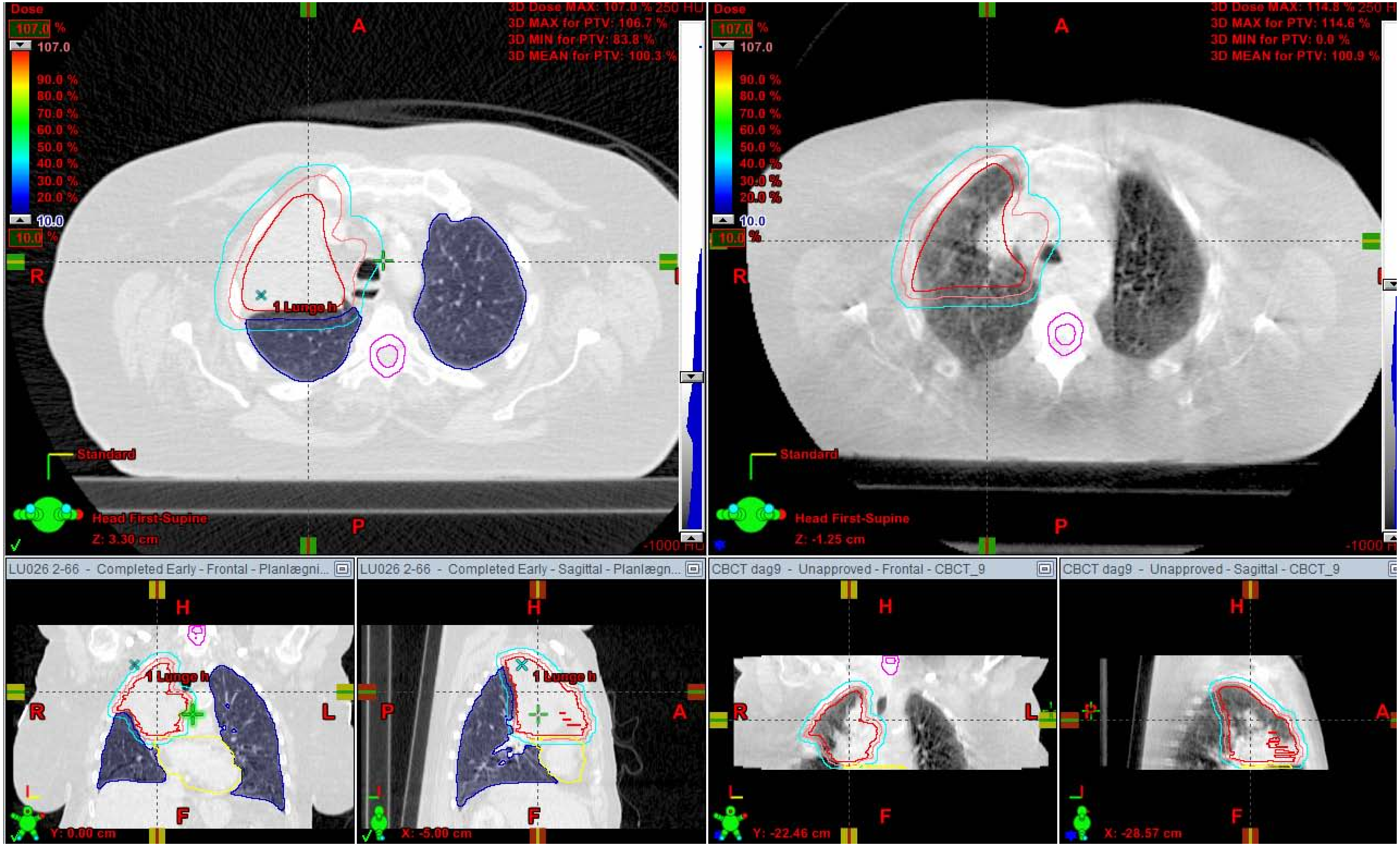
Challenges….

- Non-perfect image quality or distortions (organ motion)
- Scan artifacts
- Deformations
- Verification of individual registrations
- Connection to treatment planning system

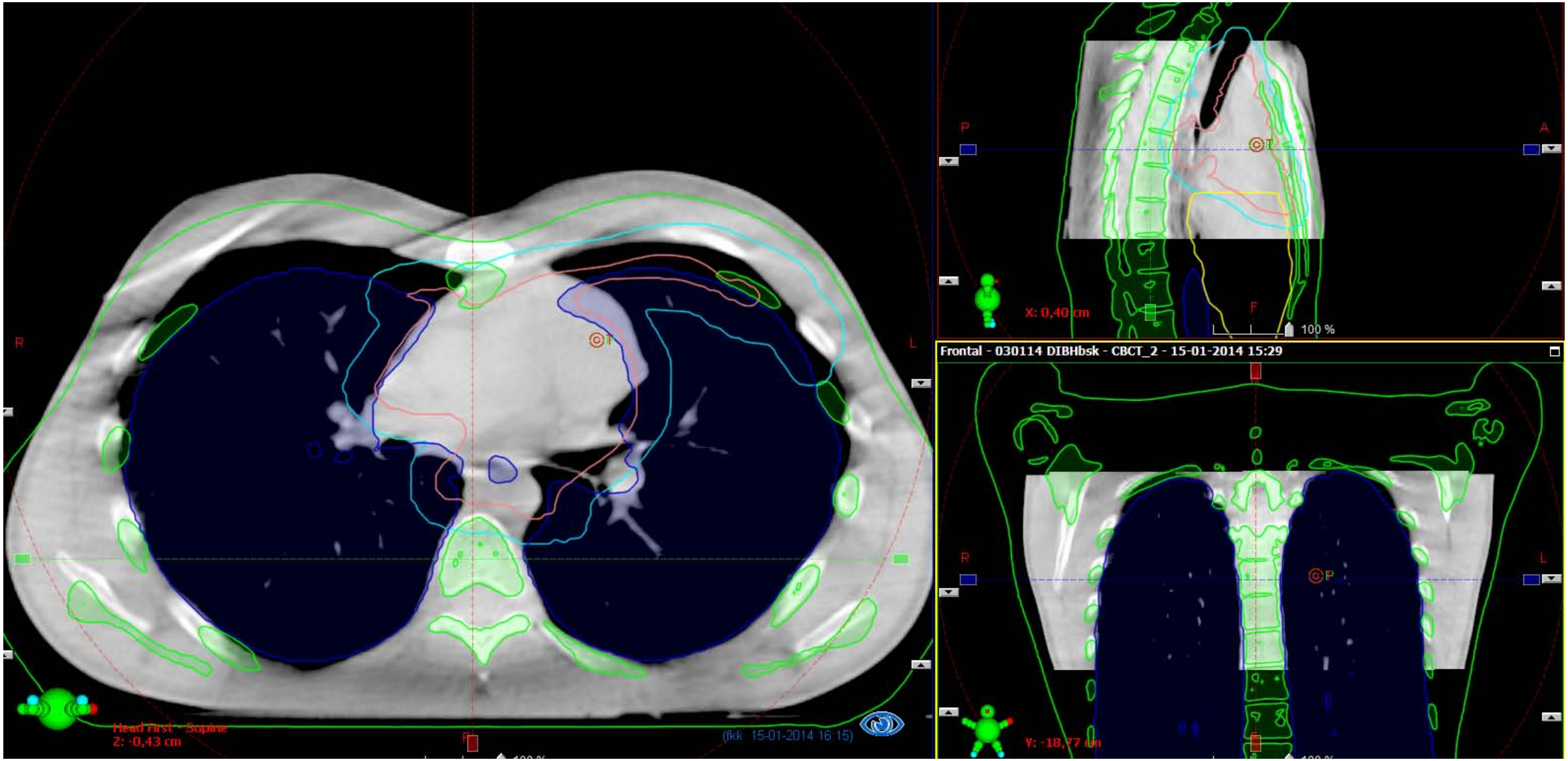
Treatment response



Day 1

Day 11

Error in automatic image registration



Automatic image registration has to be evaluated!

Focus not only on the primary structures of interest, but on the whole image!

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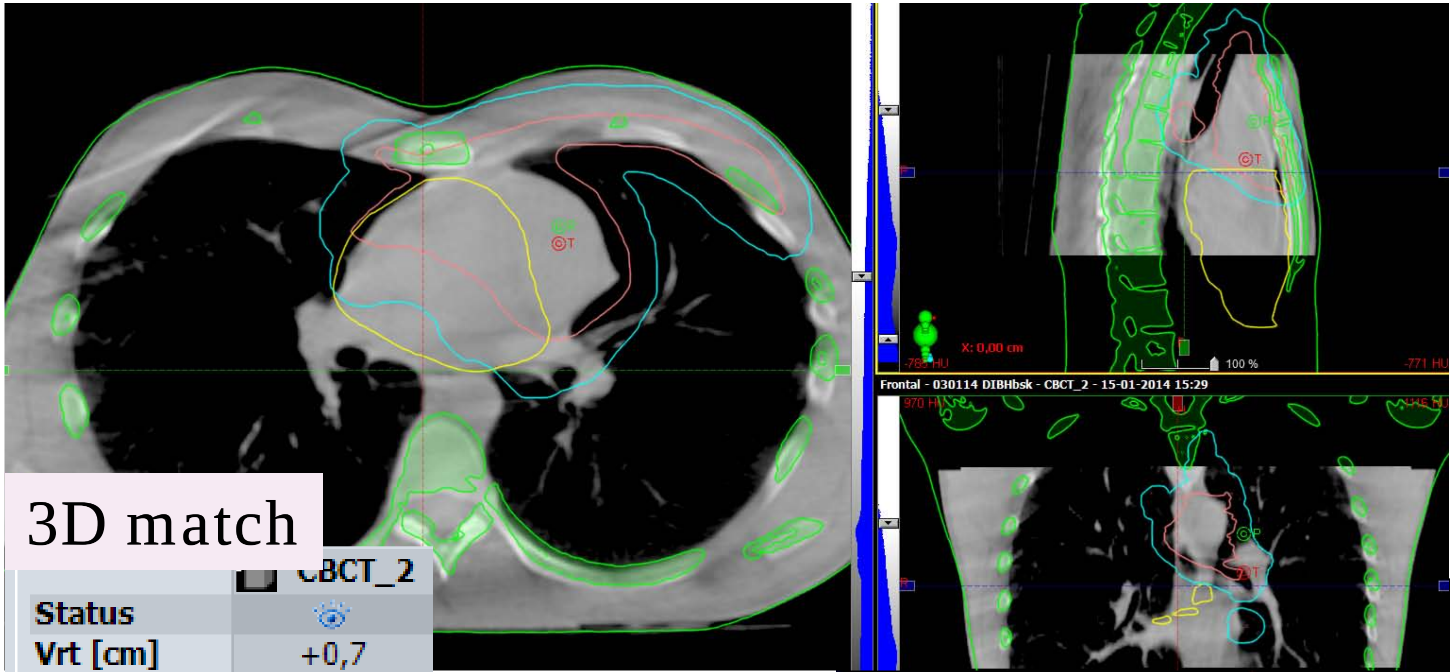
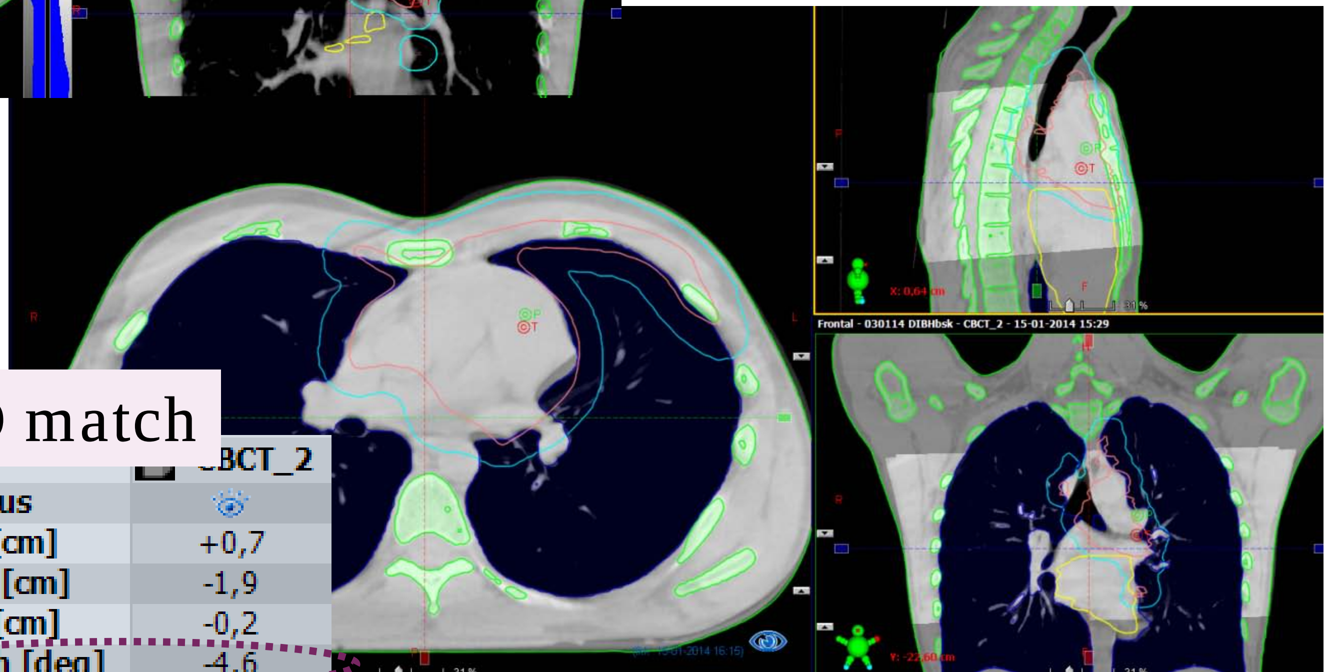
Error in automatic image registration



3D match

	CBCT_2
Status	
Vrt [cm]	+0,7
Lng [cm]	-3,0
Lat [cm]	0,0
Pitch [deg]	0,0
Roll [deg]	0,0
Rtn [deg]	0,0



6D match

	CBCT_2
Status	
Vrt [cm]	+0,7
Lng [cm]	-1,9
Lat [cm]	-0,2
Pitch [deg]	-4,6
Roll [deg]	-1,4
Rtn [deg]	-1,1

Focus on the patient set-up!

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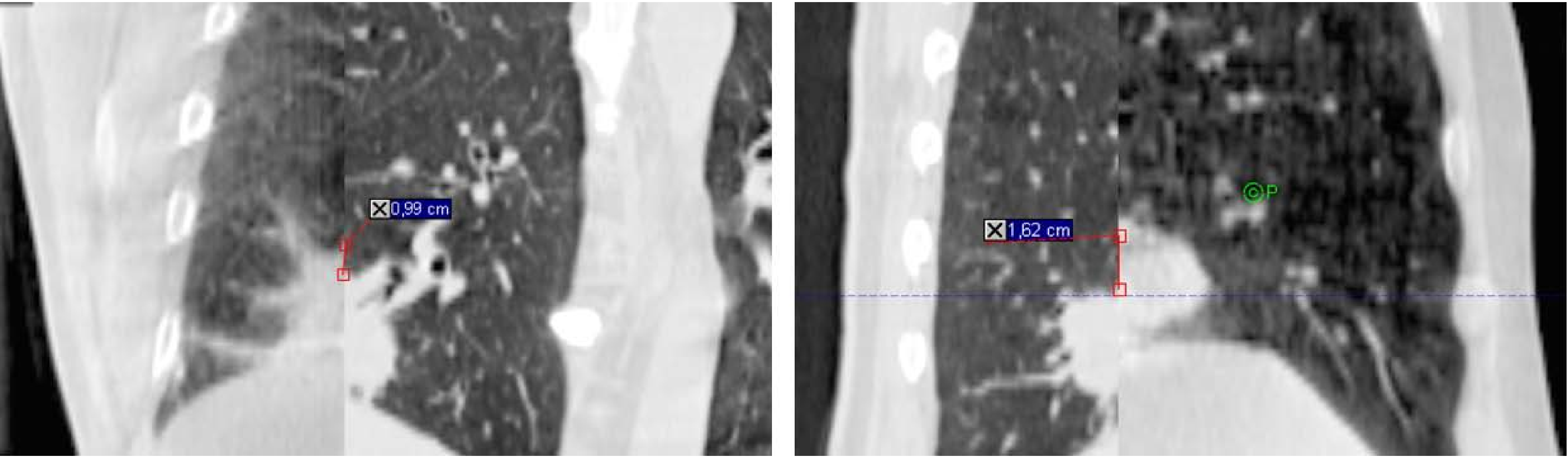
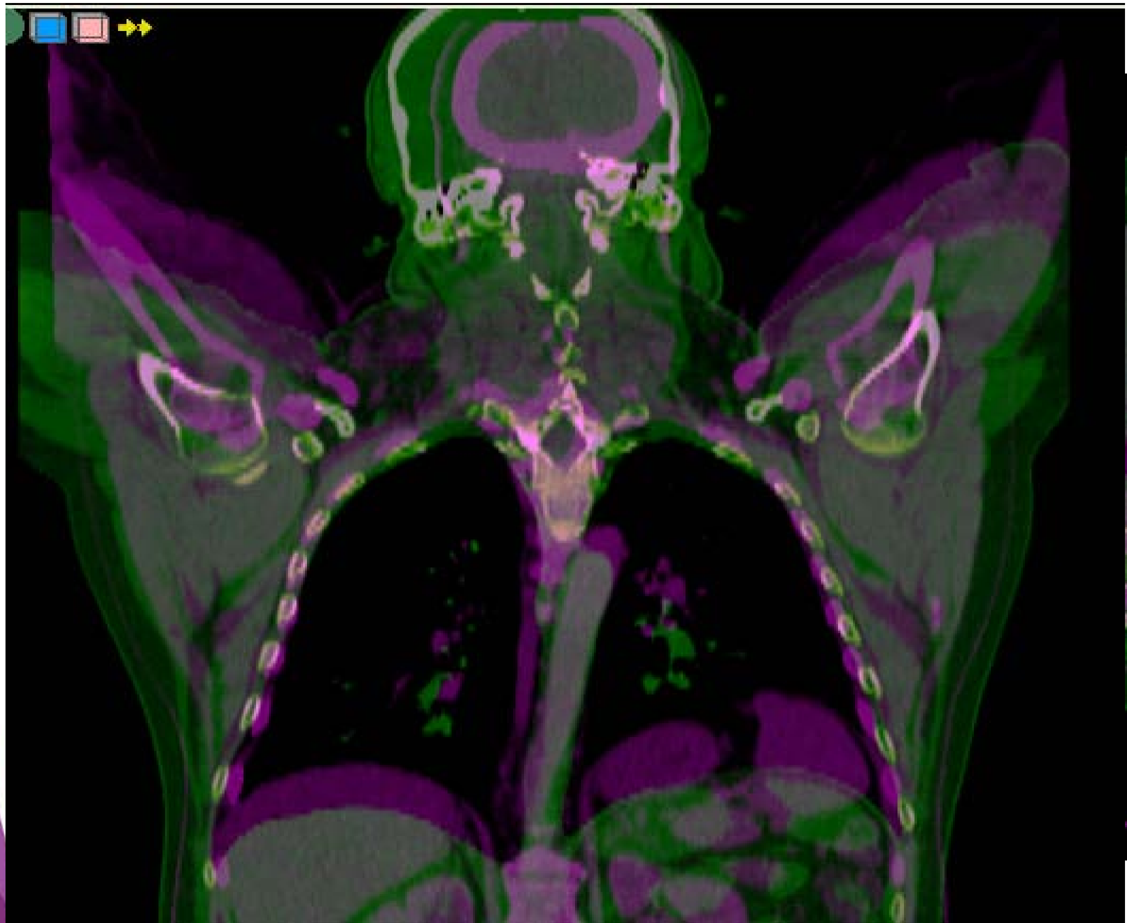
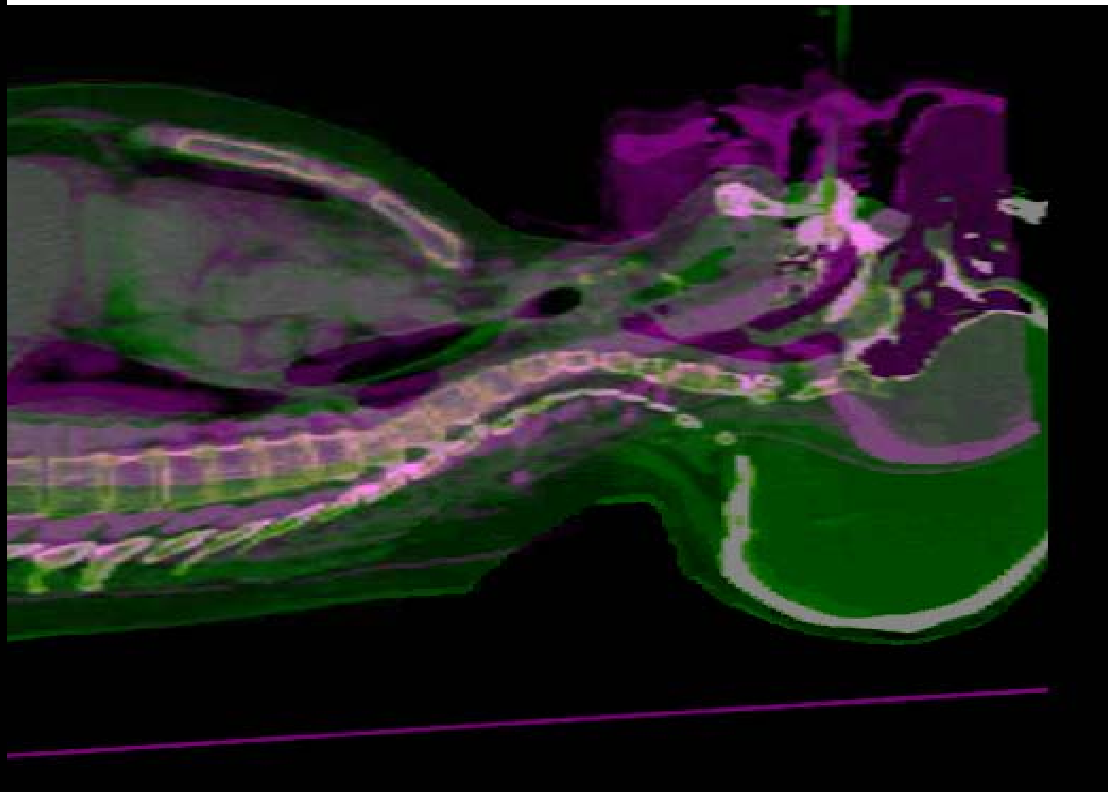
Breathing motion - breath hold images matched on bones…



… misalignment of the peripheral tumour

Fusion of pre-chemo and post-chemo scan

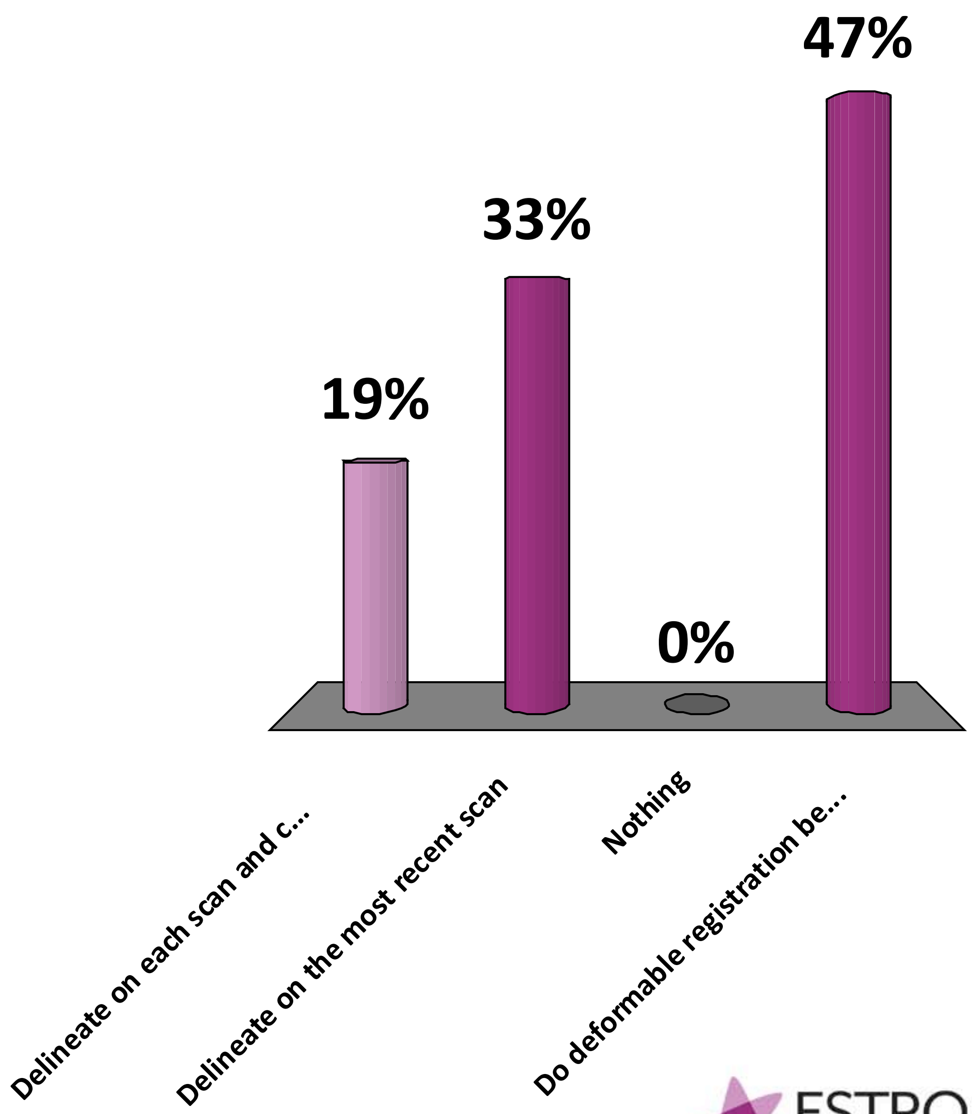


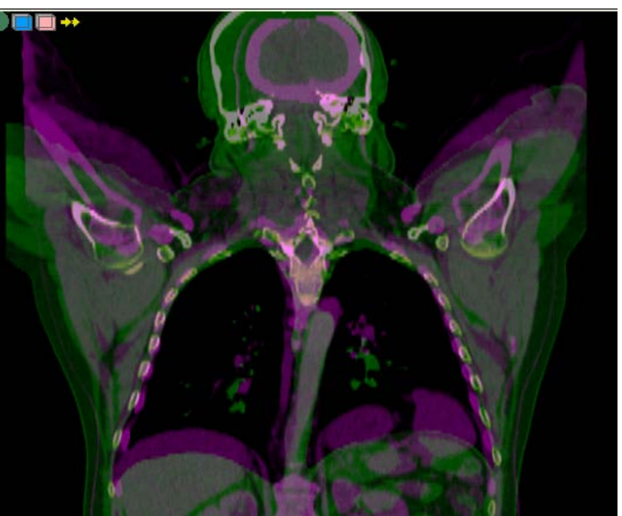


Courtesy M. Aznar

What would you do (or your radiation oncologist)?

A. Delineate on each scan and combine contours
B. Delineate on the most recent scan
C. Nothing
D. Do deformable registration before delineation





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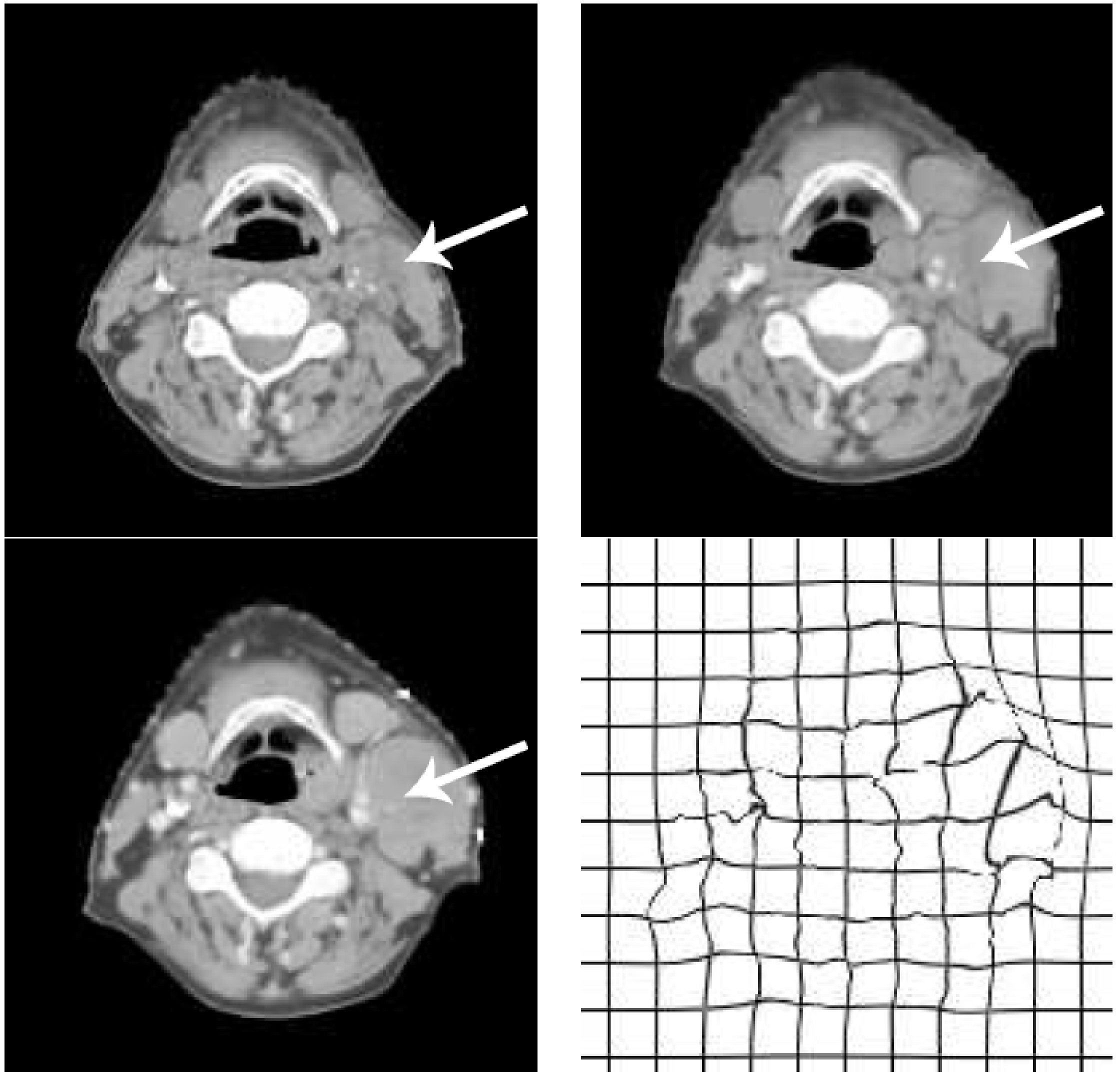
Deformable image registration - DIR

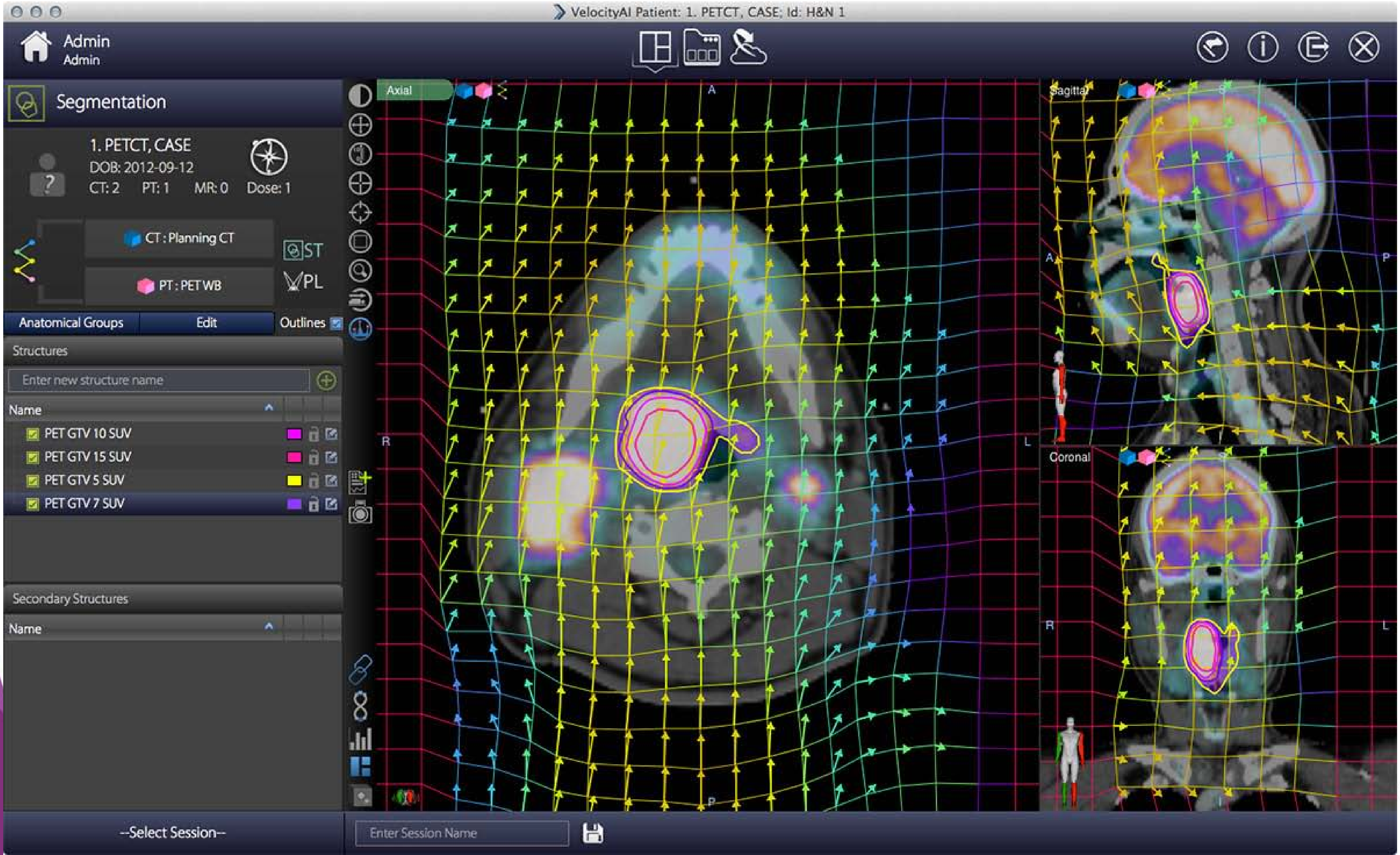
- What is DIR?
  - ➢ Non-rigid image registration

- DIR approaches
  - ➢ Feature based
  - ➢ Model based
  - ➢ Image intensity based



Images courtesy of CØ Noe

Deformable image registration - DIR

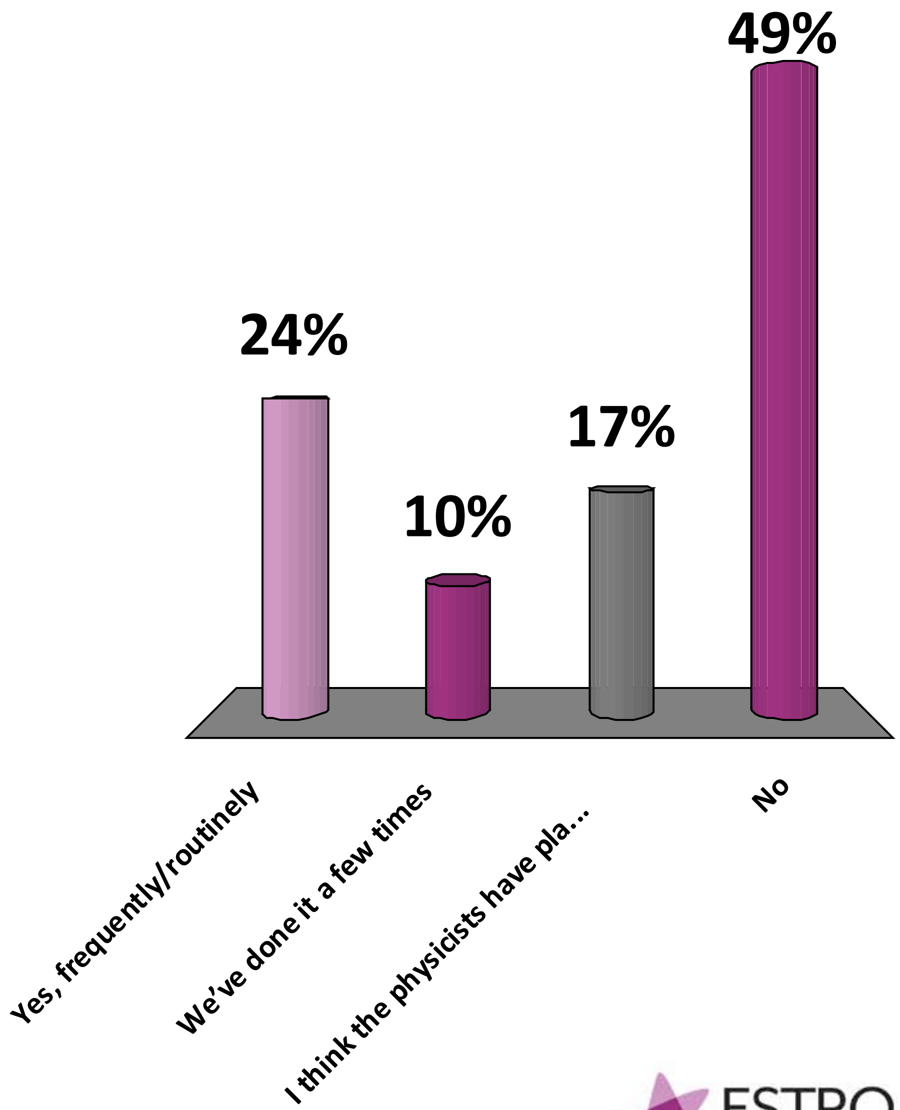


Deformable image registration

- How do you know the result is good
  - ➢ It looks ok ☺
- Getting the contours / outlines of organs right
  - ➢ Ok for IGRT
- Getting the heterogeniety/tissue cells inside the organs right
  - ➢ Necessary for dose accumulation
- Different challenges with different organs
- DIR needs to be evaluated for each clinical problem

Do you perform deformable image registrations at your clinic?

A. Yes, frequently/routinely
B. We’ve done it a few times
C. I think the physicists have played with it
D. No



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DIR and Teenage Sex

- ☺ It is on everybody's mind all the time,
- ☺ Everyone is talking about it,
- ☺ Everyone thinks everyone else is doing it,
- ☺ Almost no one is really doing it,
- ☺ The few who are doing it are:
  - ☺ Doing it poorly;
  - ☺ Sure it will be better next time.

Courtesy L.Dong, Scripps Proton Center, USA

Take home messages

- Image registration should play an important role in any clinic for:
  - routine treatment planning
  - routing treatment delivery
  - clinical studies

- Consider the effect of rotations and anatomical changes

- There is no perfect solution:
  - use best registration algorithm for each problem
  - registration algorithms are **never** perfect - **always** include a visual inspection step in the process

Correction strategies

Peter Remeijer

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Introduction

- Many ways to correct geometrical uncertainties
- Simple: couch shift
- Complex: rescan + plan in 2 minutes

Online or offline?

- No relation to the internet ☺

- Online

  → Take immediate action

- Offline

  → Correct later

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ONLINE corrections

ALL fractions

Image patient

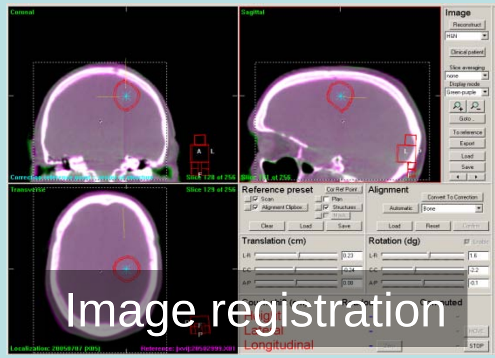
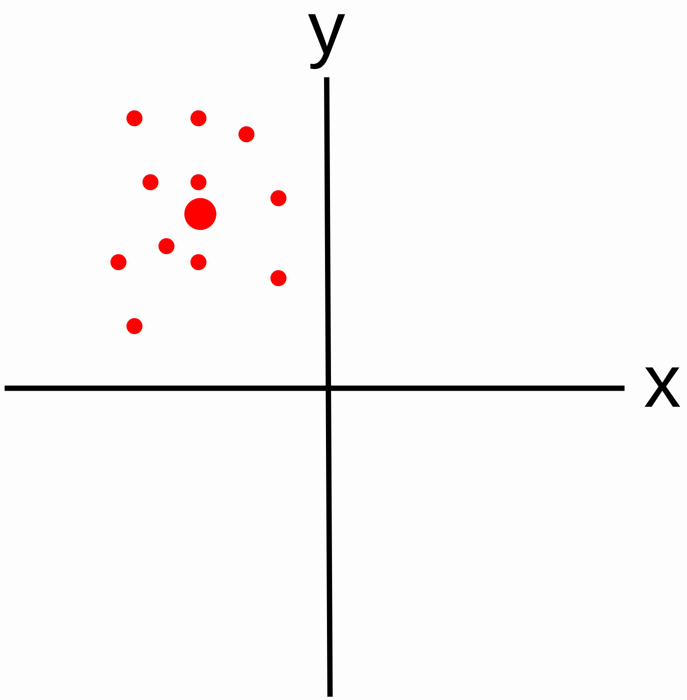


Image registration

Correction

Treat

Online corrections



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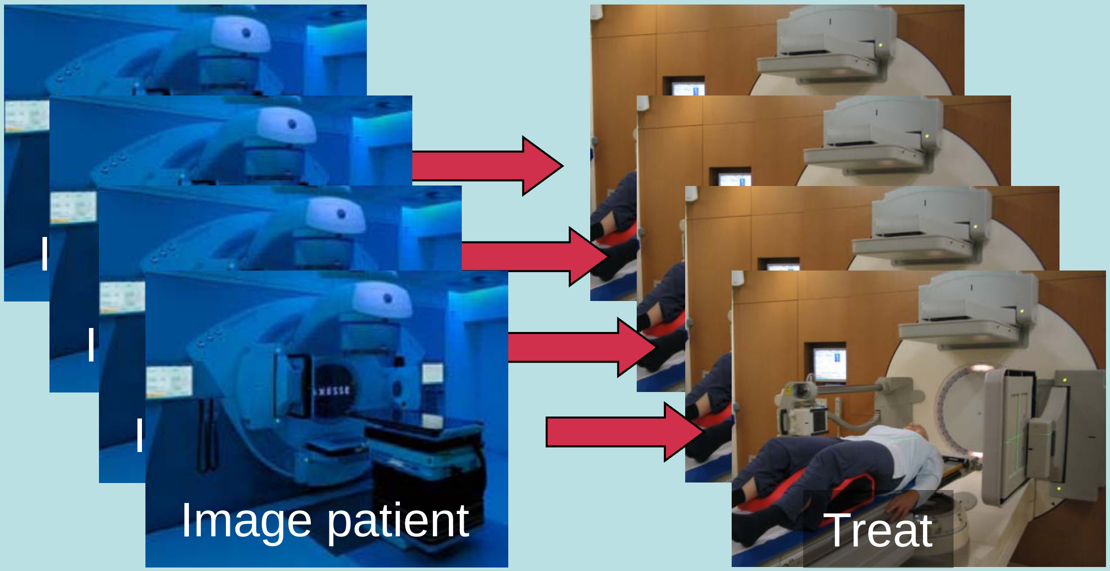
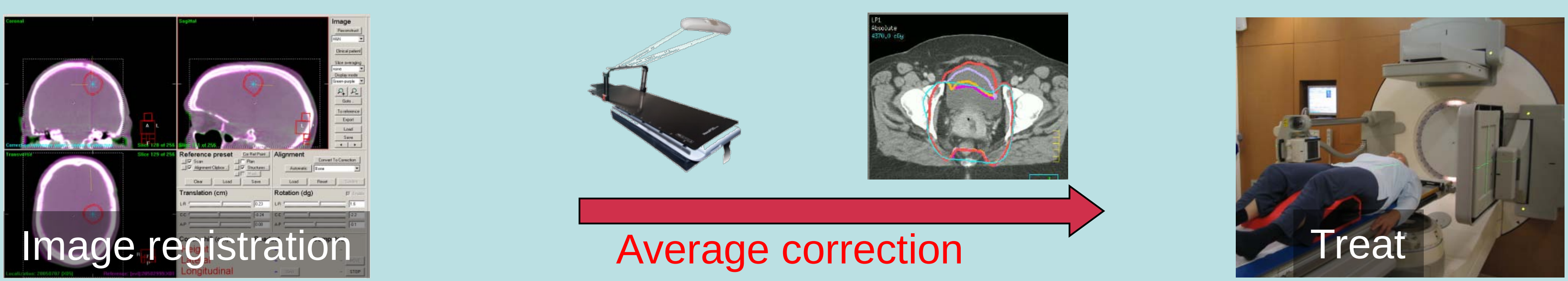
OFFLINE corrections

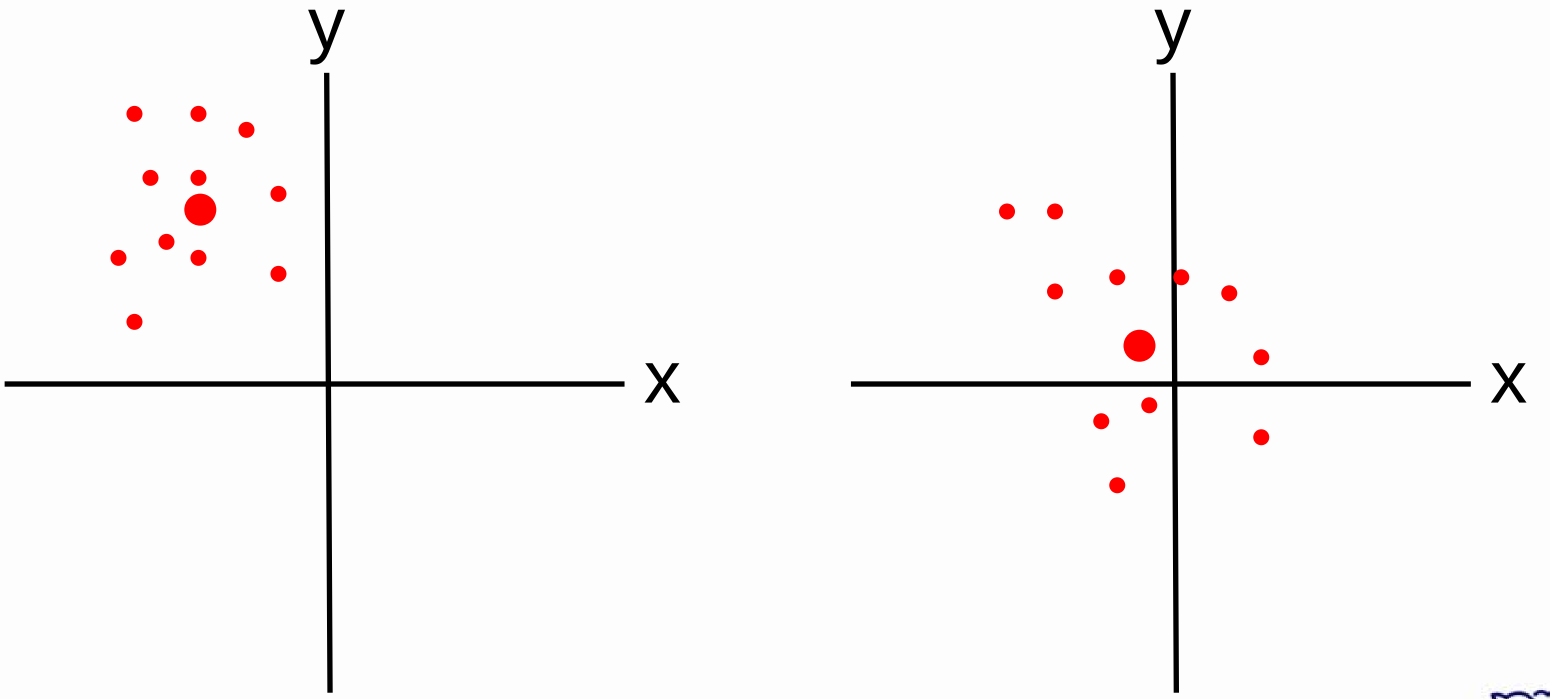
First N fractions



Remaining fractions



Offline corrections



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Online or offline?

Online

- Imaging each fraction
- More time on the linac
- Corrects random and systematic errors
- Correction procedure needs to be fast
- Correction usually only a couch shift
- Smaller effect on margin

Offline

- Limited imaging
- Time efficient
- Only corrects systematic errors
- Correction procedure can take a long time
- Correction can be a re-plan
- Largest effect on the margin

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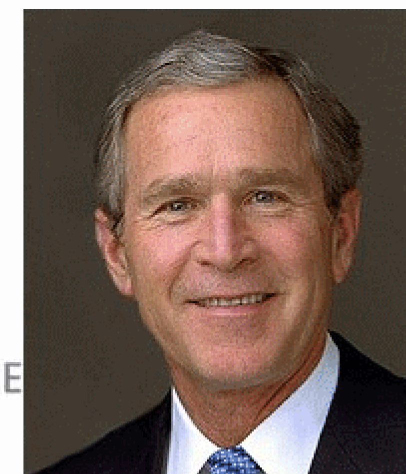
Online or offline

- Translational errors
  - Correction by couch shift
  - On- or offline

- Rotational errors
  - Limited correction some couches
  - Replan / collection of plans

- Shape changes
  - Replan / Collection of plans

- Everything that we don’t correct
  →Margin!!!



NE

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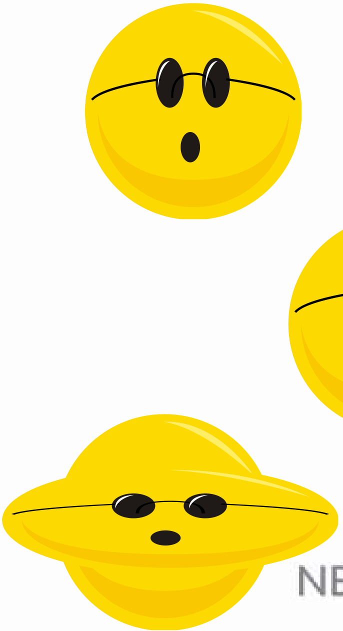
Let's put the theory to practice!

- Bladder tumor treatment interesting case because of:
  - Translations of the tumor
  - Rotations
  - Shape changes



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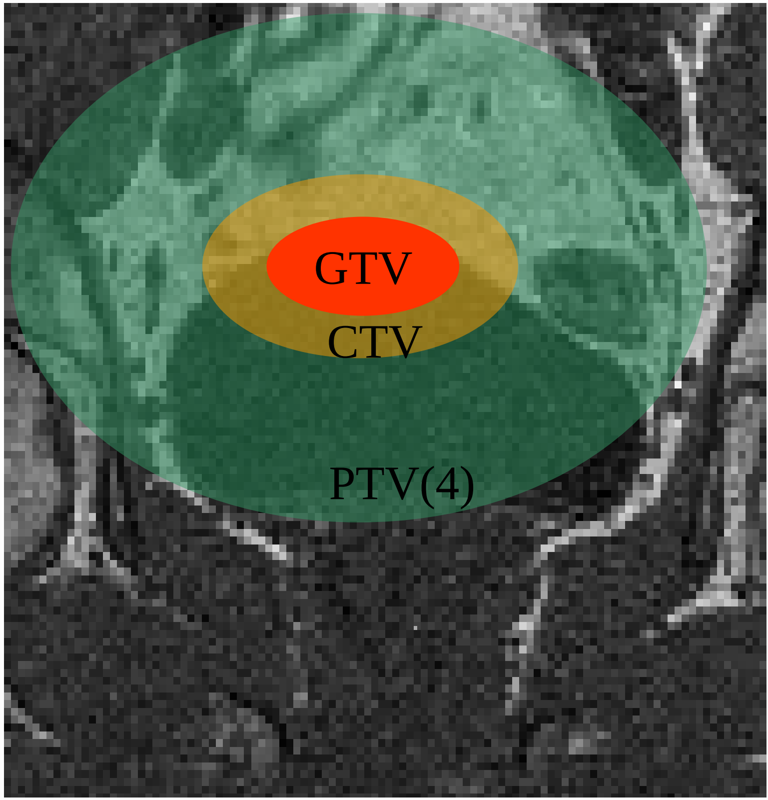
Margins?

- Bladder patients with full bladder instruction and cranially located tumor:
  - $\sigma_{translations} = 1.1$ cm
  - $\Sigma_{translations} = 1.1$ cm
  - $\sigma_{rotations+shape} = 0.3$ cm
  - $\Sigma_{rotations+shape} = 0.3$ cm

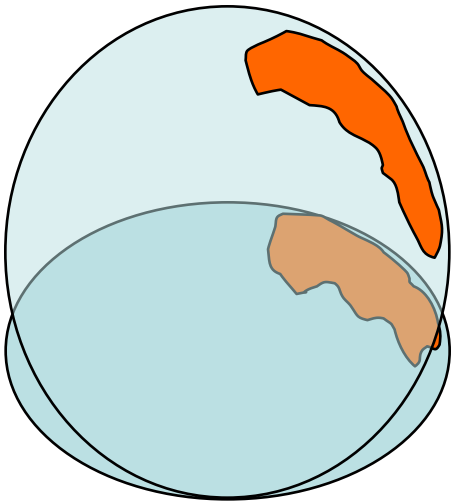
- Consequence [*]:
  - PTV Margin: 4 cm!!!

[*]Margin = 2.5 • Σ + 0.7 • σ = 4 cm



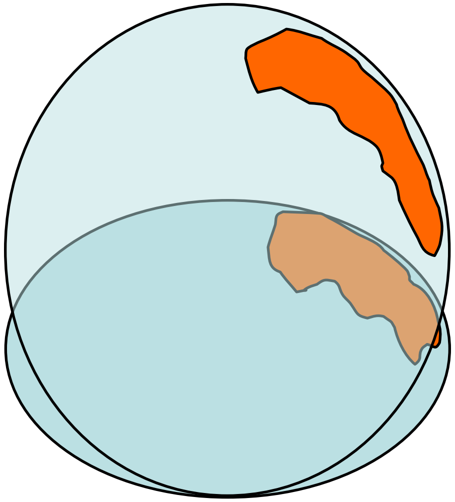
Only correcting translations

- Offline (5 measurements)
  - $\sigma_{translations} = 1.1$ cm
  - $\Sigma_{translations} = 0.4$ cm
  - $\sigma_{rotations+shape} = 0.3$ cm
  - $\Sigma_{rotations+shape} = 0.3$ cm
  - $\sigma_{total} = \sqrt{\sigma_{translations} + \sigma_{rotations+shape}} = 1.2$ cm
  - $\Sigma_{total} = \sqrt{\Sigma_{translations} + \Sigma_{rotations+shape}} = 0.5$ cm
- Margin: 2 cm



Only correcting translations

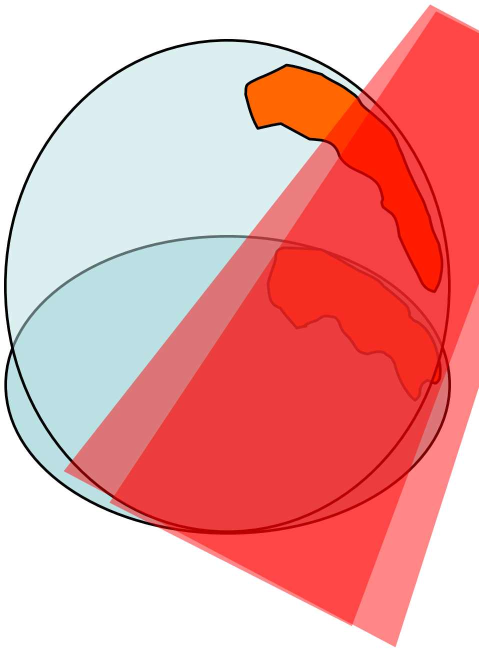
- Online
  - $\sigma_{translations} = 0.1$ cm (residual errors)
  - $\Sigma_{translations} = 0.1$ cm (residual errors)
  - $\sigma_{rotations+shape} = 0.3$ cm
  - $\Sigma_{rotations+shape} = 0.3$ cm
  - $\sigma_{total} = \sqrt{\sigma_{translations} + \sigma_{rotations+shape}} = 0.32$ cm
  - $\Sigma_{total} = \sqrt{\Sigma_{translations} + \Sigma_{rotations+shape}} = 0.32$ cm



- Margin: 1 cm

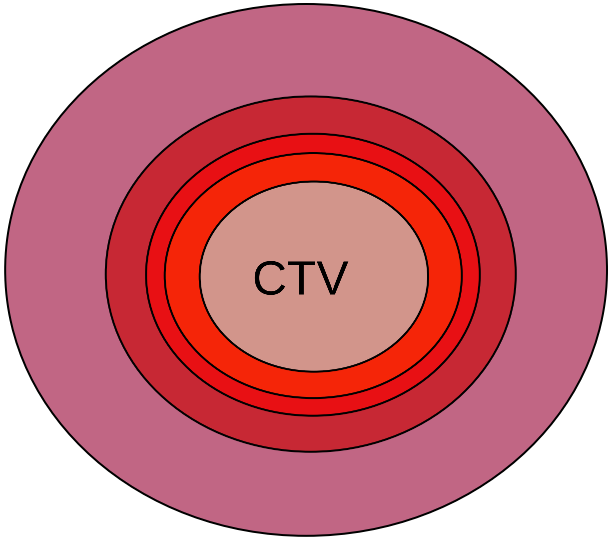
Online translations + offline re-plan!

- Online
  - $\sigma_{translations}$ = 0.1 cm (residual errors)
  - $\Sigma_{translations}$ = 0.1 cm (residual errors)
  - $\sigma_{rotations+shape}$ = 0.3 cm
  - $\Sigma_{rotations+shape}$ = 0.15 cm
  - $\sigma_{total} = \sqrt{\sigma_{translations} + \sigma_{rotations+shape}}$ = 0.32 cm
  - $\Sigma_{total} = \sqrt{\Sigma_{translations} + \Sigma_{rotations+shape}}$ = 0.20 cm
- Margin: 0.7 cm



Overview bladder example

- Do nothing : 4 cm
- Offline translations : 2 cm
- Online translations : 1 cm
- Online translations
  + offline re-plan (adapt) : 0.7 cm



Clinical examples @ NKI

SBRT lung

SBRT Lung: Protocol at NKI

- Acquire 4D CT scan
- Select mid-ventilation phase:
  Element of 4D scan closest to mid-position
- Optimize treatment plan on mid-ventilation

Planning

- Acquire 4D CBCT
- Bone match →Tumor match
- Apply correction
- Validate correction with 2nd scan
- Contact physician if
  - Shift > 1 cm
  - Anatomical changes

Treatment

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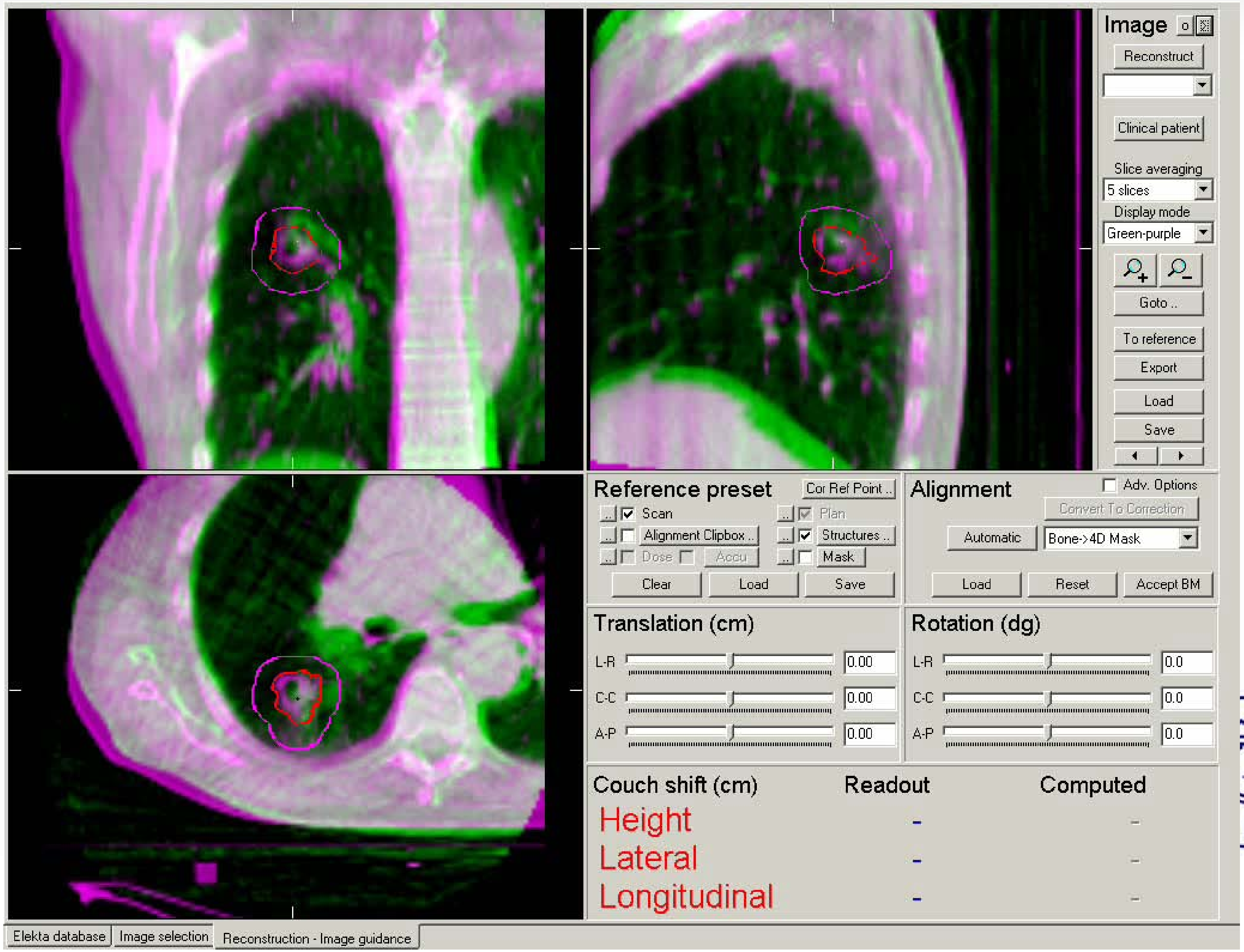
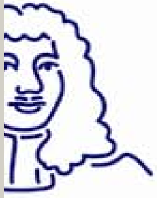
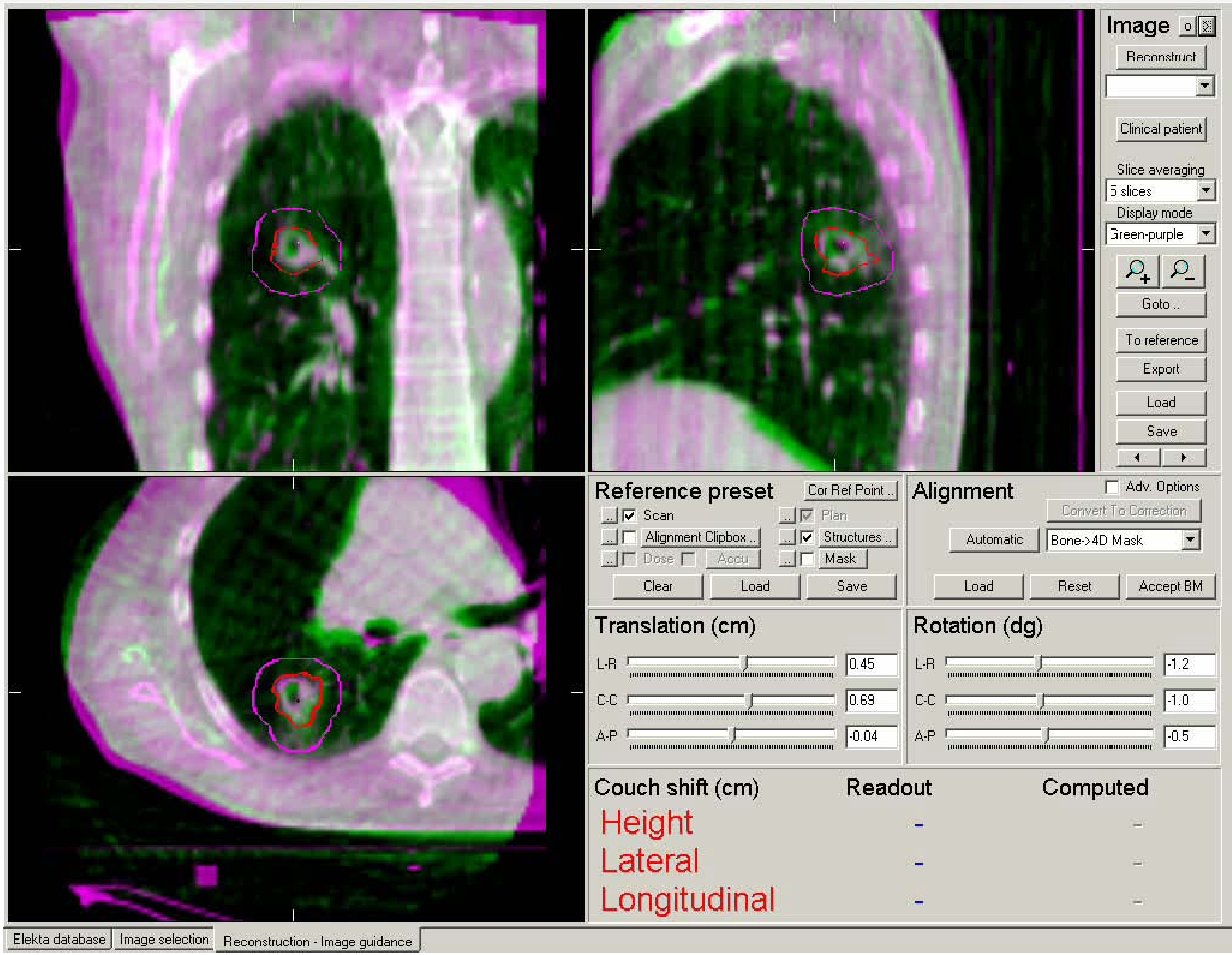
SBRT lung: first scan (4 min for 4D)

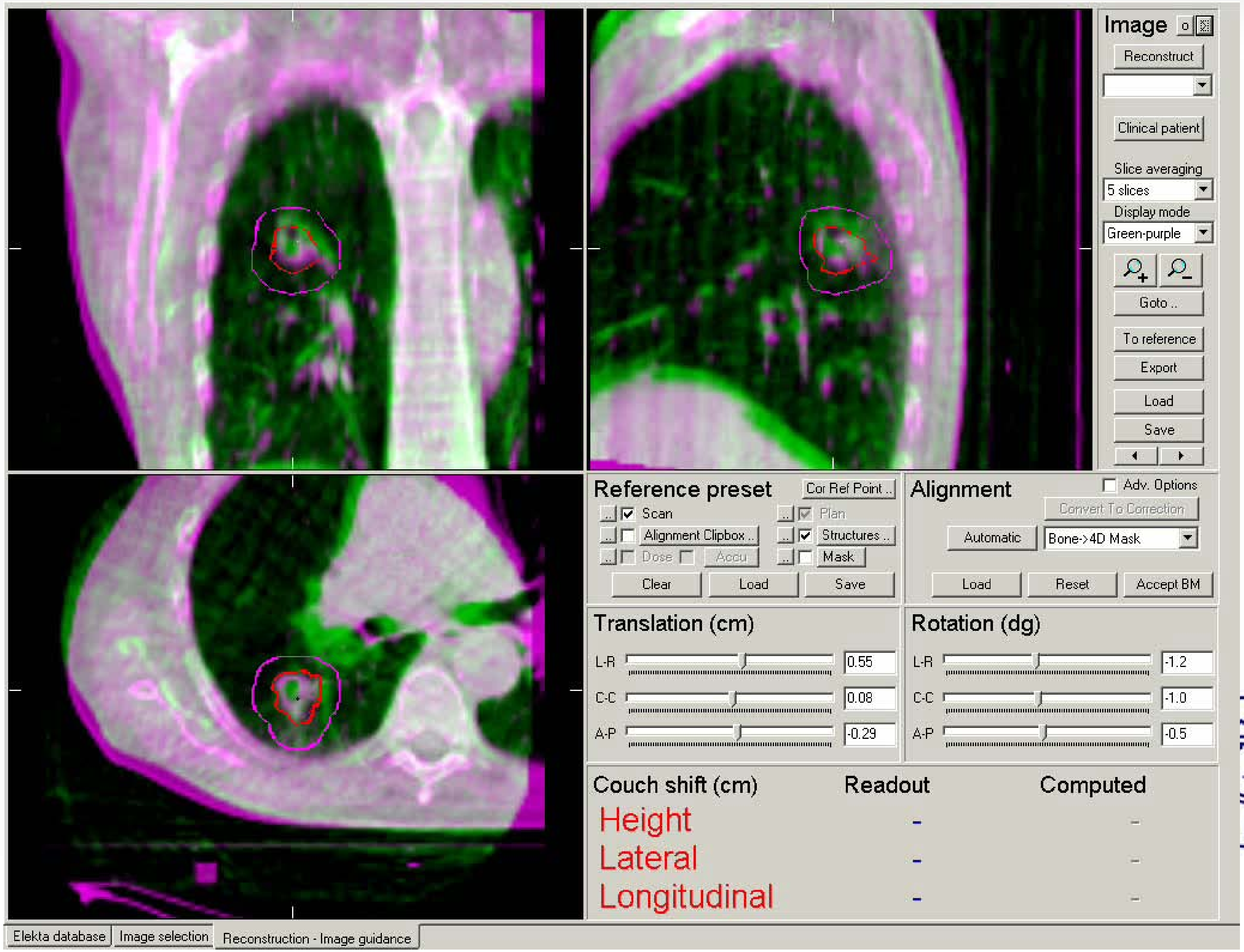




SBRT lung: matched on bone



SBRT lung: matched on tumor



Geometrical Uncertainties

59 Patients, 3 fractions per patient

		LR (mm)	CC (mm)	AP (mm)
Residual Inter-fraction	GM	0.2	0.6	-0.6
	Σ	0.8	0.8	1.0
	σ	1.1	1.1	1.4
Intra-fraction	GM	0.0	1.0	-0.9
	Σ	1.2	1.3	1.9
	σ	1.2	1.4	1.7

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Geometrical Uncertainties

59 Patients, 3 fractions per patient

		LR (mm)	CC (mm)	AP (mm)
Residual Inter-fraction	GM	0.2	0.6	-0.6
	Σ	0.8	0.8	1.0
	σ	1.1	1.1	1.4
Intra-fraction	GM	0.0	1.0	-0.9
	Σ	1.2	1.3	1.9
	σ	1.2	1.4	1.7

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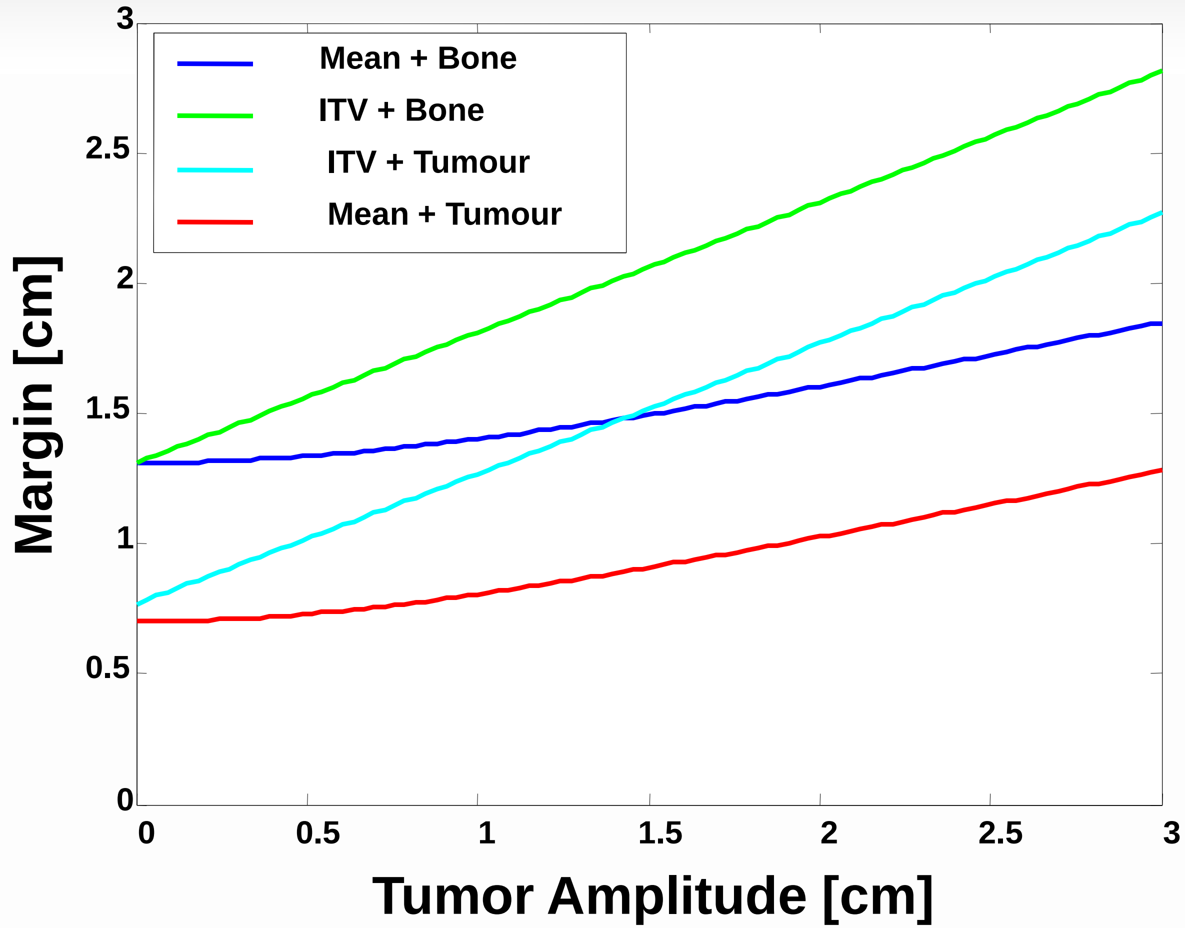
Margins versus Amplitude



$$M = 2.5\Sigma + 0.84\sqrt{(\sigma_p^2 + \sigma^2)} - 0.84\sigma_p^2 \neq 2.5\Sigma + 0.7\sigma$$

$\sigma_p \approx 6.4$ mm

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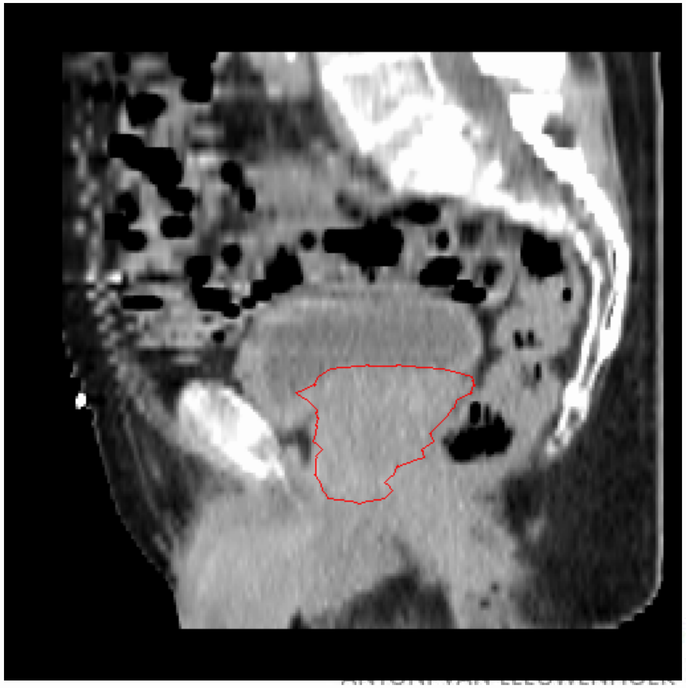
Assures 80% isodose encompasses GTV 90% of time in lung

Prostate ART

Prostate adaptive RT (ART)

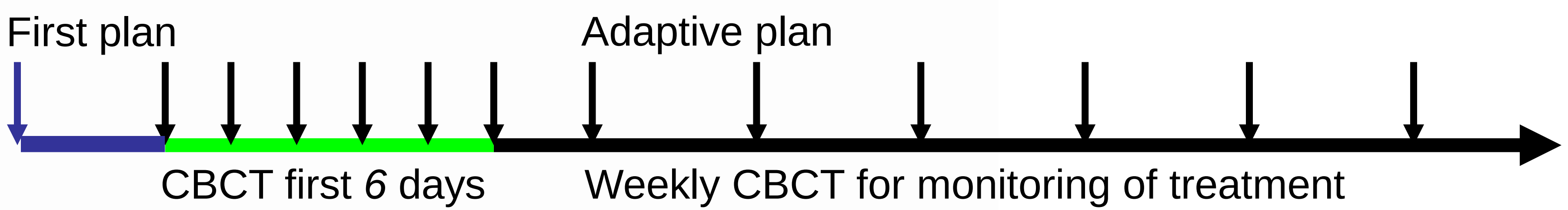
- Use first few fractions to estimate average organ position
- Re-plan after first week if average deviates too much from planning



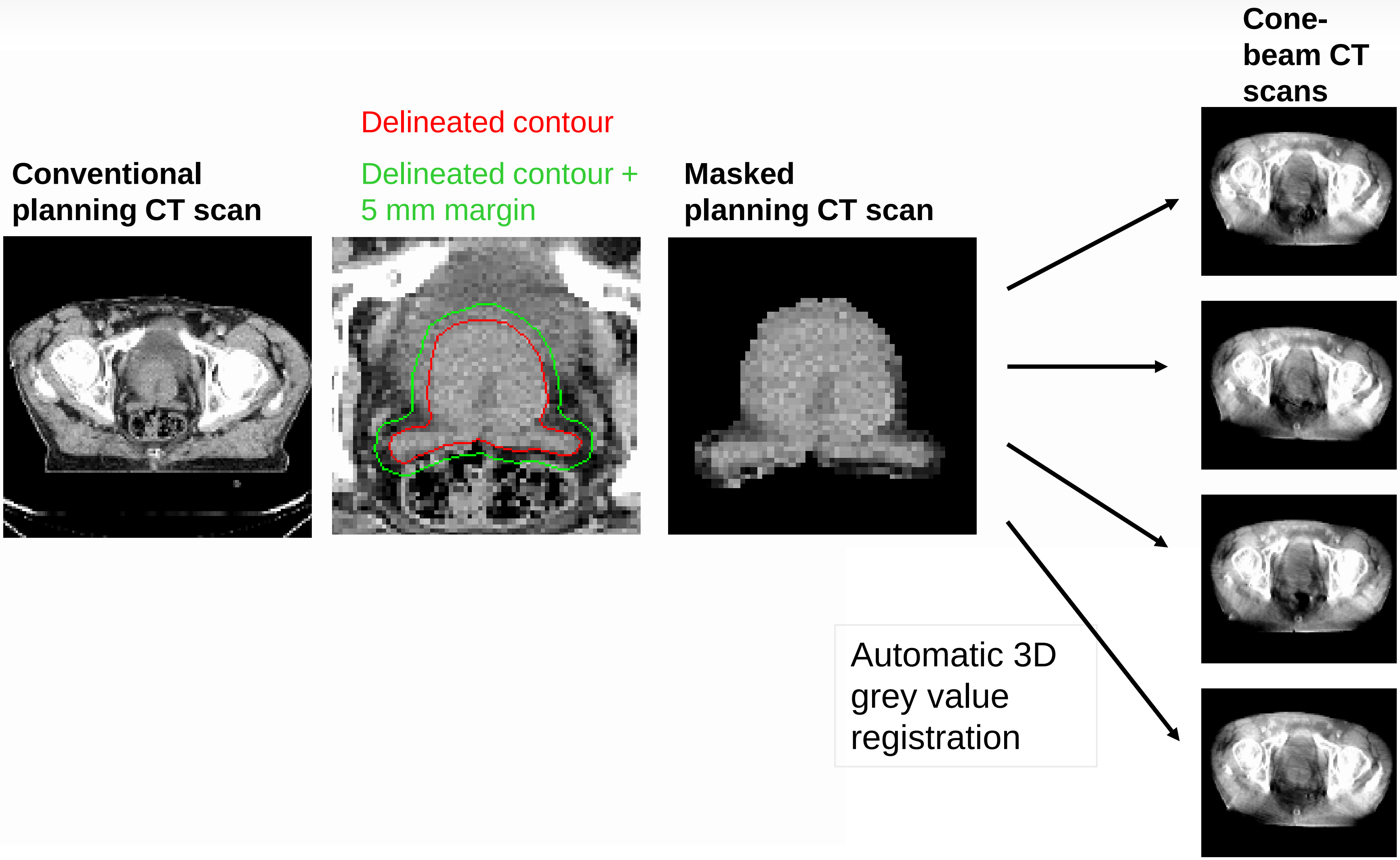
Prostate ART

- CBCT fraction 1 to 6
- Online corrections of translations (seed based)
- Grey value match with mask match on prostate + sv
- Determine average rotation of prostate + seminal vesicles

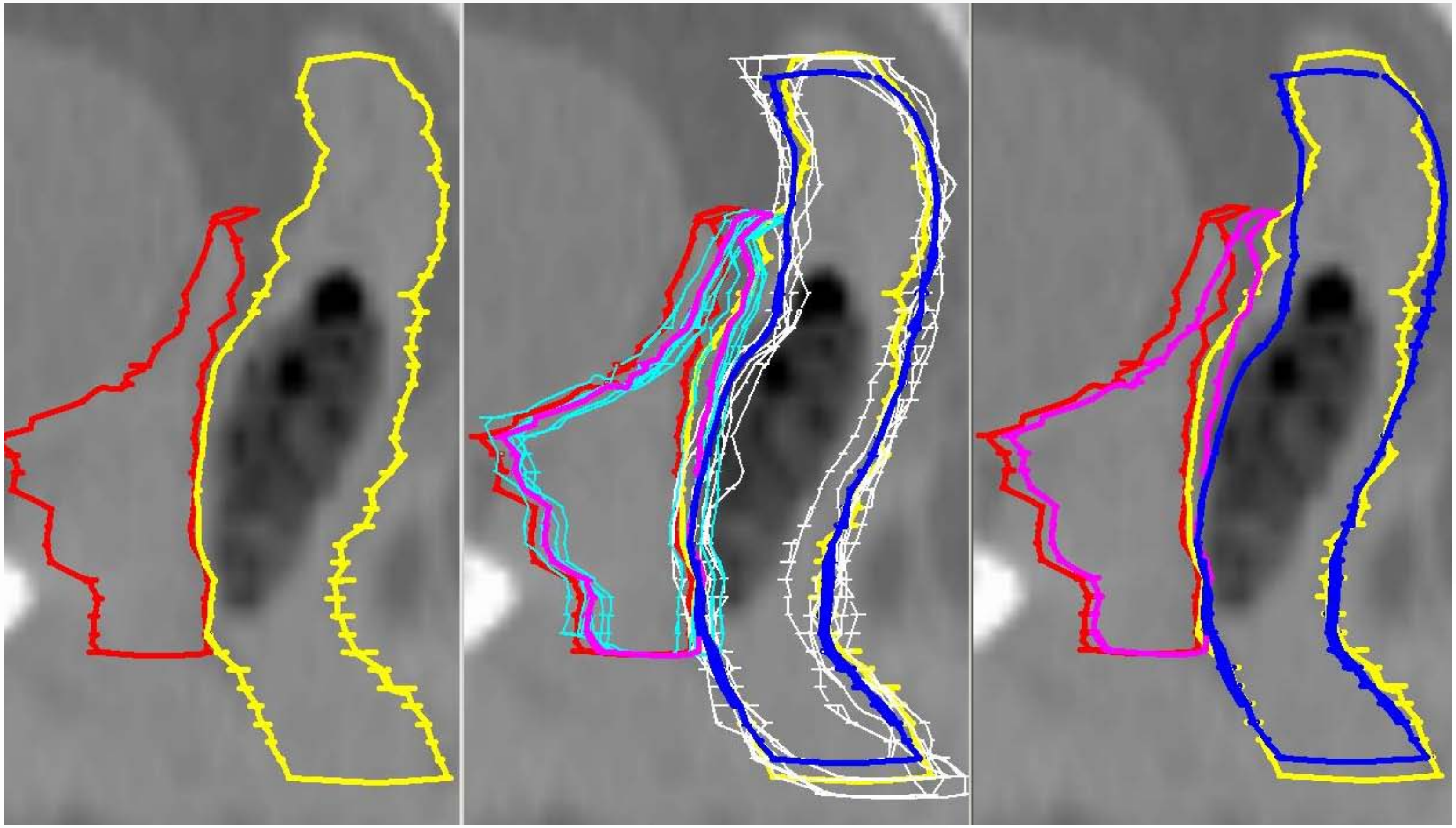
- If average rotation > 6 degr. → Re-plan on fraction 8
- New plan from fraction 9



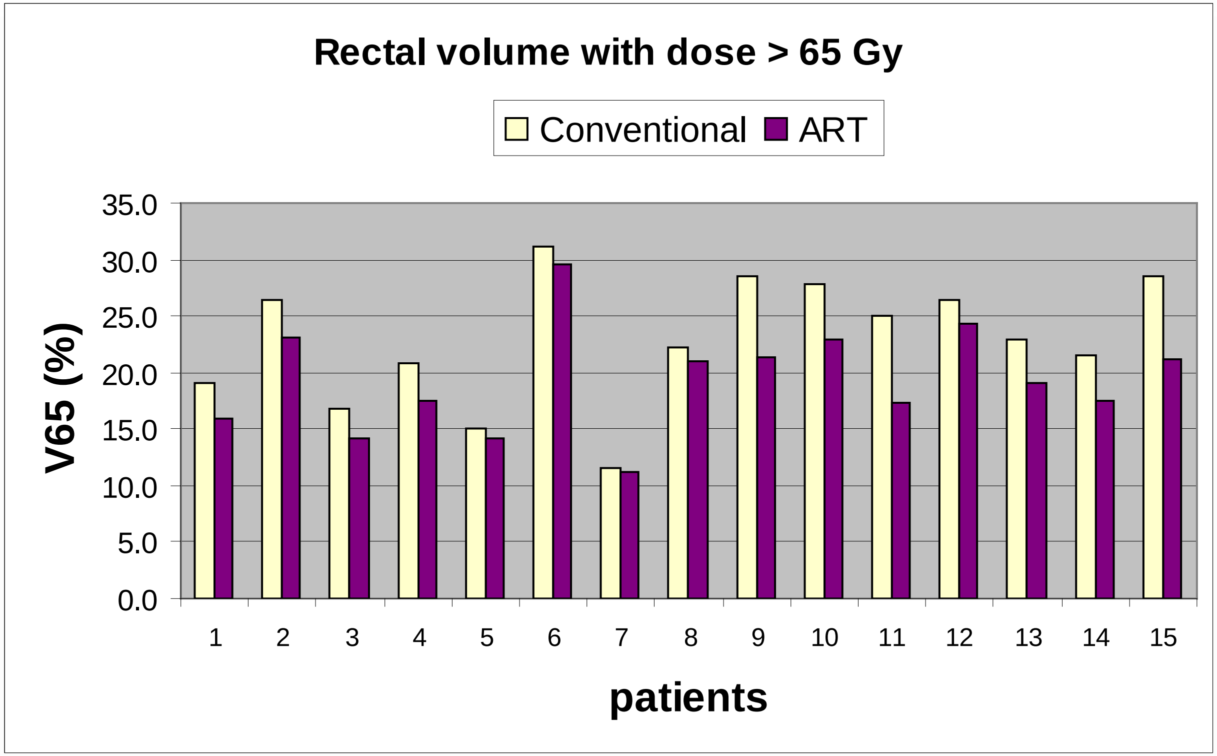
Prostate IGRT – Grey value registration



Prostate IGRT – Grey value registration



Prostate IGRT – Clinical results



Average reduction of V65 by 15% (1 SD: 8%)

Reduction probability for late rectal bleeding: 16% (1 SD: 9%)

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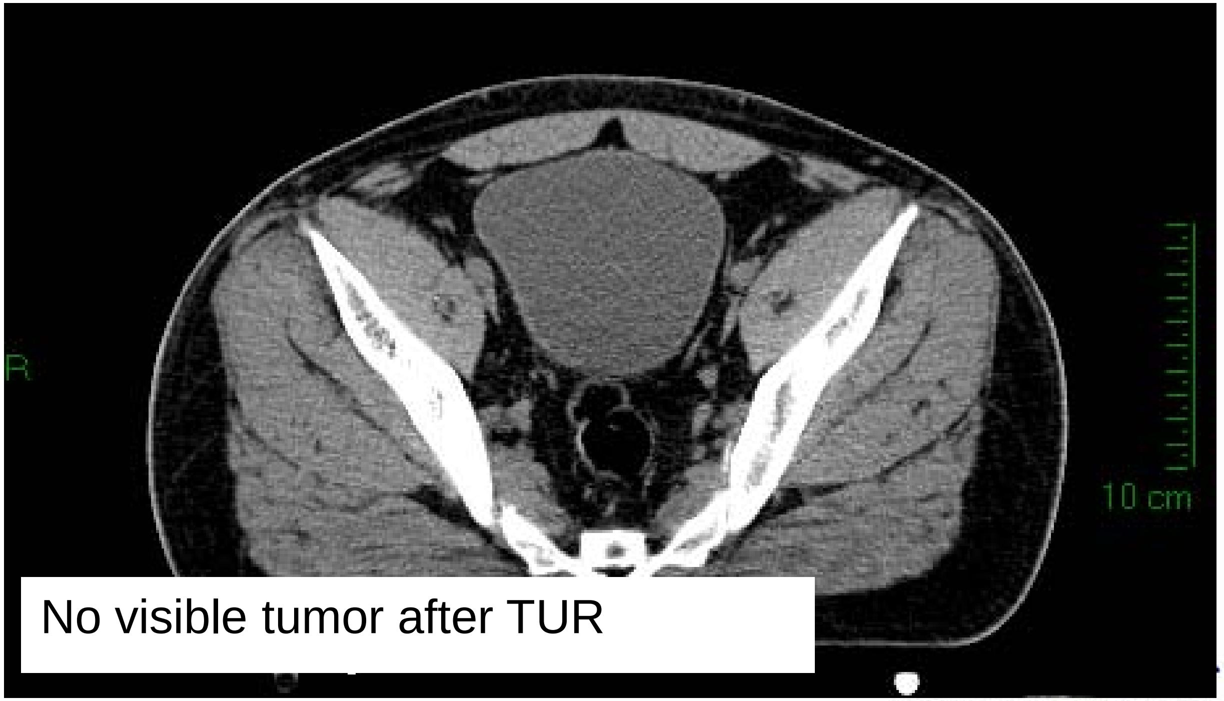
Bladder

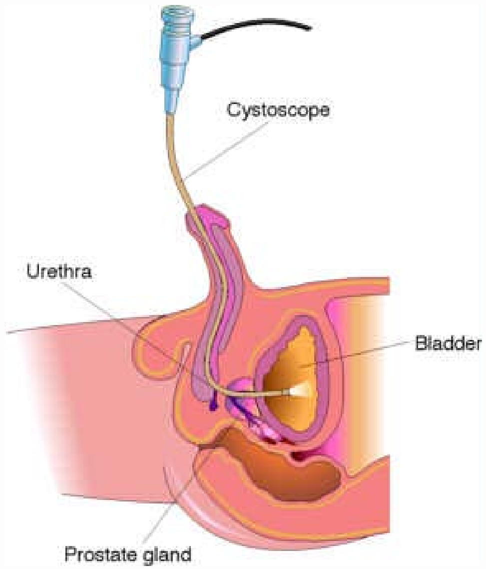
Bladder IGRT

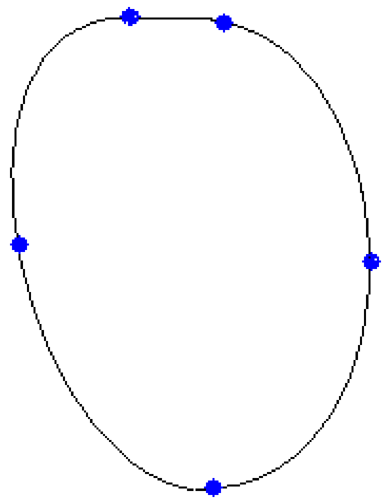
- Large geometrical uncertainties
- Poor tumor delineation

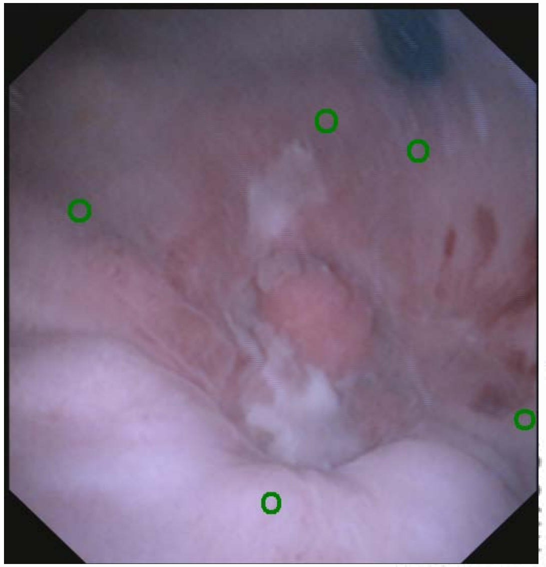


Bladder IGRT

- Tumor demarcation using lipiodol
- 40% iodine, visible on (CB)CT
- Inserted during a cystoscopy session







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Bladder IGRT

CT before injection	CT after injection

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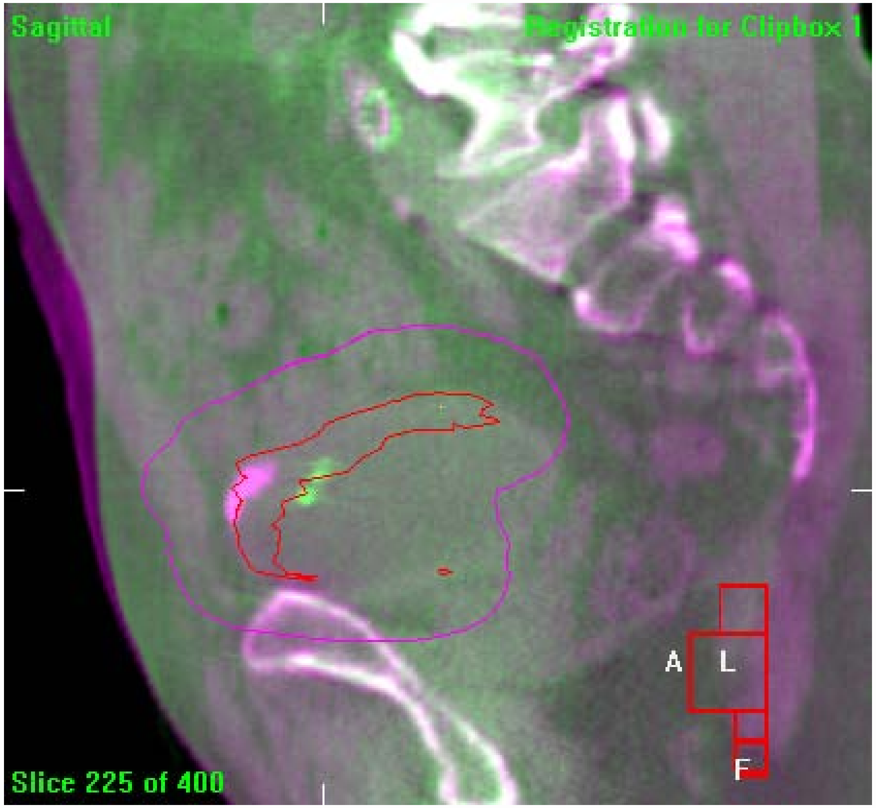
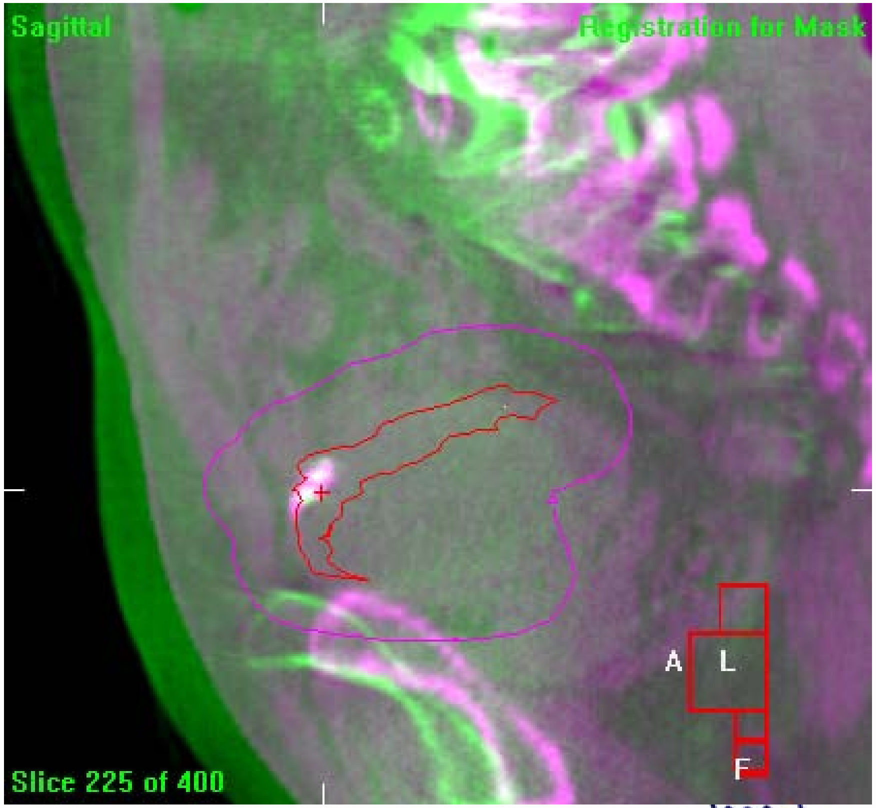
Bladder IGRT



Bone registration



Tumor registration

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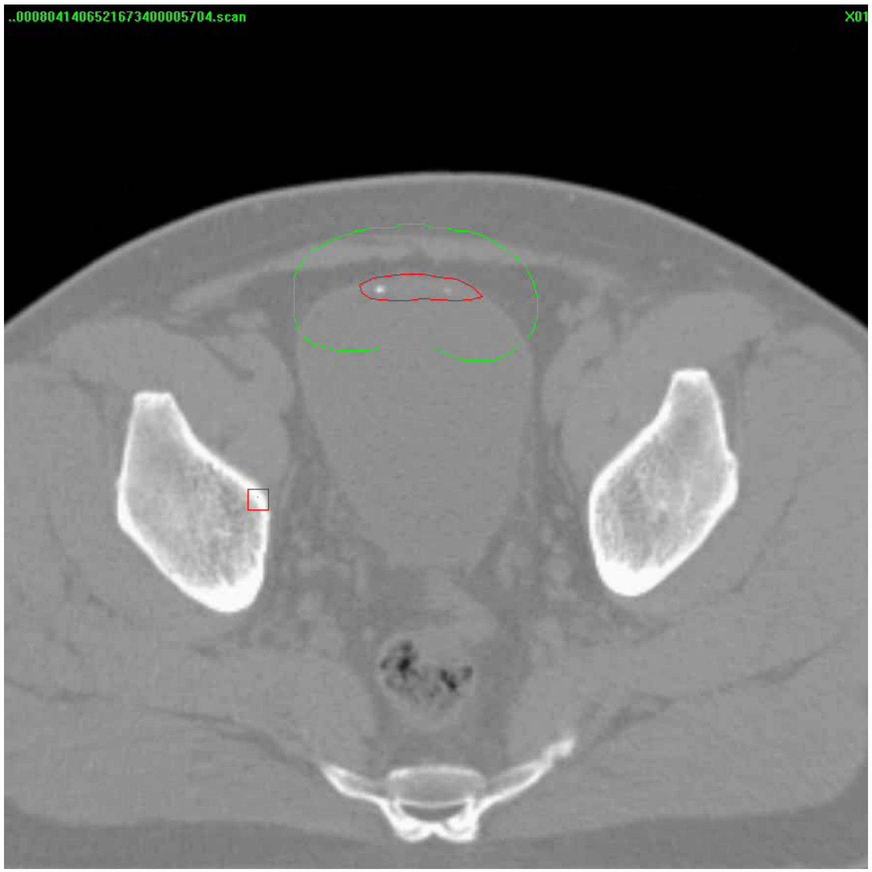
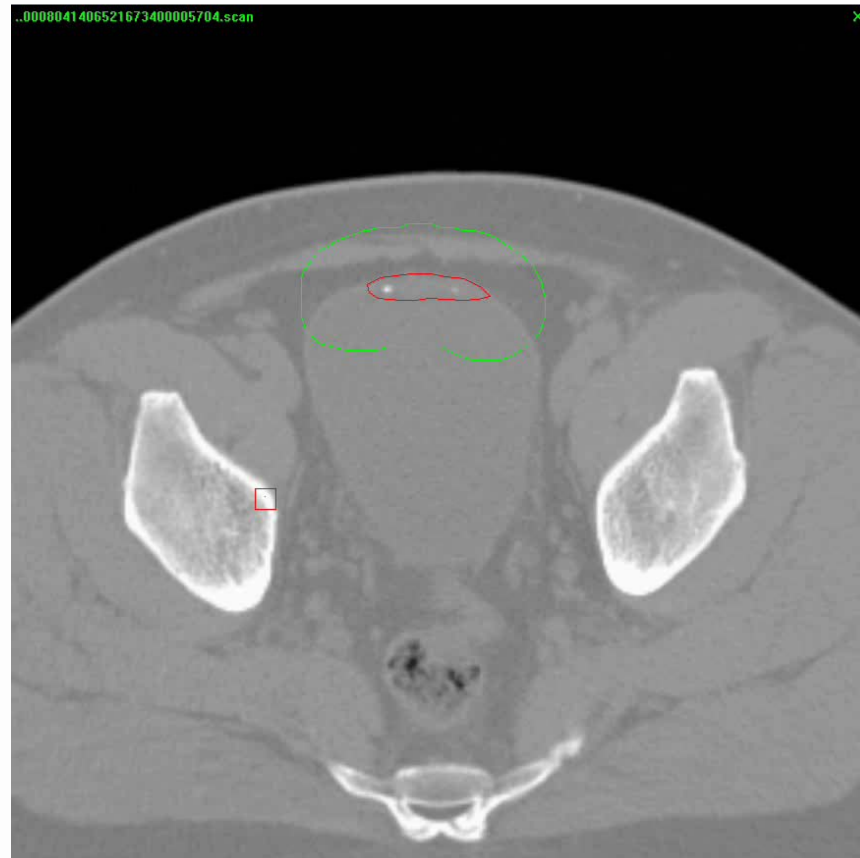
Bladder IGRT





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Bladder IGRT

- 24 patients
- Very large shifts observed
- Required margin: 13 mm

	Average translation (mm)	Systematic error Σ (mm)	Random error σ (mm)
Left-Right	0.8	1.5	2.4
Cranial-Caudal	-1.7	5.3	4.4
Anterior-Posterior	-0.4	3.9	4.4
		Range (mm)	
3D-vector	7.8	0.6 - 32.7	

Take home messages

- Most geometrical errors can be reduced significantly by translational corrections
- Further reduction requires more complicated (adaptive) correction strategies
- Offline protocols are most efficient in terms of imaging, online is the most easy to implement
- For all the errors we don’t correct for: Margin!
- IGRT does **NOT** address one of the most important geometrical uncertainties: Delineation variability!

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Workshop uncertainties and margins

Peter Remeijer

"And should there be a sudden loss of consciousness during this meeting, oxygen masks will drop from the ceiling."

Layout

- You all have 2 excel files with setup data…
  …and some additional information

- Goals
  - Determine setup error statistics (σ, Σ)
  - Discuss possible correction strategies
  - Determine margins for the different strategies

Layout

- Second sheet is for the results (overview)

All patient data

PAT	**SETUP**						**ORGAN MOTION**					
	Average			Standard deviation			Average			Standard deviation		
	LR	CC	AP	LR	CC	AP	LR	CC	AP	LR	CC	AP
1	-1.6	-2.5	0.5	3.0	1.9	2.2	-2.7	-4.4	0.5	2.0	2.2	5.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Systematic SD			Random SD			Systematic SD			Random SD		
	0.5	0.8	0.1	1.0	0.6	0.7	0.8	1.4	0.2	0.6	0.7	1.6

  - Still all zeroes
  - Will contain SDs once you fill in the patient forms

Layout

- Next sheets (1-10) are patient data
  - Translations in all three directions
  - For setup and organ motion

PAT 1	SETUP			ORGAN MOTION		
Frac	LR	CC	AP	LR	CC	AP
1	0.2	-5.1	1.5	-3.8	-3.4	-2.7
2	-2.1	-0.9	0.3	-3.5	-2.7	8.4
3	-1.4	-2.3	0.3	-3.4	-10.0	2.9
4	-0.6	-1.7	-1.1	-0.4	-2.1	2.4
5	-4.2	-2.0	4.0	1.3	-5.5	-6.9
6	-0.3	-1.0	4.4	-4.2	-7.9	-2.3
7	-3.8	-4.8	-1.3	-3.2	-7.9	1.2
8	-1.5	-4.8	3.4	-5.8	-6.6	6.9
9	3.1	-0.9	4.4	-1.4	-7.4	-5.2
10	-4.3	-1.4	-0.9	-3.6	-1.7	1.2
11	0.7	-3.4	1.2	-3.2	-5.1	6.8
12	1.4	-0.1	-1.5	-4.9	-2.7	2.7
13	-0.9	0.1	0.3	-0.1	-3.9	3.2

Layout

- Determine the following on each patient sheet
  - Average
  - Standard deviation

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	26	1.7	-4.1	-0.7	-2.3	-6.9	-5.5
31	27	-4.5	-0.3	-4.6	-1.9	-6.9	-1.8
32	28	-4.9	-1.0	-1.1	-1.1	-6.2	-0.5
33	29	4.4	-1.8	-1.6	-3.5	-1.7	-7.2
34	30	-2.1	-4.4	0.8	-1.2	-2.2	-1.3
35	31	-5.2	-5.5	2.2	-3.6	-0.4	1.4
36	32	-5.0	-2.4	-0.8	-4.3	-3.3	8.3
37	33	-1.9	-4.7	1.3	-4.6	-3.3	-3.8
38	34	-0.2	-6.8	3.6	-1.3	-4.4	10.8
39	35	-6.1	-3.0	2.1	-0.7	-4.4	-3.9
40							
41	AV	-1.6	-2.5	0.5	-2.7	-4.4	0.5
42	SD	3.0	1.9	2.2	2.0	2.2	5.0
43							

  - Patient 1 is given as an example
  - You can copy from this sheet to the others
  - Overview will update automatically

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Layout

- Once all patients are done the statistics will be shown in the bottom row of the overview

	SETUP						ORGAN MOTION					
	Average			Standard deviation			Average			Standard deviation		
Patient #	LR	CC	AP	LR	CC	AP	LR	CC	AP	LR	CC	AP
1	-1.4	-2.1	1.4	3.6	3.4	2.0	0.2	16.0	10.6	3.4	11.4	9.7
2	0.7	-1.1	1.8	3.0	3.6	1.8	1.7	0.8	-2.6	3.1	9.8	8.9
3	1.2	-0.1	2.8	2.8	2.7	2.1	-1.7	5.3	1.8	2.4	8.7	8.0
4	-0.2	-3.6	0.3	2.3	3.4	1.9	-1.2	13.7	-2.7	3.1	12.3	9.7
5	-0.6	-2.6	3.0	3.0	3.5	1.8	-0.2	-5.3	4.4	3.6	10.1	7.2
6	-2.3	0.9	2.8	2.8	2.7	2.4	0.3	-9.0	-12.6	3.3	11.3	8.6
7	3.9	-0.5	1.9	3.2	3.2	1.9	-1.6	4.6	3.7	2.2	11.0	10.7
8	-0.9	1.3	2.3	3.0	2.9	1.8	-2.7	-7.8	4.6	3.8	11.6	8.2
9	0.8	-0.8	0.9	3.4	2.5	2.0	0.4	3.1	-1.7	3.0	12.8	9.2
10	4.0	1.5	1.2	3.1	2.7	1.7	2.8	-7.4	-2.6	3.1	11.4	9.5
	Systematic SD			Random SD			Systematic SD			Random SD		
	2.1	1.7	0.9	3.0	3.1	2.0	1.7	8.9	6.2	3.1	11.1	9.0

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Layout

- You can now fill in the margin sheet (first one)
- Statistics are shown in top table
- Copy values to the second table to get the margin

How to compute the margin?

Standard deviations are automatically taken from patient statistics (see overview sheet)

	Systematic			Random		
	LR	CC	AP	LR	CC	AP
Setup errors	0.5	0.8	0.1	1.0	0.6	0.7
Organ motion	0.8	1.4	0.2	0.6	0.7	1.6

Standard deviations for margin calculation - use values above, or adapt depending on correction protocol

	Systematic						Random					
	LR	sqr	CC	sqr	AP	sqr	LR	sqr	CC	sqr	AP	sqr
Delineation errors	1.0	1.0	1.0	1.0	1.0	1.0	n/a		n/a		n/a	
Setup errors		0.0		0.0		0.0		0.0		0.0		0.0
Organ motion		0.0		0.0		0.0		0.0		0.0		0.0
Intrafraction errors		0.0		0.0		0.0		0.0		0.0		0.0
Registration errors	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sum of squares		2.0		2.0		2.0		1.0		1.0		1.0
Total error	1.4		1.4		1.4		1.0		1.0		1.0	

Add

Population percentage	90	Factor	2.5
Dose level	95	Factor	0.7

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Layout

- Using the numbers without adaptation will give you the margin without using a correction protocol

How to compute the margin?

Standard deviations are automatically taken from patient statistics (see overview sheet)

	Systematic			Random		
	LR	CC	AP	LR	CC	AP
Setup errors	0.5	0.8	0.1	1.0	0.6	0.7
Organ motion	0.8	1.4	0.2	0.6	0.7	1.6

Standard deviations for margin calculation - use values above, or adapt depending on correction protocol

	Systematic						Random					
	LR	sqr	CC	sqr	AP	sqr	LR	sqr	CC	sqr	AP	sqr
Delineation errors	1.0	1.0	1.0	1.0	1.0	1.0	n/a		n/a		n/a	
Setup errors		0.0		0.0		0.0		0.0		0.0		0.0
Organ motion		0.0		0.0		0.0		0.0		0.0		0.0
Intrafraction errors		0.0		0.0		0.0		0.0		0.0		0.0
Registration errors	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sum of squares		2.0		2.0		2.0		1.0		1.0		1.0
Total error	1.4		1.4		1.4		1.0		1.0		1.0	

Add

+

Population percentage	90	Factor	2.5
Dose level	95	Factor	0.7

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Layout

- Adapt numbers to fit protocol
- Tip: save the file under a different name for each change

Standard deviations are automatically taken from patient statistics (see overview sheet)

	Systematic			Random		
	LR	CC	AP	LR	CC	AP
Setup errors	0.5	0.8	0.1	1.0	0.6	0.7
Organ motion	0.8	1.4	0.2	0.6	0.7	1.6

Standard deviations for margin calculation - use values above, or adapt depending on correction protocol

	Systematic						Random					
	LR	sqr	CC	sqr	AP	sqr	LR	sqr	CC	sqr	AP	sqr
Delineation errors	1.0	1.0	1.0	1.0	1.0	1.0	n/a		n/a		n/a	
Setup errors		0.0		0.0		0.0		0.0		0.0		0.0
Organ motion		0.0		0.0		0.0		0.0		0.0		0.0
Intrafraction errors		0.0		0.0		0.0		0.0		0.0		0.0
Registration errors	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sum of squares		2.0		2.0		2.0		1.0		1.0		1.0
Total error	1.4		1.4		1.4		1.0		1.0		1.0	

Add

+

Population percentage	90	Factor	2.5
Dose level	95	Factor	0.7

Case #1 – Prostate patient

- 35 fractions
- Assumptions
  - Delineation error = 1 mm (SD)
  - Registration error = 1 mm (SD)
  - Intrafraction motion = 1 mm (SD)
  - Offline: Divide systematic error by 3, random stays the same
  - Online: Both systematic and random are 0 mm

Case #1 – Prostate patient

- No markers / no cone-beam CT
  - Determine statistics of motion
  - Determine margins for following situations
    - Do nothing
    - Offline correction protocol (you can assume the systematic setup errors are reduced by a factor 3)
    - Online correction protocol (setup errors are 0)

- Which protocol would you use, and why?

Case #1 – Prostate patient

- Markers
  - Determine statistics of motion
  - Determine margins for following situations
    - No corrections
    - Offline correction protocol on the markers (assume the all setup errors are zero and systematic organ motion is reduced by a factor 3)
    - Online correction protocol on markers. Assume that all setup and organ motion errors are zero)

- Which protocol would you use, and why?

Case #2 – Bladder patient

- 25 fractions
- Assumptions
  - Delineation error = 1 mm (SD)
  - Registration error = 1 mm (SD)
  - Intrafraction motion = 2 mm (SD)
  - Offline: Divide systematic error by 3, random stays the same
  - Online: Both systematic and random are 0 mm

Case #2 – Bladder patient

- Only setup corrections
  - Determine statistics of motion
  - Determine margins for following situations
    - Do nothing
    - Offline correction protocol (you can assume the systematic setup errors are reduced by a factor 3)
    - Online correction protocol (all setup errors are 0)

- Which protocol would you use, and why?

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Case #2 – Bladder patient

- Markers
  - Determine statistics of motion
  - Determine margins for following situations

    Offline correction protocol on the markers (you can assume the systematic setup errors are reduced by a factor 3)

  - Online correction protocol on markers

- Which protocol would you use, and why?

Finally

- Split up in groups of 3-4
- “Solve” the three cases
- Discuss them. For example, compare with your own experience
- Give the answers during the case discussion with TurningPoint

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Workshop uncertainties and margins – Results

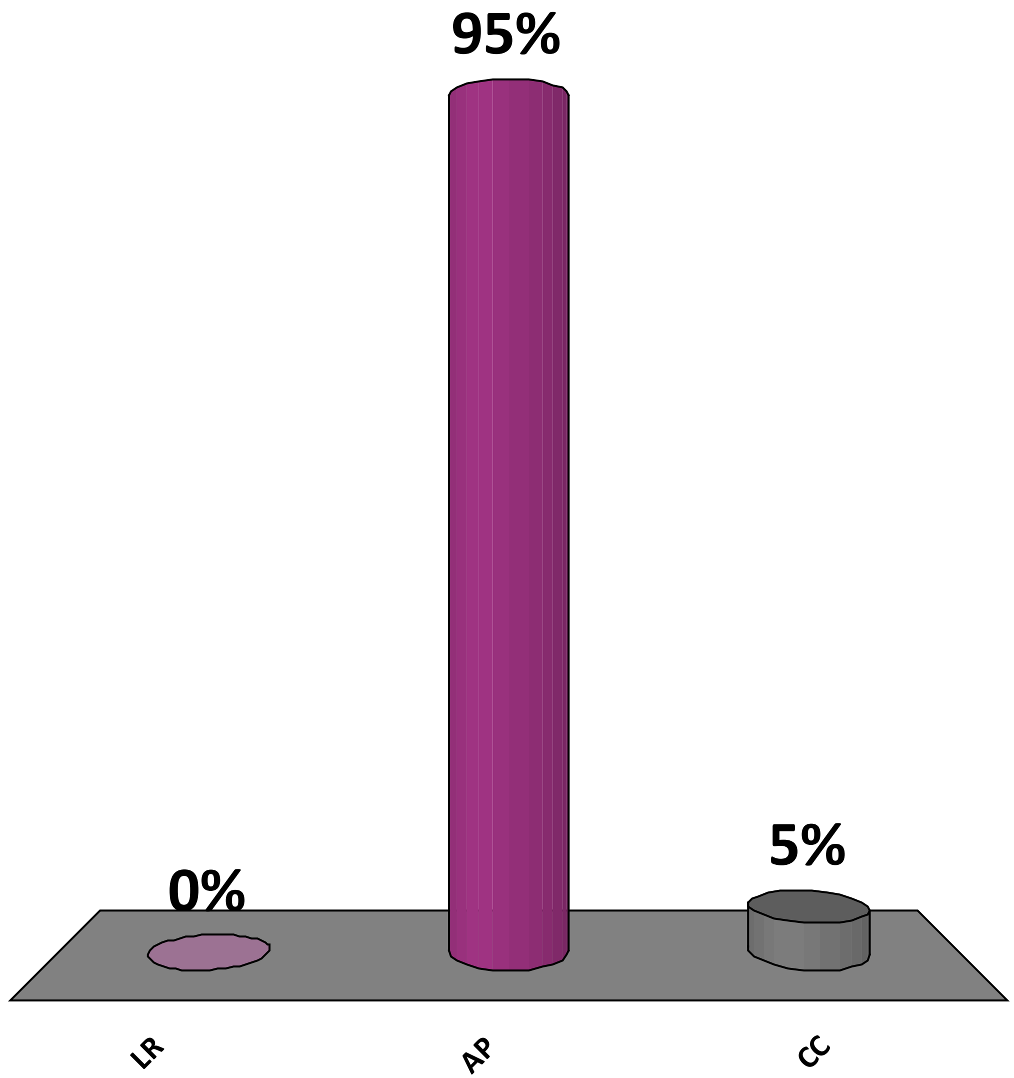
Peter Remeijer

AS workshop results

Prostate case

Which direction had the largest margin when no corrections are performed?

A. LR
B. AP
C. CC

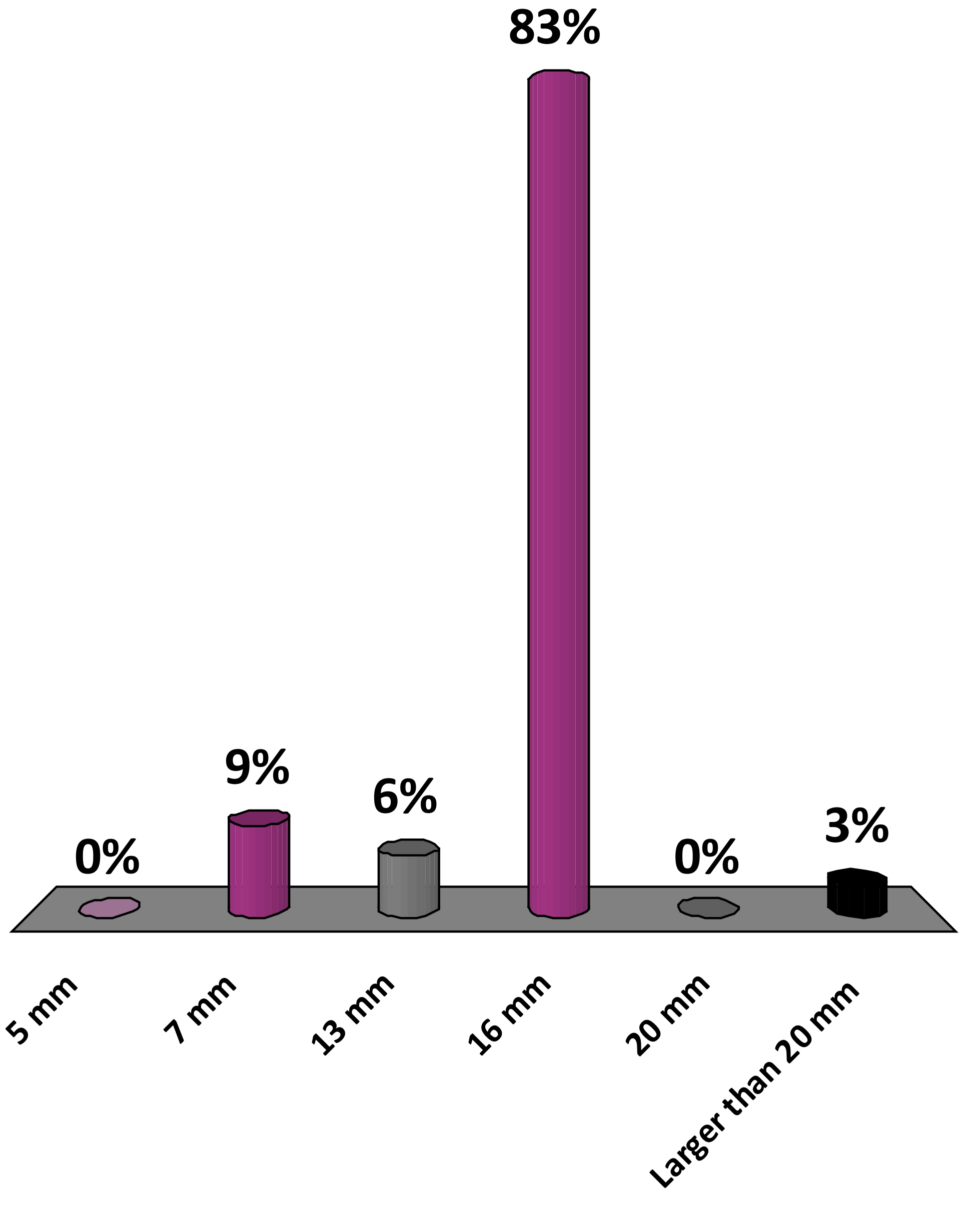


Results

- AP!
- This is usually the case for prostate cases
- Variability of rectum filling

What was the margin in the AP direction when no corrections were performed?

A. 5 mm
B. 7 mm
C. 13 mm
D. 16 mm
E. 20 mm
F. Larger than 20 mm



Results

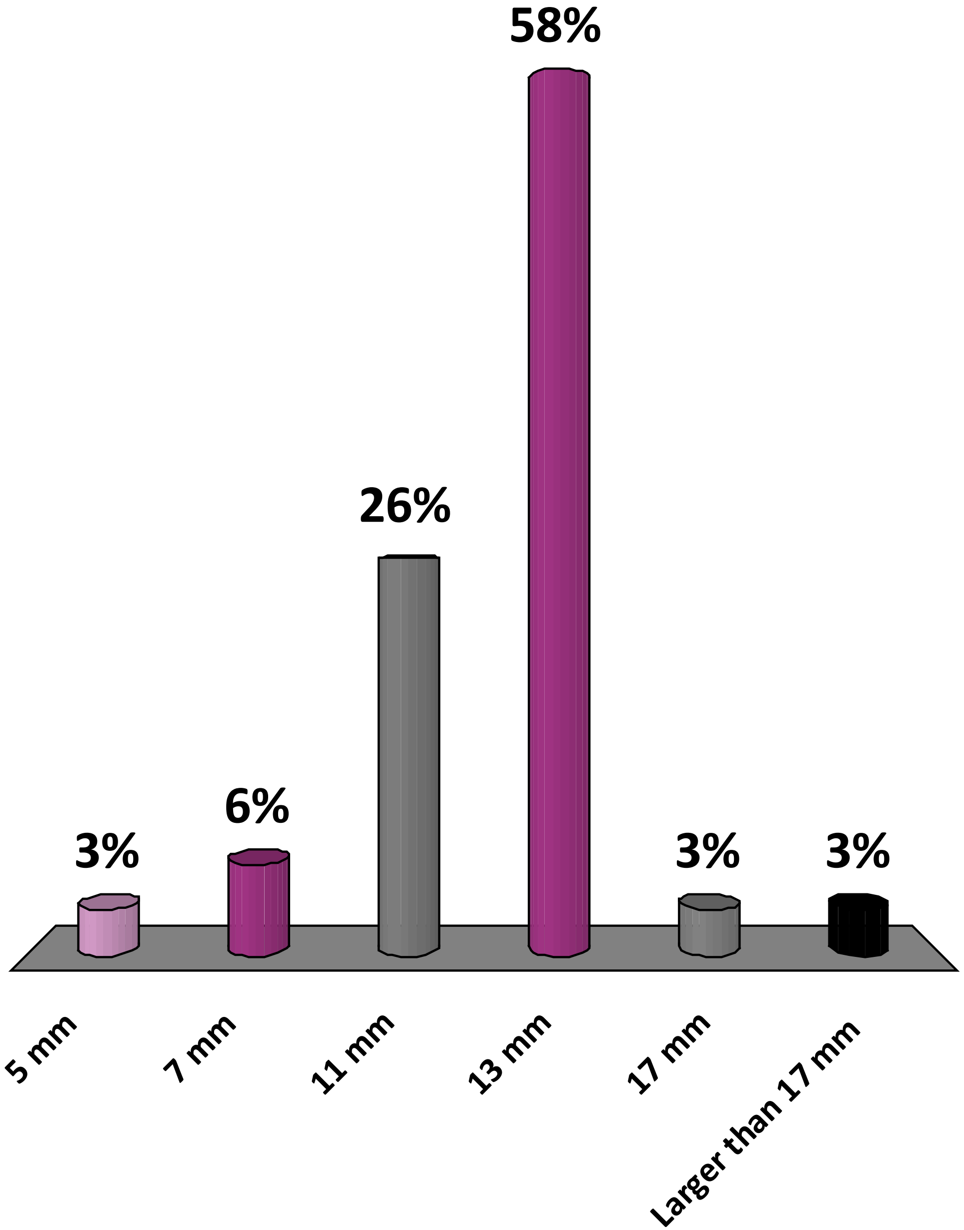
- The margin was 16 mm
- Clearly, not using image guidance is not an option!

Offline protocol based on bone registration

- Systematic **setup** errors reduce by a factor 3
- Random **setup** errors remain the same
- All organ motion errors remain the same

What was the margin in the AP direction when an offline setup error protocol was used?

A. 5 mm
B. 7 mm
C. 11 mm
D. 13 mm
E. 17 mm
F. Larger than 17 mm



Results

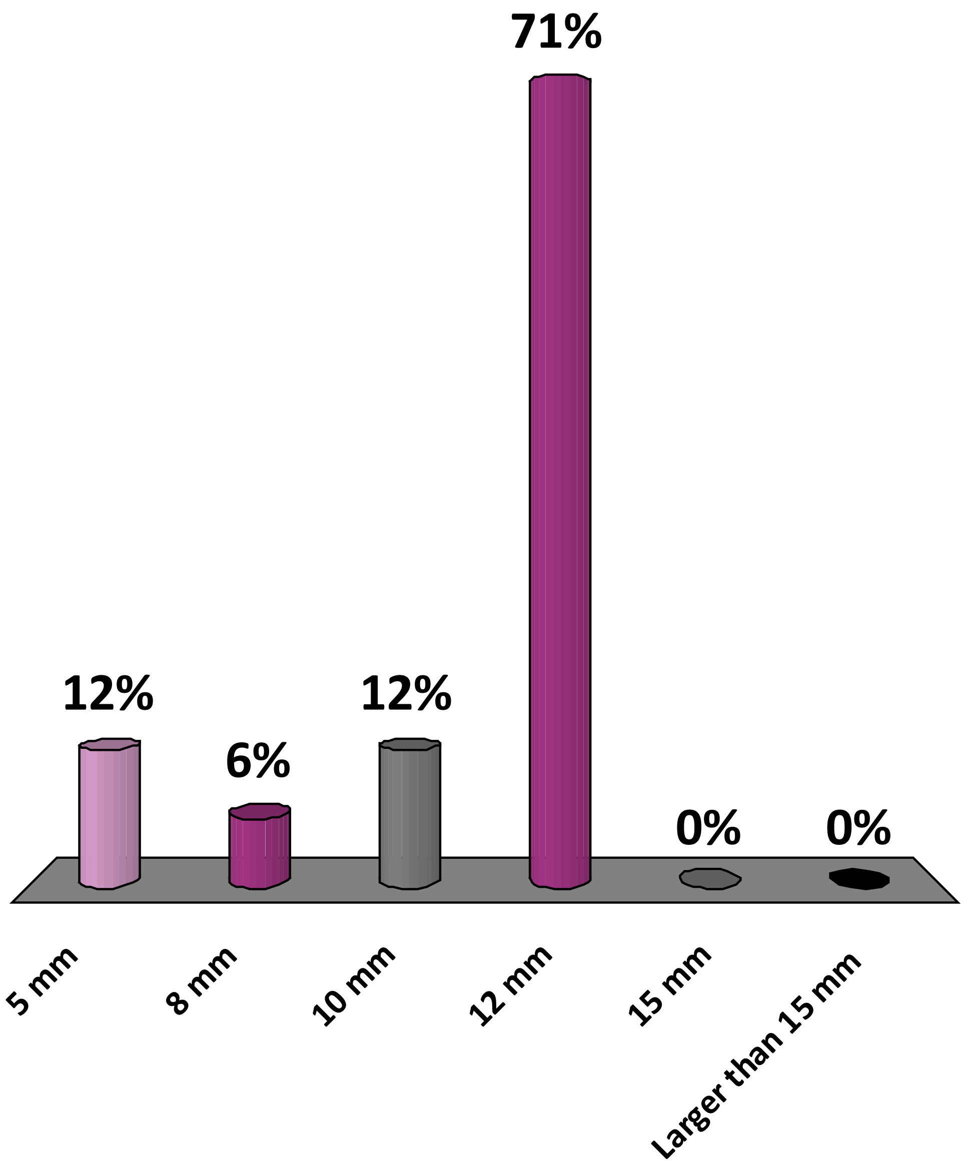
- 13 mm
- Effect is a bit disappointing ….

Online protocol based on bone registration

- Systematic and random **setup** errors are “0”
- Organ motion remains the same

What was the margin in the AP direction when an **online** setup error protocol was used?

A. 5 mm
B. 8 mm
C. 10 mm
D. 12 mm
E. 15 mm
F. Larger than 15 mm



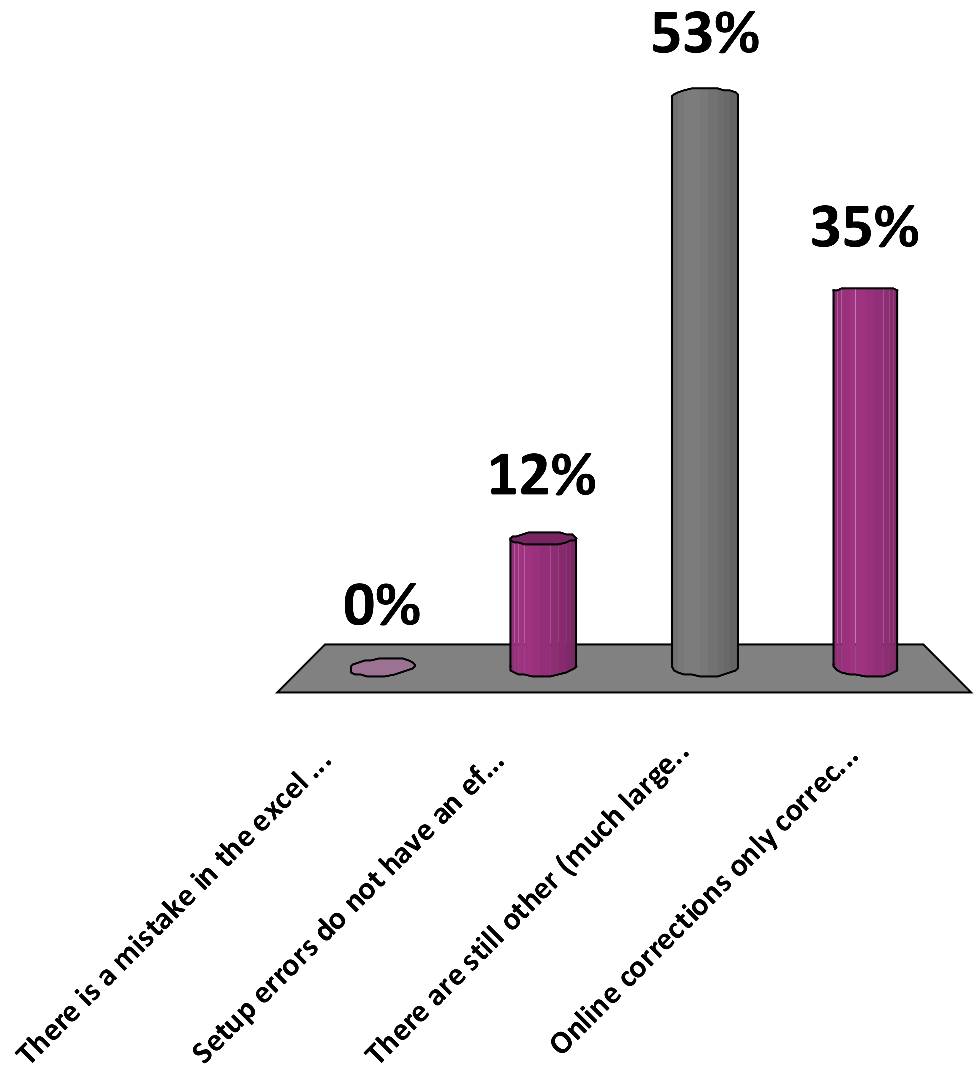
Results

- 12 mm

- Even more disappointing!

Why did the margin not become much smaller?

A. There is a mistake in the excel sheet
B. Setup errors do not have an effect on margins
C. There are still other (much larger) errors which are not addressed
D. Online corrections only correct the random errors

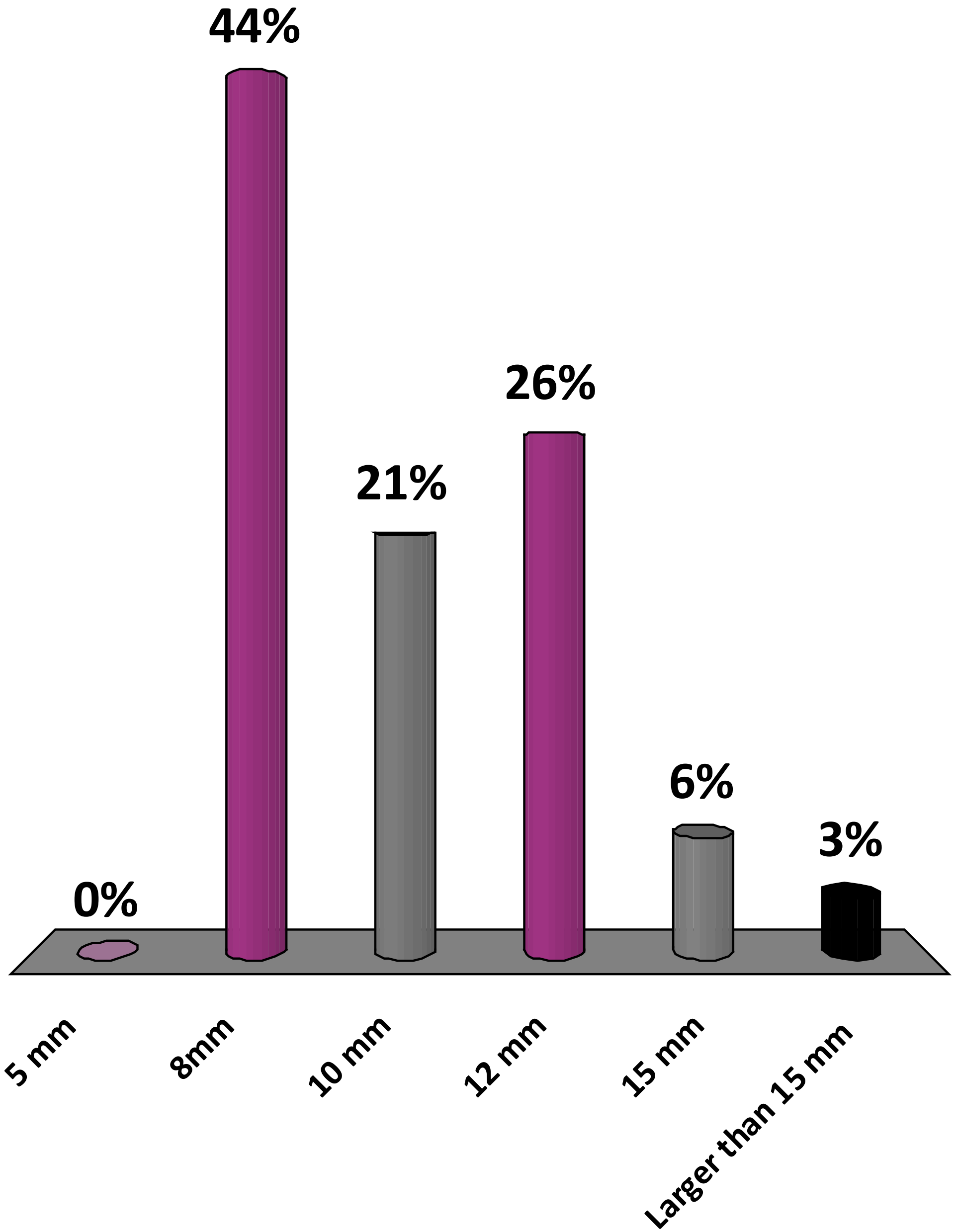


Offline protocol based on marker registration

- Setup errors are not relevant anymore because we are guiding on markers
- So all setup errors should be set to zero
- Systematic OM errors are reduced by a factor 3
- Random OM errors stay the same

What was the margin in the AP direction when an **offline** marker based correction protocol was used?

A. 5 mm
B. 8mm
C. 10 mm
D. 12 mm
E. 15 mm
F. Larger than 15 mm



Results

- 8 mm

- Organ motion has an important impact on the margin!

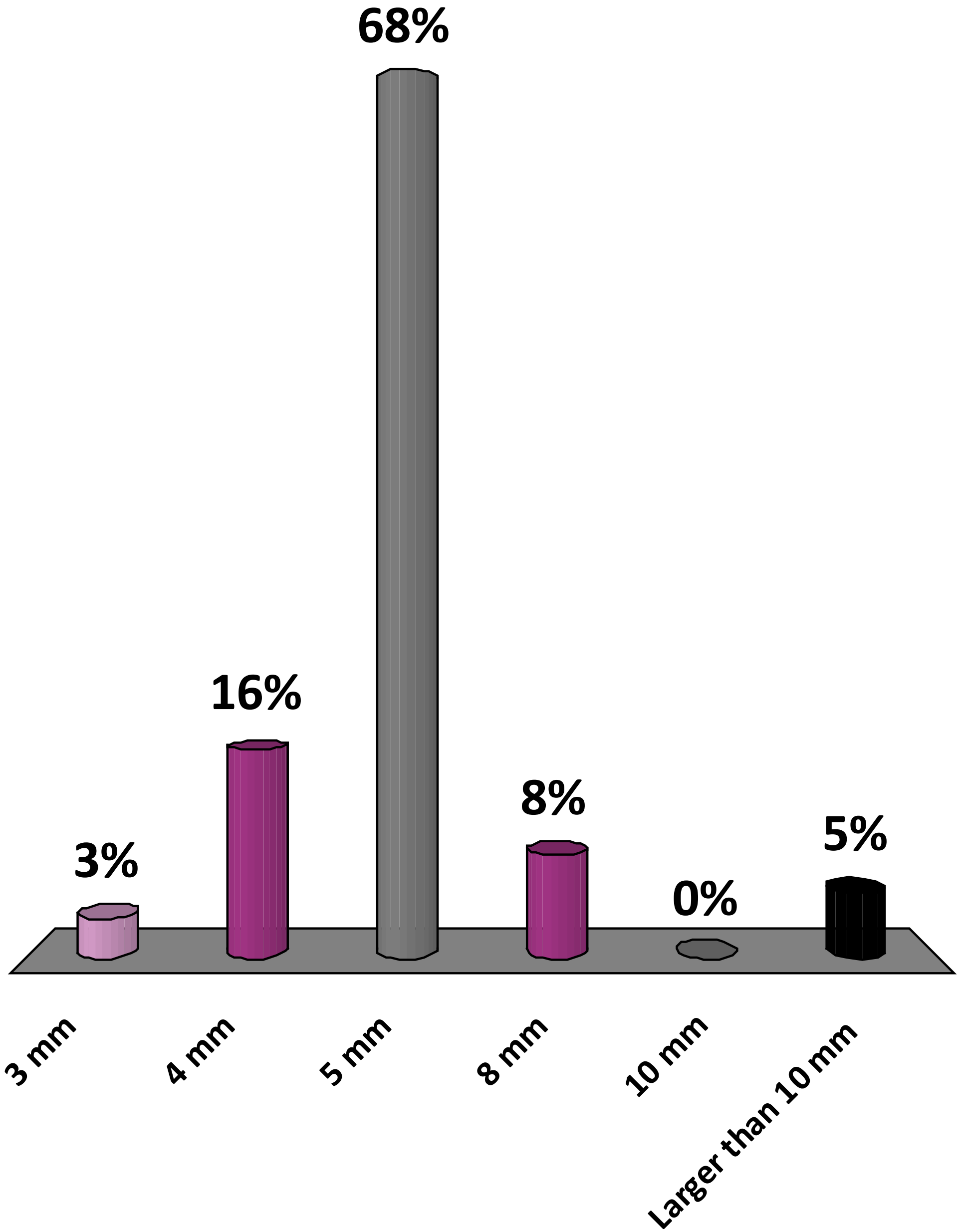
- We found the predominant error ☺

Online protocol based on marker registration

- **All** OM and setup errors become zero
- Residual errors (registration/delineation) stay the same

What was the margin in the AP direction when an **online** marker based correction protocol was used?

A. 3 mm
B. 4 mm
C. 5 mm
D. 8 mm
E. 10 mm
F. Larger than 10 mm

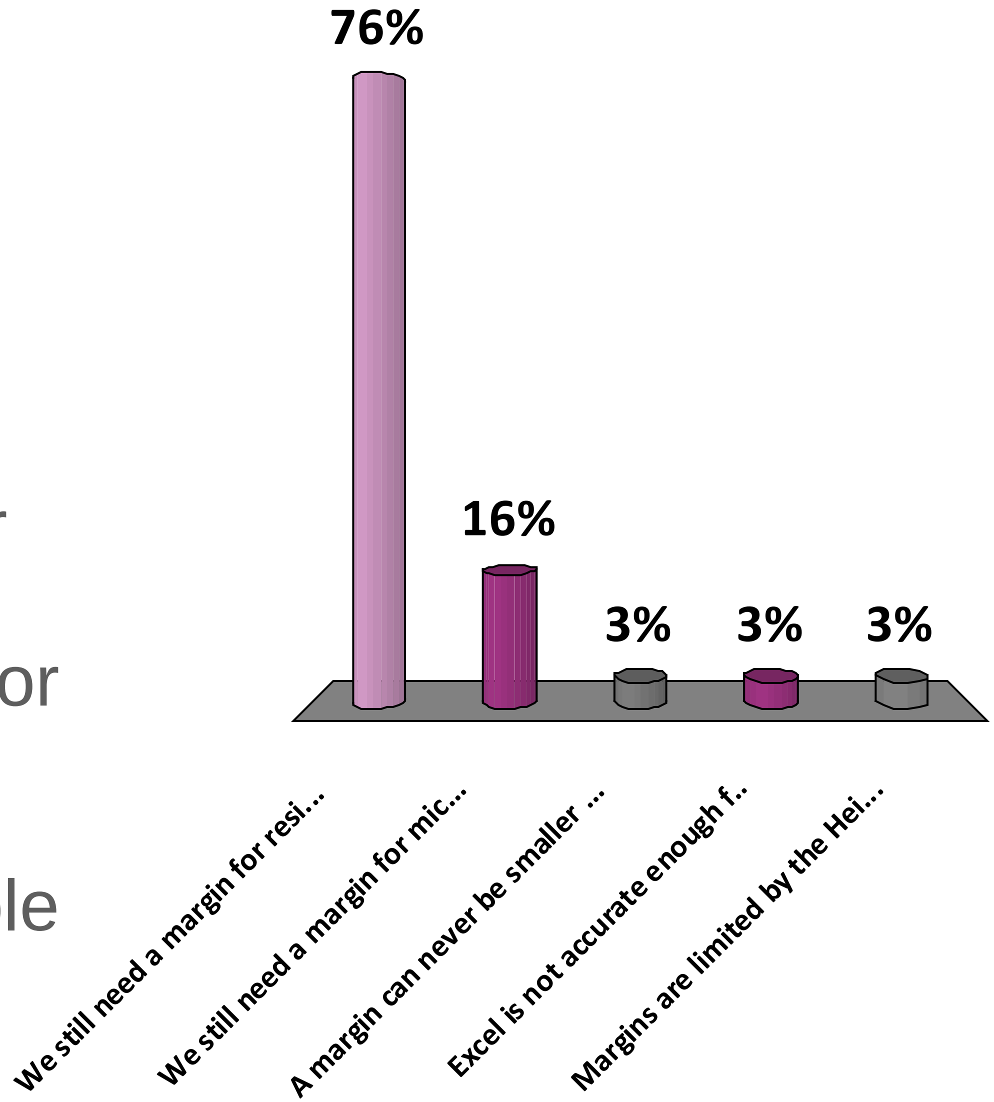


Results

- 5 mm (5.4 mm to be exact)

Given that we correct all organ motion and setup errors, why is the margin not zero?

A. We still need a margin for residual errors
B. We still need a margin for microscopic disease
C. A margin can never be smaller than 5 mm
D. Excel is not accurate enough for small margins
E. Margins are limited by the Heisenberg uncertainty principle

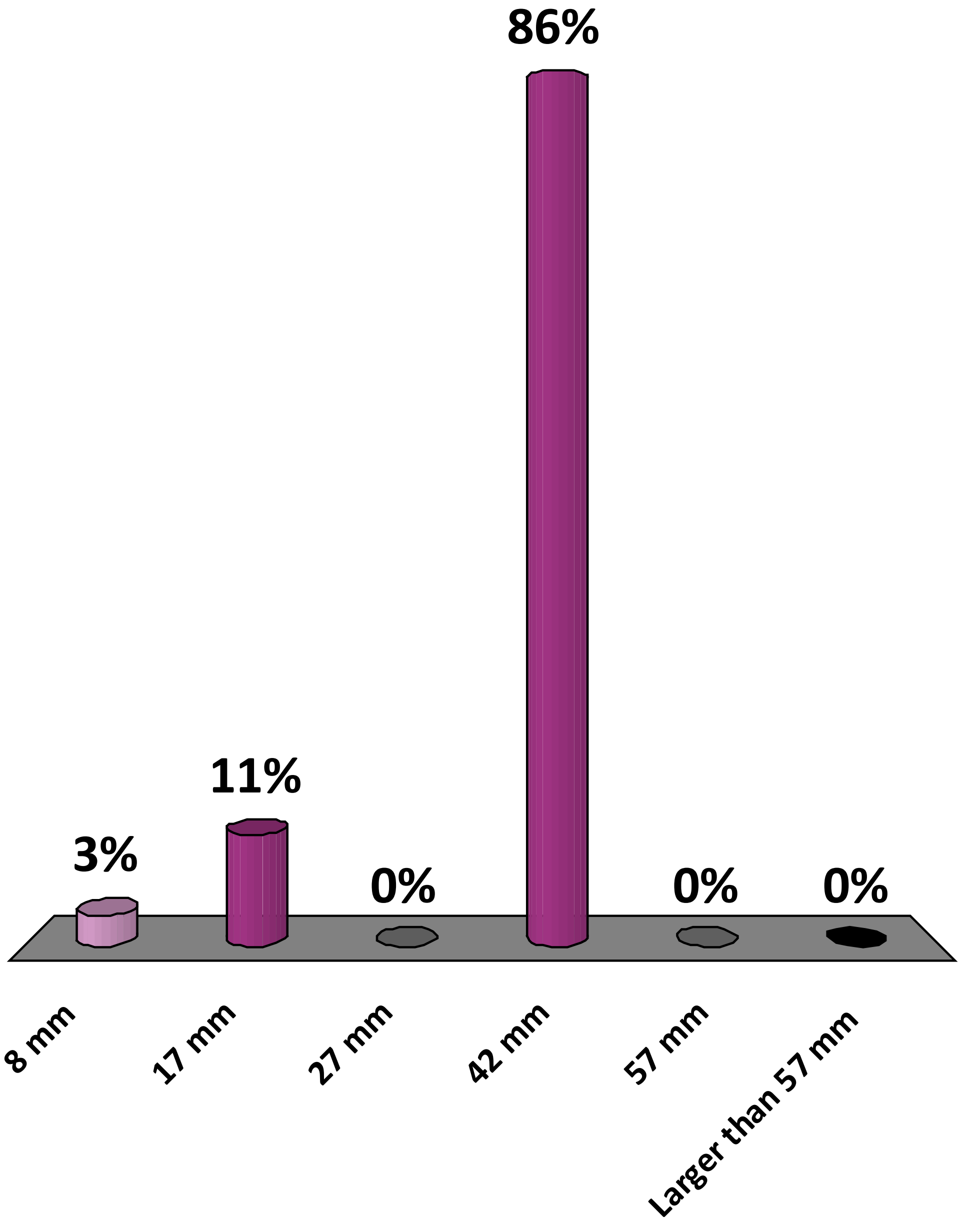


Case 2 - Bladder

- Largest motion CC, then AP
- Setup errors in the CC direction:
  - Systematic: 3 mm
  - Random: 3 mm
- Organ motion in the CC direction:
  - Systematic: 14 mm
  - Random: 9 mm

What was the margin in the CC direction when not using any correction protocol?

A. 8 mm
B. 17 mm
C. 27 mm
D. 42 mm
E. 57 mm
F. Larger than 57 mm



Case 2 - Bladder

- CC margin for no corrections: **42mm !**
- Clearly some kind of image guidance is needed

Case 2 - Bladder

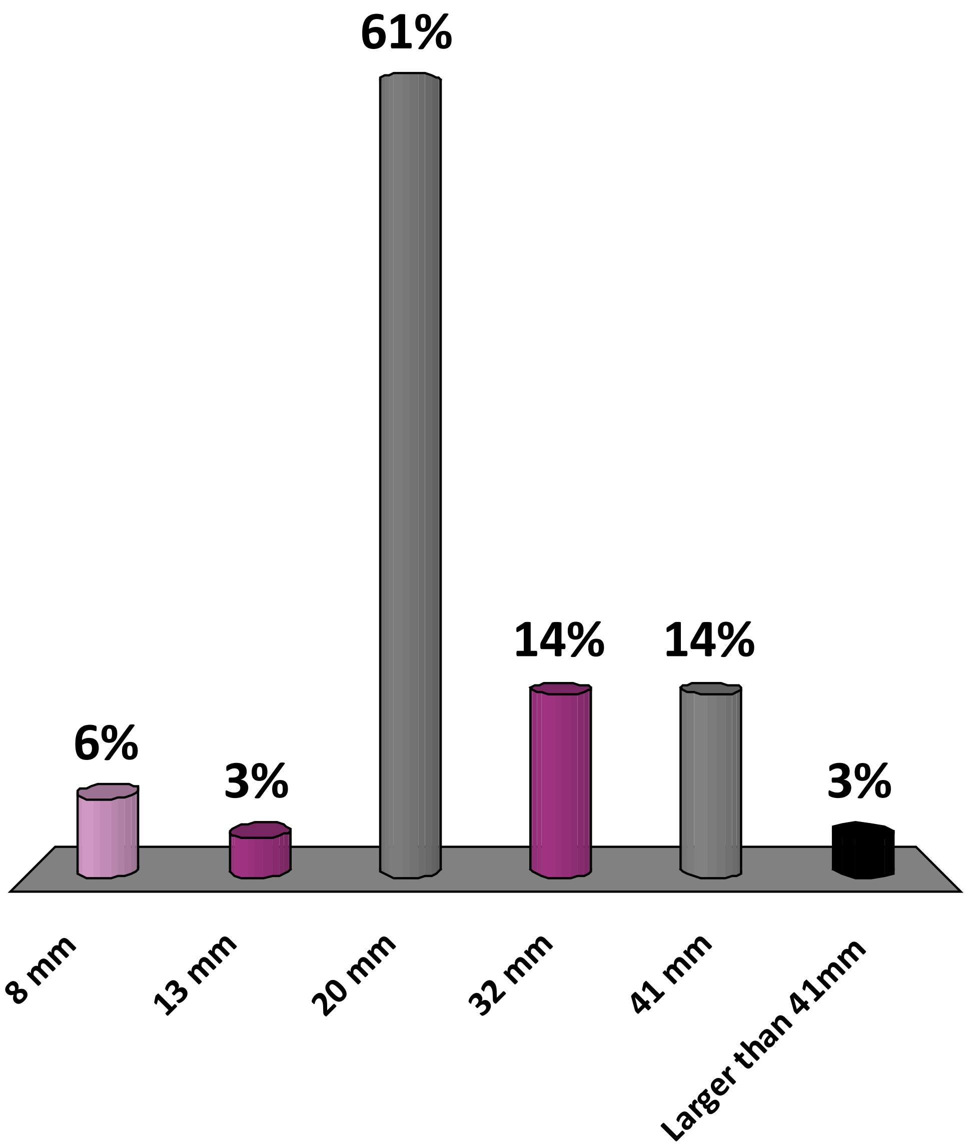
- Offline setup corrections:
  - Systematic setup becomes 3 times smaller
  - Random setup remains the same
  - Organ motion remains the same
- Online setup corrections:
  - Systematic and random setup become zero
  - Organ motion remains the same
- Margin when doing offline or online setup corrections: **41 mm** ☹
- Because organ motion is so much larger than setup, almost no effect of setup correction protocols on the margin

Case 2 - Bladder

- Offline correction protocol on markers
  - Setup errors are not relevant anymore → zero in the sheet
  - Systematic organ motion errors become three times smaller
  - Random organ motion errors remain the same

What was the margin in the CC direction using an offline marker based protocol?

A. 8 mm
B. 13 mm
C. 20 mm
D. 32 mm
E. 41 mm
F. Larger than 41mm



Case 2 - Bladder

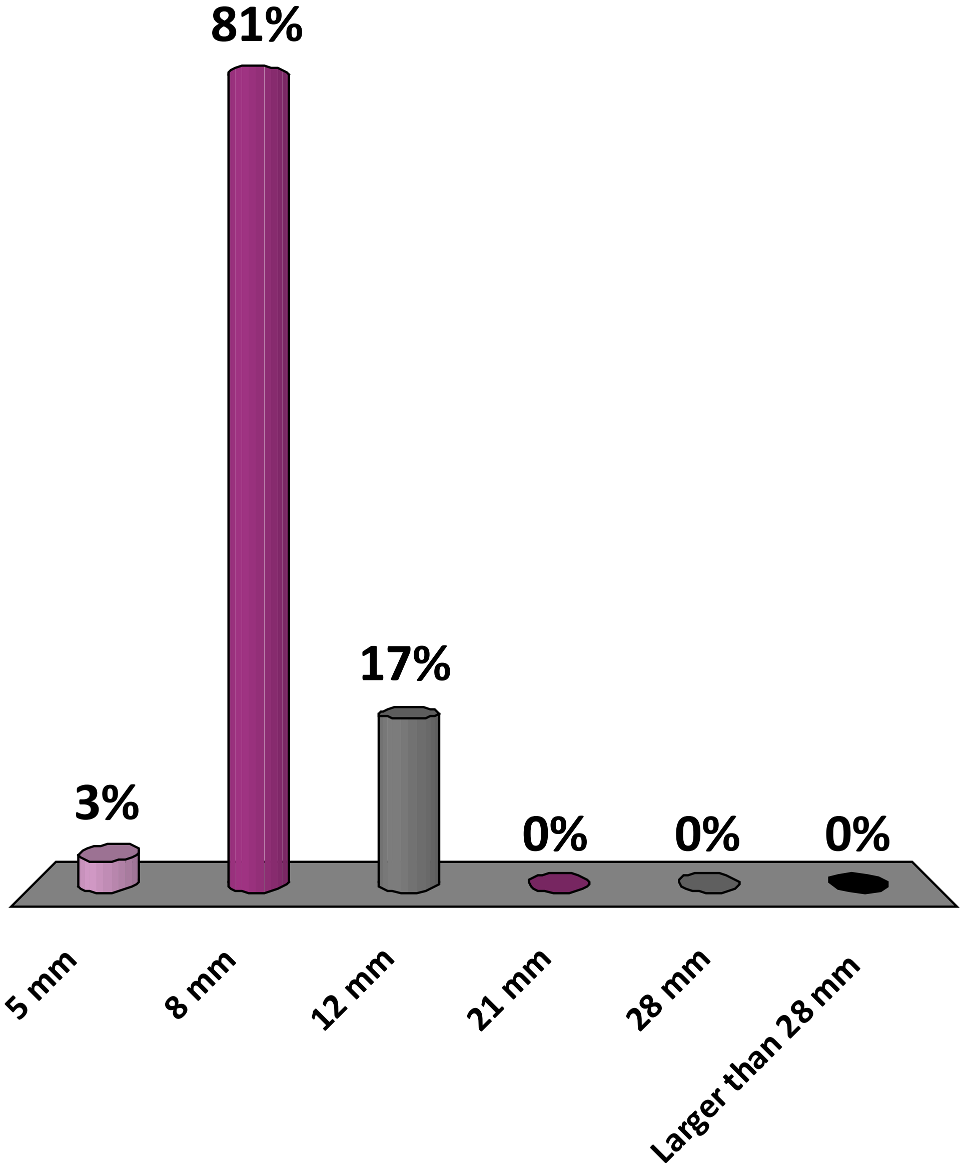
- Offline correction protocol on markers
  - All setup errors are not relevant anymore → zero in the sheet
  - Systematic organ motion errors become three times smaller
  - Random organ motion errors remain the same
- Margin for offline marker corrections **20 mm**

Case 2 - Bladder

- Online correction protocol on markers
  - All setup errors are not relevant anymore → zero in the sheet
  - Systematic and random organ motion errors become zero

What was the margin in the CC direction using an online marker based protocol?

A. 5 mm
B. 8 mm
C. 12 mm
D. 21 mm
E. 28 mm
F. Larger than 28 mm



Case 2 - Bladder

- Offline correction protocol on markers
    - All setup errors are not relevant anymore → zero in the sheet
    - Systematic and random organ motion errors become zero
- Margin for online marker corrections 8 mm

Take home messages

- 10 patients is a good start, but the results will still be an estimate of the required margin

- The margin can only be reduced of you address ALL geometrical uncertainties, i.e.
    - Setup errors
    - Organ motion
    - Intra-fraction motion
    - Delineation errors
    - Other residual errors

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Management of respiratory motion in radiation therapy

Mirjana Josipovic
Dept. of Radiation Oncology
Rigshospitalet
Copenhagen, Denmark

Advanced skills in modern radiotherapy
June 2015

Management of respiratory motion in radiation therapy

- Respiratory gating technique
- Breath hold methods
- Motion encompassing methods
- Respiration synchronized techniques

AAPM TG 76 definition

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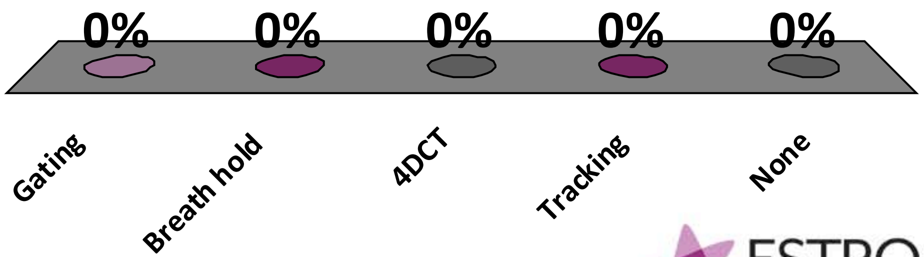
Which motion management do you use?

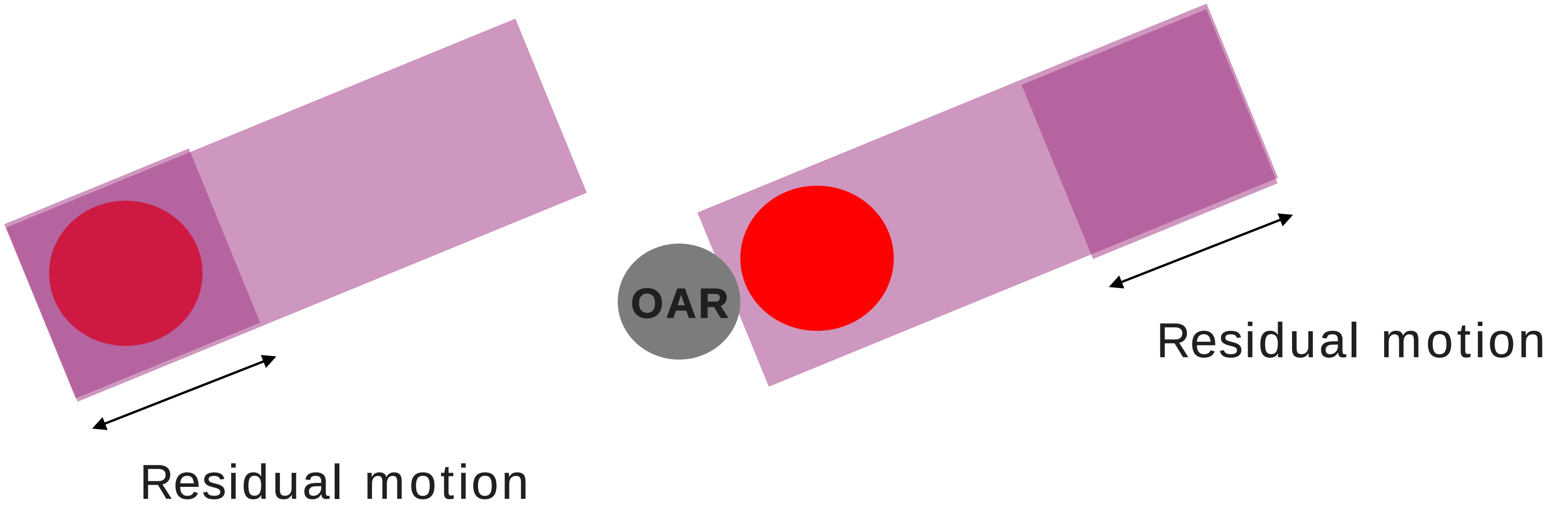
A. Gating
B. Breath hold
C. 4DCT
D. Tracking
E. None



Multiple answers alowed

What is respiratory gating?

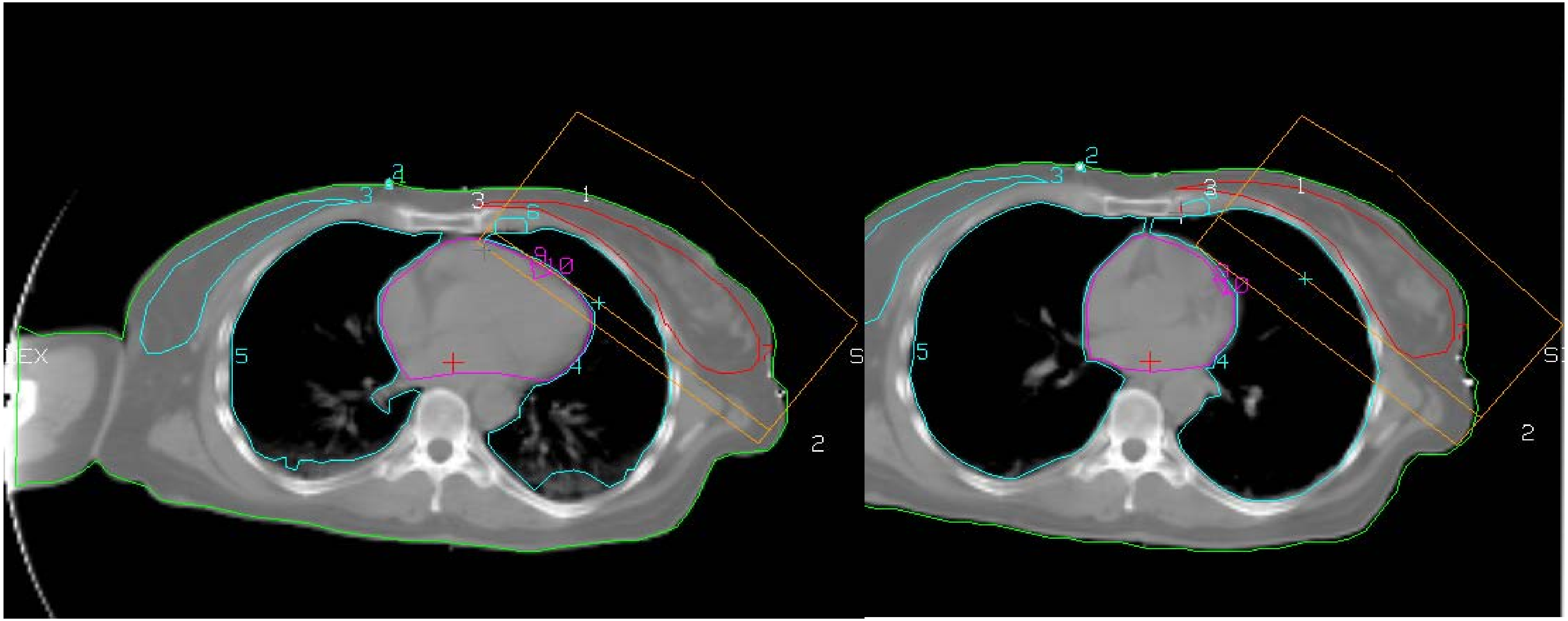
- Applying radiation within a particular part of the patient's breathing cycle



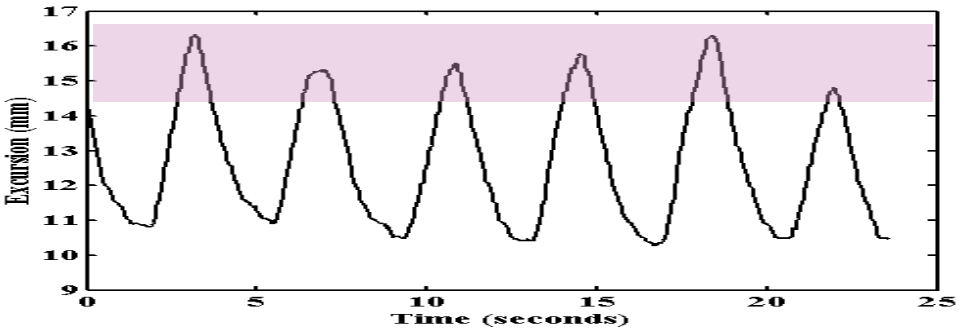
→ Reduce motion during treatment

→ Move target away from OAR

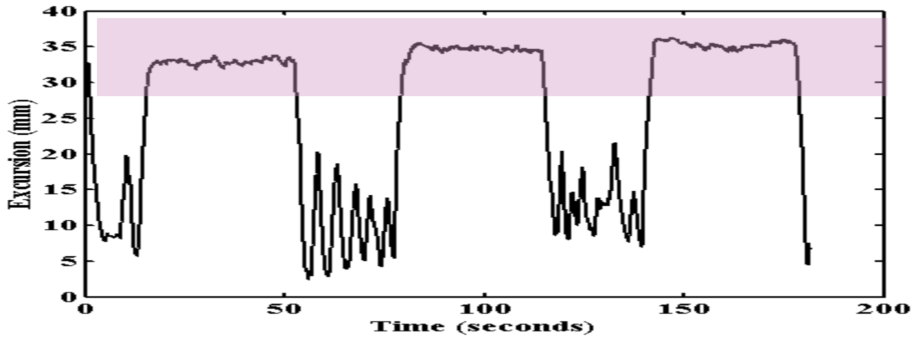
Expiration: Inspiration:



Respiratory gating



Free breathing INSPIRATION gating



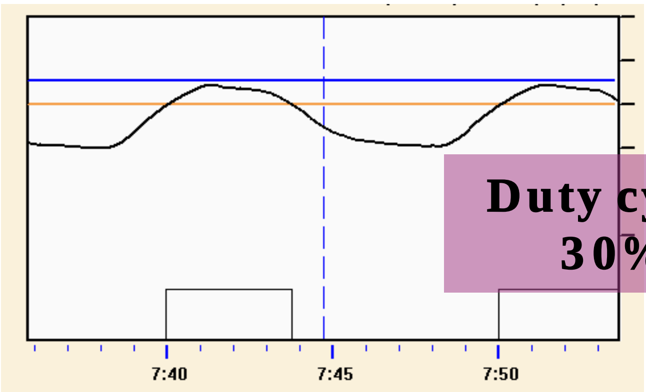
Deep Inspiration Breath-hold gating; DIBH

Breathing technique

When choosing gating threshold

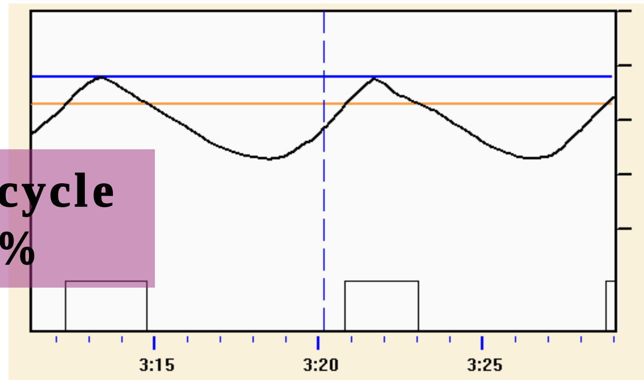
(...size of gating window...)

Decreased tumour motion ⟷ Increased delivery time



Duty cycle 30%

Duty cycle 15%



Acceptable residual motion ?

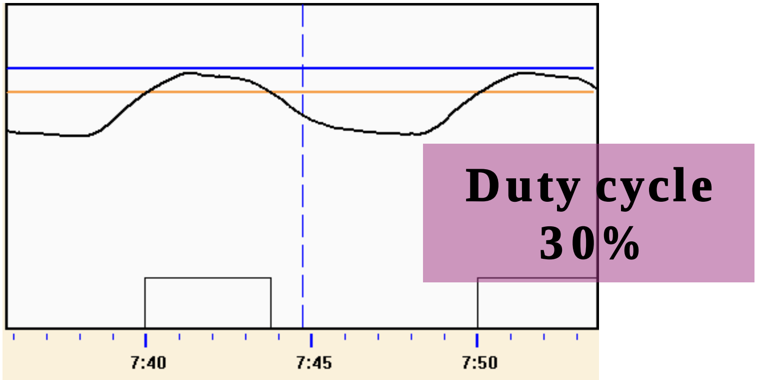
→ CTV-PTV margin!

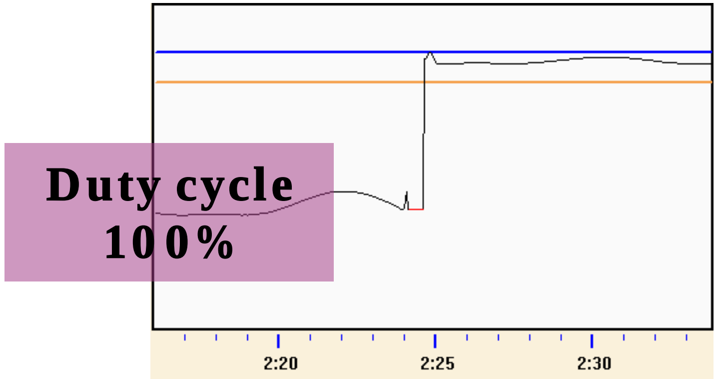
→ risk of patient movement due to discomfort

Breathing technique

When choosing gating technique

Gating ⟷ Breath hold





Accelerator dosimetry

Respiratory gating induces repeated interruption to the beam delivery!

Dosimetric considerations for short beam-on times

Output stability

Beam symmetry and flatness

Accelerator should be checked at:

Decreasing no. of MUs pr beam-on window

Relevant dose rates

Beam intensity modulation

Accelerator dosimetry

Literature on small MUs / short beam-on windows:

Ramsey et al., Med Phys 1999

Kriminski et al., J App Clin Med Phys 2006

Results:

output < ±0.8%

energy deviation < 0.4%

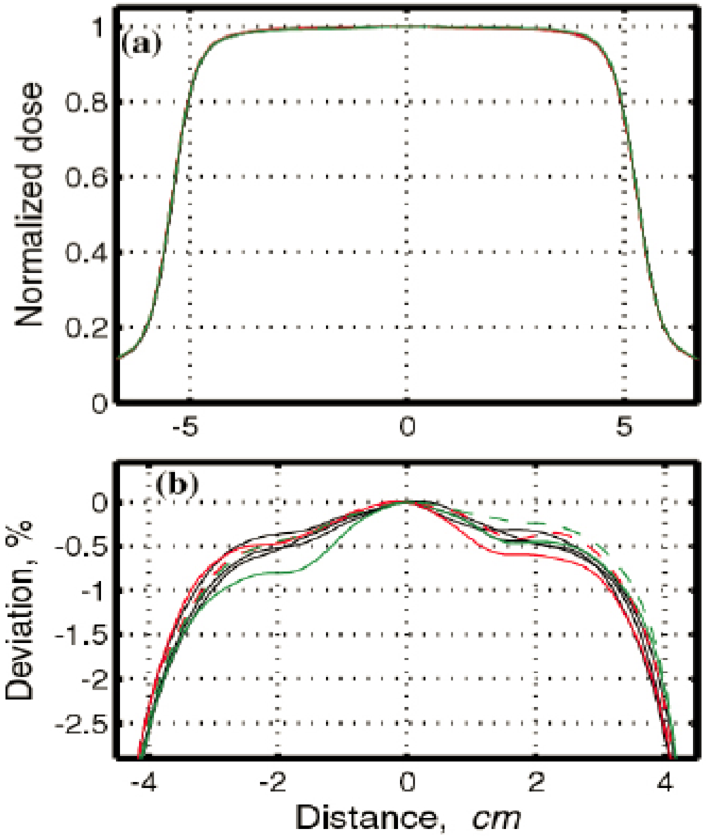
flatness deviation < ±1.9%

mean 0.2 ±0.4 %

symmetry deviation < ±0.8%

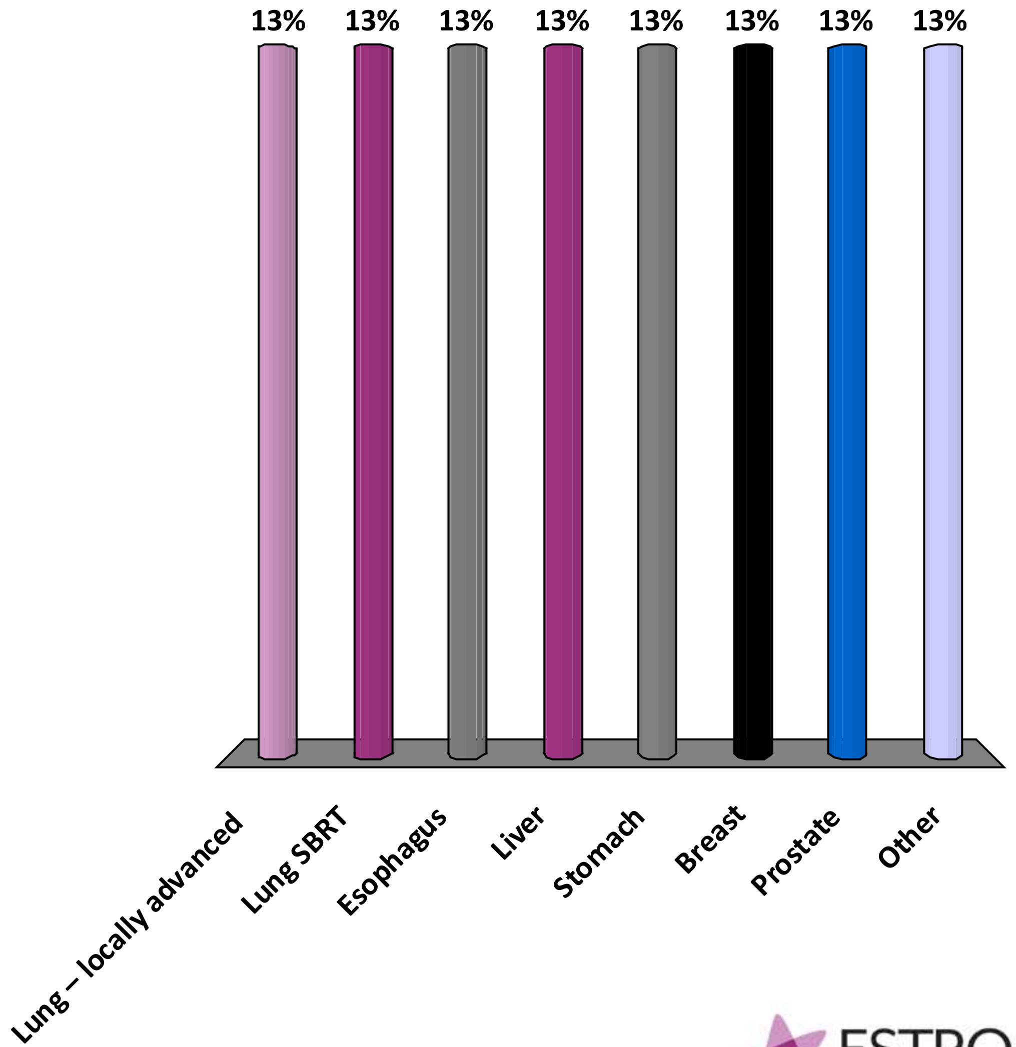
mean 0.1 ±0.2 %

clinically acceptable variations



In which sites do you use gating / breath hold?

A. Lung – locally advanced
B. Lung SBRT
C. Esophagus
D. Liver
E. Stomach
F. Breast
G. Prostate
H. Other

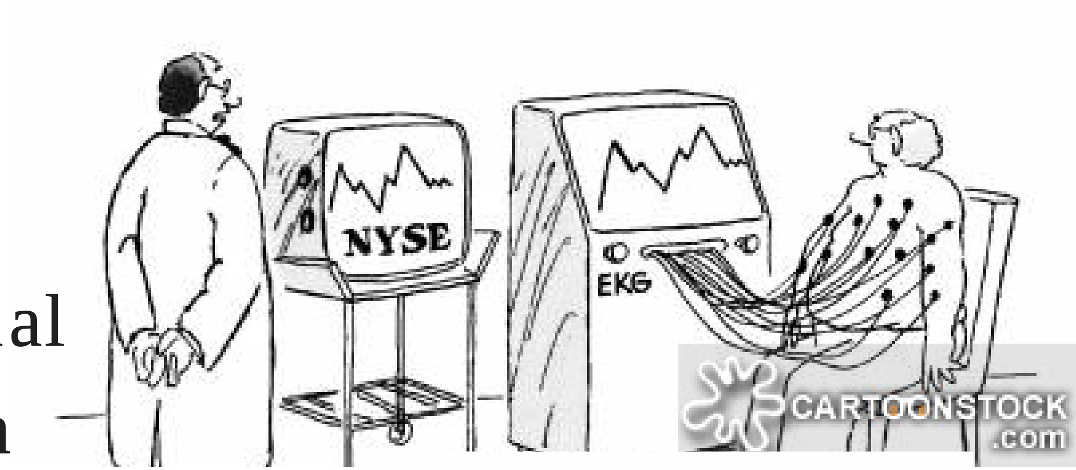


Condition for success with gating & breath hold

Strong correlation

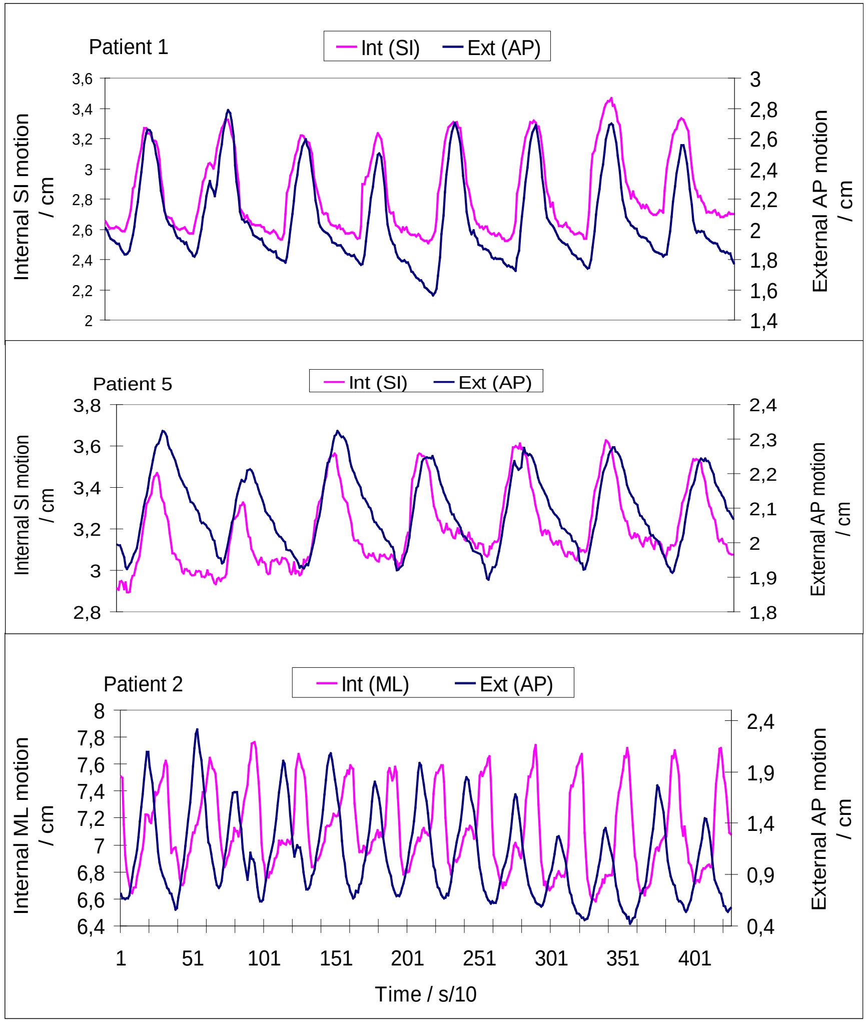
Internal organ motion - External chest motion

- Tumour type and location
- Source of the respiratory signal
- Reproducibility of respiration



" Amazing . . the patterns are the same ! "

External vs. internal motion



Correlation can be established

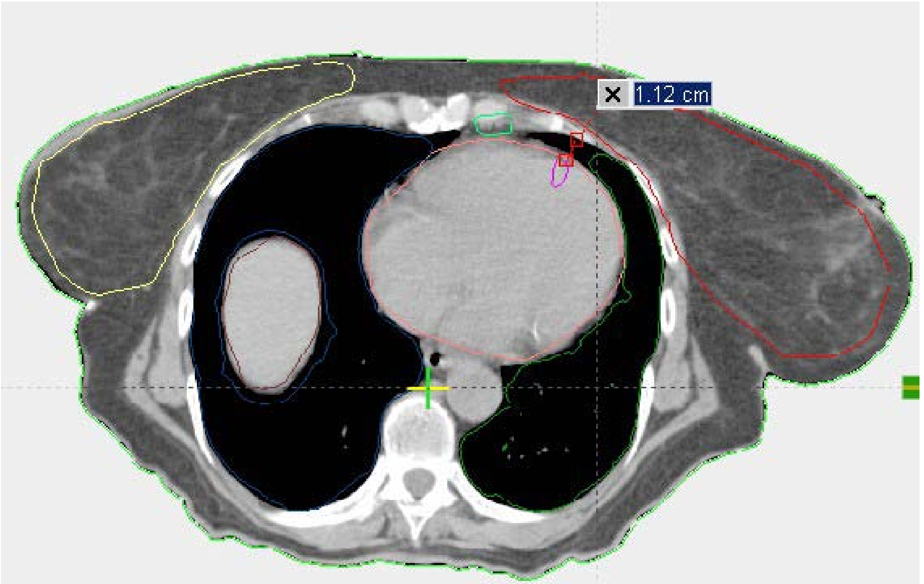
Phase difference

- Phase drift
- No correlation

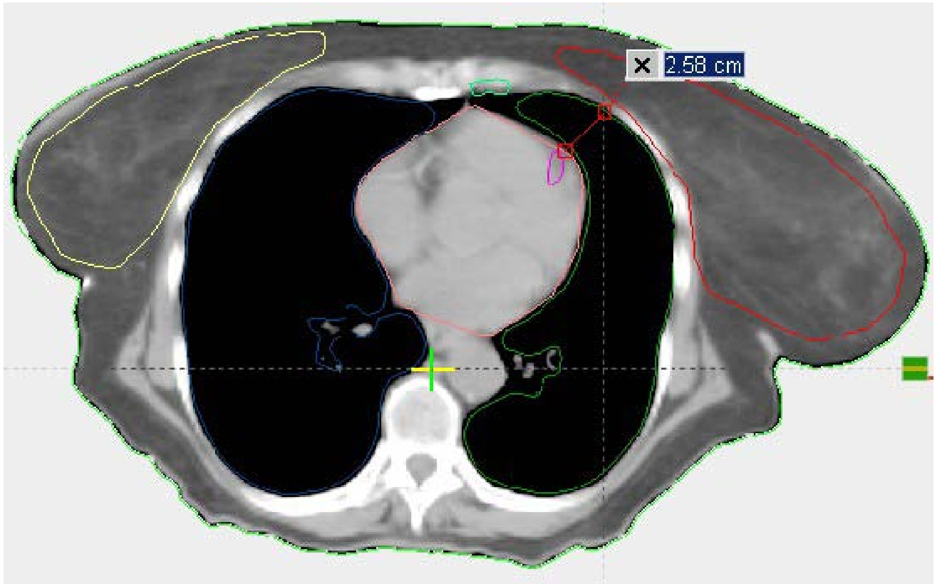
SS Korreman, ICCR 2007

External vs. “external” motion

- Good correlation in breast RT

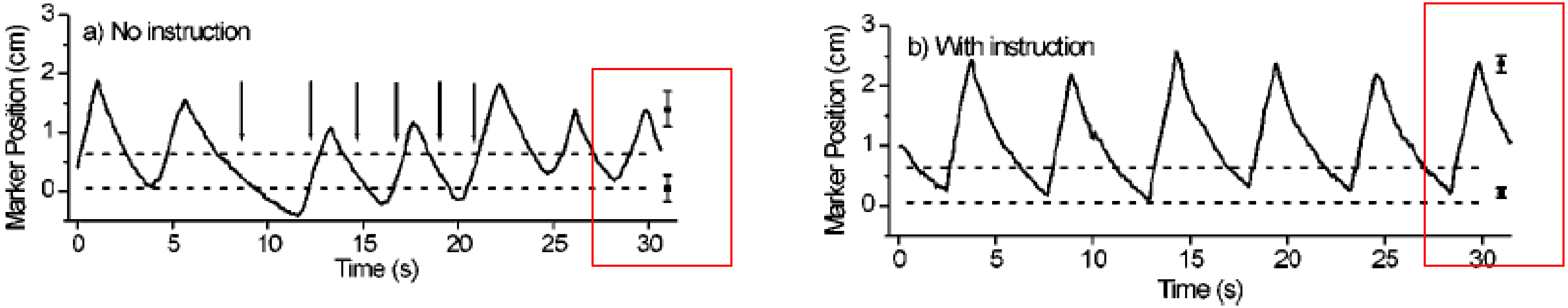


Spontaneous breathing

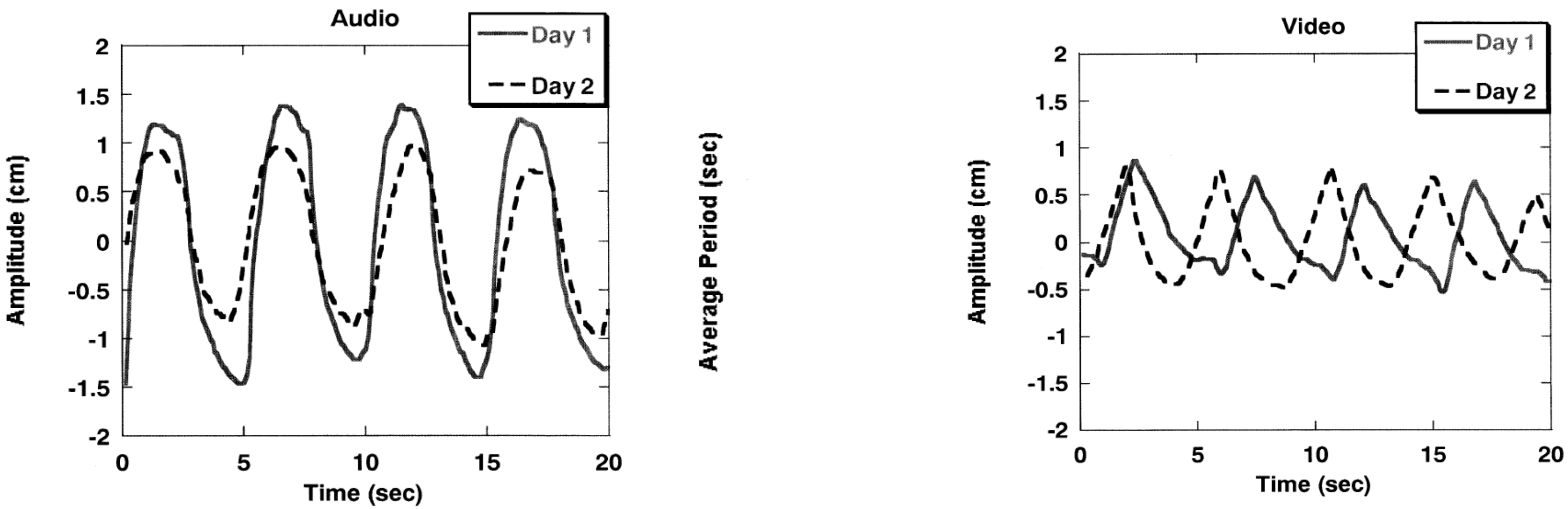


Enhanced inspiration gating

Reproducibilty of respiration



Mageras et al., J. Appl. Cl. Med. Phys., 2001

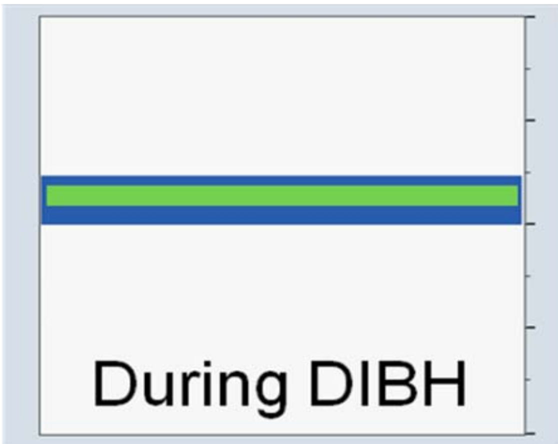


Kini et al. Med. Dosimetry, 2003

Reproducibilty of respiration

Breathing **coaching** can be done by means of:

- audio instructions to ”breath in” and ”breath out”
- visual feedback of the patient’s own breathing




- Individually adjusted!
  - If the patient doesn’t comply – exclude!

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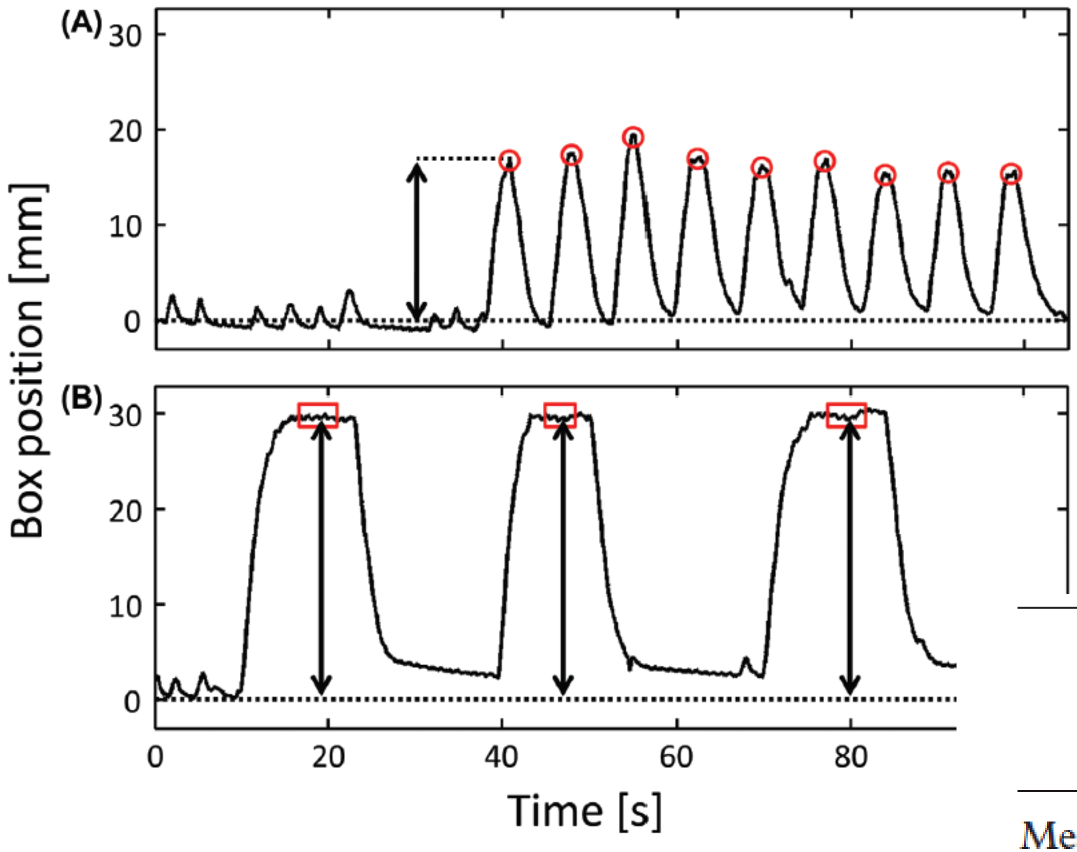
Reproducibilty of respiration



← **audio coaching + gating**

← **visual guidance + DIBH**

	Audio-coached EIG mean (range)	Visually guided DIBH mean (range)
Mean inspiration level [mm]	16.6 (5–35)	20.5 (5–34)
Mean standard deviation [mm]	1.66 (0.5–3.5)	0.38 (0.2–0.6)

Damkjær et al. Acta Oncologica, 2013

The breath hold methods

Deep inspiration breath hold

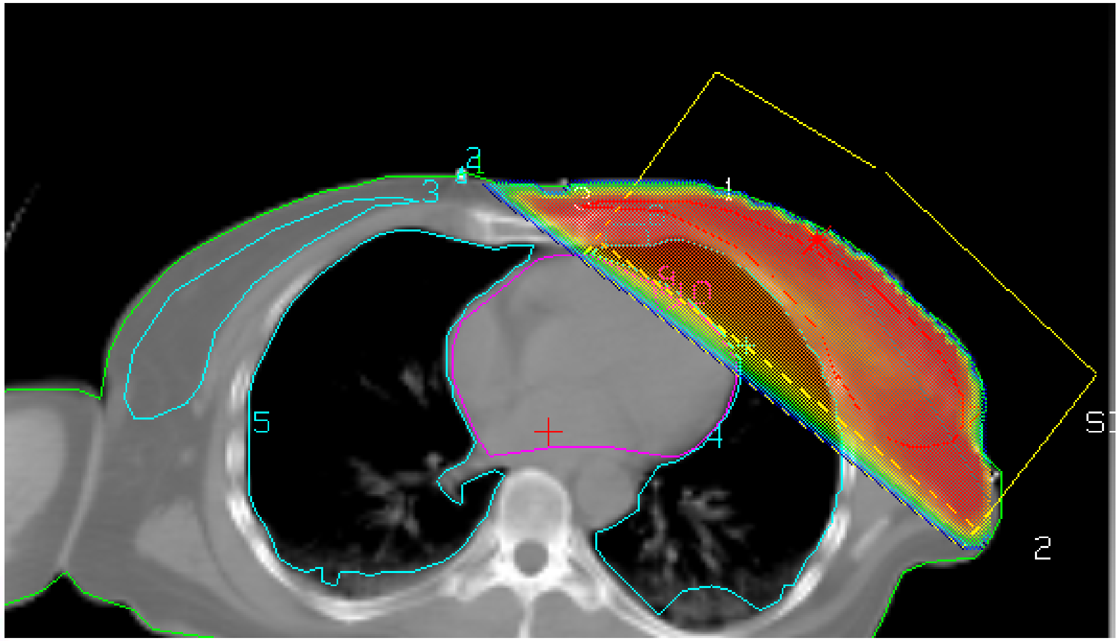
- Voluntary

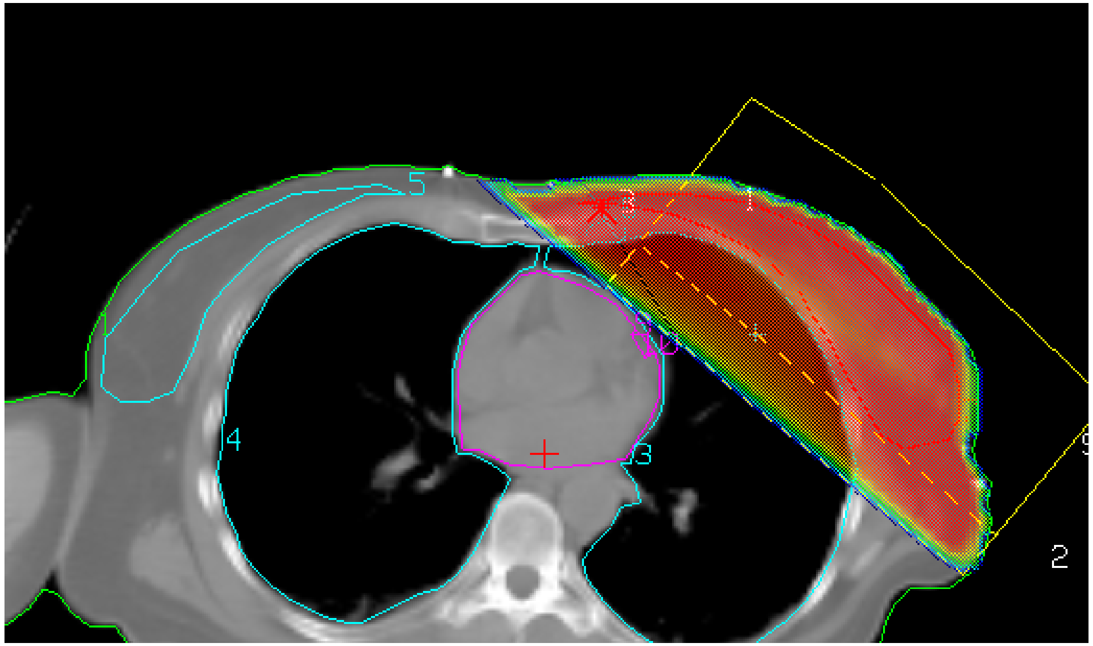
- Assisted

ABC system, Elekta

Dosimetric potential of DIBH – breast

Free breathing **DIBH**





Separation of target / OAR

- Sparing of cardiac structures
- IMN coverage not compromised

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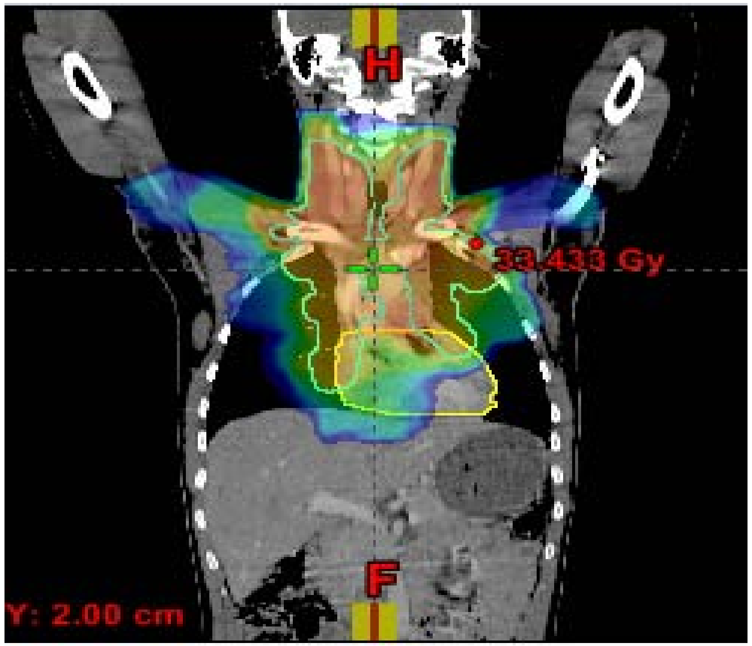
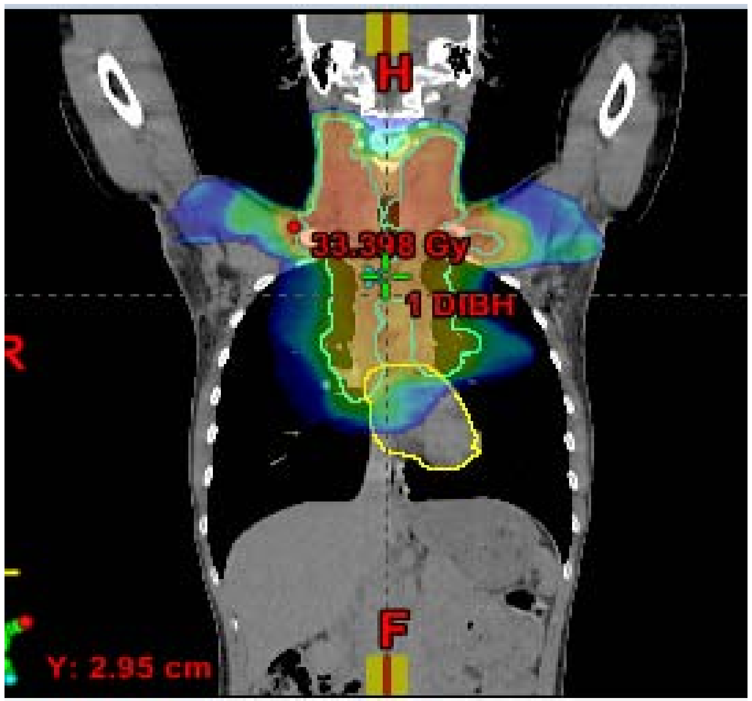
Dosimetric potential of DIBH – lymphoma

Free breathing



DIBH

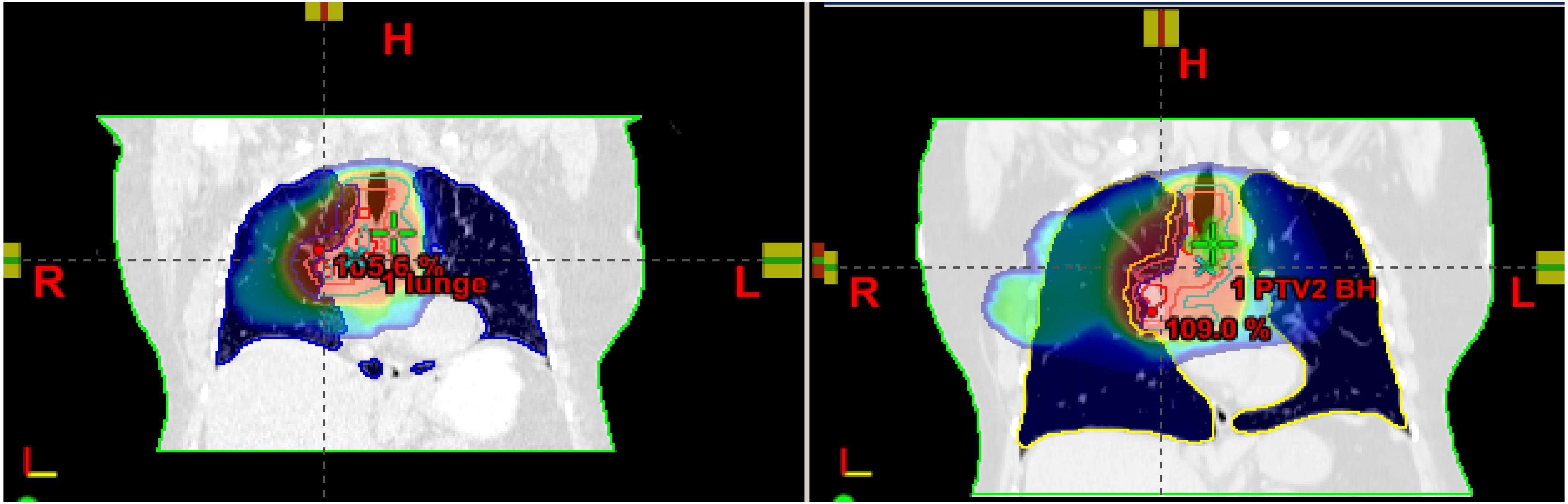


Reduction of dose to the lung & heart

Courtesy of M. Aznar – more details on Wednesday ☺

Dosimetric potential of DIBH – lung

Free breathing DIBH



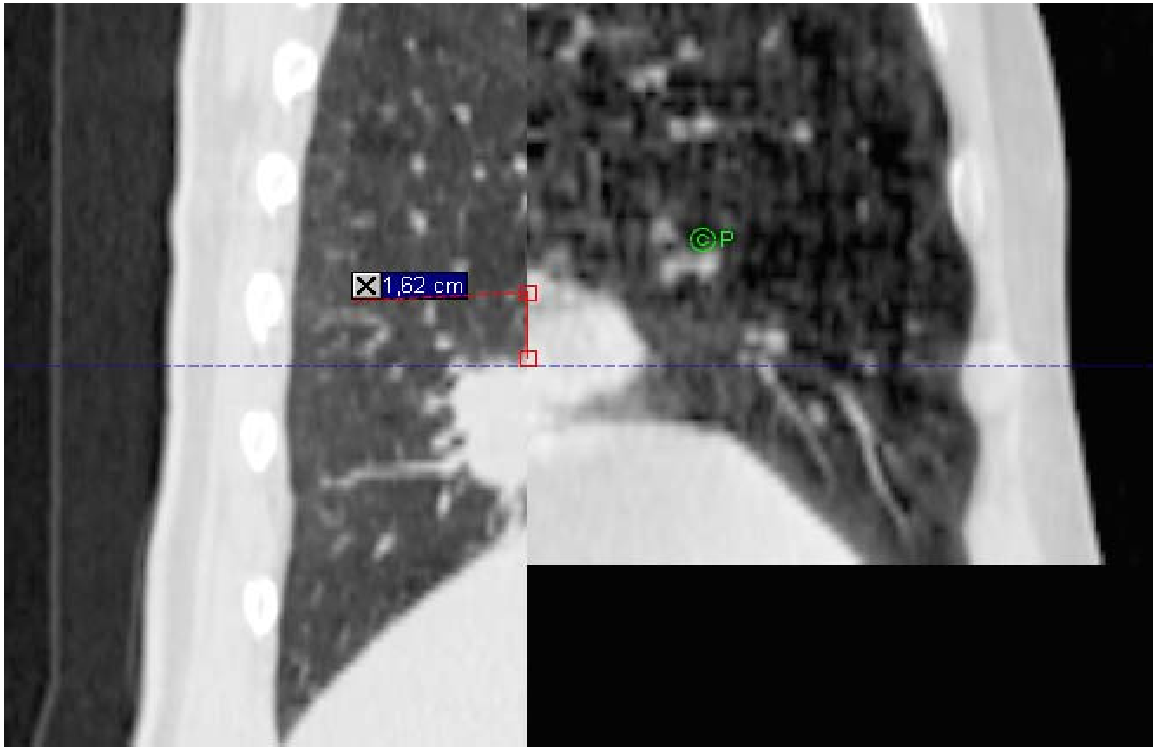
1st lung cancer pt treated in DIBH

Patients with small lung volume – too high toxicity

- regardless tumour motion!

Josipovic et al, Acta Oncologica 2013 & 2014

Reproducibility of target position?



Josipovic et al, Acta Oncologica 2014

PTV margins depend on:

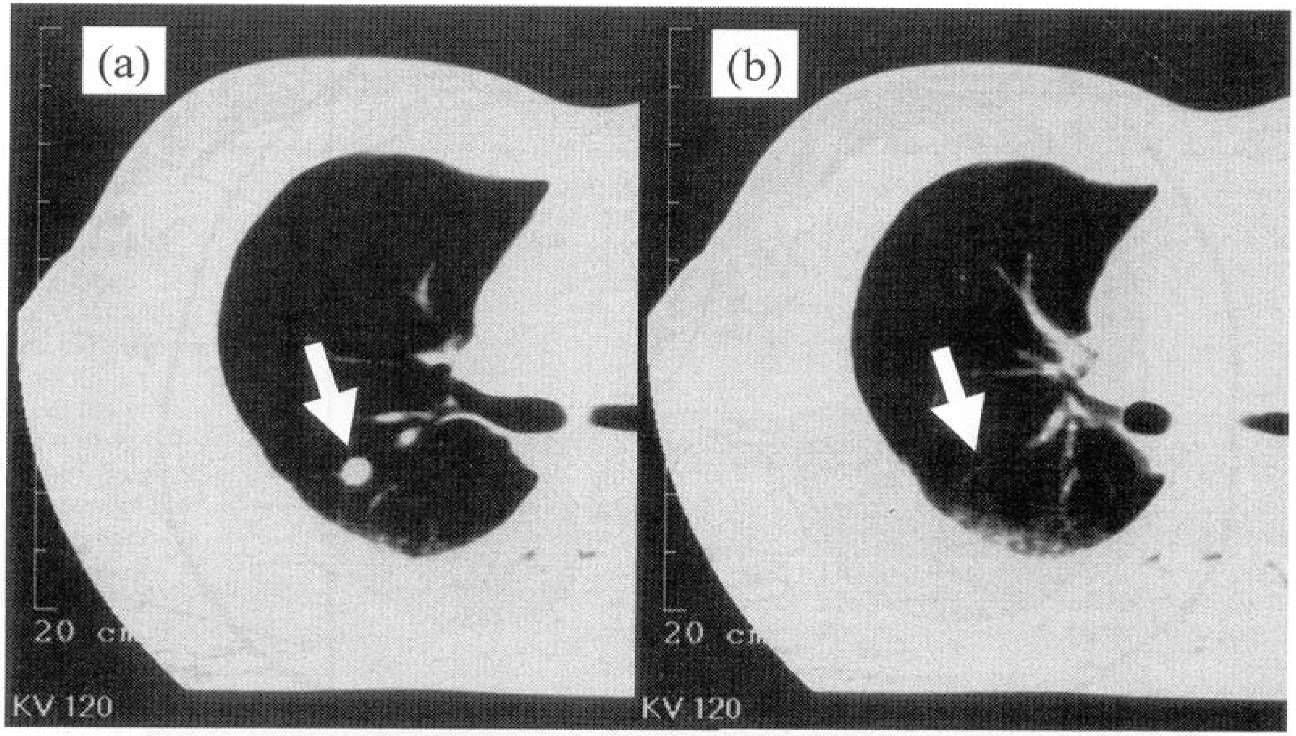
•Breath hold method reproducibility

•IGRT strategy

Motion encompassing methods

- Large target motion
- Small moving target

- Slow CT
- 4DCT

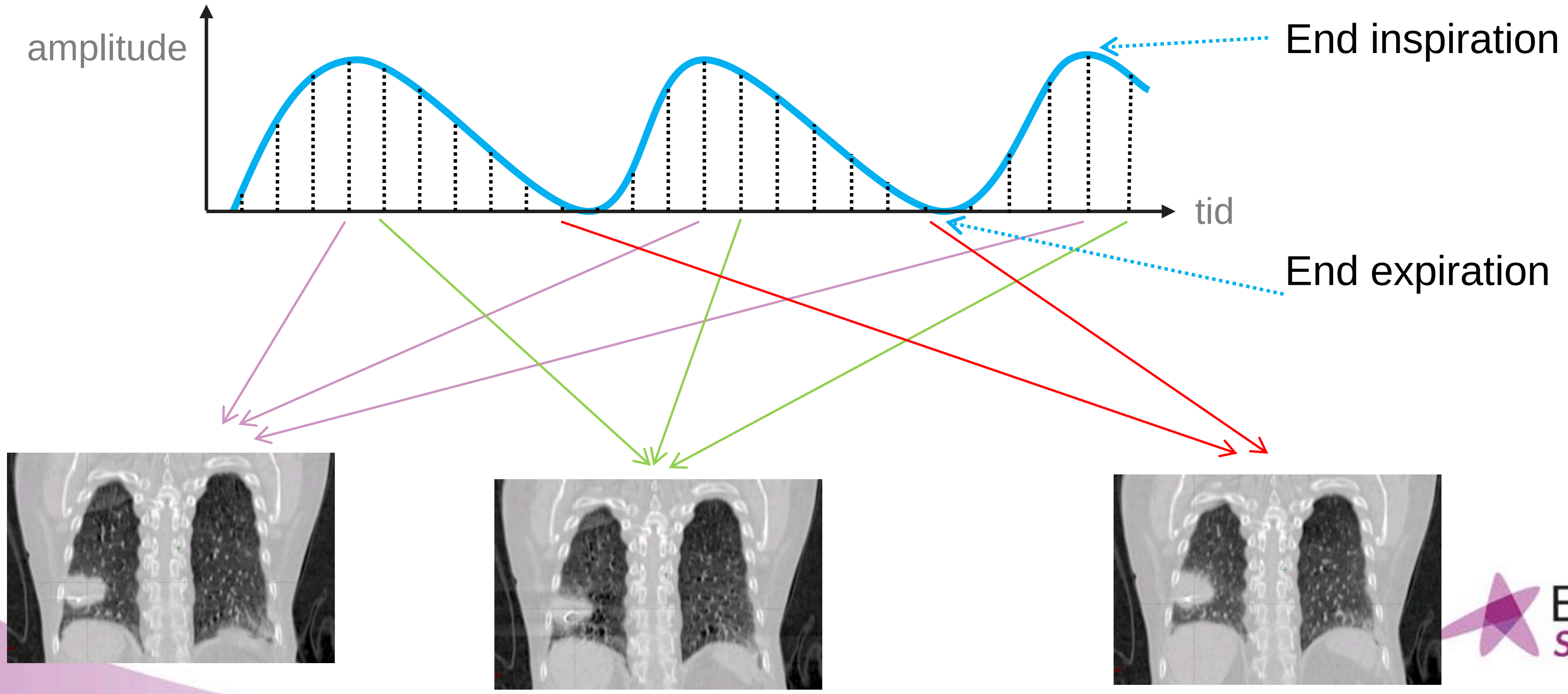


Shimizu *et.al.*, IJROBP 2000

4DCT

BINNING = sorting of images acc. to respiration

- Resp. phase
- Resp. amplitude



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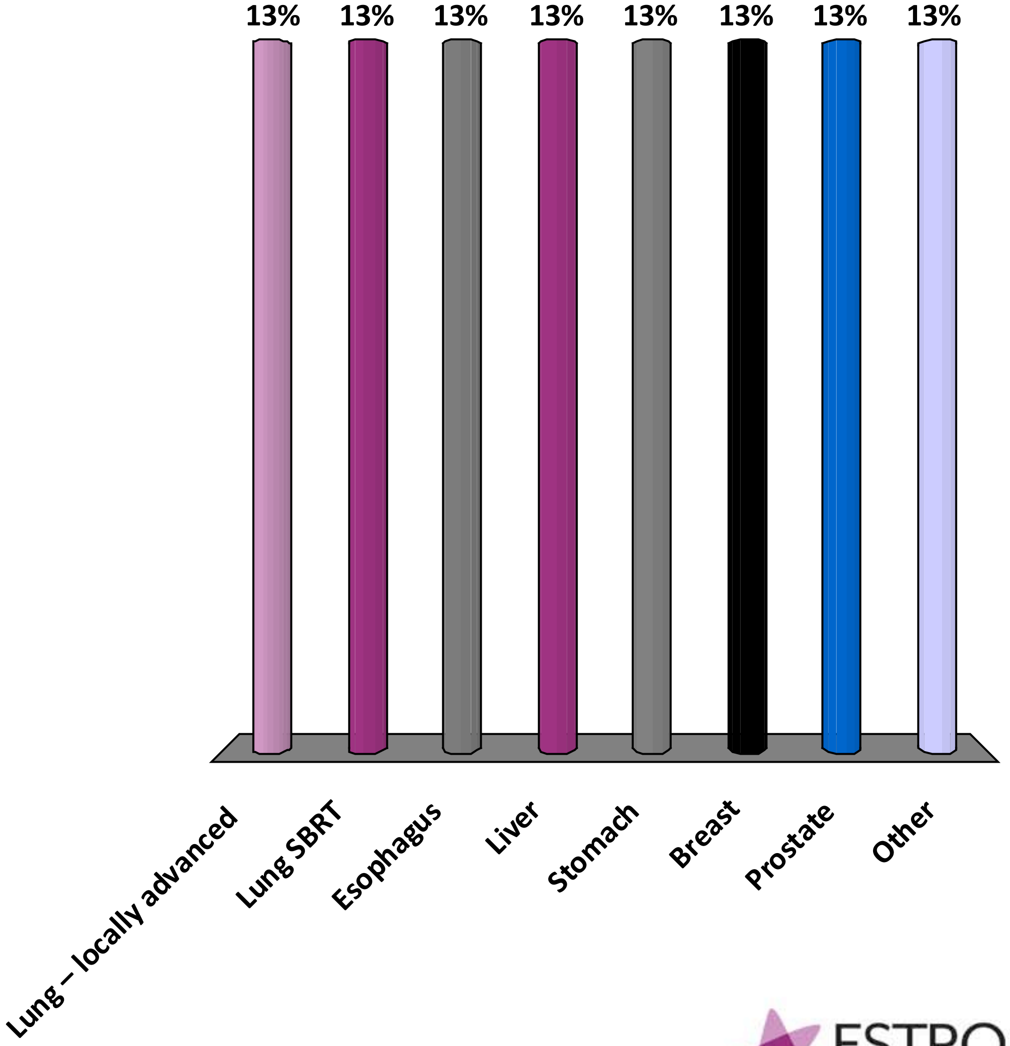
In which sites do you use 4DCT ?

A. Lung – locally advanced
B. Lung SBRT
C. Esophagus
D. Liver
E. Stomach
F. Breast
G. Prostate
H. Other



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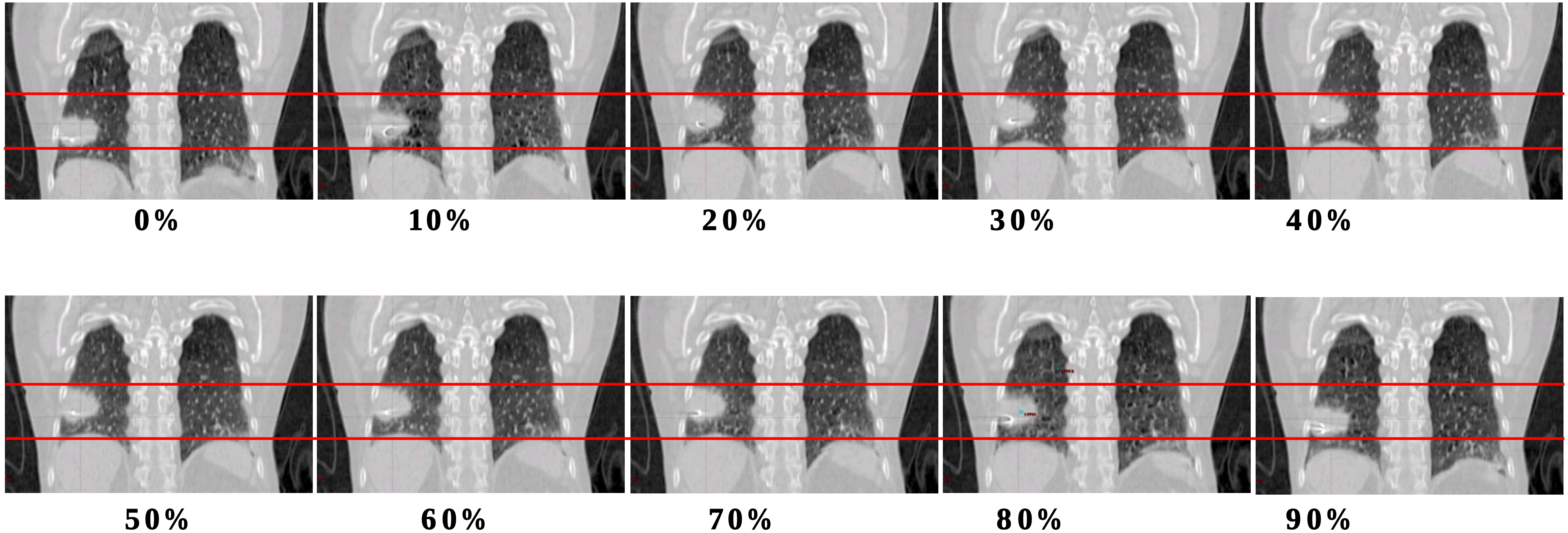
4DCT

10 3D images representing 10 bins:



- Evaluation of tumour motion
- Selection of midventilation phase or definition of the ITV

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ITV = internal target volume

- ITV = adding a margin for tumour motion to the CTV
- iGTV = sum of GTVs in all phases of 4DCT

- ICRU 62: ITV = CTV + margin for uncertainties in size, shape & position of CTV <u>within</u> the patient

ICRU REPORT 83

Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT)

- ICRU 83: resulting PTVs were too big

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ICRU REPORT 83

Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT)

4.4 Internal Target Volume

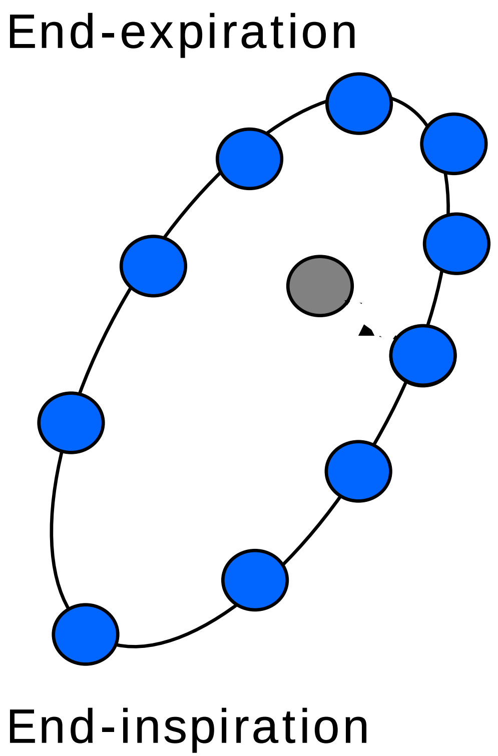
In ICRU Report 62 (ICRU, 1999), the ITV was defined as the CTV plus a margin taking into account uncertainties in size, shape, and position of the CTV within the patient. Such a margin was called the *internal margin* as opposed to the *set-up margin*. In ICRU Report 62, it was recommended that internal and external margins be added quadratically, but often in practice they are instead added linearly, which can lead to an unacceptably large margin. The ITV might be useful only in clinical situations in which uncertainty concerning the CTV location dominates setup uncertainties and/or when they are independent. The ITV is considered an optional tool in helping to delineate the PTV.

In choosing margins, the risk of missing part of the CTV must be balanced against the risk of complications due to making the PTV too large. For instance, if margins are added linearly, the resulting PTV may often be too large, with a consequent risk of exceeding patient tolerance.

Since margins are introduced to compensate for both random and systematic uncertainties, a qua-

ICRU Report 62, 1999

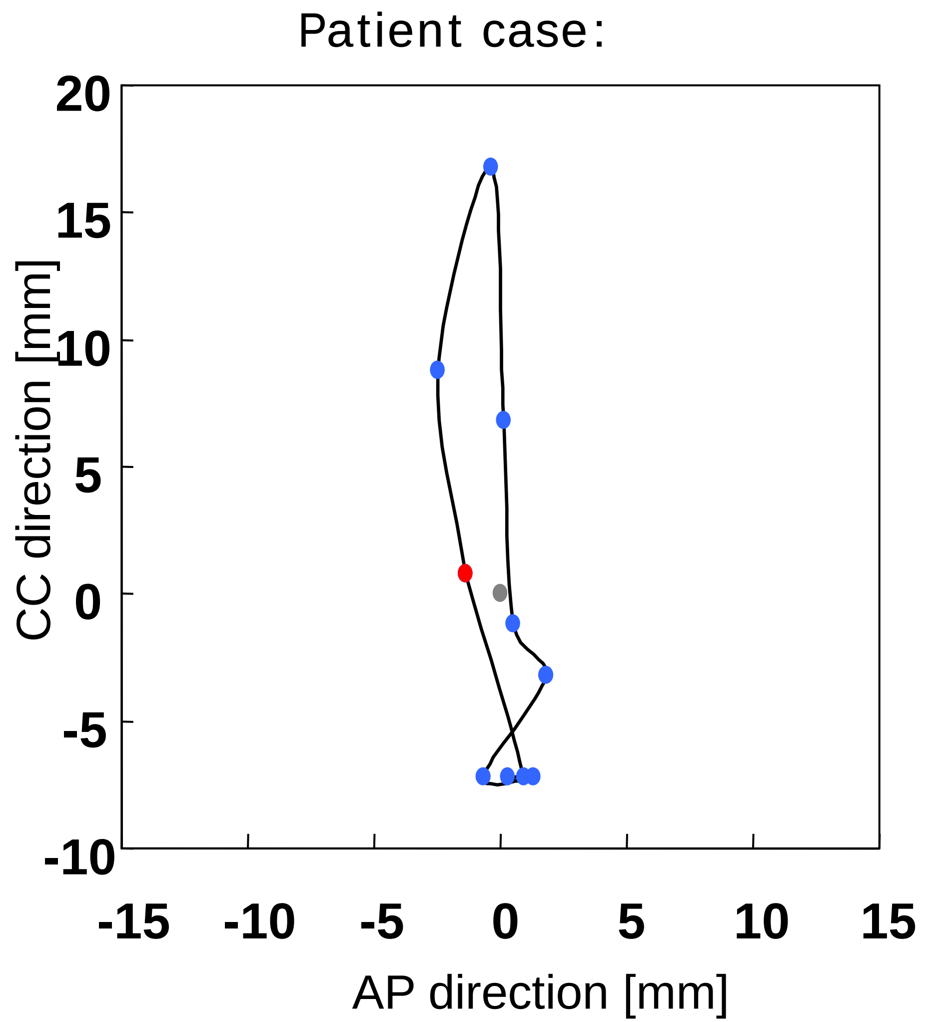
Midventilation bin selection



Tumour position in phases 1-10

Time-weighted mean tumour position

Midventilation



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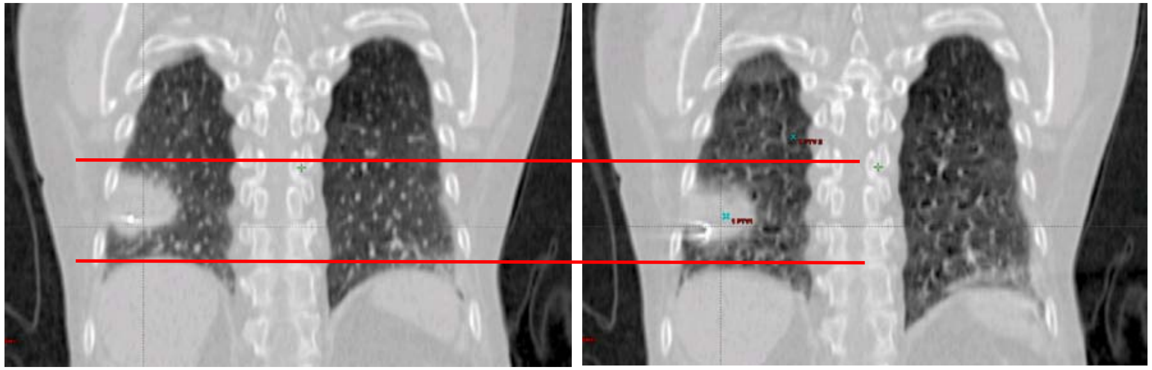
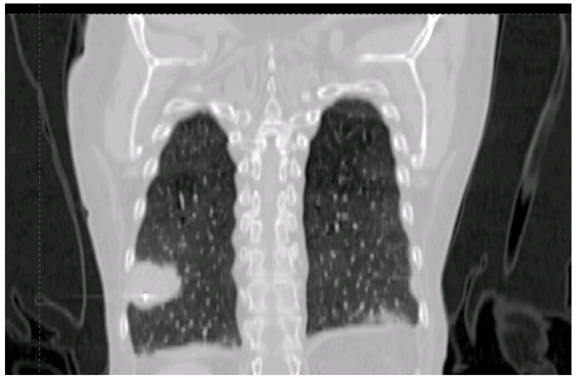
Midventilation bin selection



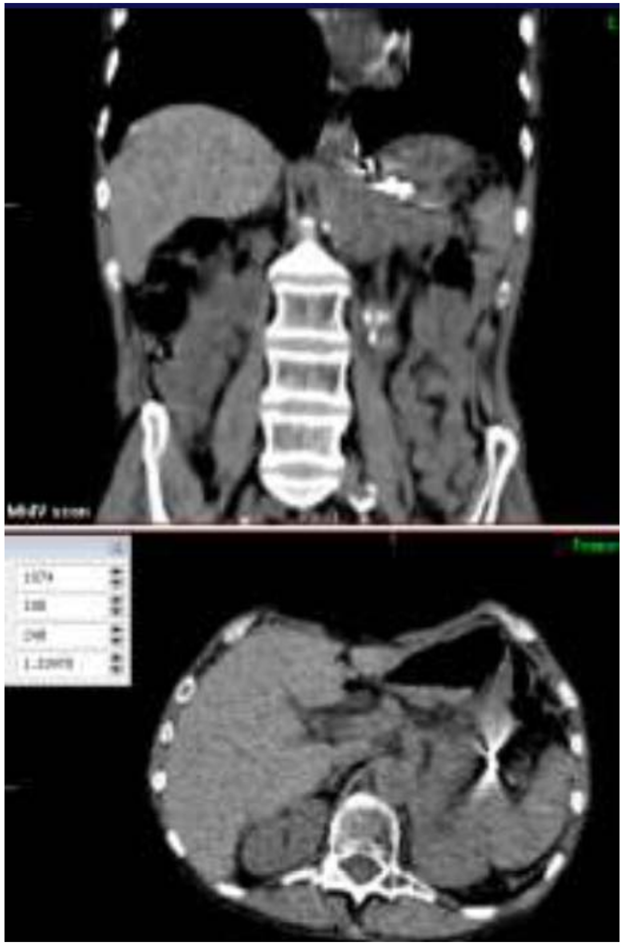
50%   80%

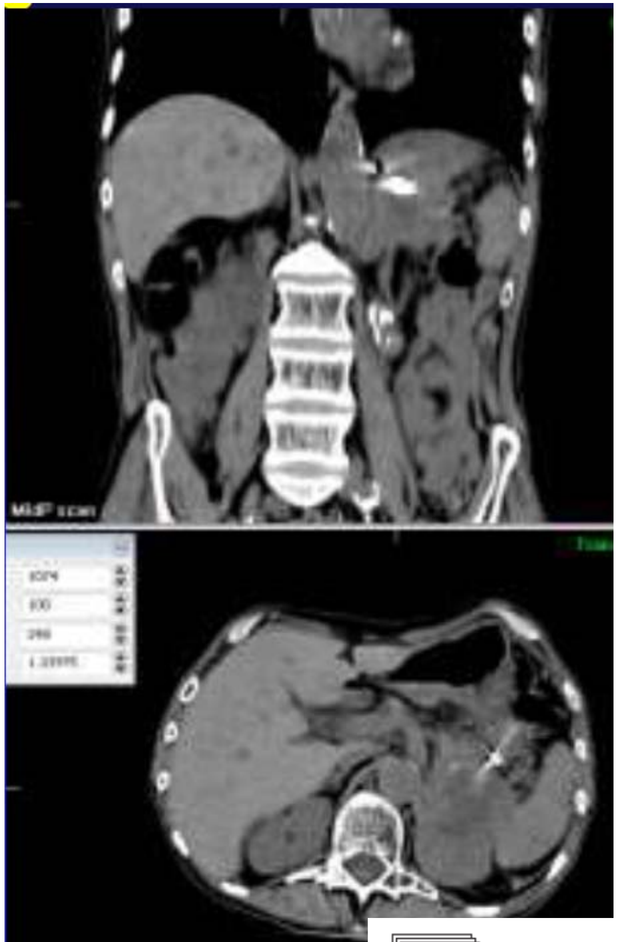
- Comparison of tumour size and shape with the breath-hold scan



Breath Hold scan

Midventilation vs. midposition





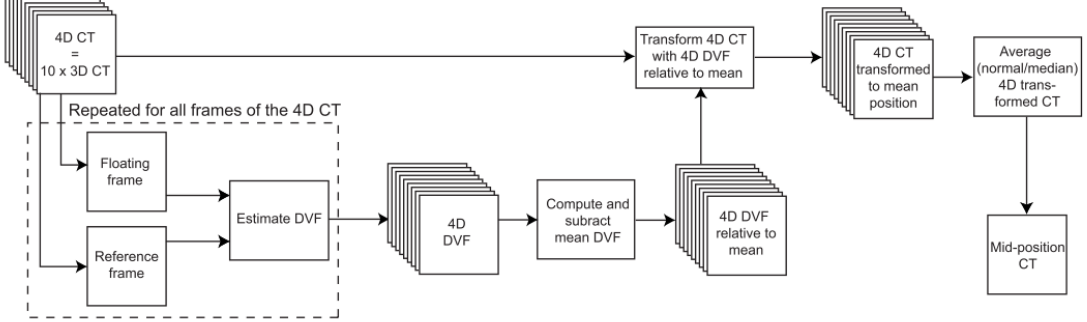
MIDPOSITION

Deformable registration of bins

Deforming bins to time-weighted midposition

Averaging (median)

Wolthaus 2008



MIDVENTILATION =

1 bin of the 4DCT

Pt. images courtesy of Marcel van Herk

Respiration synchronized techniques

Rationale of motion tracking...

Letting the beam move with the target

How

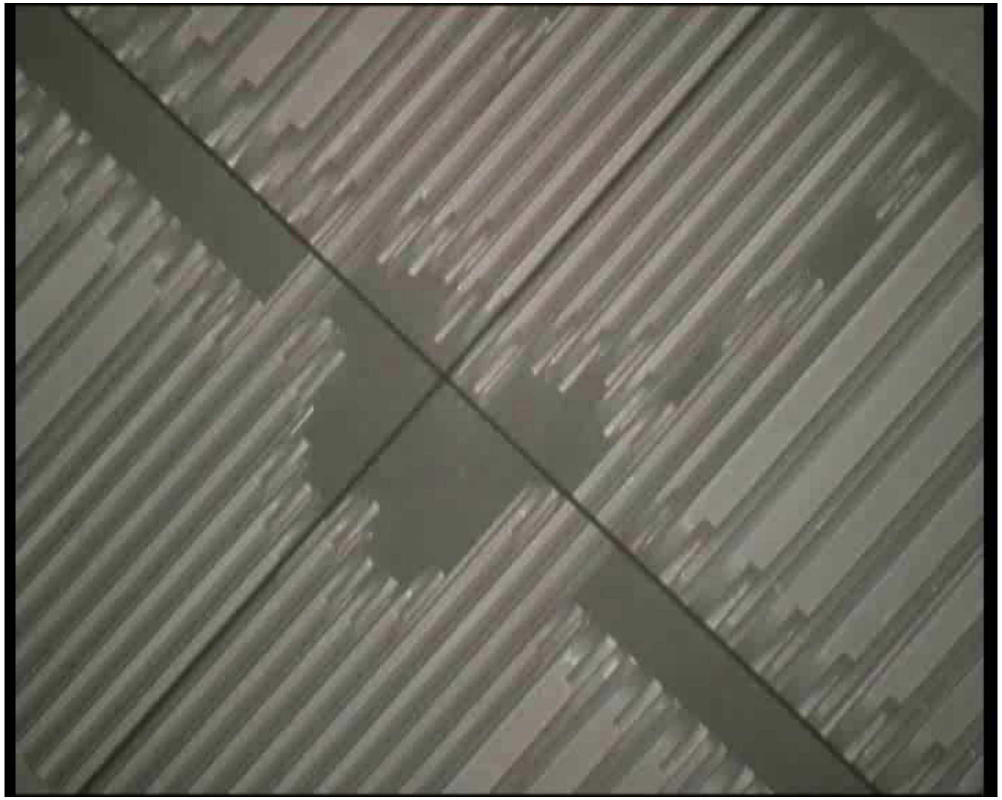
- By using surrogate for tumor motion:
    - external or internal
- Prediction algorithms

More on **Cyberknife & tracking** on Thursday

Respiration synchronized techniques

Tracking on linac

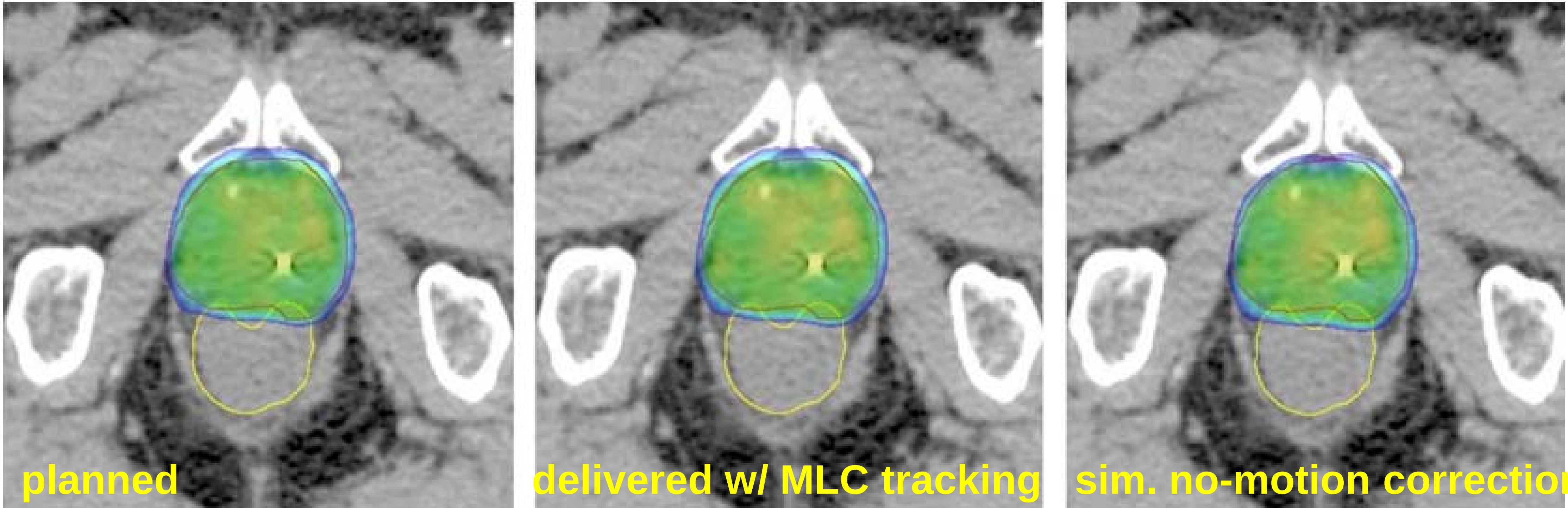
- MLC shape adjusted to compensate for target motion in real-time



You need to KNOW the target motion!

Respiration synchronized techniques

First patient treated with electromagnetic transponder MLC tracking



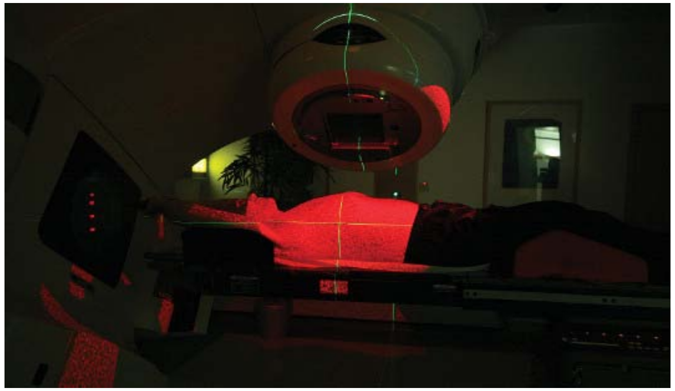
Keall Med Phys 2014

Equipment

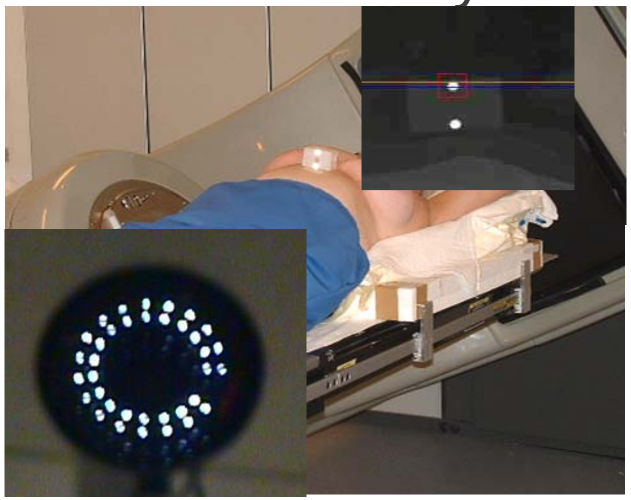
- BrainLab ExacTrac 6D

- Elekta – ABC

- Vision RT



- Varian – RPM system



- C-rad

- Accuray – Cyberknife

- Siemens – Anzai

Equipment

You need go get comfortable with all parts of your equipment

Installation

- Training room
- Scanner
- Linac

No equipment works without staff!

Take home messages

- Different motion management strategies
  - Gating
  - Breath hold
  - Tracking
  - 4D imaging
- Good correlation between respiration surrogate & target motion
- Coaching improves reproducibility
- Dosimetric benefit

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Treatment Planning

ESTRO School

Liz Forde, MSc (RTT)
Assistant Professor
Discipline of Radiation Therapy
Trinity College Dublin

ARTT
Applied Radiation Therapy
Trinity Research Group

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Learning Outcomes

- Discuss the role of the RTT in the treatment planning process
- Discuss key concepts of ICRU 50, 62 and 83
- Identify key features of inverse planning techniques
  - IMRT
  - VMAT (Varian Rapid Arc)
- Identify evidence for the use of inverse planning
  - Debate IMRT vs VMAT
- Describe the inverse planning process for IMRT and VMAT
- Describe the importance of target and organ definition and it’s impact on the inverse planning process
- Review the benefits of inverse planning to “non standard” sites

RTT Lead Planning

- Scope of practice may vary significantly

- Often seen as a "Specialist role"
  - ➢ Rotations may be limited

- Regardless of level of involvement in planning, a basic understanding of key principles increase your ***"clinical intelligence"***

RTT Lead Planning

- Take home messages from research:

1. Having Strong and Well Developed Protocols & Guidelines
2. Planning Experience, Confidence and Competence
3. A Good Understanding of Dosimetry Techniques
4. Postgraduate Training/Dosimetry Training/Specialist Training
5. Help/Support from other Radiation Therapy Staff

Dempsey and Burr, 2009

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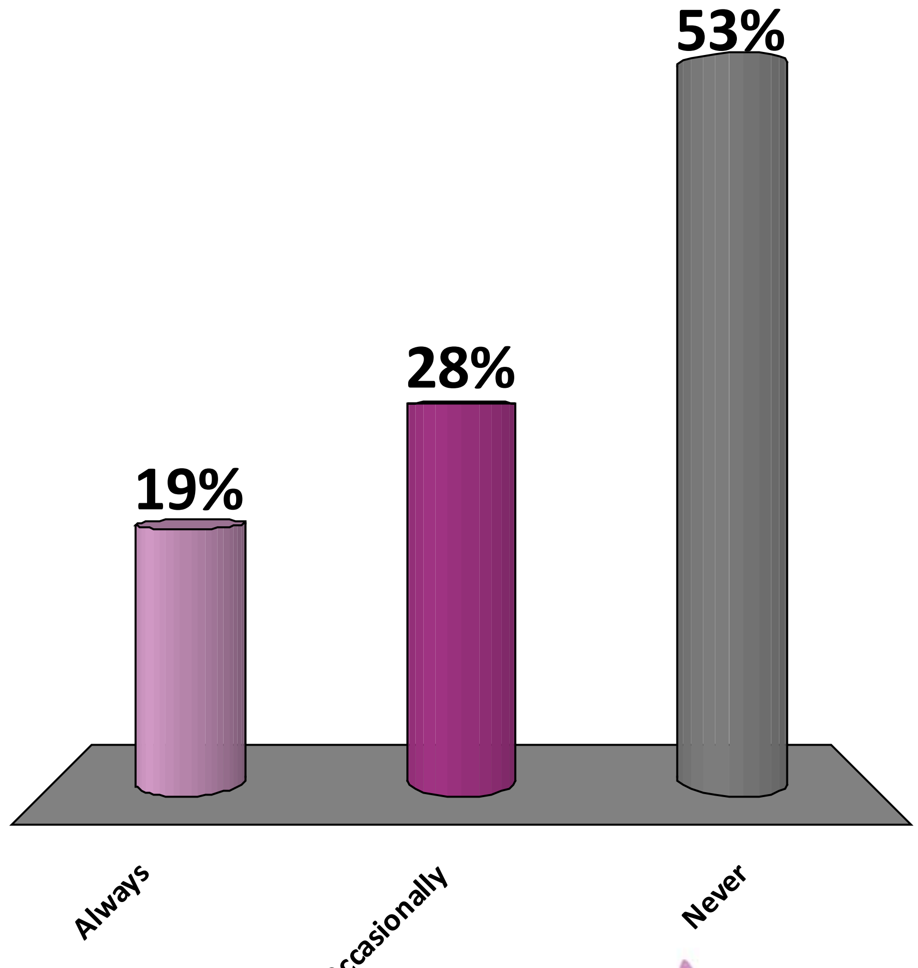
In my work, I am involved in treatment planning:

A. Always
B. Occasionally
C. Never



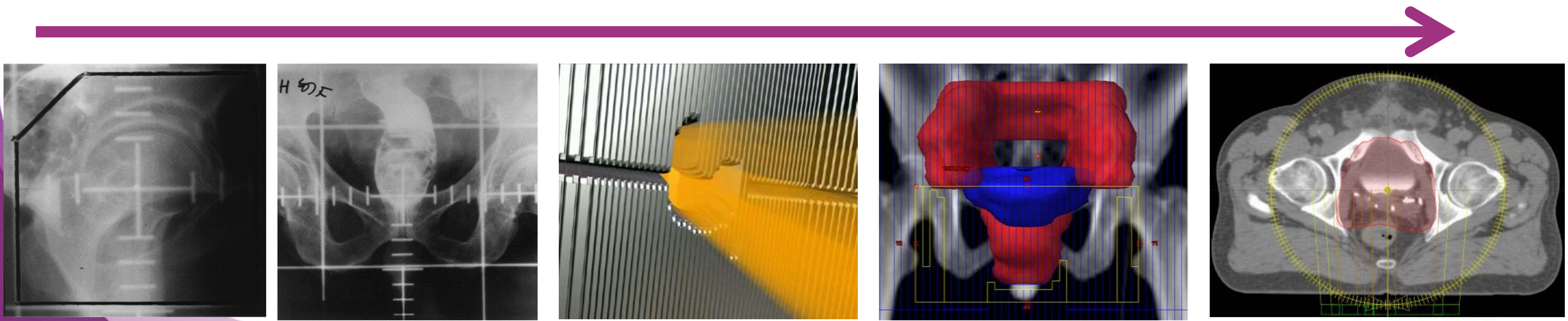
Planning: Where are we now?

- Technology boom

- From 2D to 3D
- From 3D to 4D, ART and tumour tracking

- From block shielding to conformal shielding
- From conformal shielding to dynamic shielding

- Inverse planning allows for greater control



“it is important that clear well defined unambiguous, and universally accepted concepts and terminology are used to ensure a common understanding” *(ICRU 62)*

ICRU 50	ICRU 62	ICRU 83
• GTV • CTV • PTV • Irradiated Volume • Treated Volume • OAR • ICRU reference point • Dose heterogeneity • (>95%, <107%)	• Reference points • Coordinate Systems • PRV • ITV	• Detailed labelling of structures • Volumetric prescription • Median dose (D50%) • Near min (D98%) • Near max (D2%)

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The Planning Process

What do you think is missing from this flowchart?

Field Setup

Optimisation

Dose Calculation

Plan Evaluation

This is a dynamic process

Pre Planning Considerations *(Martijn)*

Image Registration *(Mirjana)*

Target Volume Definition *(Sofia and Peter)*

Contouring *(Liz)*

Additional Contouring

Field Setup

Optimisation

Dose Calculation

Plan Evaluation

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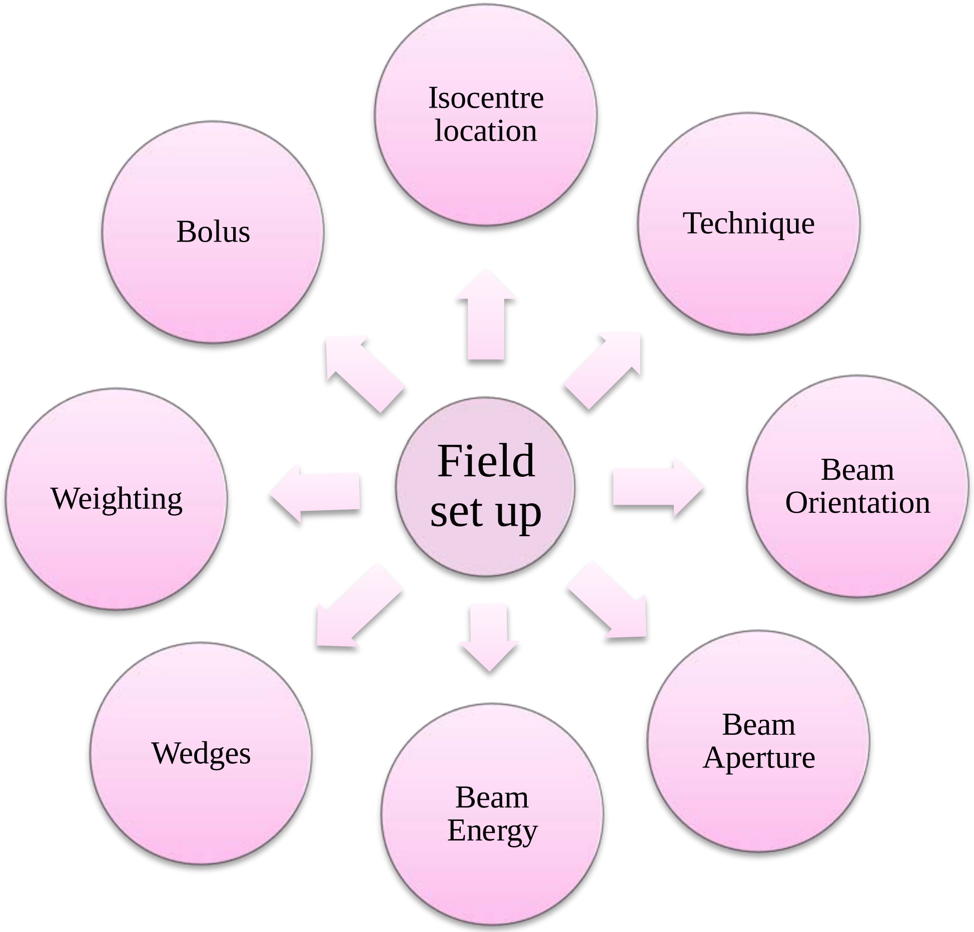
Key Concepts of 3DCRT

- Field set up… *“Finally we get to put some beams on!”*

- User defines:



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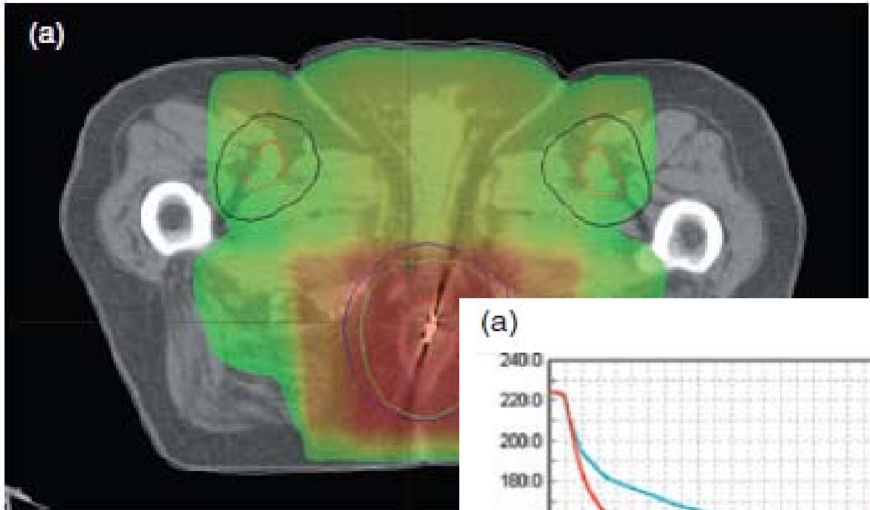
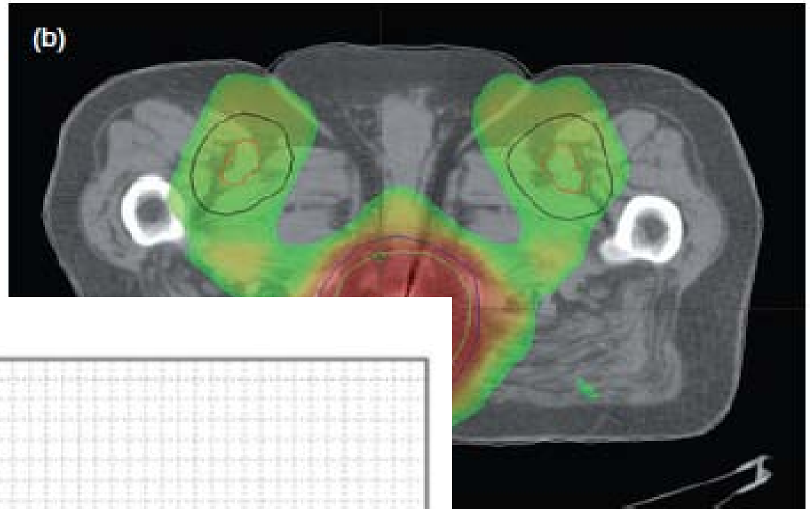
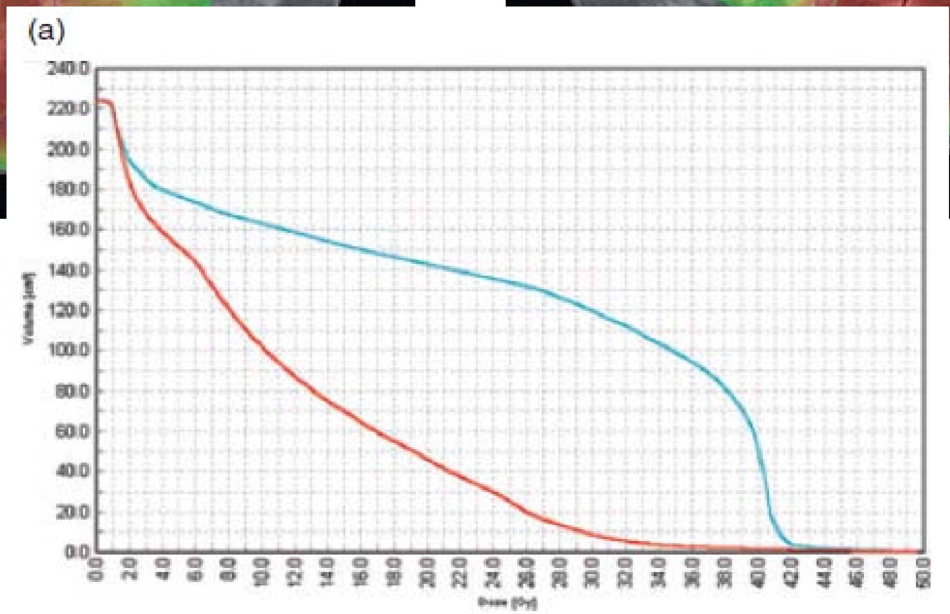
Key Concepts of 3DCRT

- With 3D targets now being delineated, 3DCRT techniques have become more complex

- "Genital sparing" technique







Bui et al., 2009

Key Concepts of 3DCRT

- But…
- How many fields are we up to now?
- ***Enter IMRT…***

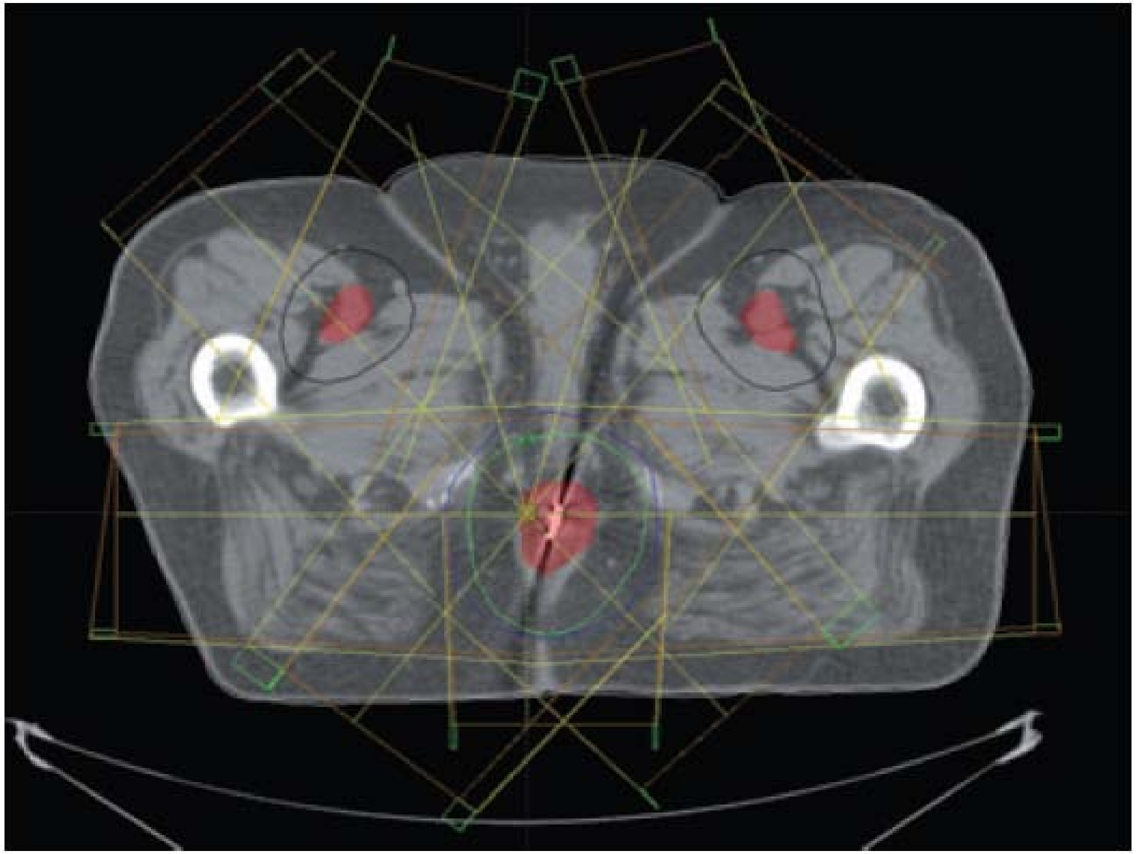


Fig. 2. Example of three-dimensional conformal radiotherapy technique field arrangement. Gross tumour anus and inguinal, red; planning target volume (PTV) anus, green; PTV inguinal, black; PTV pelvis, dark blue.

Bui et al., 2009

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Key Concepts of IMRT

- The multiple-static-field MLC technique
  - Step and Shoot
- The dynamic MLC technique
  - Sliding Window
- Intensity modulated arc therapy
  - IMAT
- Intensity modulated proton therapy
  - IMPT

- *"IMRT requires expertise and careful target design to avoid reduction in local control by marginal miss"* *(NCCN 2013)*

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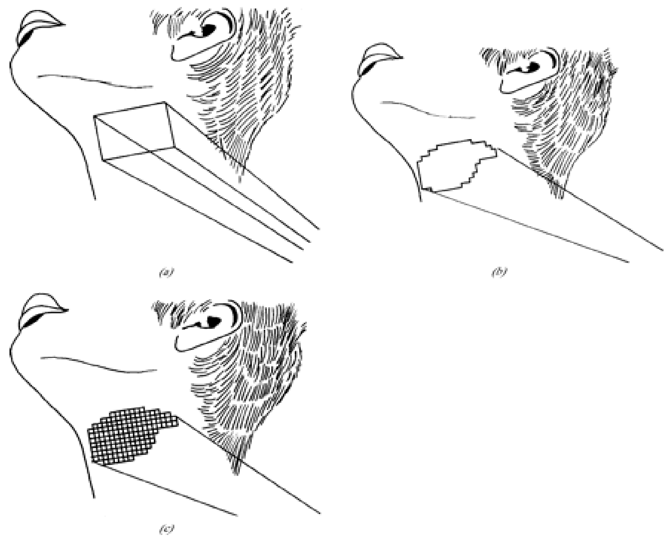
Key Concepts of IMRT

- IMRT is the delivery of radiation to the patient via fields that have a non-uniform radiation distribution across a field.
- Progression from geometric to **fluence** shaping of a field



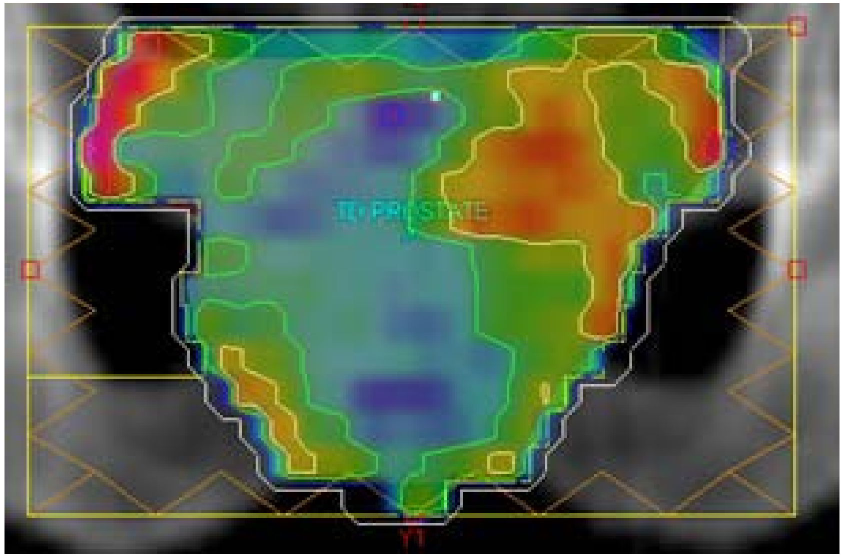
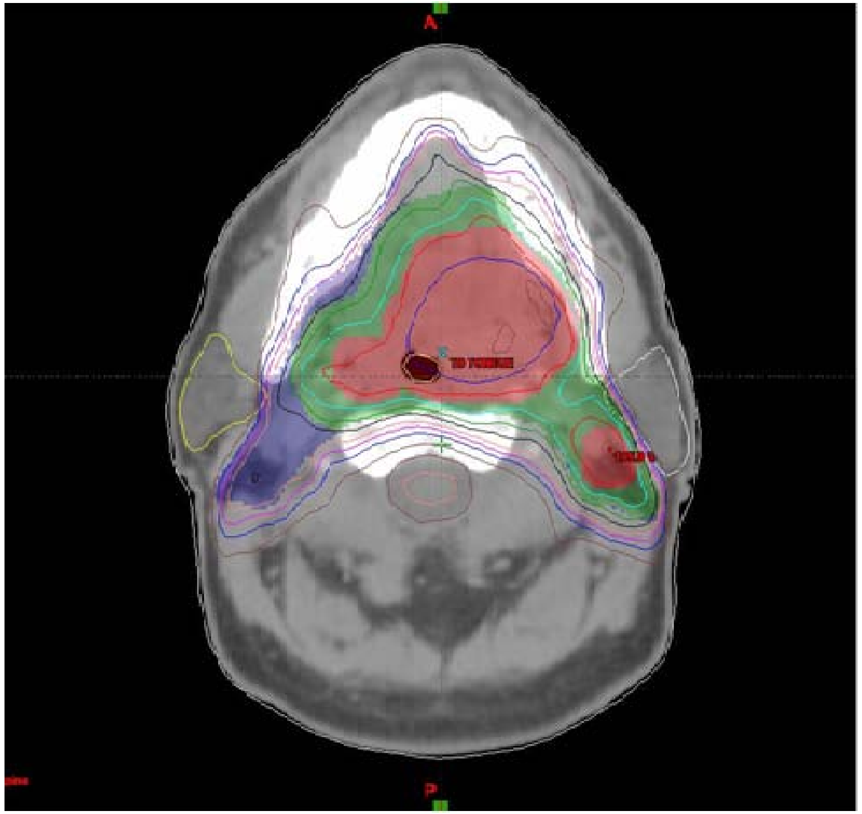


Image taken from: S Webb (2003) The physical basis of IMRT and inverse planning British Journal of Radiology 76: 678-689

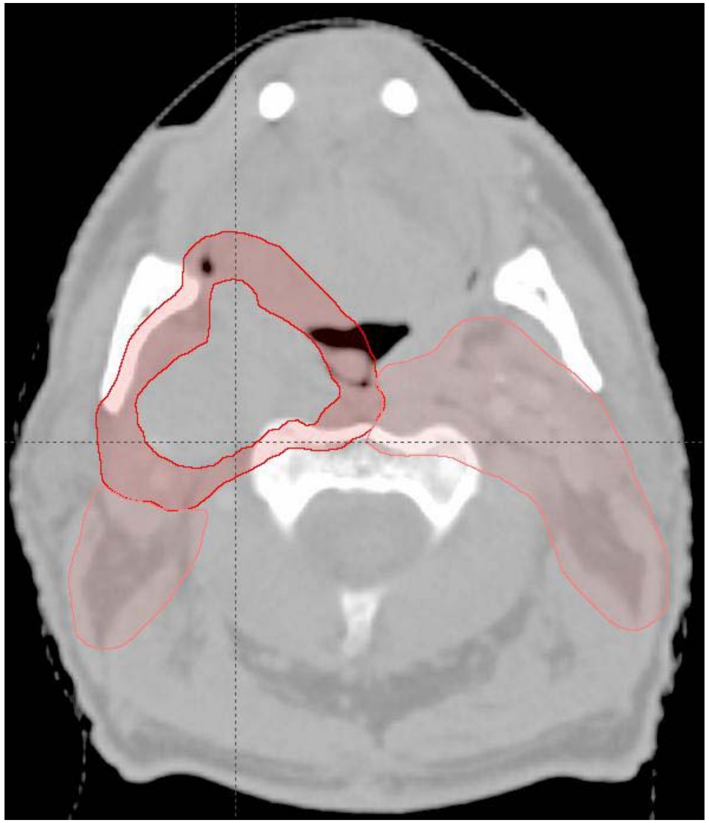
Key Concepts of IMRT

- This fluence is **modulated**
- The intensity of the fluence changes across the beam
- This changing intensity is based on the required dose to be delivered across a field
- This modulated fluence will determine the dMLC leaf motion

The Benefits of Inverse Planning



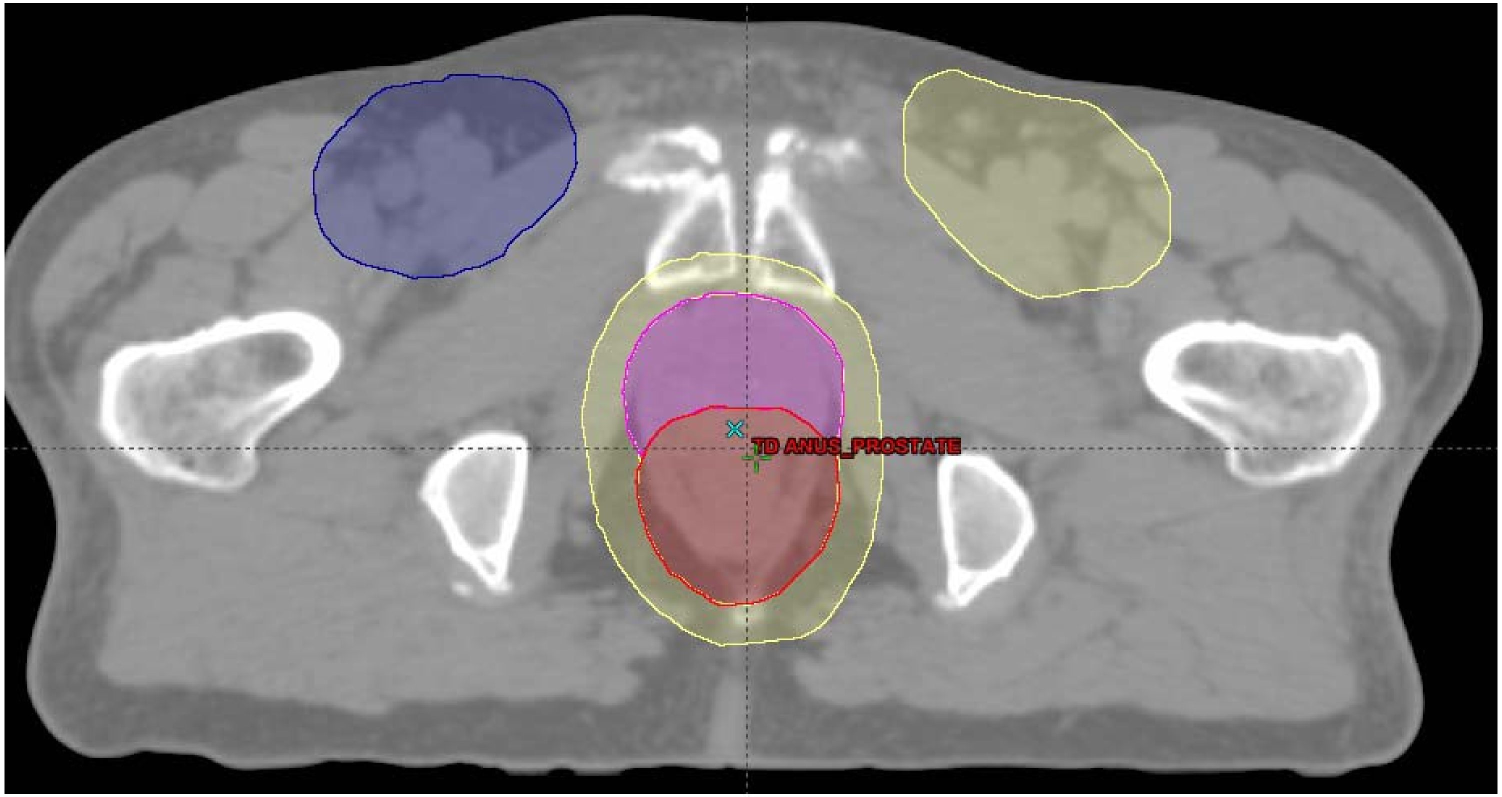
Complex concave volumes



Increased control over distribution

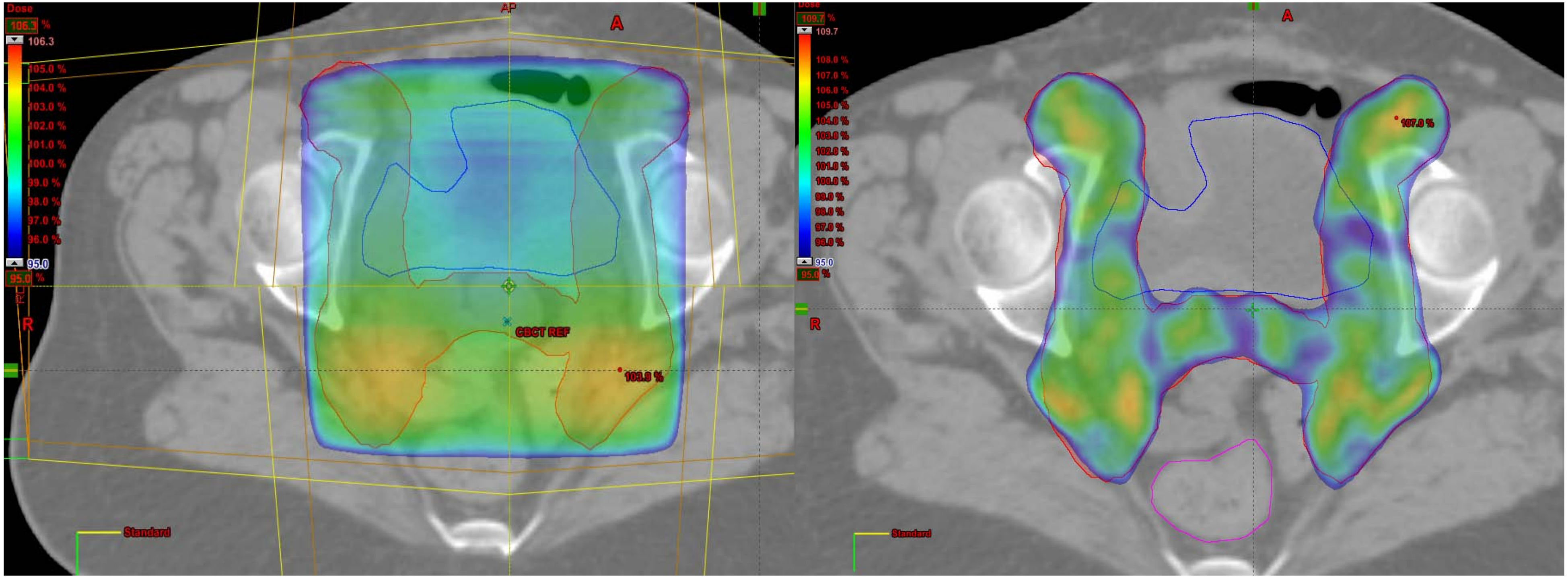
Boosting targets within targets

The Benefits of Inverse Planning



Multiple targets
Simultaneous integrated boost

The Benefits of Inverse Planning

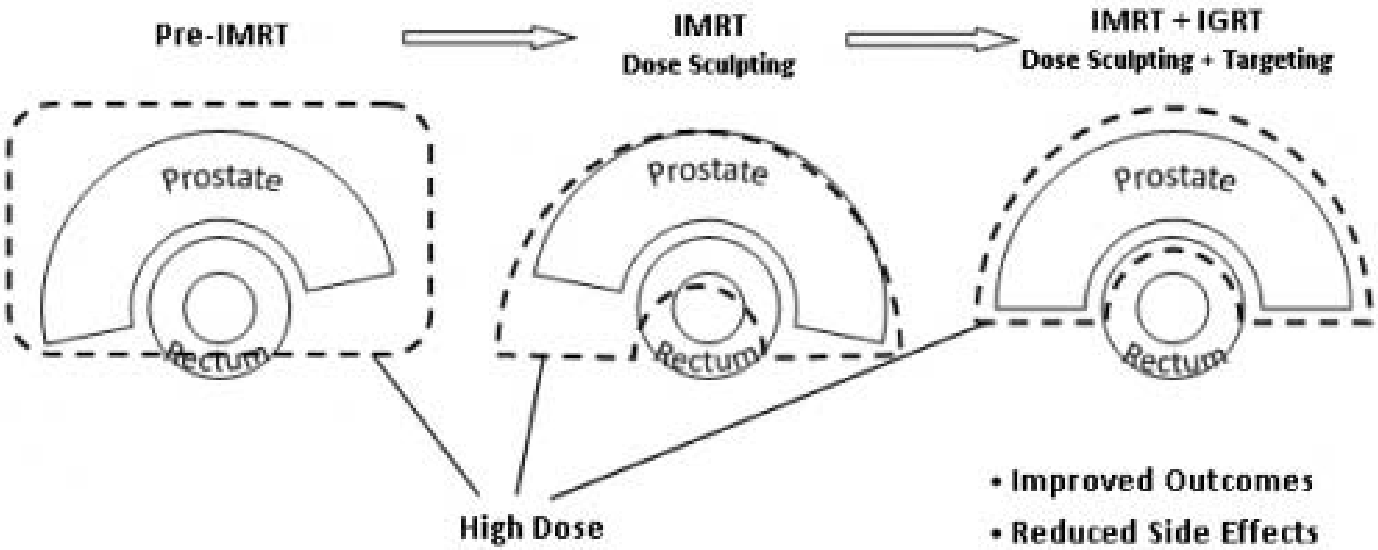


Sharp dose fall off
Improved OAR sparing

Need robust IGRT!

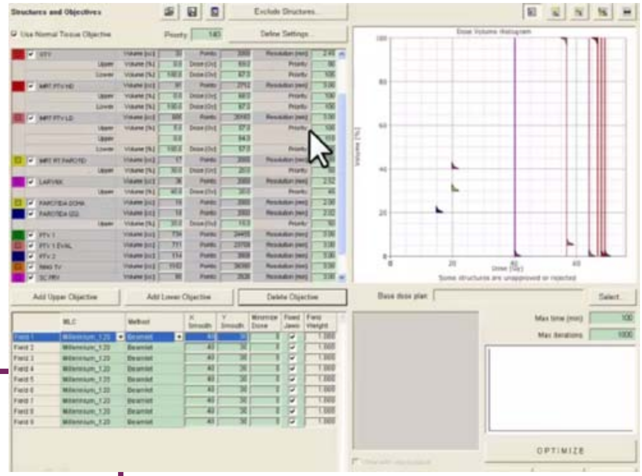
The Benefits of ***IG***-IMRT

- Jose will cover this in more detail this afternoon!



http://radiotherapy.blog.co.uk

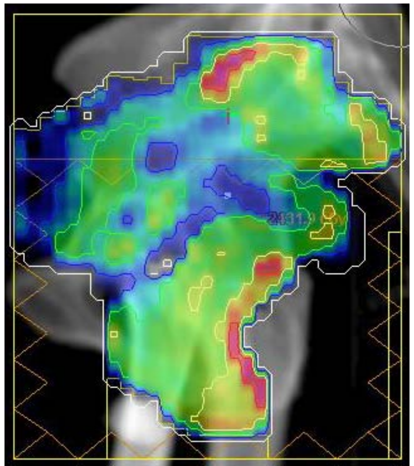
Limitations of IMRT



1. Multiple PTVs
2. Complex PTVs (close to skin edge)
3. Multiple OARs with multiple DVCs

Sophisticated optimisation parameters

Complex fluence patterns



High MUs

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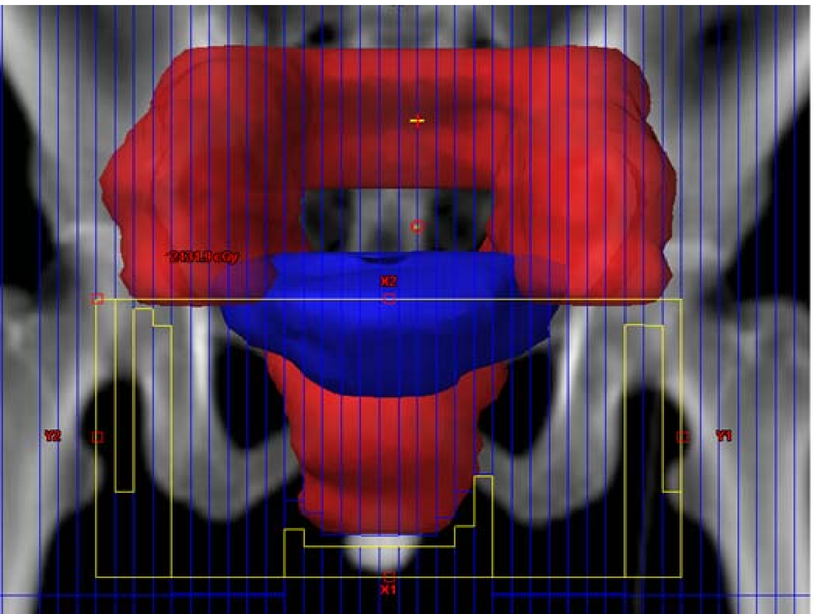
Limitations of IMRT

Large PTVs

Increased number of planning fields

Enter VMAT...

Due to restrictions ... motion for SW IMRT, even more treatment fields (for some Varian machines)



NB: this image demonstrates the concept of split carriages

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Key Concepts of VMAT (Specifically RapidArc)

- Inverse planning based on Progressive Resolution Optimisation Algorithm (PRO)

- Simultaneously changing 3 main features
  - MLC leaf motion
  - Gantry speed
  - Variably dose rate

Key Concepts of VMAT (Specifically RapidArc)

- PRO 2
- 5 Multi resolution levels
- Additional control points are added to each level (total 178)
- Manipulation through each level

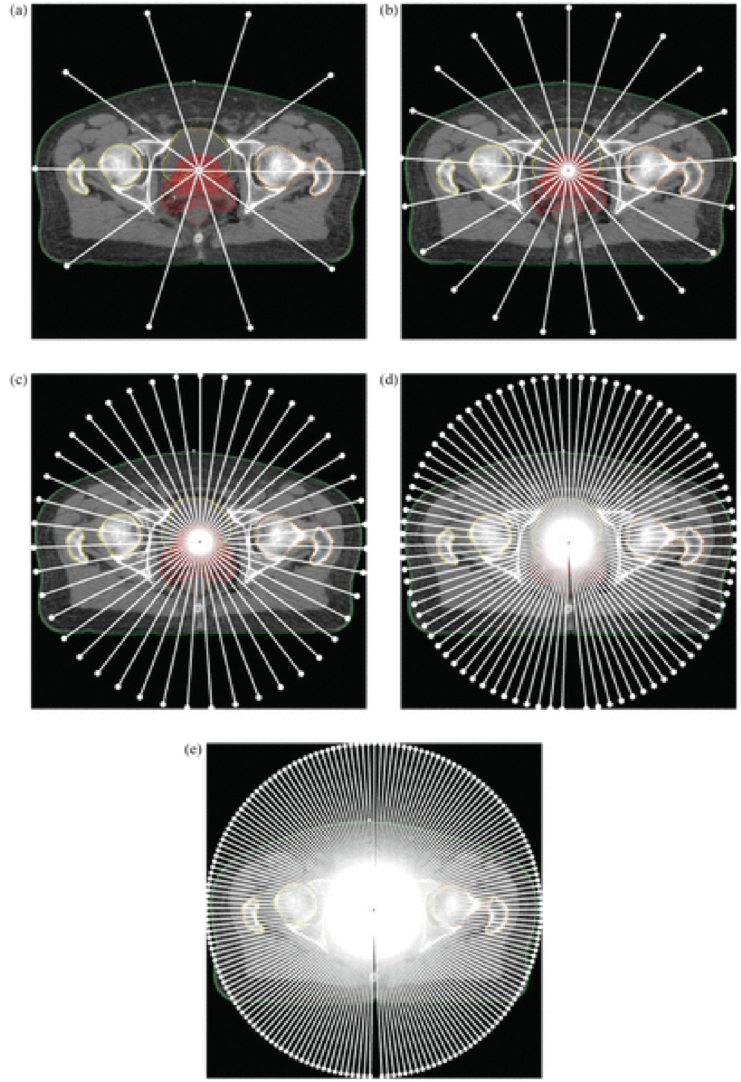


Image taken from: Jolly D, Alahakone D and Meyer J A RapidArc planning strategy for prostate with integrated boost. J Appl Clin Med Phys 2010

Key Concepts of VMAT (Specifically RapidArc)

- PRO 3
  - 4 multi resolution levels
  - All 178 control points are included in each level
  - Internal logic
  - Intermediate dose calculation

On the role of the optimization algorithm of RapidArc® volumetric modulated arc therapy on plan quality and efficiency

Eugenio Vanetti and Giorgia Nicolini[a)]
Oncology Institute of Southern Switzerland, Medical Physics Unit, CH-6500 Bellinzona, Switzerland

Janne Nord and Jarkko Peltola
Varian Medical Systems, SF-00270 Helsinki, Finland

Alessandro Clivio, Antonella Fogliata, and Luca Cozzi
Oncology Institute of Southern Switzerland, Medical Physics Unit, CH-6500 Bellinzona, Switzerland

(Received 21 March 2011; revised 4 August 2011; accepted for publication 31 August 2011; published 11 October 2011)

Clinical Applications of VMAT

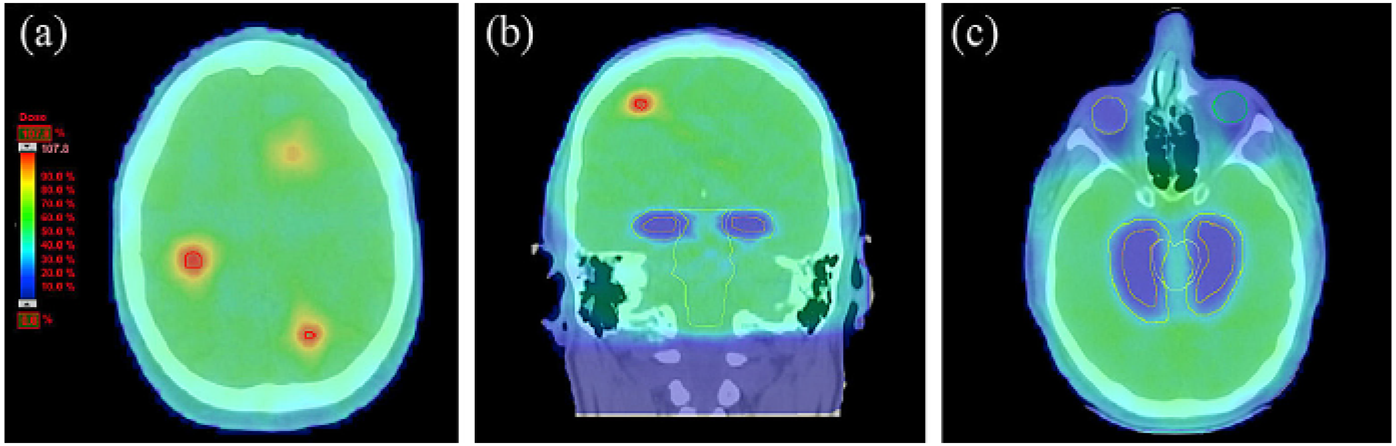
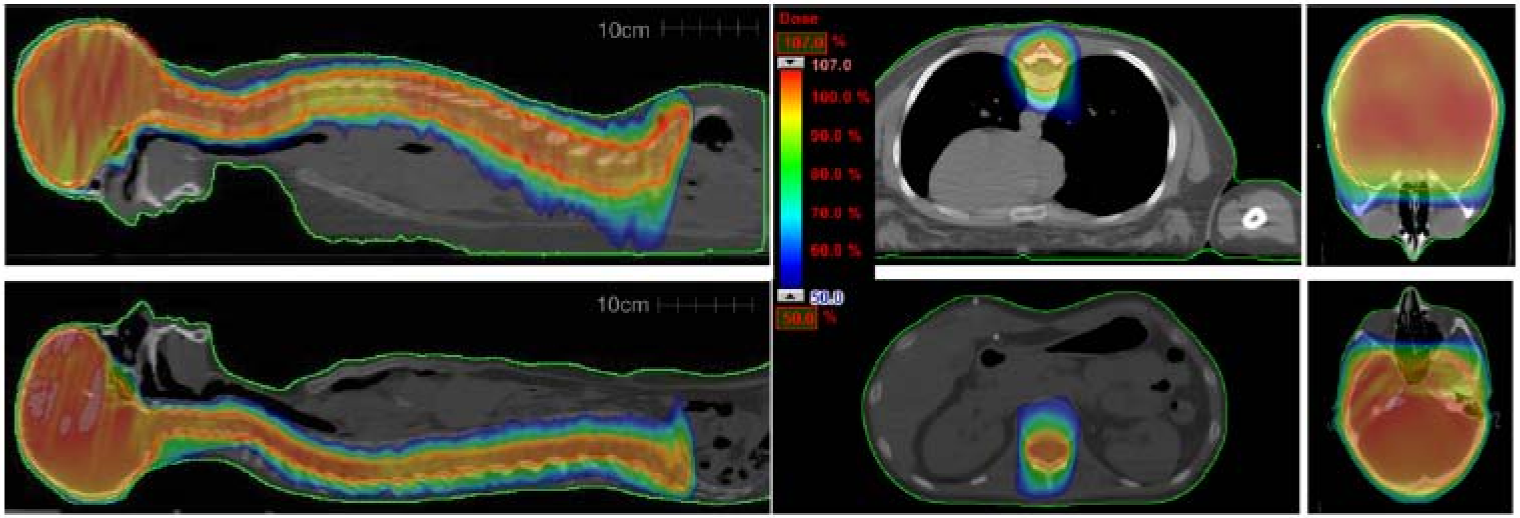


Fig. 1. Examples of isodose distributions for whole brain radiotherapy with hippocampal avoidance and simultaneous integrated boost for three brain metastases using volumetric modulated arc therapy. The whole brain clinical target volume was prescribed to 32.25 Gy in 15 fractions. Three metastases were prescribed 70.8 Gy in 15 fractions. (a) Axial image with three metastases. (b) Coronal image with one metastasis and the hippocampi. (c) Axial image with the hippocampi and eyes.

Hsu et al., 2010



Fogliata et al., 2011

Clinical Applications of VMAT

The British Journal of Radiology, 84 (2011), 967–996

REVIEW ARTICLE

Volumetric modulated arc therapy: a review of current literature and clinical use in practice

[1]M TEOH, MRCP, FRCR, [2,3]C H CLARK, MSc, PhD, [1]K WOOD, FRCR, MD, [1]S WHITAKER, FRCR, DM and [2]A NISBET, MSc, PhD

[1]*Departments of Oncology,* [2]*Department of Medical Physics, St Luke's Cancer Centre, Royal Surrey County Hospital, Guildford, Surrey, UK, and* [3]*National Physical Laboratory, Hampton Road, Teddington, Middlesex, UK*

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Let's Look at the Inverse Planning Process in Closer Detail...

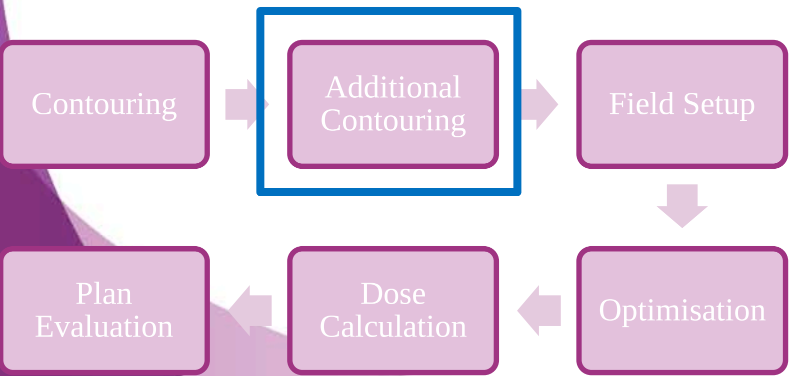
Contouring → Additional Contouring → Field Setup → Optimisation → Dose Calculation → Plan Evaluation

Additional Contouring

- Virtual contours used only in optimisation but ***not*** plan evaluation

- Ease the optimisation process/algorithm

- How and when you use them will depend on the case and also on your experience as a planner
  - Also what point of the optimisation process you are at for VMAT



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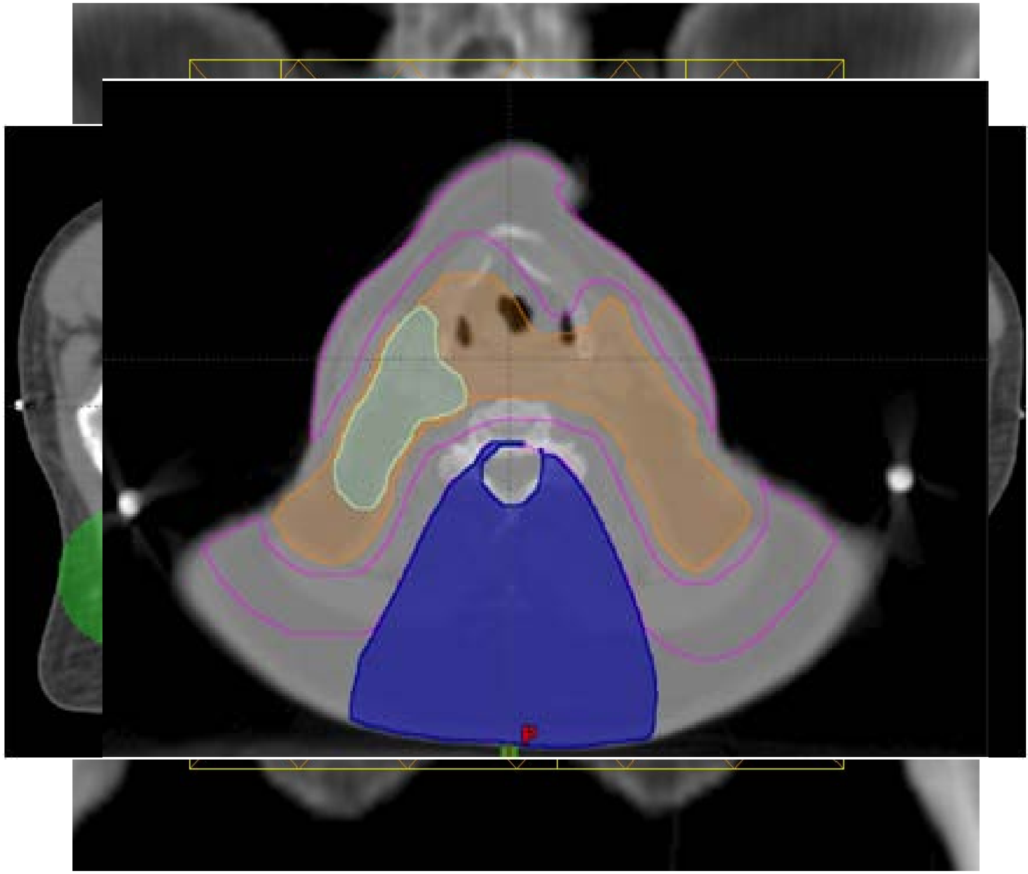
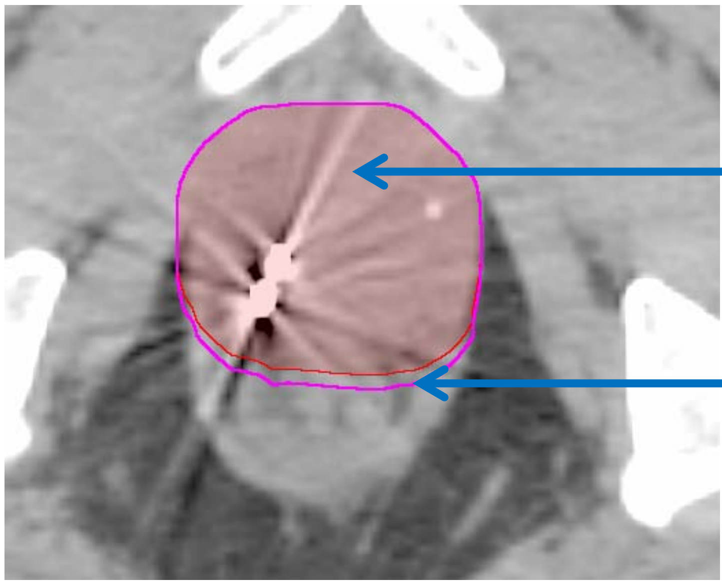
Additional Contouring

- Increase control over dose distribution
  - Dose escalate within a PTV
  - Dose fall off across a structure
  - Dose directly surrounding PTV
  - Dose dumping in healthy tissue



Additional Contouring

- Improve coverage of whole or partial target
  - ➢ We can’t manually adjust the MLC
  - ➢ Inverse planning is volume based planning
  - ➢ Can be “cold” on superior or inferior slices
  - ➢ Can be “cold” where there is a competition between structures
  - ➢ “IMRT PTV”



“True” PTV
Used for plan evaluation

“IMRT” PTV
Used for optimisation

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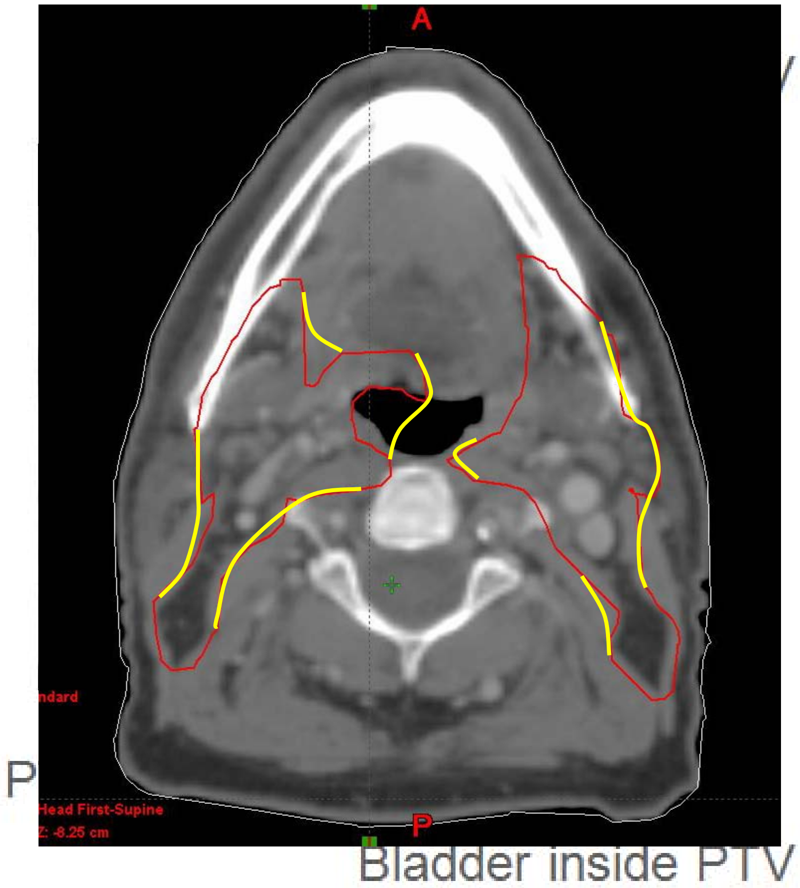
Additional Contouring

- Lessen the competition between structures
    - OAR and target

- Smoother contours and gradients between slices of target structure



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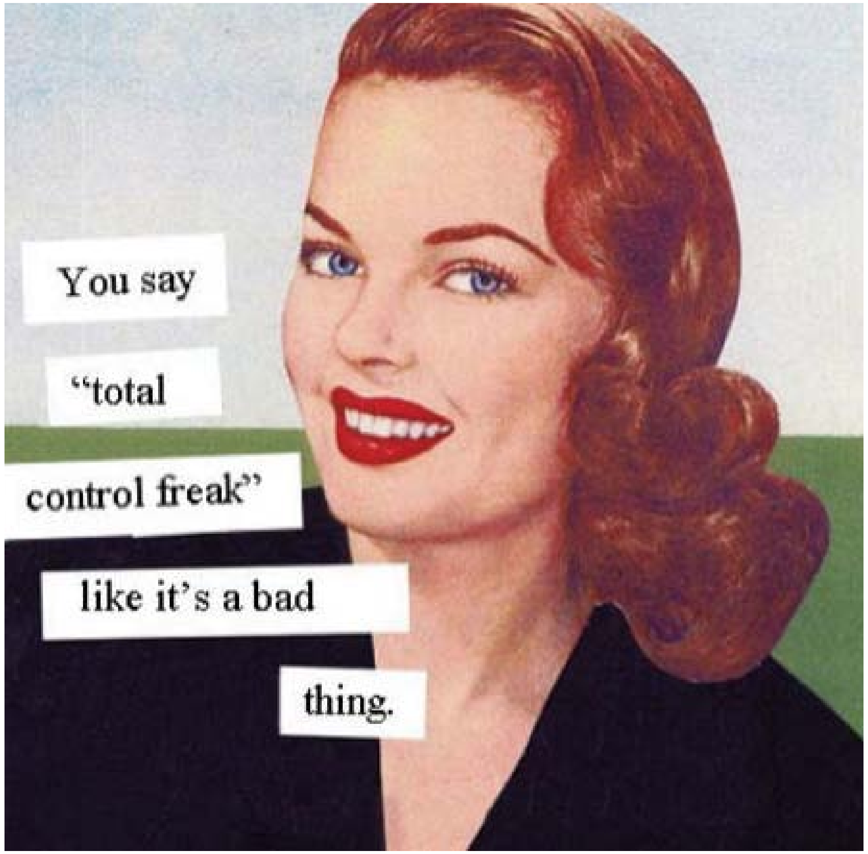
Field Setup

- Isocentre placement
- Beam arrangement
- Field size
- Collimator angle
- Dose rate



IMRT

Isocentre placement

Not crucial but consider MLC carriage and IGRT match

Beam arrangement

Odd number of non opposing

5, 7, 9

Field size

Generated during the leaf motion calculator

Consider fixed jaws (shoulders, hips, ineffective fluence)

Collimator angle

Consider for large fields (MLC direction)

Dose rate

400MU/min

VMAT

Isocentre placement

Not crucial but consider MLC carriage and IGRT match

May need multiple isocentres

Beam arrangement

SA vs. multiple arcs

Partial arcs, avoidance sectors

Field size

Automatic or manual

View the arc/s

Collimator angle

“Off zero” and counter coll’d

Dose rate

600MU/min

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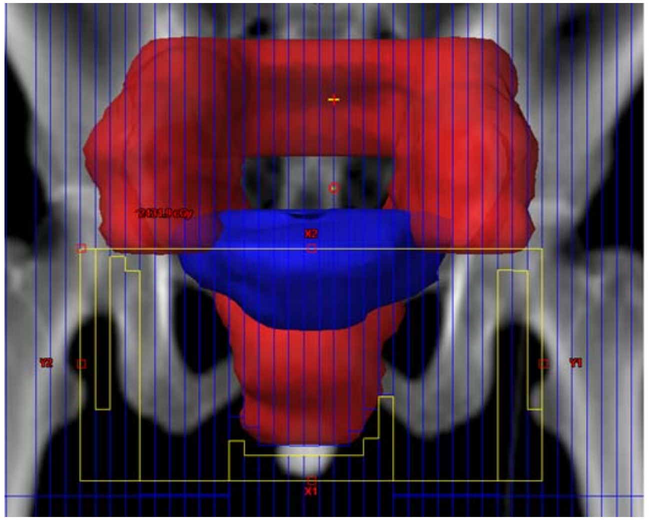
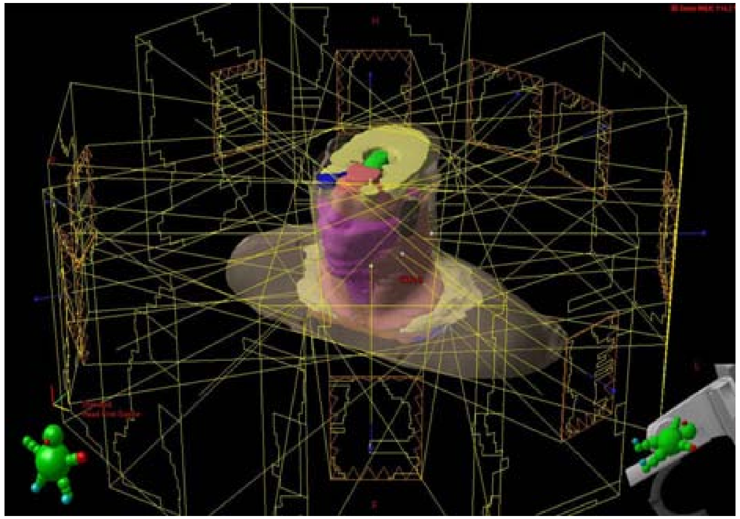
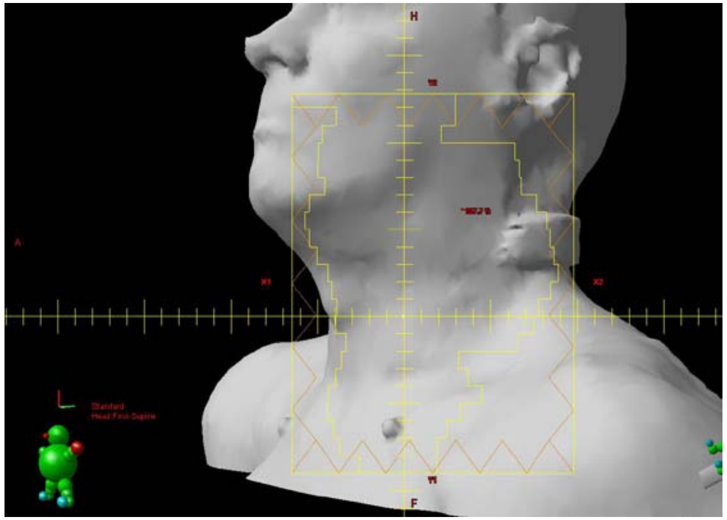
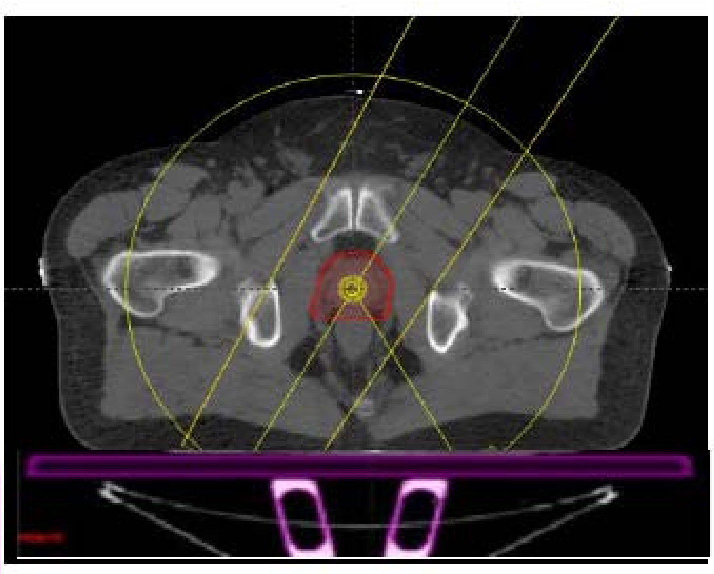
IMRT

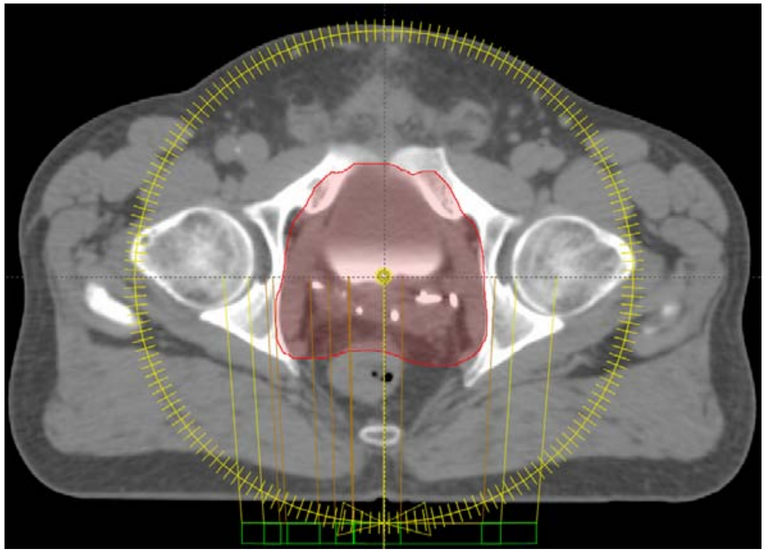






VMAT





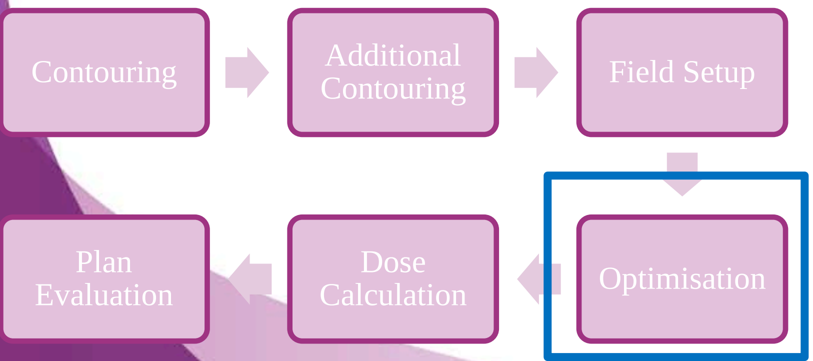
Shoulders:
Angle gantry to avoid
Angle couch to avoid
Fix jaw to avoid
(sup or ant/post)

Inverse Planning Optimisation

- Planner decides on required dose coverage with dose constraints for surrounding structures
  - ➢ Cost function algorithm

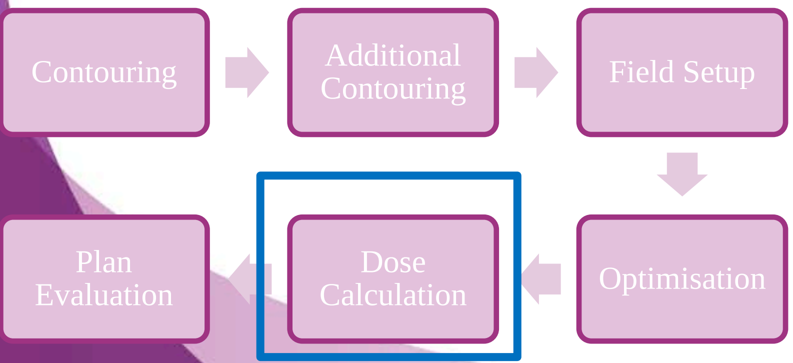
- Upper and lower dose limits are to be nominated
  - ➢ Target structures have both

- Planning systems allow for dose constraints to be specified
  - ➢ Either as a dose max, mean dose or as a %volume to receive a specified dose
  - ➢ Can have either a single point, a series of points or a line

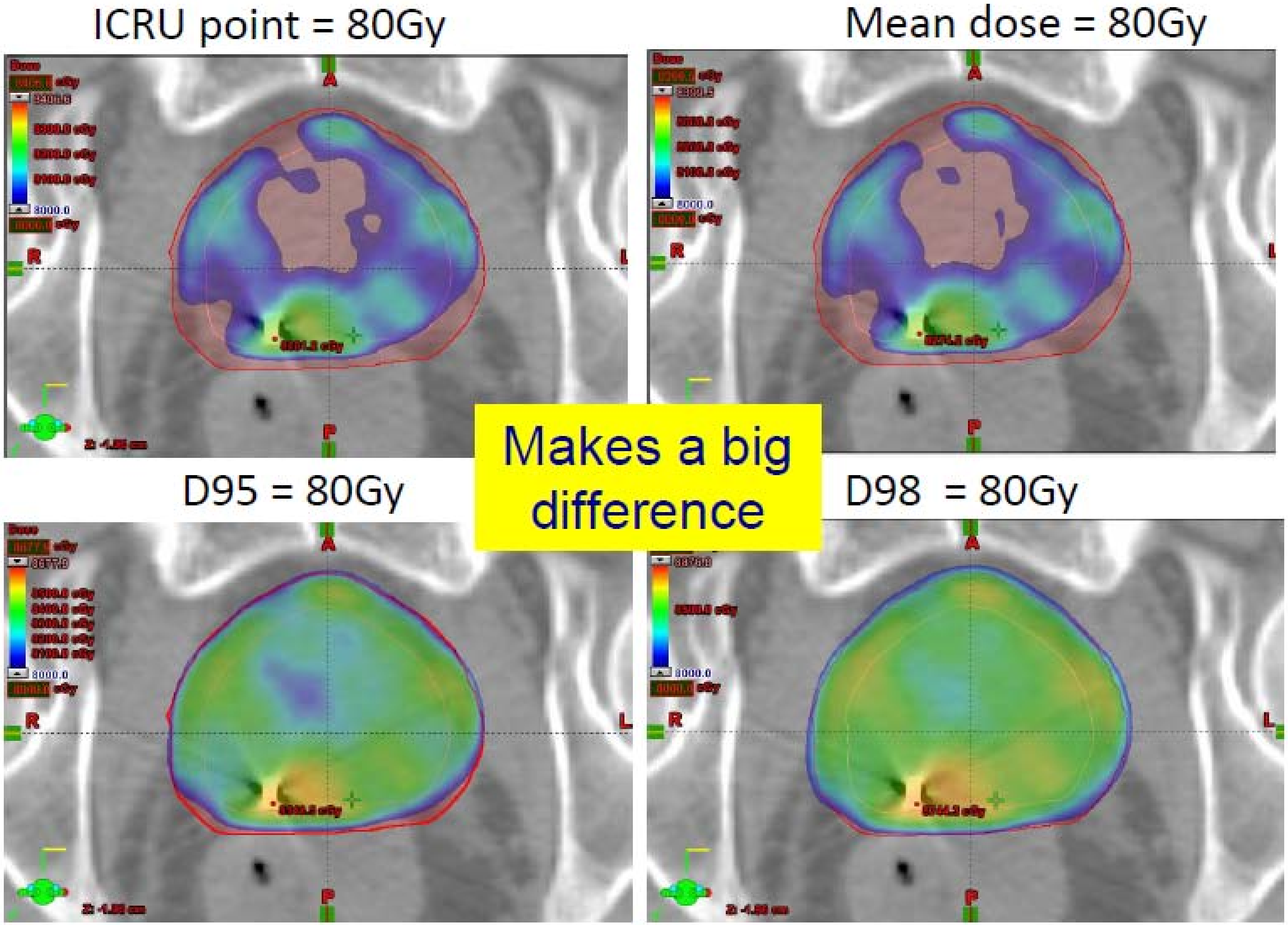


IMRT Dose Calculation

- The fluence maps are generated at the time of optimisation
- The leaf motion is then calculated to enable the delivery of this
- The 3D dose calculation is then carried out generating a dose distribution
- Note the subtle changes:
  - ➢ Fluence now reflected the deliverable values
  - ➢ The DVH is now based on AAA as opposed to PBC



Plan Normalisation

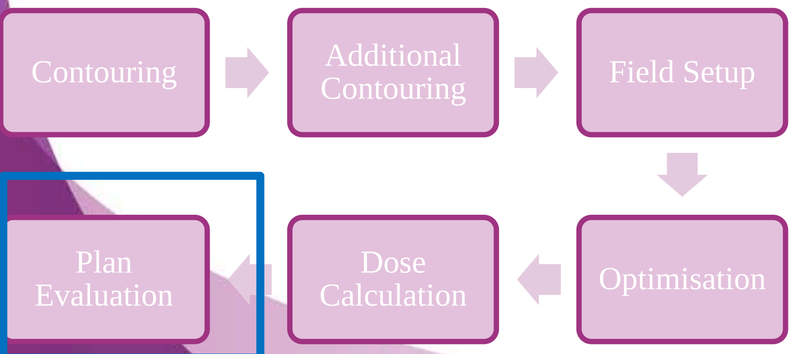


Plan evaluation

List what you think needs to be considered during a plan evaluation

- This is a crucial component of the planning process and should not be rushed or undervalued

- Target Coverage
- Target Conformity
- Target Homogeneity
- OAR doses
- Integral Dose
- Field arrangement used
- Fluence maps or segments for IMRT
- Monitor Units
- Treatment time



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Plan Evaluation

- Select appropriate tools
  - Modern TPS are developed to make our life easier but are only as good as the user who is interpreting the information
- Qualitative
  - Visual inspection is vital
  - Clinical judgement
- Quantitative
  - ICRU 56, 62, 83
  - DVH
  - Conformity and homogeneity indices

Revise ICRU!
You must know and use the correct terminology
You must know the main recommendations

Be clear and consistent with definition

Plan evaluation

- Need to prioritise your planning objectives
  - Trade off between target and OAR doses
    - Treat the disease, but at what cost to the patient?
  - Department specific protocols
  - Clinical trials
    - Process may be outlined for you

6.5.4 *Planning Priorities*

Critical normal structure constraints followed by the prescription goals are the most important planning priorities. The priorities in addressing the protocol aims and constraints will be in the following order:

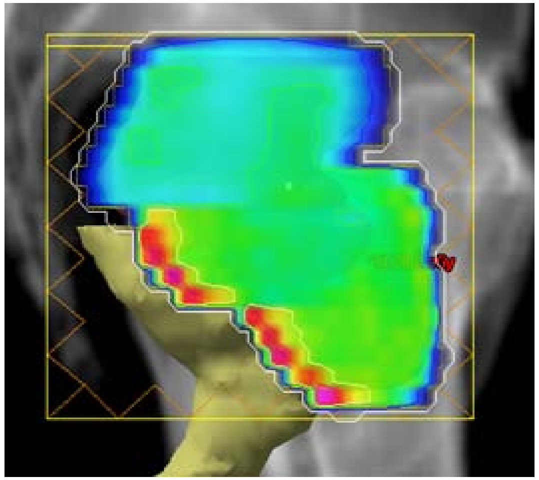
1) Critical Normal Structure Constraints (Section 6.5);
2) Dose Specifications (Section 6.1);
3) Planning Goals: Salivary glands (Section 6.5.3);
4) Planning Goals: Other normal structures (Section 6.5.3).

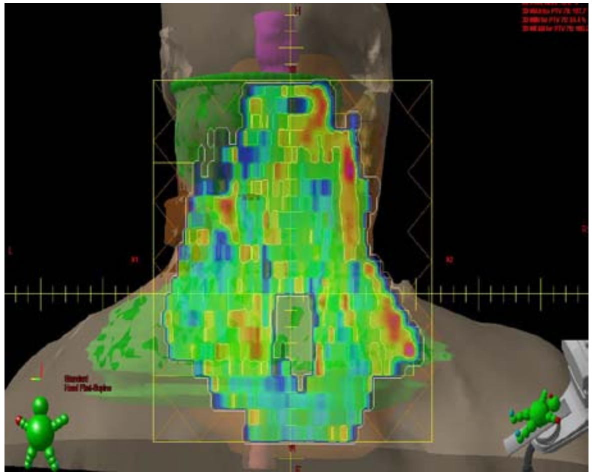
NCI-supplied agent: Bevacizumab (NSC 704865; IND 79211)

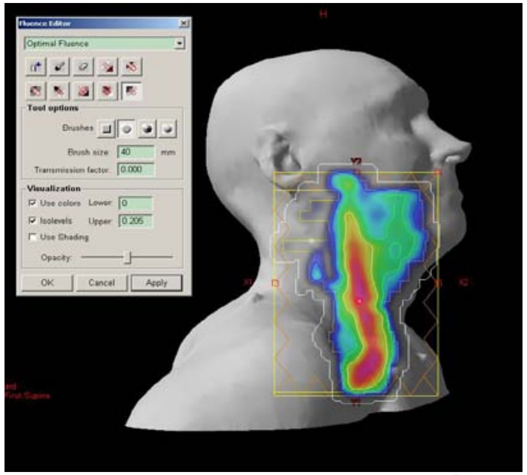
Plan Evaluation

- RTTs care about fluence maps too!

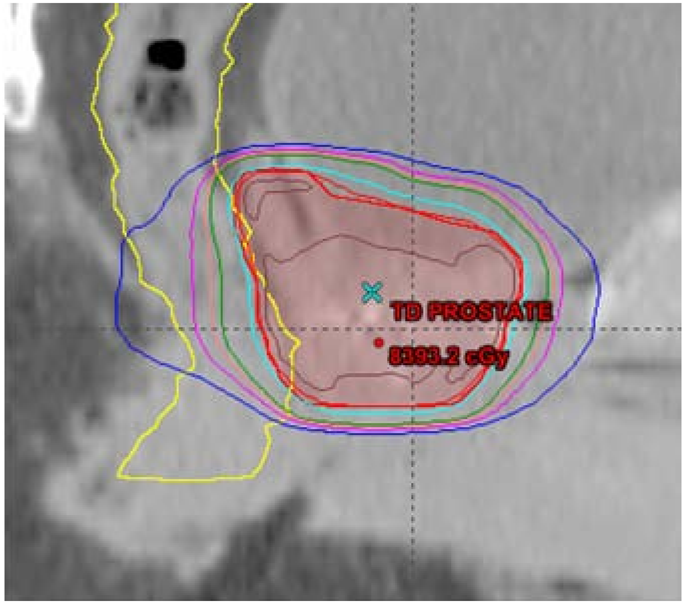
- What is level of modulation
- Is this necessary
- What impact does this have on the dose distribution
- What impact does this have on treatment delivery

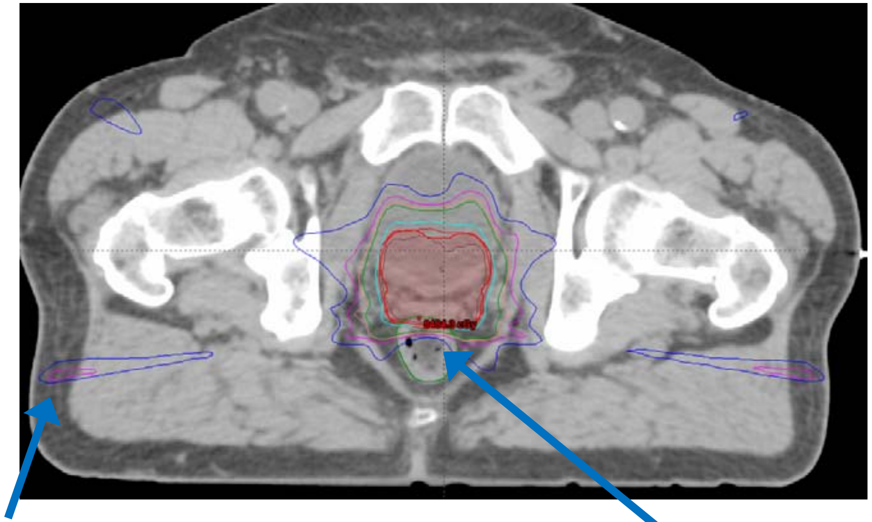






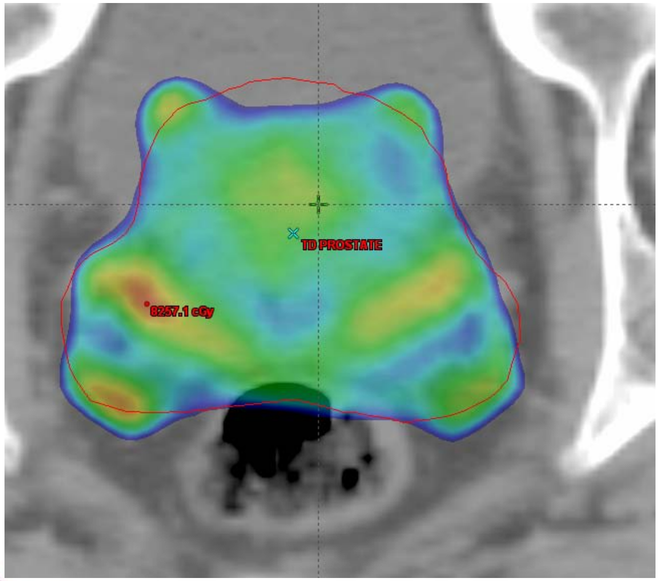
Plan Evaluation

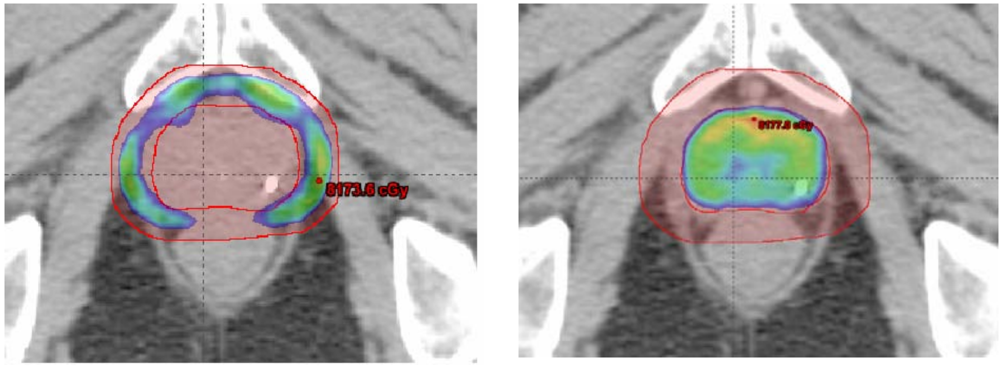




Lateral Hot Spot 50Gy

Max in Rectum





How To Improve a Bad Plan

- Beam Angles
  - Number and position
  - Bare in mind length of treatment (Split Carriage Groups)
- Plan normalisation
  - Heat up or cool down the whole plan
  - Quick, does not require re calc
- Reoptimise
  - Think about what you are trying to achieve
  - Relax constraints if possible
  - Try to keep it simple

What Will Planning Look Like in the Future?

- Will continue to increase in complexity
  - Biological optimisation

- Will move from a separate planning room to the linac
  - MRI linac
  - Online reoptimisation
  - Online ART

Take Home Message

- Have an awareness of what to expect from your plan

- If you don't get that, always ask ***why***?
  - Having an understanding of why the dose has behaved that way will help you find a solution to the problem

- Be guided by the literature
  - Almost all dosimetry papers will outline their planning process
    - Beam arrangement
    - Energy
    - Prescription method used
  - Critical analysis is needed!

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Take Home Message

- When reading the literature, ***read carefully!***

Good, that sounds like ICRU 50

- Methodology:

  "The radiation dose was prescribed to the PTV, such that 100% of the PTV received >95% of the prescribed dose and that no region in the field received greater than 107% of the prescribed dose"

Hang on a minute?!

- Results:

  "All treatment plans showed adequate coverage of the target volume, with more than 95% of volume of PTV1 and PTV2 receiving greater than 95% of the prescribed dose."

Menkarios et al

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Take Home Message

Planning is a collaborative and dynamic process

I want a better plan!

This is the best plan!

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In-room imaging modalities

Martijn Kamphuis MSc, MBA Candidate
Radiation Therapist IGRT

Department of Radiotherapy
Amsterdam, the Netherlands

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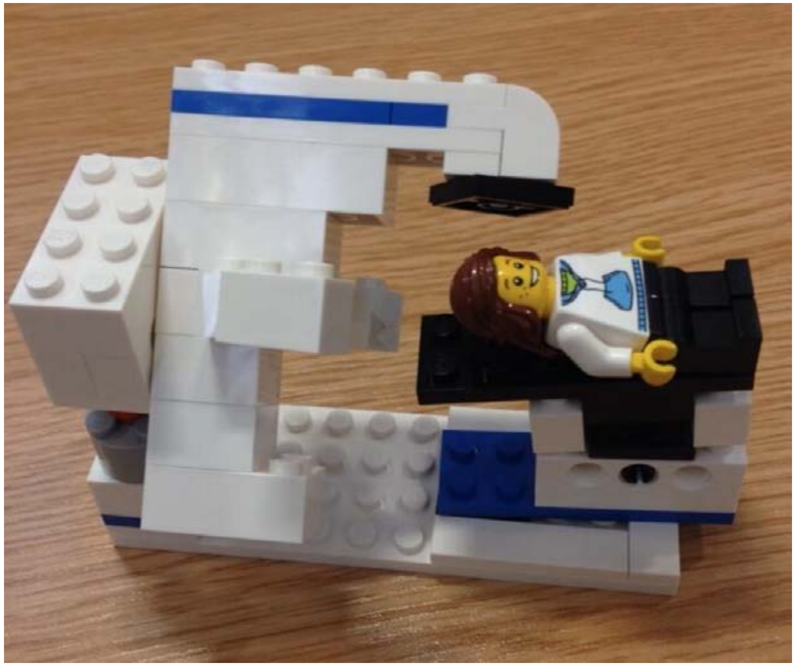
Content of the presentation

- Why do we need imaging on the linac?

- Imaging modalities
  - ➢ How do the work?
  - ➢ What can we do with them?



Why do we need imaging on the linac?

Errors in the radiotherapy chain

Physical patiënt

Patient

1 time

CT room
- Lasers
- Skin markers
- Images
- Bone
- Tumour
- Delineation
- Margin
- Planned Beam

Treatment room
- Lasers
- Skin markers
- Bone
- Tumour

- Beam
- Accelerator
- Treatment room

35 x

Beam data

Why do we need imaging on the linac?

- To reduce systematic and random geometrical errors

- To document the treatment accuracy
  - Margin calculation
  - Incident analyses
  - Changing patient anatomy/pathology

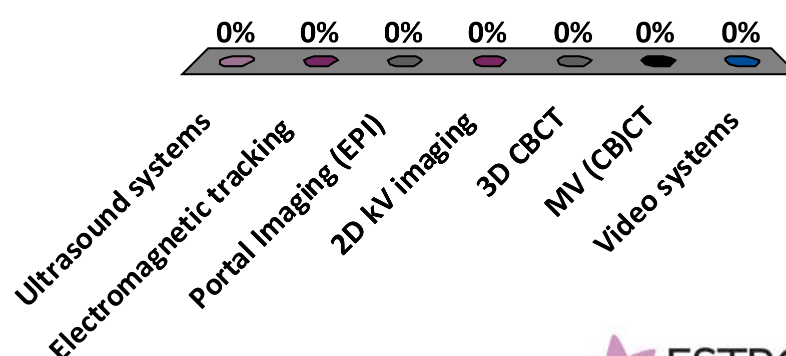
Imaging modalities

- Ultrasound systems
- Electromagnetic tracking
- Portal Imaging (EPID)
- kV cone beam CT
- 3D CBCT
- MV (CB)CT
- Surface scanning

- MR linac

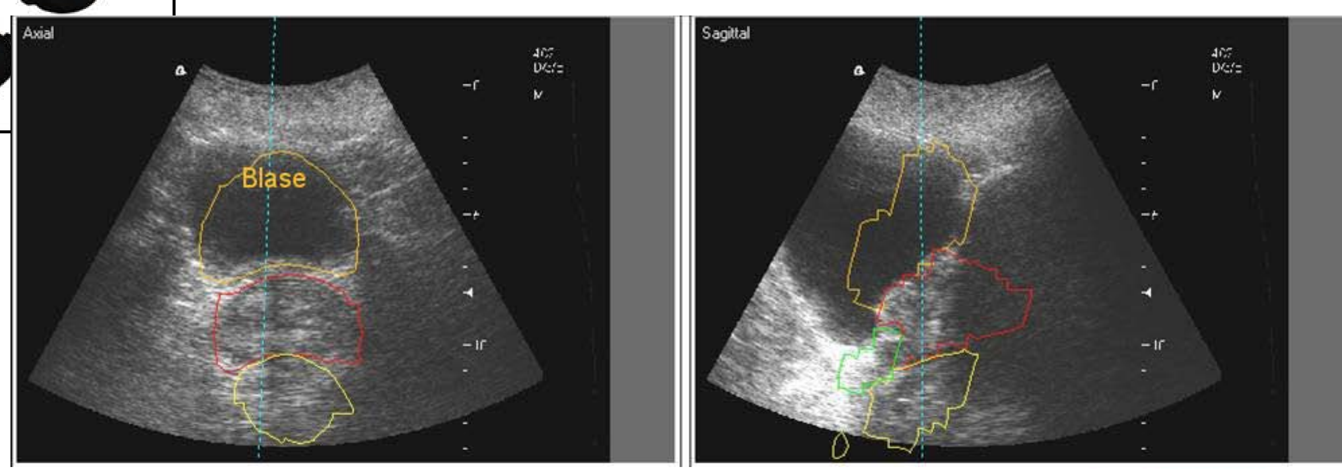
Polling: Who is using what?

A. Ultrasound systems
B. Electromagnetic tracking
C. Portal Imaging (EPI)
D. 2D kV imaging
E. 3D CBCT
F. MV (CB)CT
G. Video systems



Ultrasound systems

- With probe define position target
- Infrared enables correlation with linac



Ultrasound system

Pros:

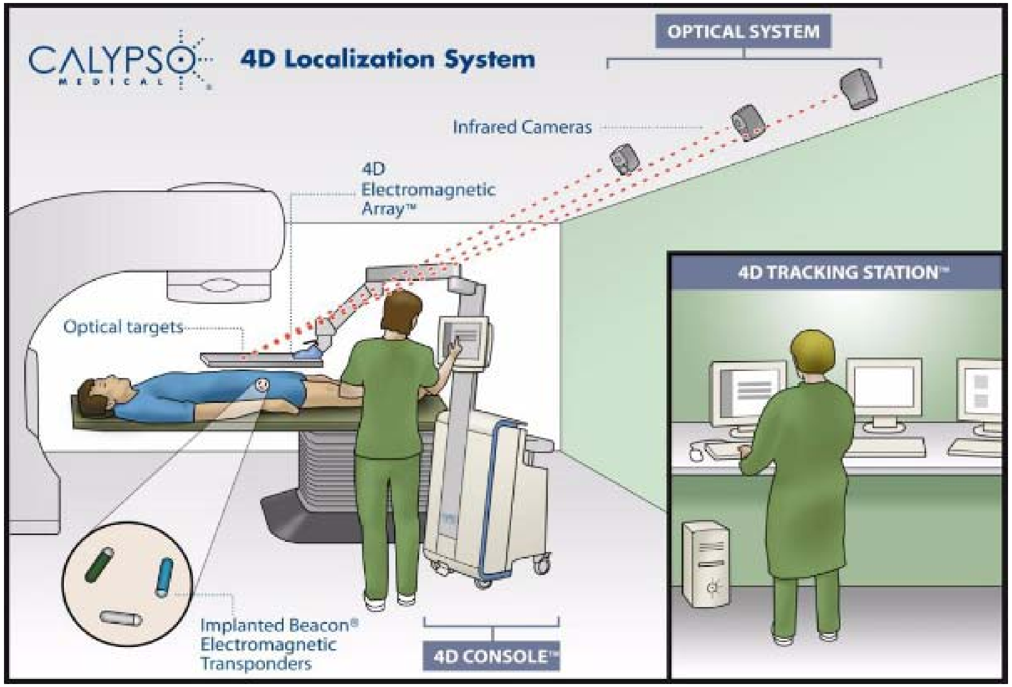
- Non invasive
- No imaging dose

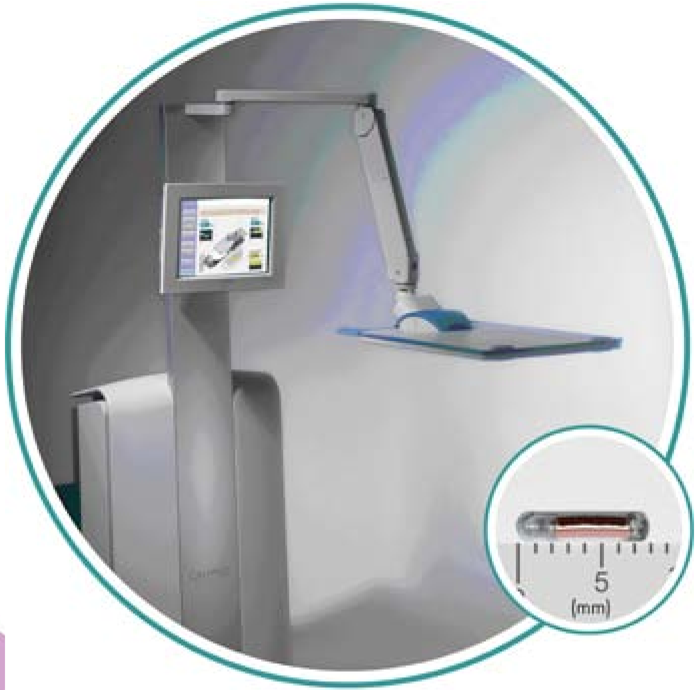
Cons:

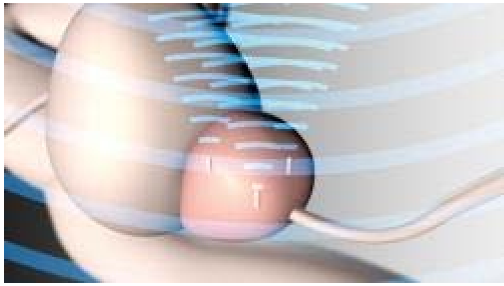
- User dependent accuracy
- No intra fraction information
- Limited number of indications
  - ➢ Prostate
  - ➢ Upper abdominals
- Probes influences position target
  - ➢ Systematic error

Electromagnetic tracking

- Uses implanted fiducials
- Lower magnetic field
- Transponder emits RF







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Electromagnetic tracking (GPS)

Pros:

- Continuous real time measurements (25Hz)
- Non ionizing
- Linked to linac

Cons:

- Limited number of indications
  - Mostly prostate
  - Lung
  - Breast (PBI)
  - Pancreas
- No anatomical information
- Invasive pre imaging procedure

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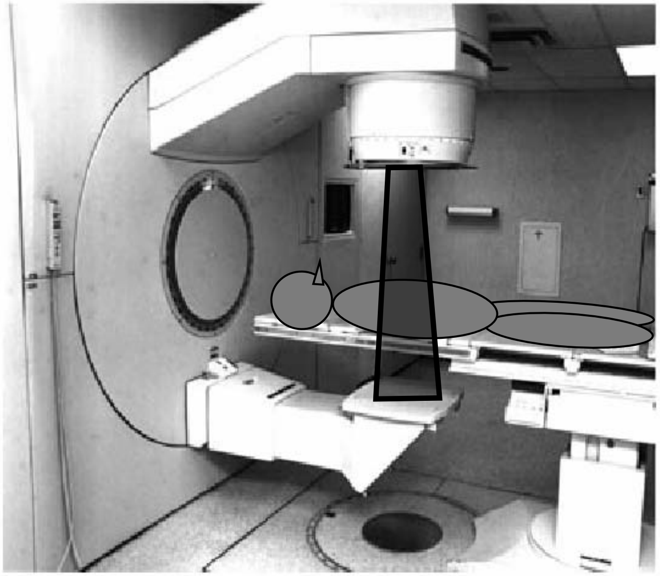
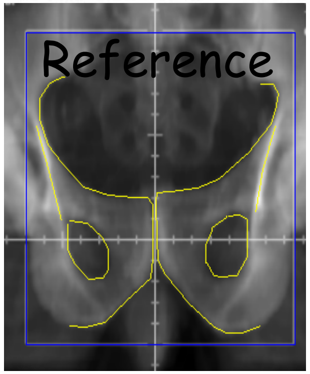
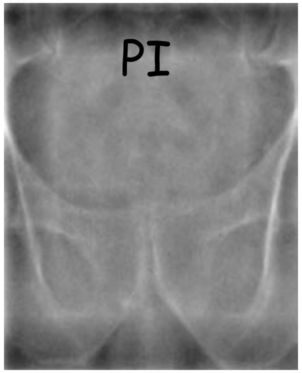
Portal Imaging - *physics*

- An imager used to detects the photons that cross the patient

- The portal image is compared to a reference image







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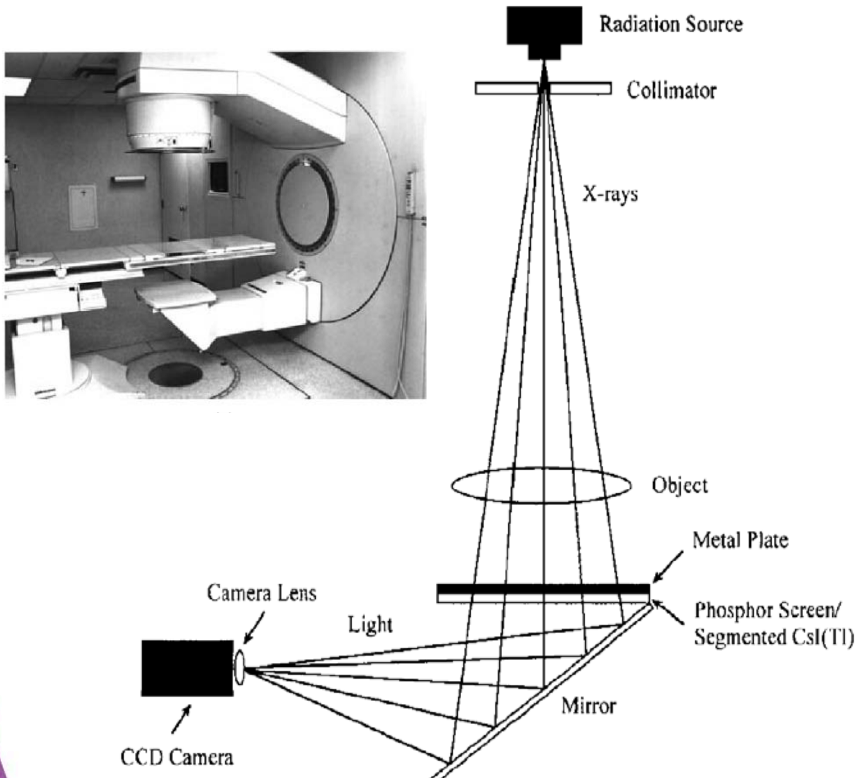
Goals of Portal Imaging

- Position verification

- Documentation of treatment
- Portal dosimetry (in-vivo)
- QA (MLC adjustment)

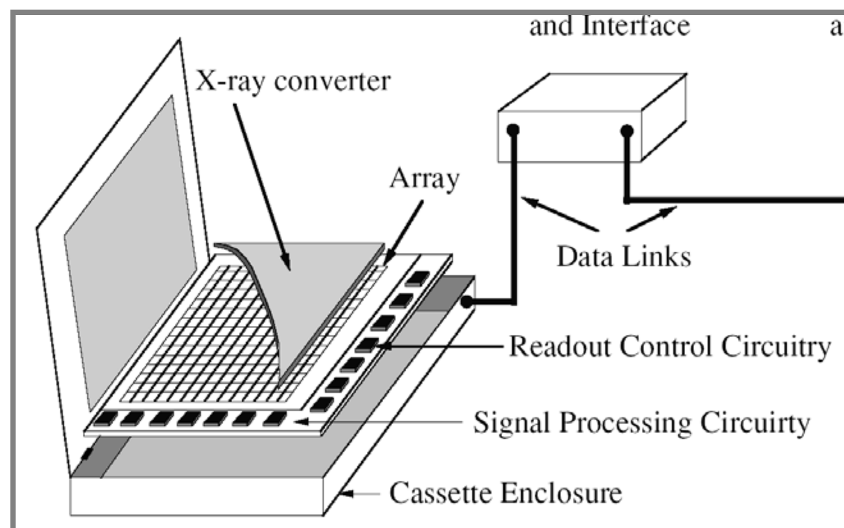
Technical aspects of EPIDs

Camera-mirror based systems

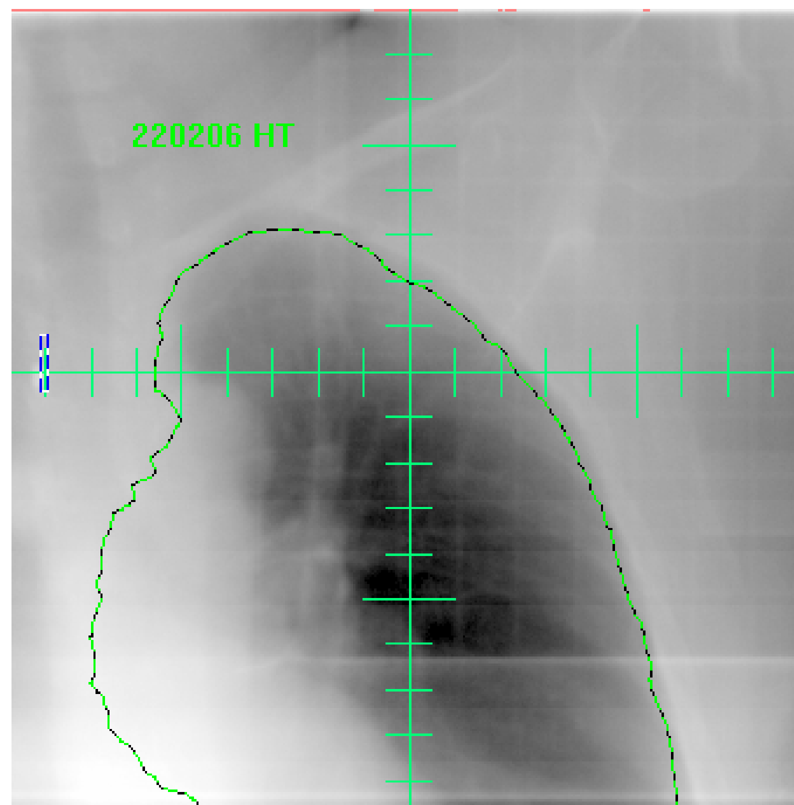


Active matrix flat panel imagers (AMFPI)

- also called amorphous silicon imagers

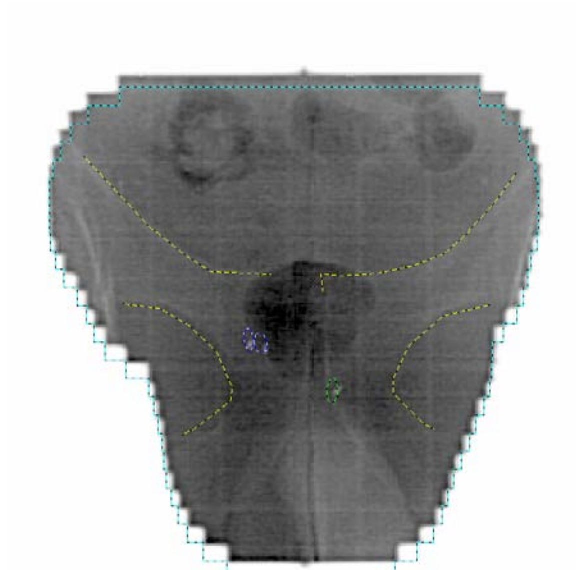


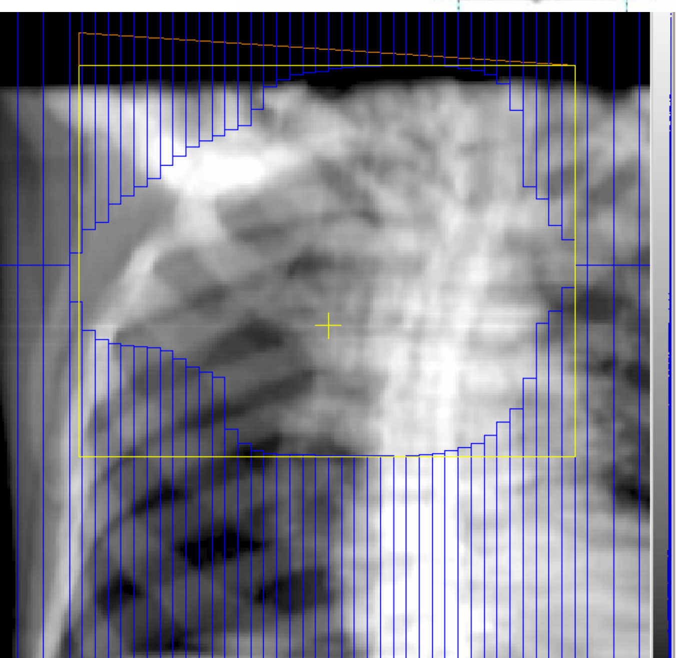
Examples of portal images

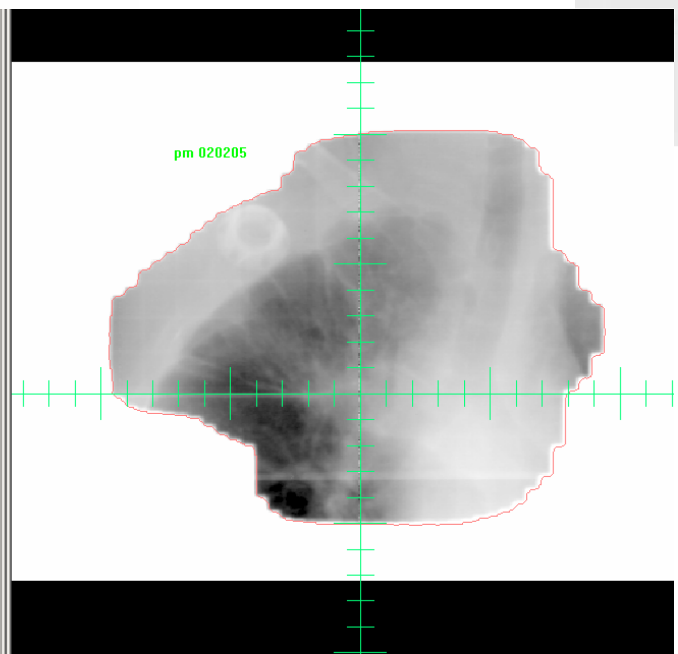


Images: M. Josopovic

EPID – field images







Images: M. Josopovic

Electronic Portal Imaging

Pros

- Image made with treatment beam
- Imaging during treatment
- Possible to perform dosimetry

Cons

- Surrogate imaging
  - ➢ Additional margins
- Imaging dose
  - ➢ Although it is possible to compensate for
- Imaging quality

kV imaging

kV source & detector panel

Different approaches:

- kV source moutend on linac
- kV sources on fixed position in room

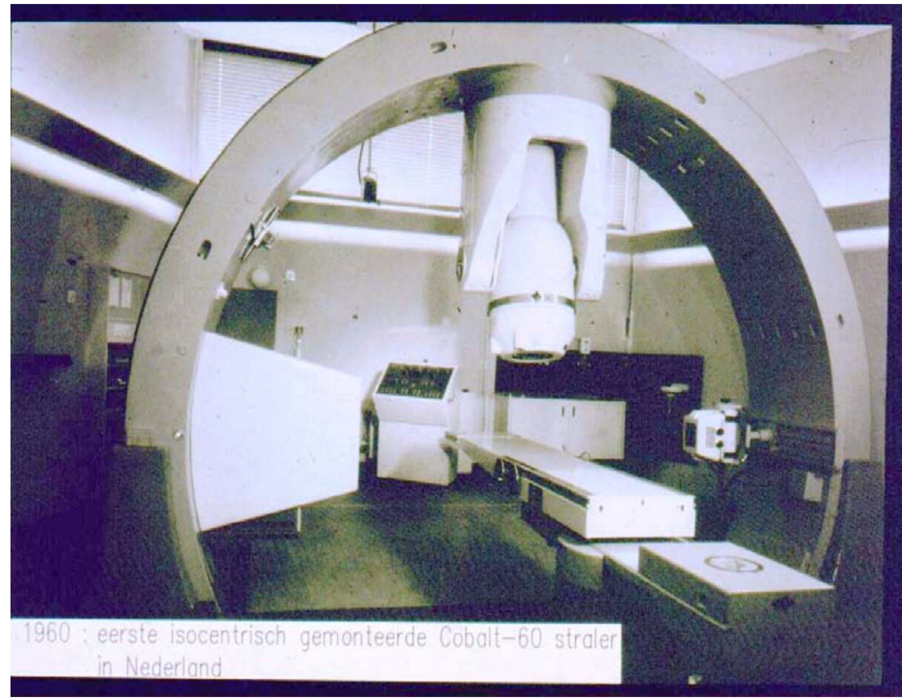
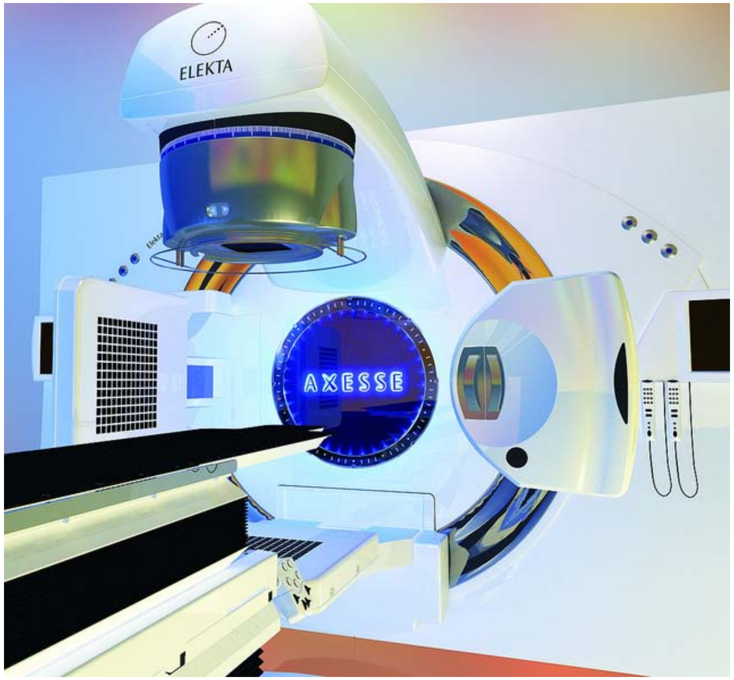


Image: Ben Mijnheer (NKI)

kV source moutend on linac



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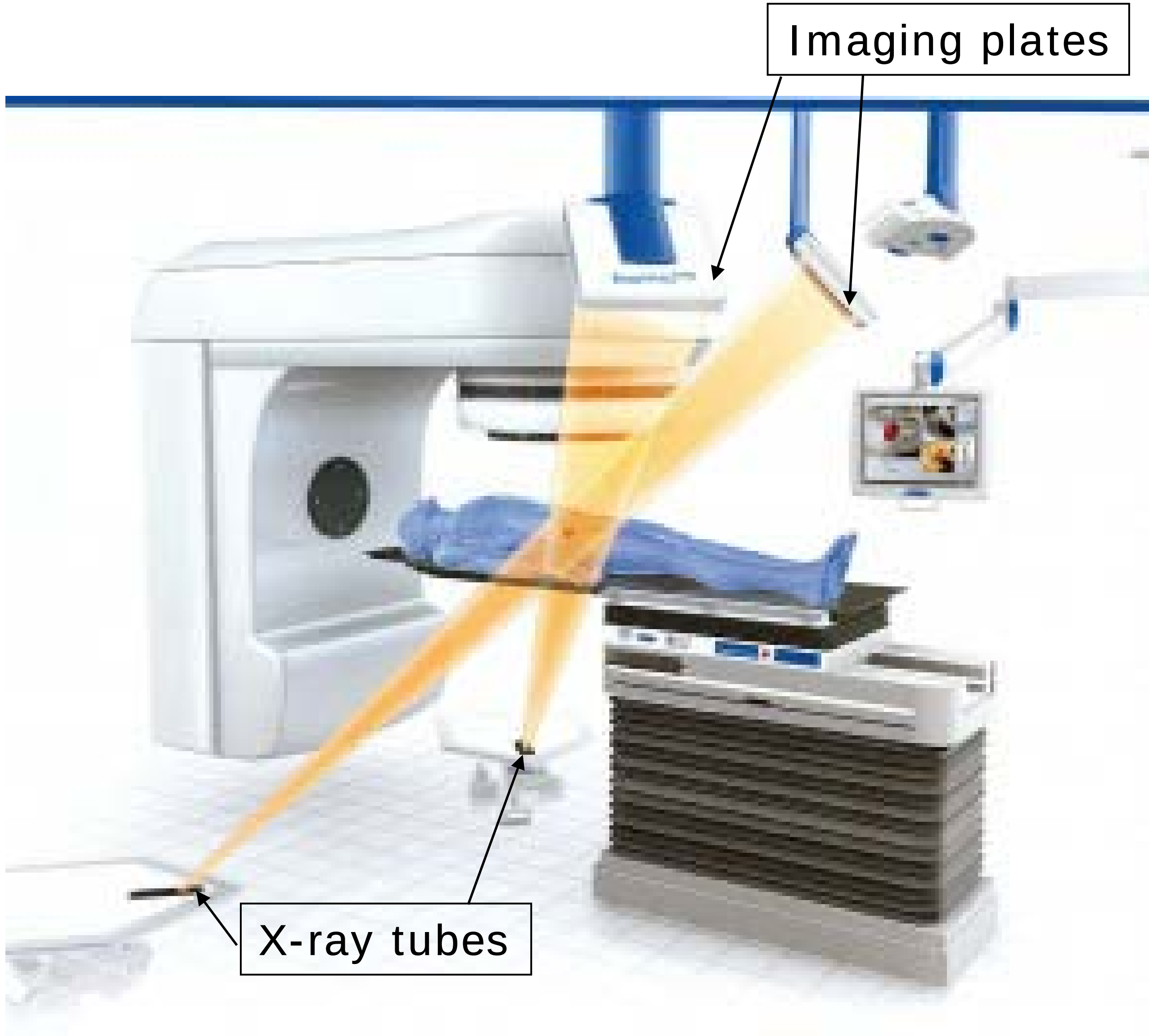
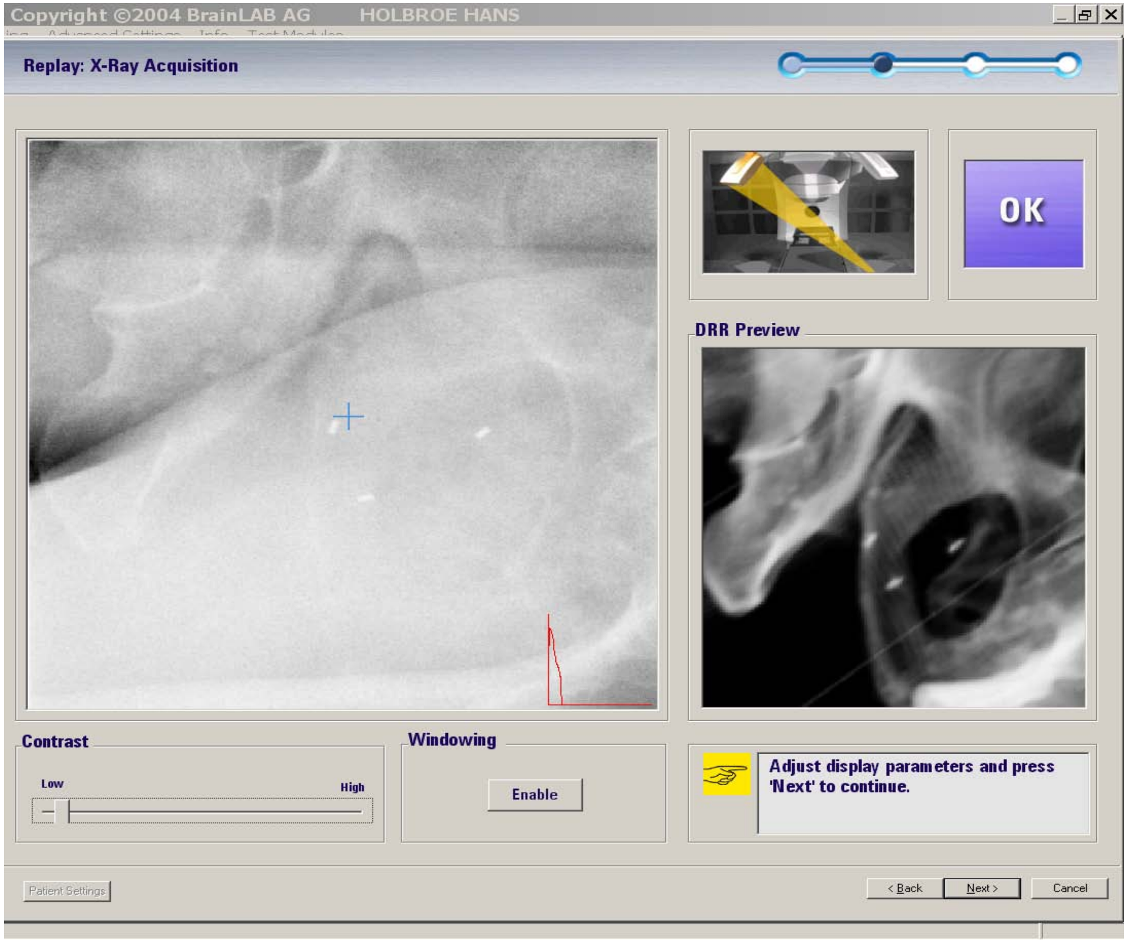
kV imaging: Cyberknife

Exac Trac® IGRT system

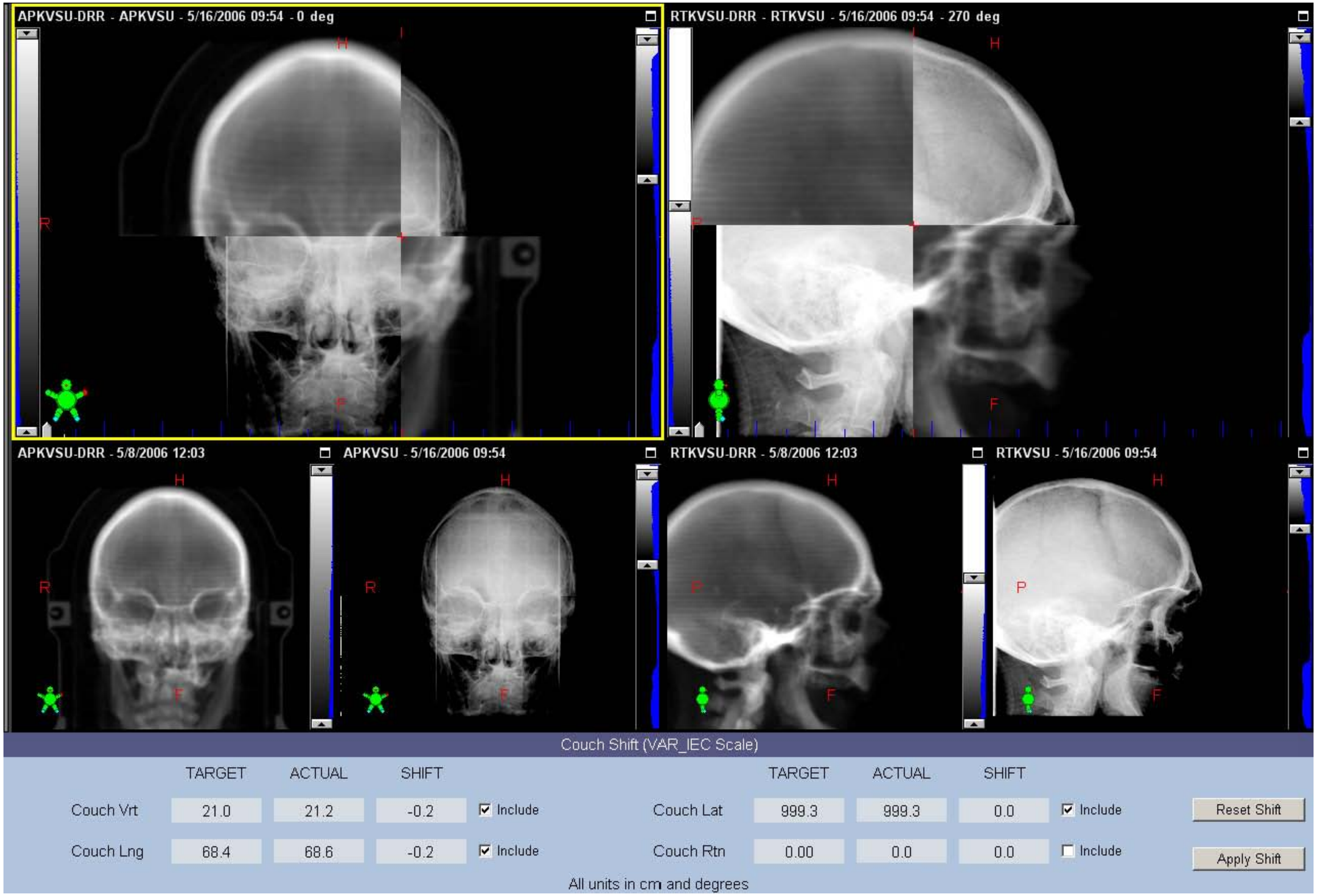


Exac Trac® IGRT system



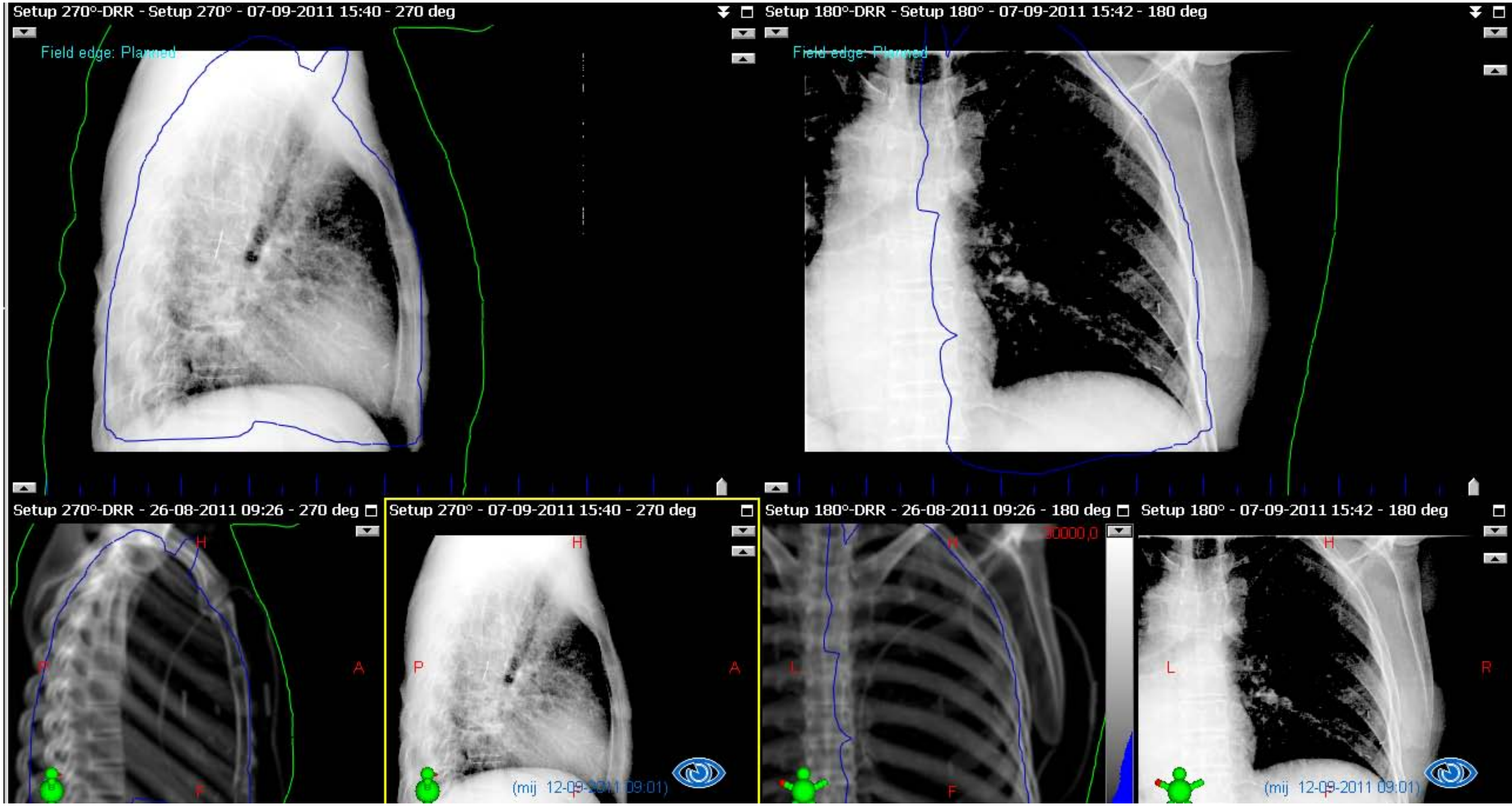
Images: M.Josopovic

OBI kV imaging



Images: M.Josopovic

More images



Images: M.Josopovic

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kV imaging

Pros:

- Imaging dose is low
- High 2D imaging quality
- Real time imaging in some systems

Cons

- No anatomical information

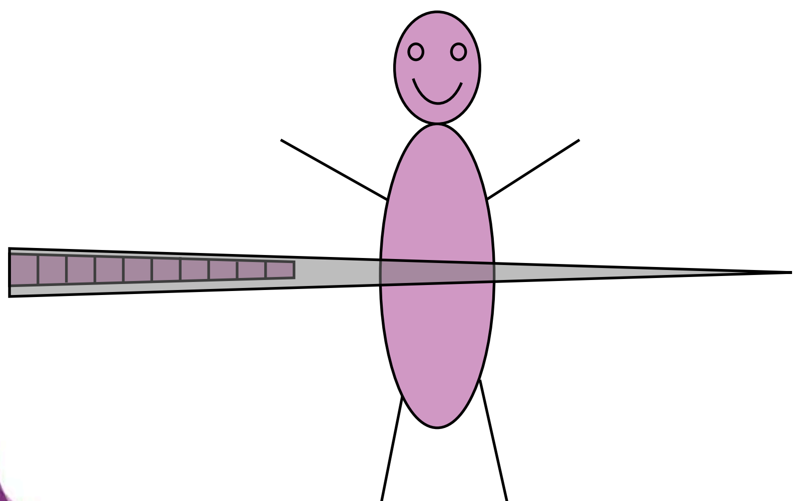
Cone beam CT

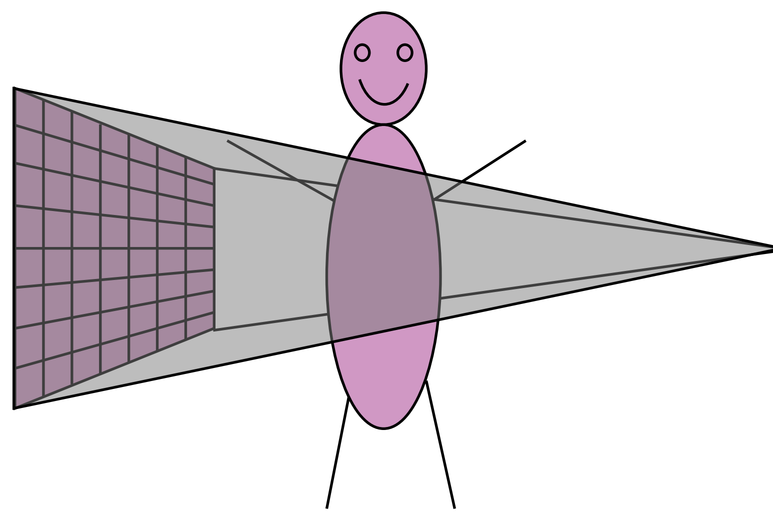
handheld detector X-ray tube

CBCT Acquisition

Conventional CT
- ‘Fan’ beam
- 1D detector
- 1 rotation = 1 slice

Cone-beam CT
- ‘Cone’ beam
- 2D detector
- 1 rotation = volume (many slices)





Courtesy: Peter Remeijer

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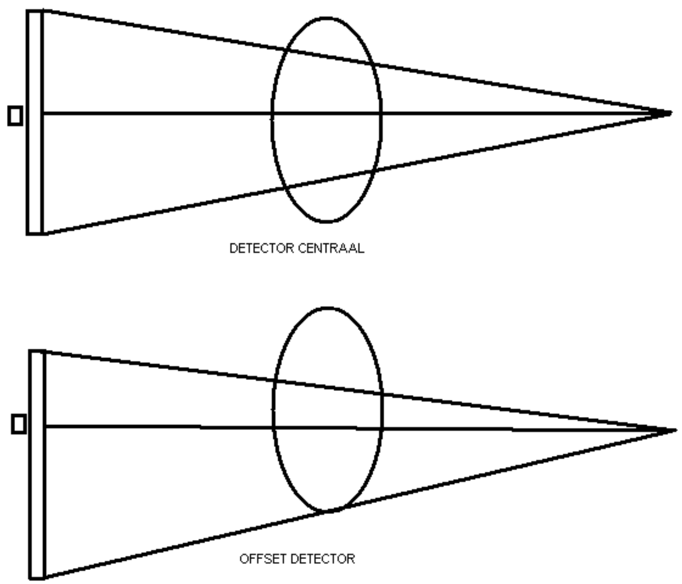
How does it work?

Variable detector position



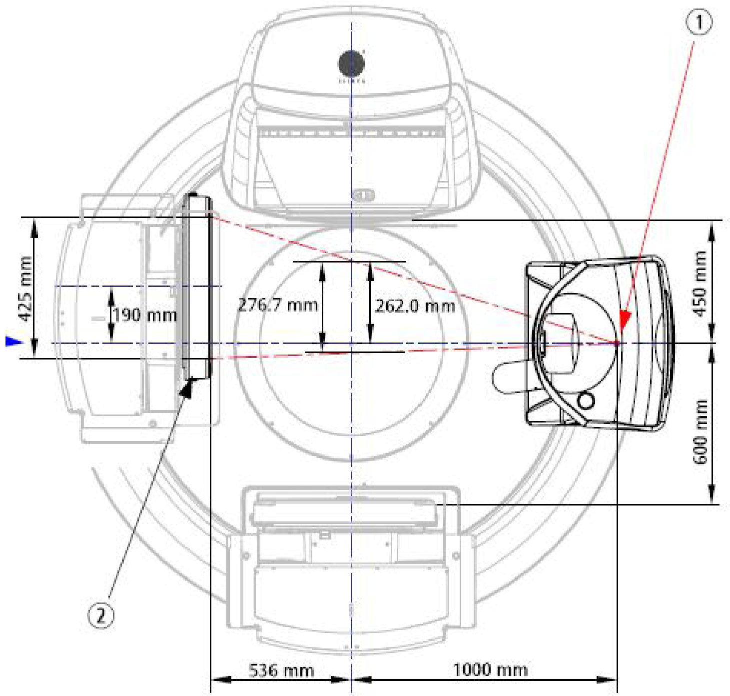


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Image registration: Defining the ROI

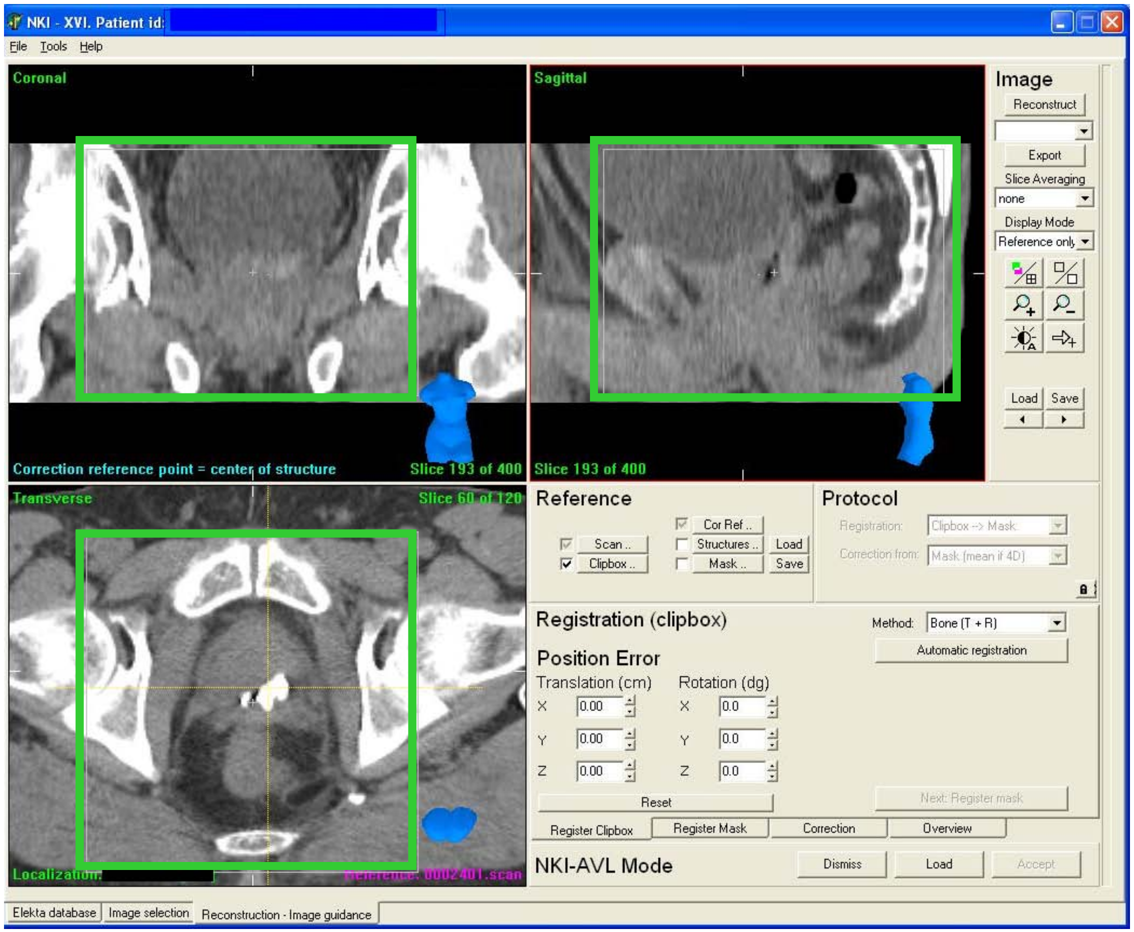

Image registration: Defining the ROI

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Image registration

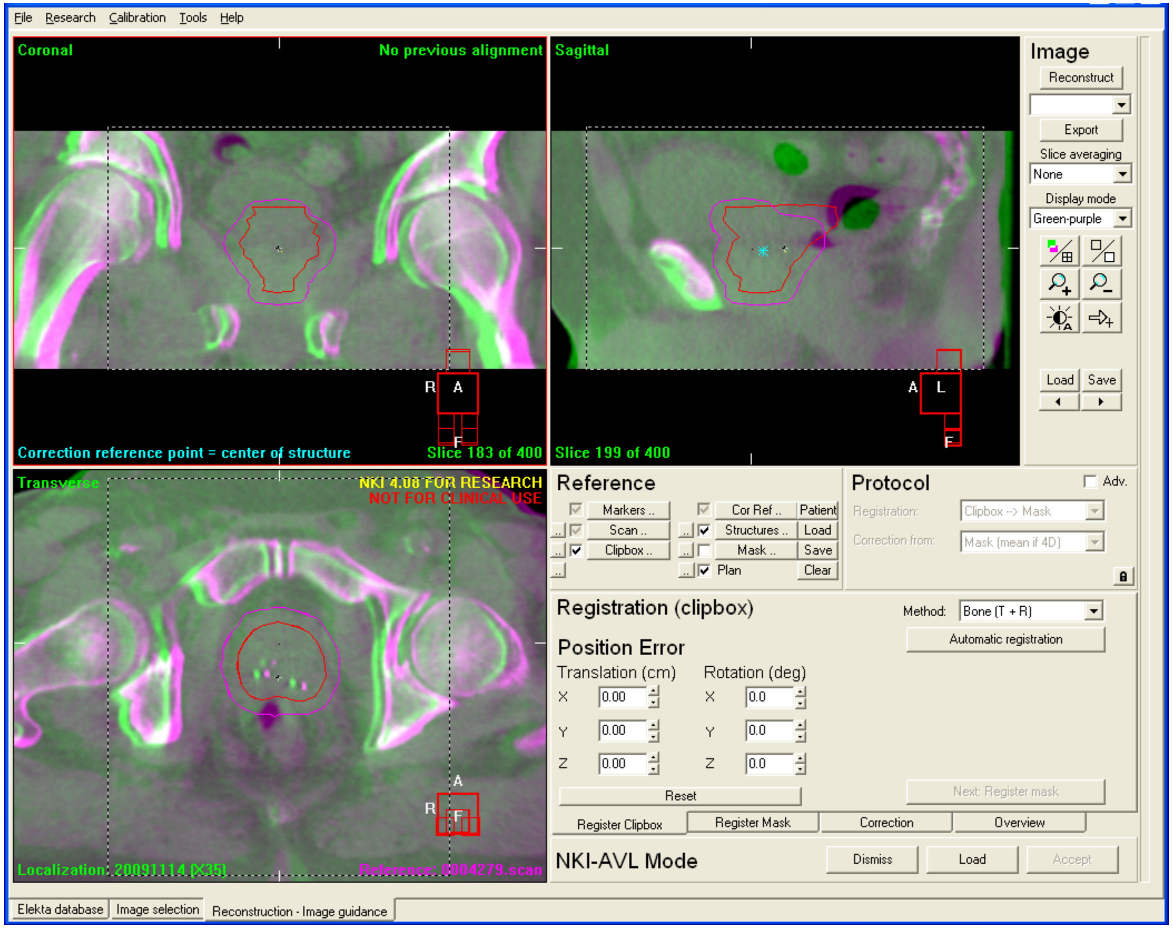

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Image registration: bony anatomy

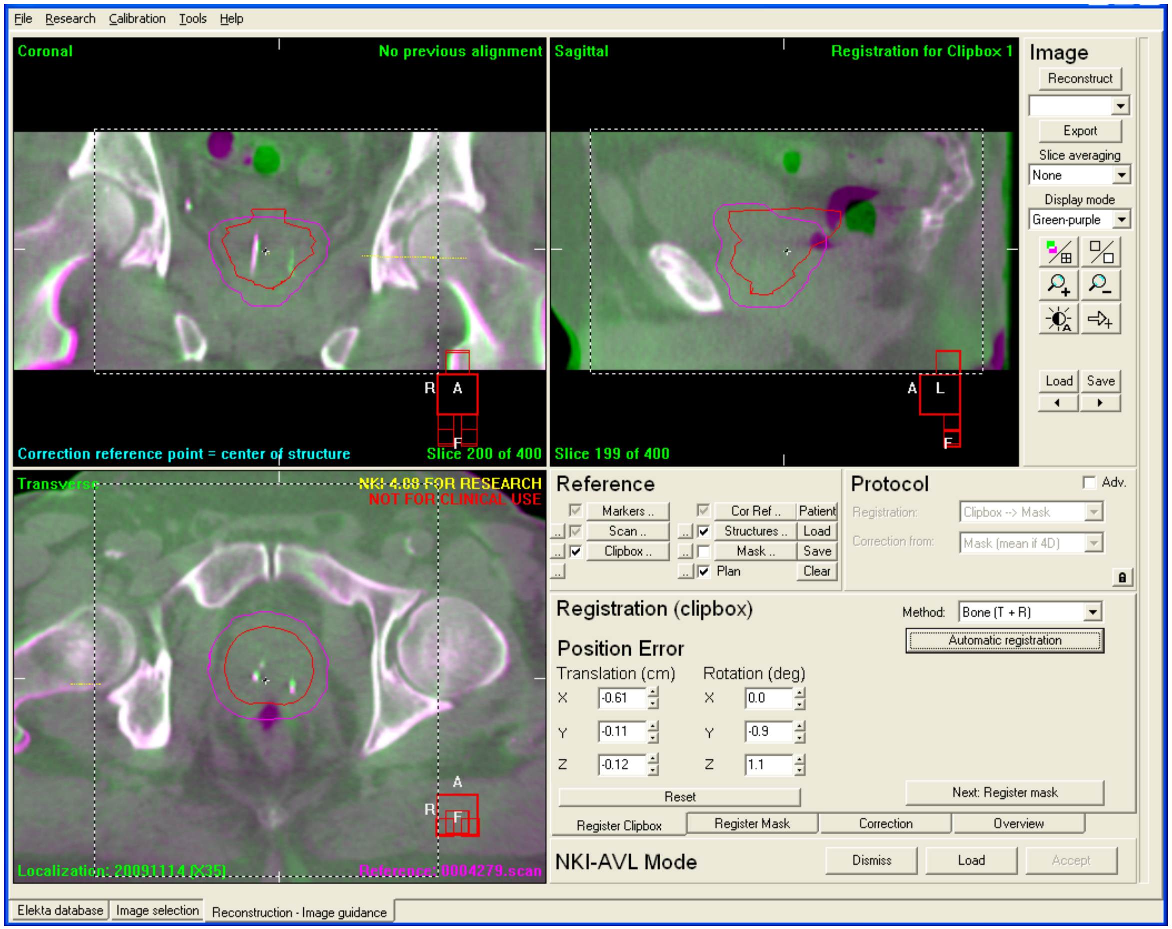
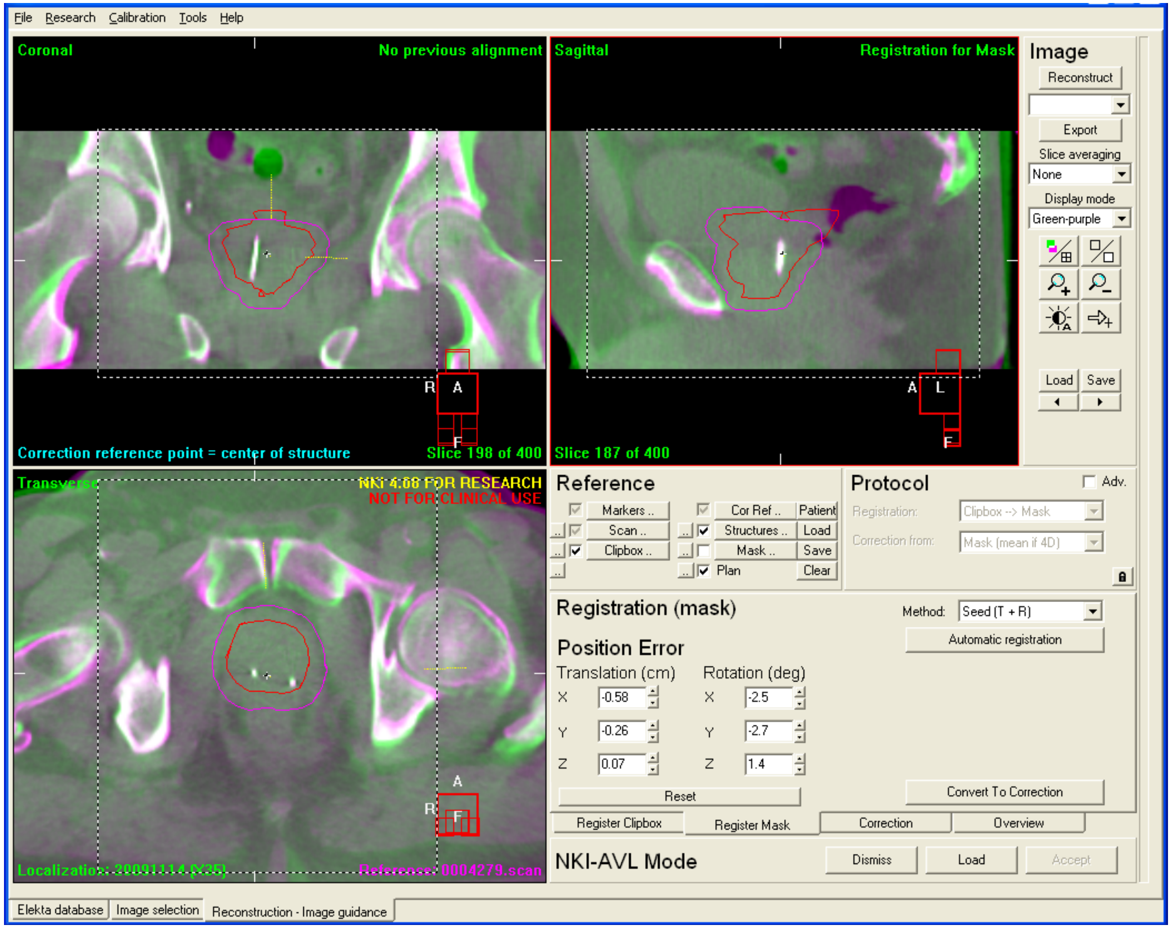


Image registration: fiducial markers



MV-(CB)CT

Using:

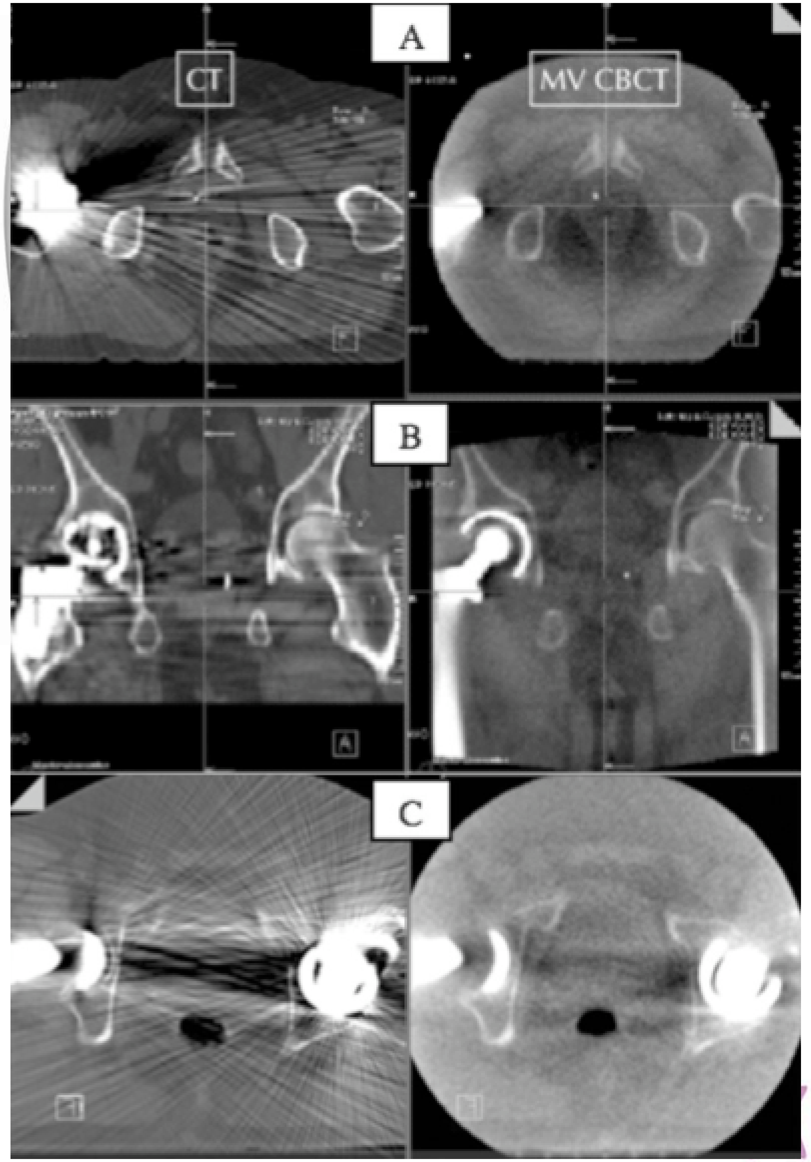
- Treatment beam
- Flat panel
- 3D acquisition

MV-CT:

- Helical acquisition
- TomoTherapy

MV-CBCT:

- 360 degrees acq.
- Siemens Oncor



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MV-CT

Pros:

- Anatomical information
- Limited influence of high densities (prostheses)
- Image of the actual absorbed dose

Cons

- Image quality not as good as kV CBCT
- Imaging dose
- MV-CBCT: Only available as Siemens
- MV-CT: Long acquisition times

Videosystems

Different approaches:

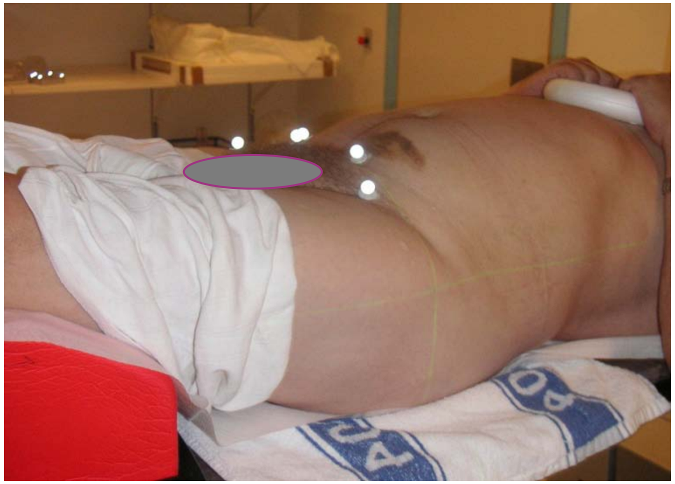
- Infrared tracking of external markers
- Surface scanning

What can you do with these systems?

- Set-up aid
- More important: monitor the patient during treatment:
    1. Passive: monitoring set-up accuracy
    2. Active: correlate motion with treatment (e.g. gating or DIBH)

Exac trac infrared

- Infrared marker,
  - placed on fixed spots
- Tracking of the markers during RT
  - Correlate with respiration (tracking/gating)



Images: M.Josopovic

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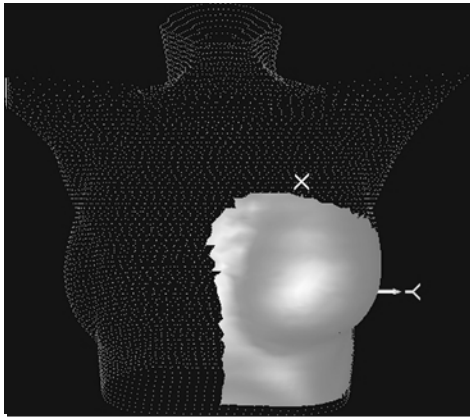
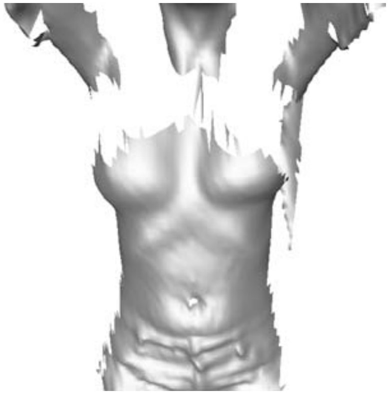
Surface scanning



Left side



Images: T.Alderliesten

Infrared systems

Pros

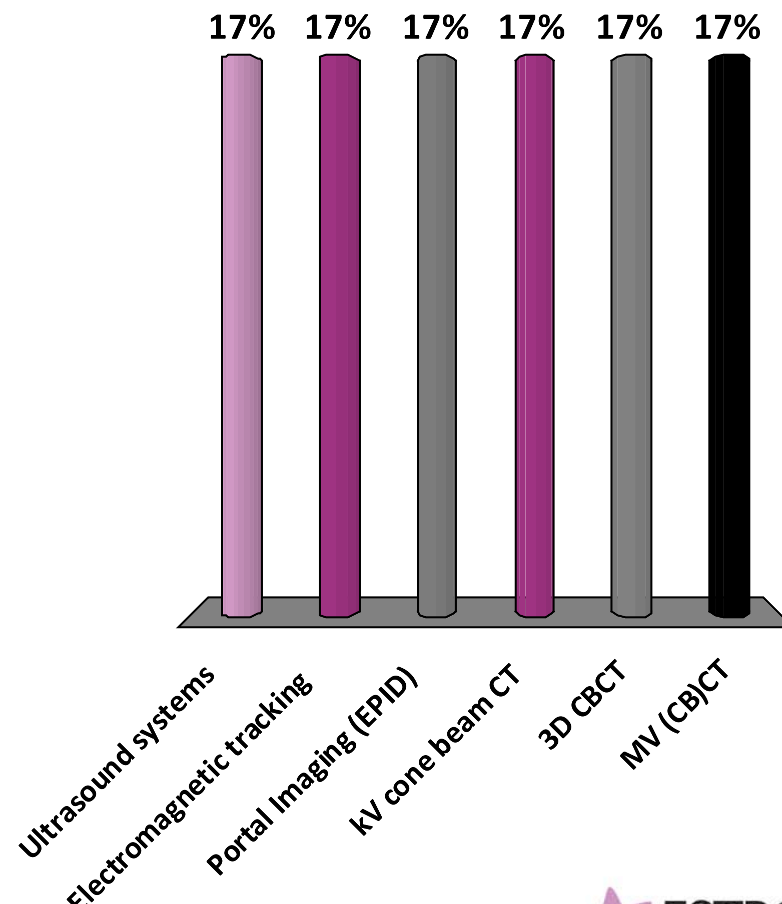
- No imaging dose
- Enables tracking and gating
- Real time measurements

Cons

- It's an aid
  - ➢ Can never be a stand alone system
- Surrogate

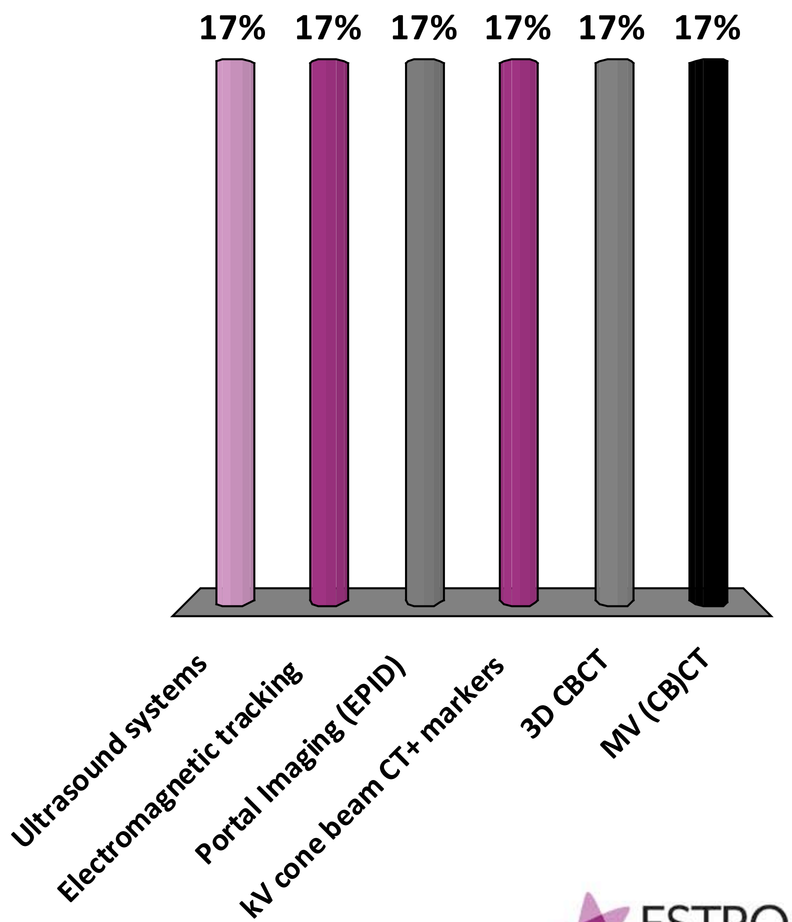
Which one do you prefer most in prostate without seminal vesikel invasion?

A. Ultrasound systems
B. Electromagnetic tracking
C. Portal Imaging (EPID)
D. kV cone beam CT
E. 3D CBCT
F. MV (CB)CT



Which one do you prefer most in lung SBRT?

A. Ultrasound systems
B. Electromagnetic tracking
C. Portal Imaging (EPID)
D. kV cone beam CT+ markers
E. 3D CBCT
F. MV (CB)CT



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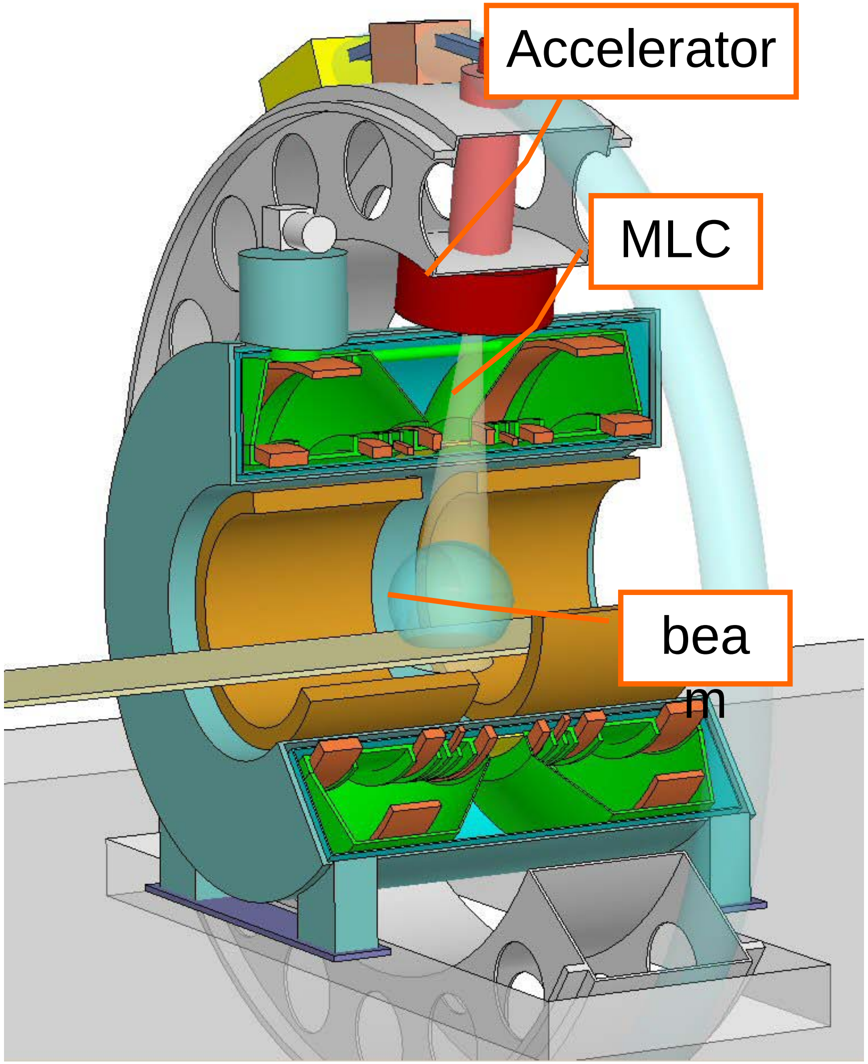
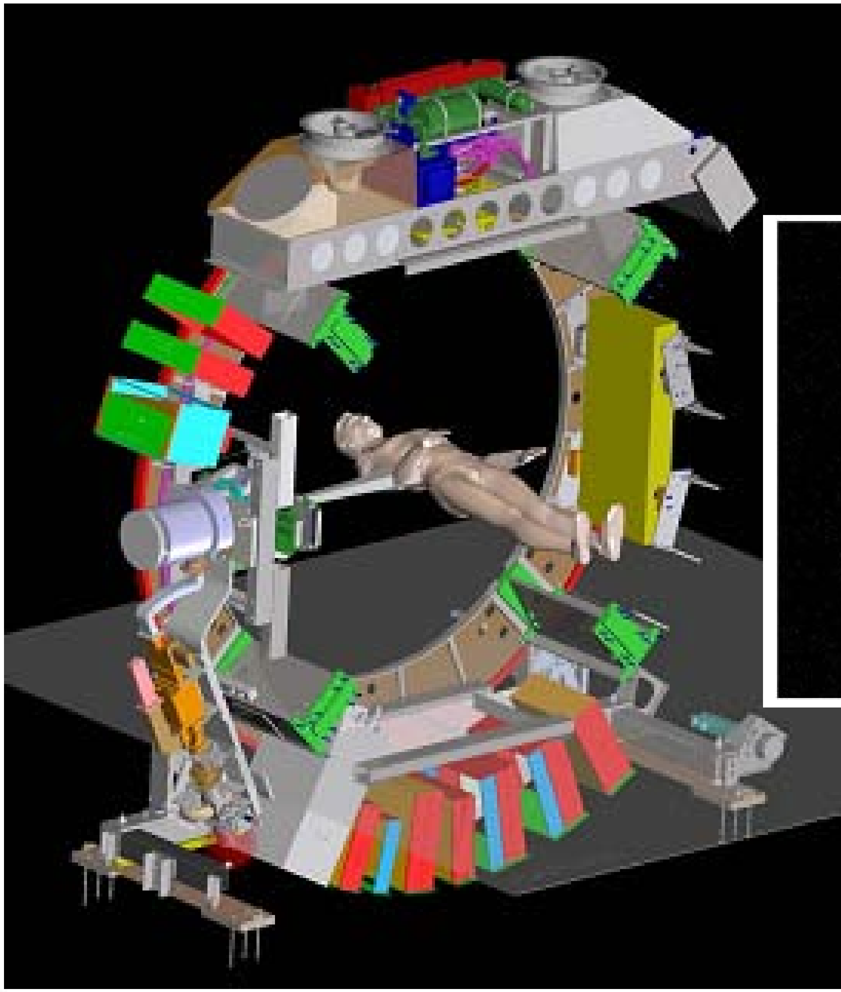
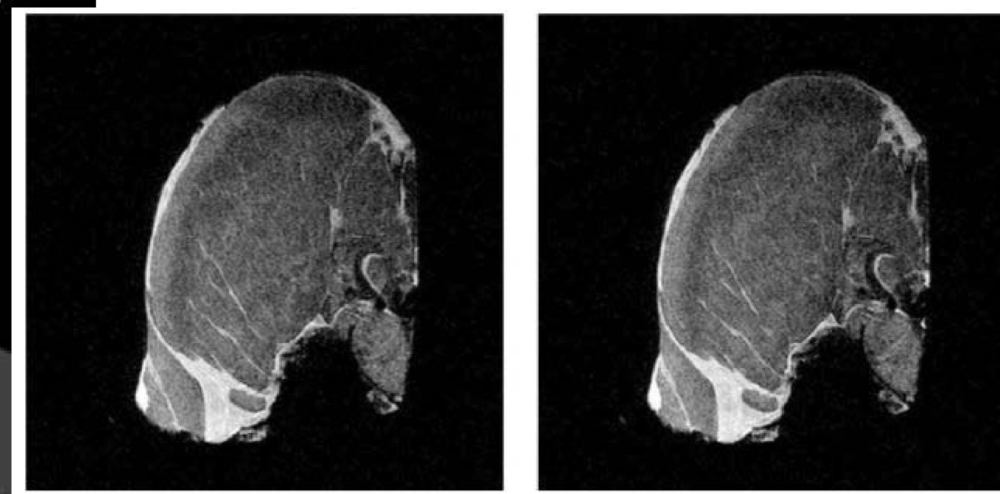
Integrating MRI functionality with external beam radiotherapy



Gantry design MRL: (MRI-Linac)





MR linac

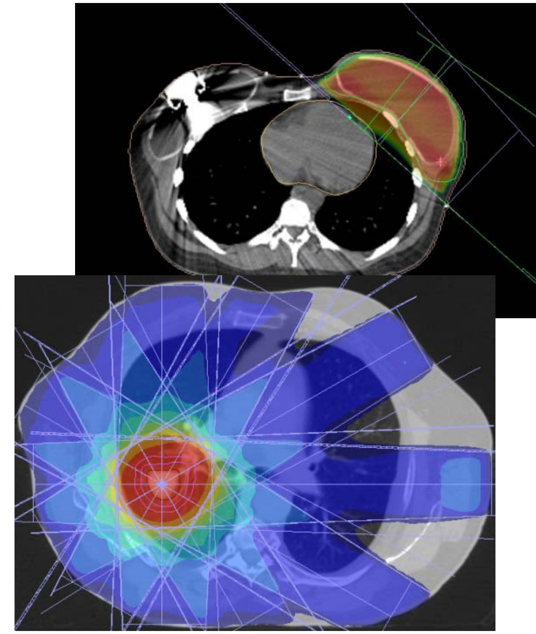
Pros

- Optimal image quality
- Intra fraction imaging

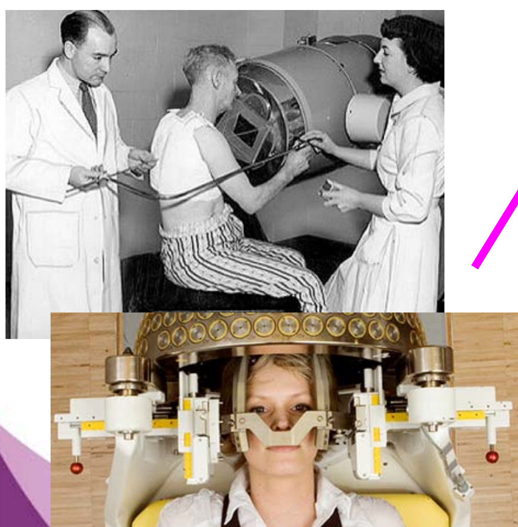
Cons

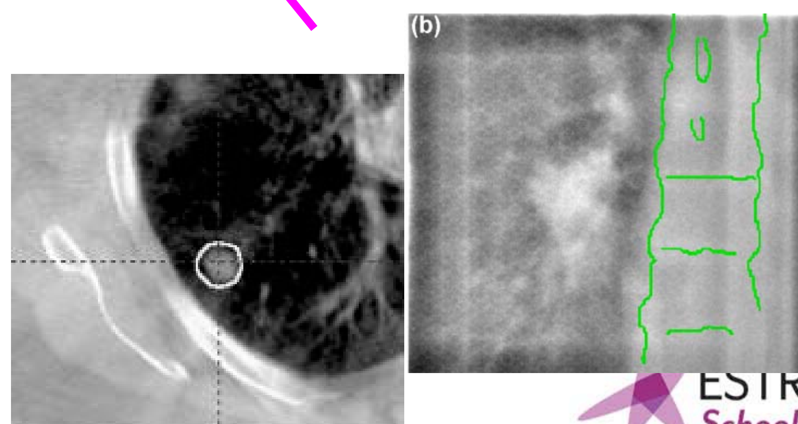
- (Still) not commercially available yet ☹
- Challenging Treatment planning
  - ➢ Secondary electrons are influenced by the magnetic field

How accurate should the delivery be?



Balance!





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Clinical rationale for image-guided radiation therapy (IGRT)

ESTRO School

Jose Lopez, M.D., Ph.D
Radiation Oncology
University Hospital Virgen del Rocio
Seville, Spain

Advanced skills for modern radiotherapy
28 June-02 July, 2015
Copenhagen, Denmark

Disclosure Information

- I have no financial relationships to disclose.
- I will **NOT** include discussion of investigational or off-label use of a product in my presentation.

Learning Objectives (IGRT)

- Learn the **clinical rationale** for IGRT
- Learn the challenges in achieving **precision and accuracy** in treatment sites influenced by organ motion.
- Identify the **technologies available** or being developed for image-guided RT.
- Understand the **benefits and limitations** of IGRT
- Learn the **evidence** that supports the use of IGRT

Why do we need IGRT?

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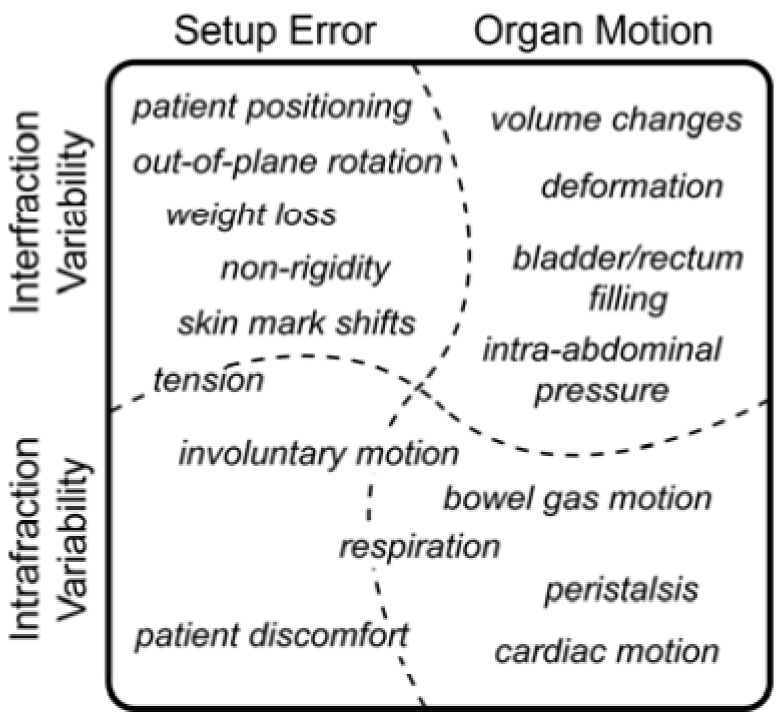
Rationale for IGRT

- Objetive: **Treat the defined tumour and spare the surrounding normal tissue**

Enemies: **Uncertainties**



Friends: **IGRT**

Wikipedia

- **Image-guided radiation therapy** (IGRT) is 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 radiation treatment plan.

- The patient is localized in the treatment room in the **same position as planned** from the reference imaging dataset.

- An example of IGRT would include localization of a cone-beam computed tomography (**CBCT**) dataset with the planning computed tomography (**CT**) dataset from planning. IGRT would also include matching planar kilovoltage (**kV**) radiographs or megavoltage (**MV**) images with digital reconstructed radiographs (**DRRs**) from the planning CT.

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Imaging for treatment verification

1980's – port films	
1990's -	emergence of MV portal imagers
	in-room ultrasound localization
	marker-based localization
	Fluoroscopic tracking
2000's –	flat panel imaging
	KV digital imaging
	CBCT
	MV CBCT
	CT "on rails"
Emerging -	Electromagnetic localization and tracking
	surface tracking
	in-room MRI

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Imaging for treatment verification

1980's – port films
1990's - emergence of MV portal imagers
in-room ultrasound localization
marker-based localization
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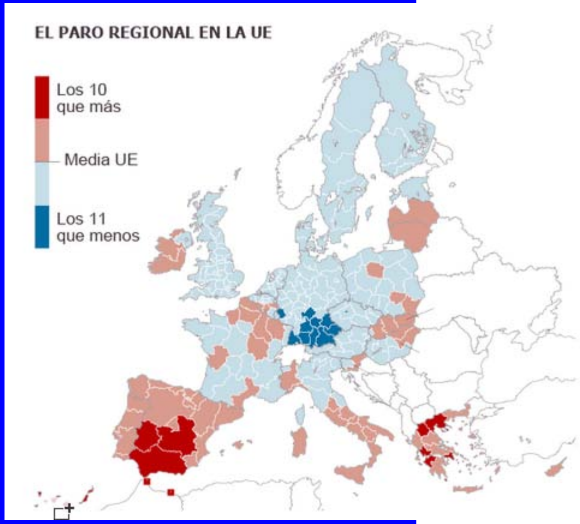

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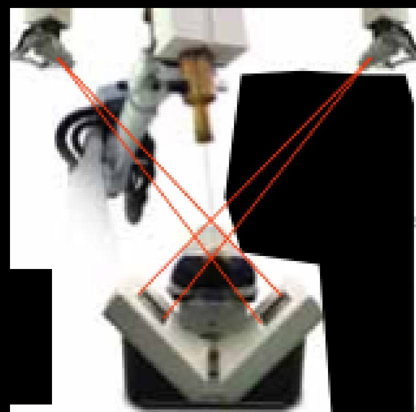
Technologies available for IGRT

Ultrasound



kV Radiographic

Portal Imaging

Markers (Active and Passive)

Technologies available for IGRT

Siemens PRIMATOM™

TomoTherapy Hi-Art™

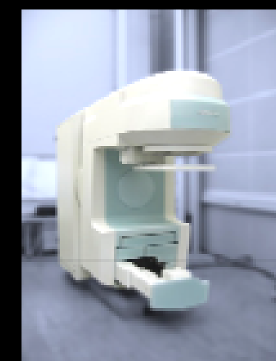
kV CT Approach

MV CT Approach

Elekta Synergy™

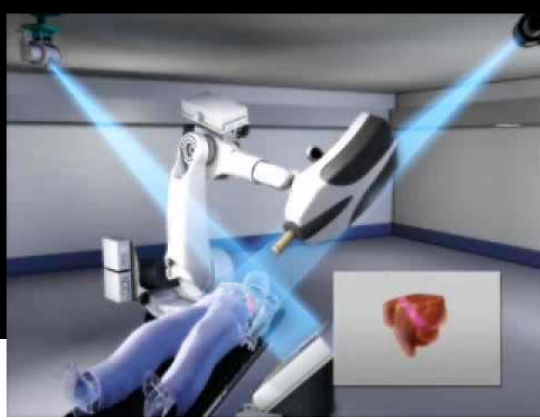
Siemens MVision™

Varian OBI™



Siemens Artiste™

kV and MV Cone-beam CT Approach



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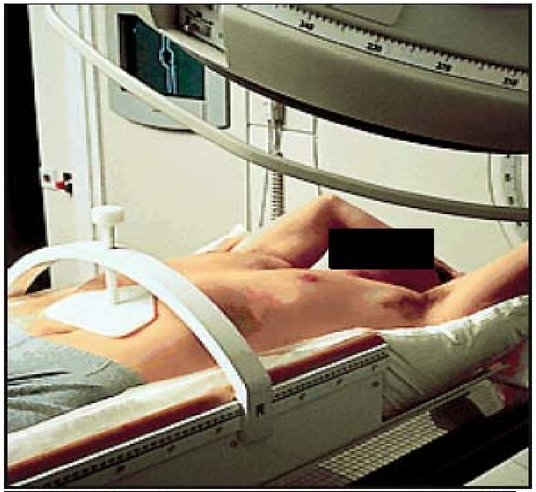
Many immobilization devices

Many immobilization devices



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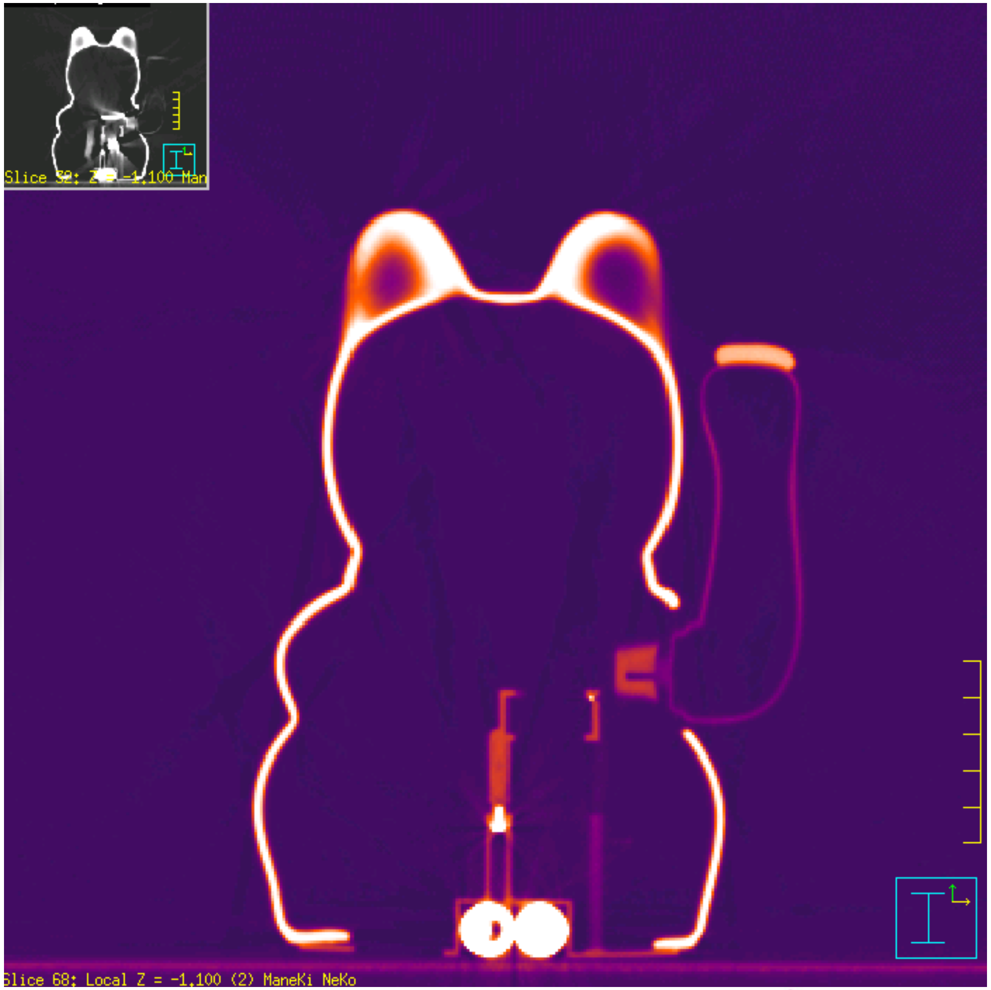
SlowCT/CT Fusion

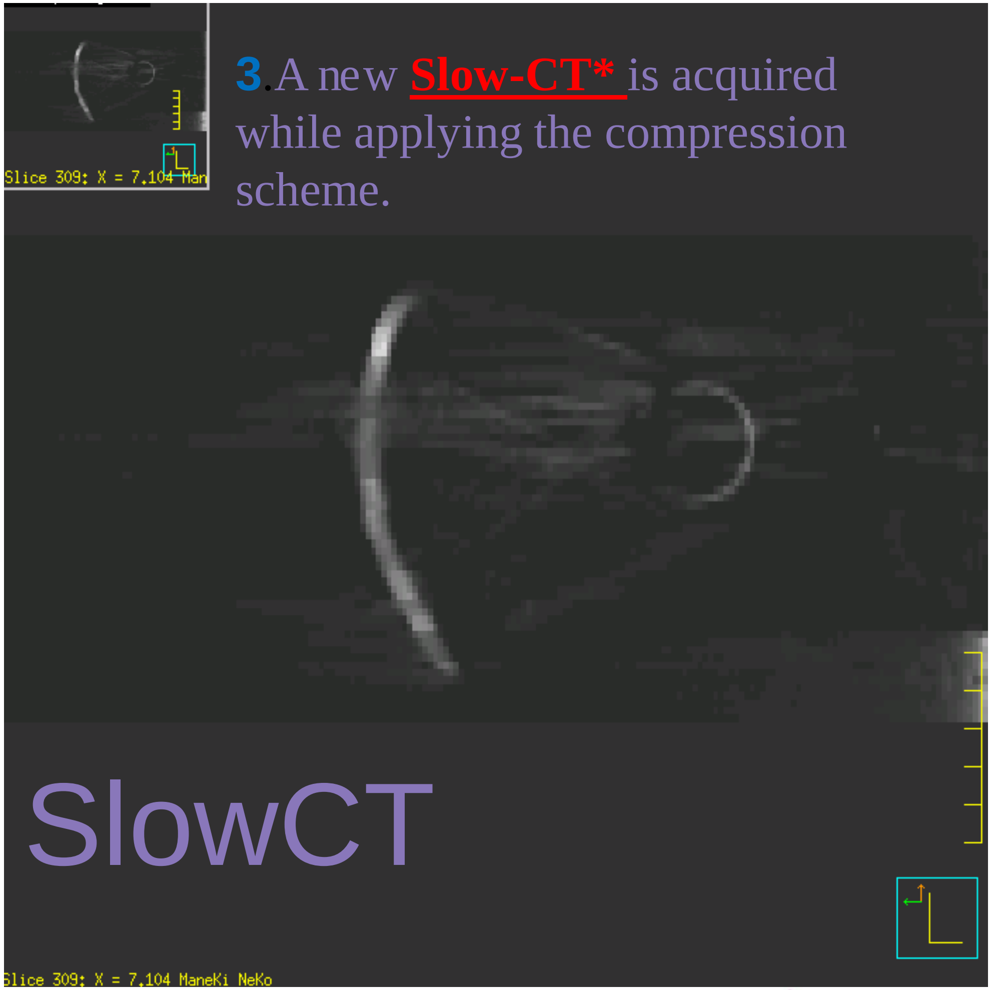
Can get more than 10cm movement



Courtesy Santiago Velazquez

SlowCT/CT Fusion

Can get more than 10cm movement



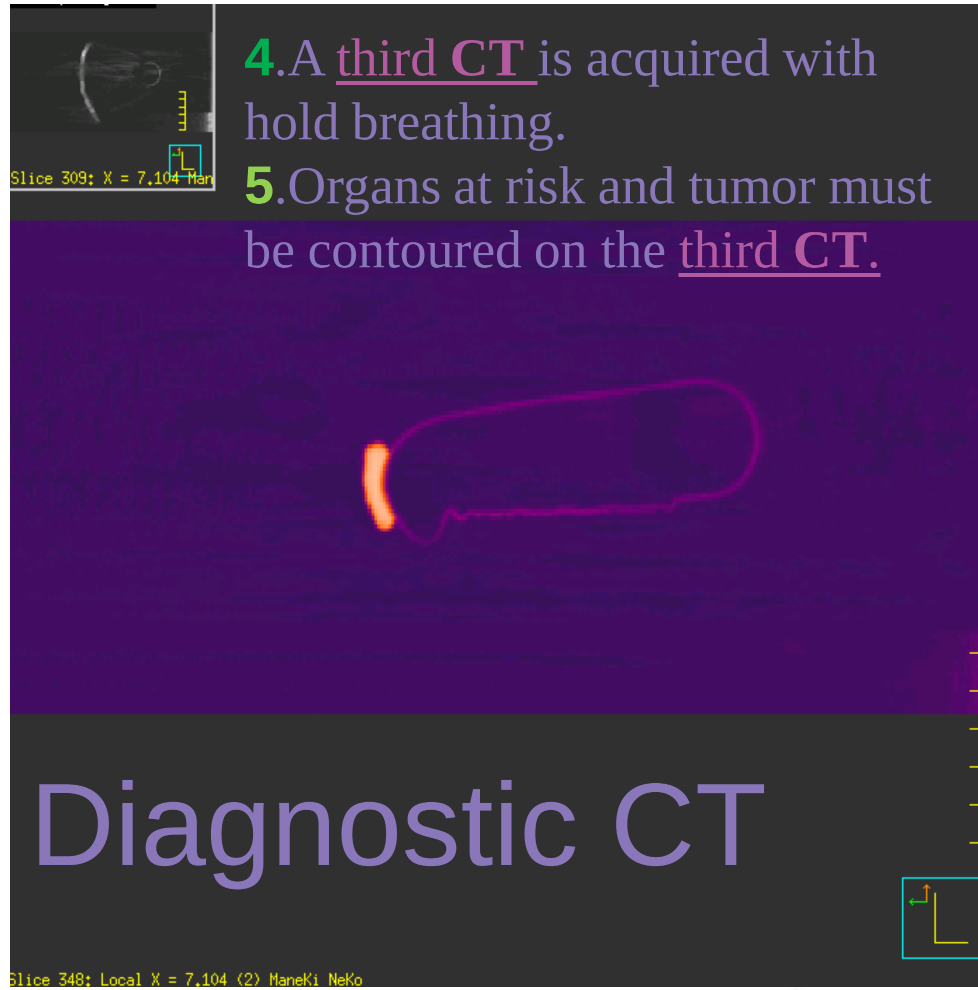
3. A new **Slow-CT*** is acquired while applying the compression scheme.

SlowCT

Courtesy Santiago Velazquez

SlowCT/CT Fusion

Can get more than 10cm movement



4.A third CT is acquired with hold breathing.

5.Organs at risk and tumor must be contoured on the third CT.

Diagnostic CT

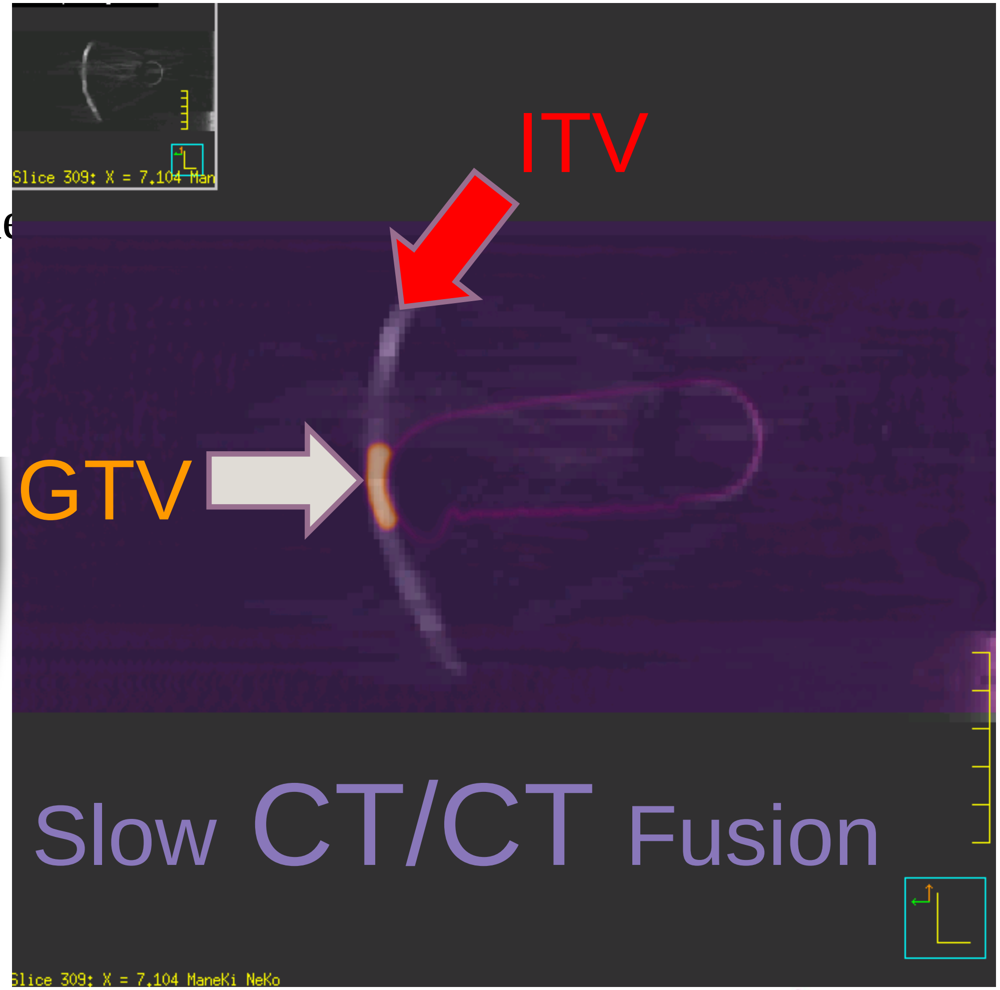
Courtesy Santiago Velazquez

SlowCT/CT Fusion

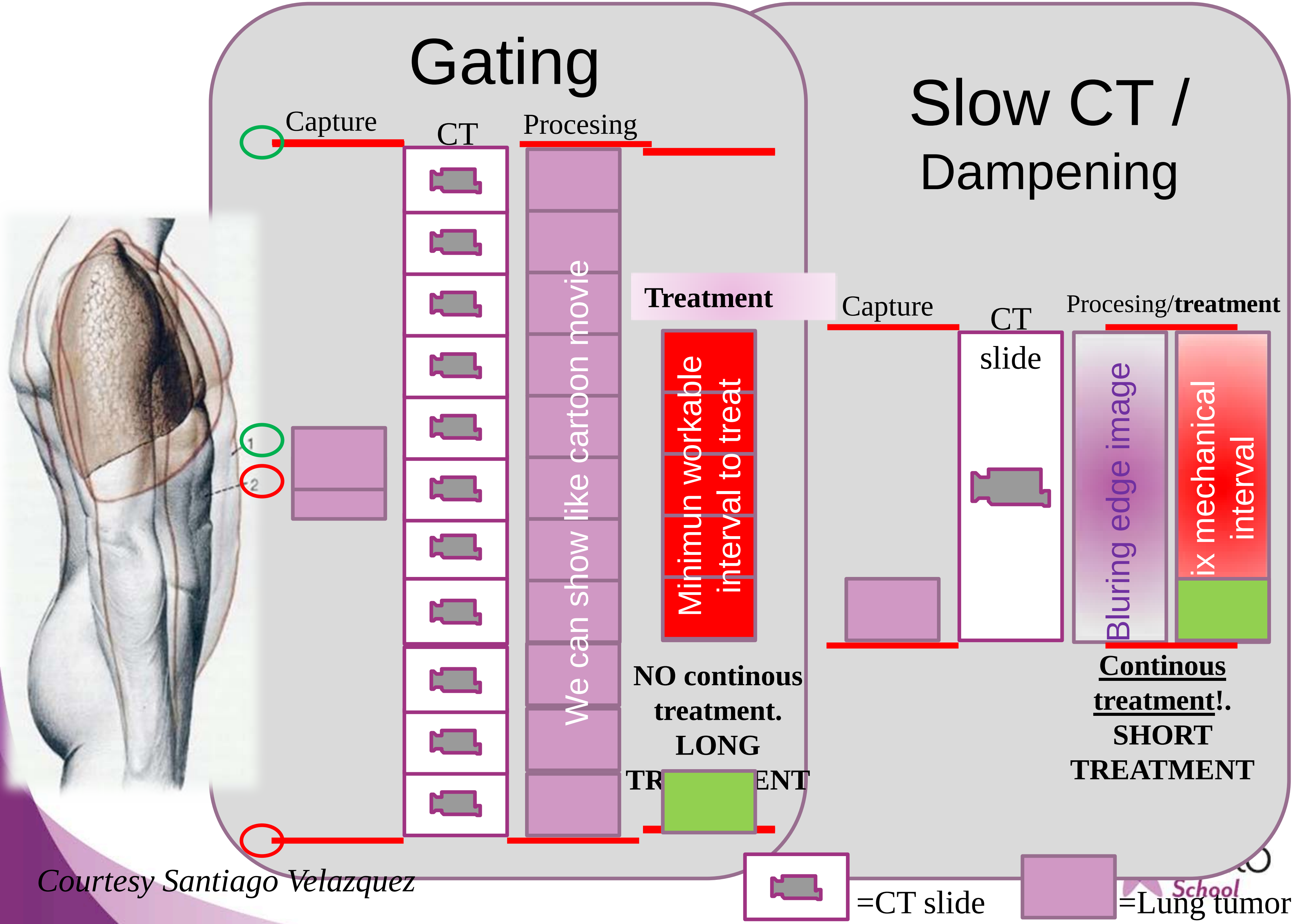
Can get more than 10cm movement

6.The third CT and the **Slow-CT*** are fused. Around the tumor, its movement blurring will be clearly visible. This is the ITV.

7.The treatment is designed on the **Slow-CT*.**



Courtesy Santiago Velazquez


Gating
Capture
CT
Procesing
We can show like cartoon movie
Treatment
Minimun workable interval to treat
NO continous treatment. LONG TREATMENT
Slow CT / Dampening
Capture
CT slide
Procesing/treatment
Bluring edge image
mechanical interval
Continous treatment!. SHORT TREATMENT
=CT slide
=Lung tumor
Courtesy Santiago Velazquez

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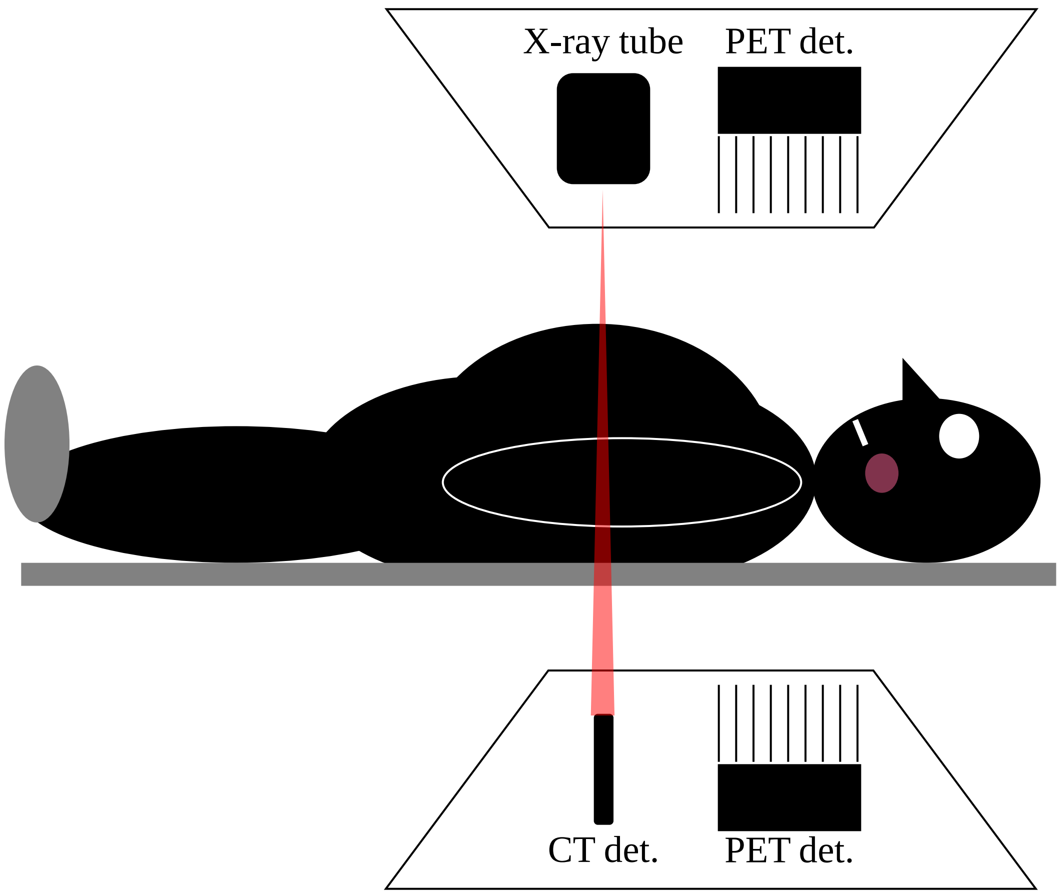
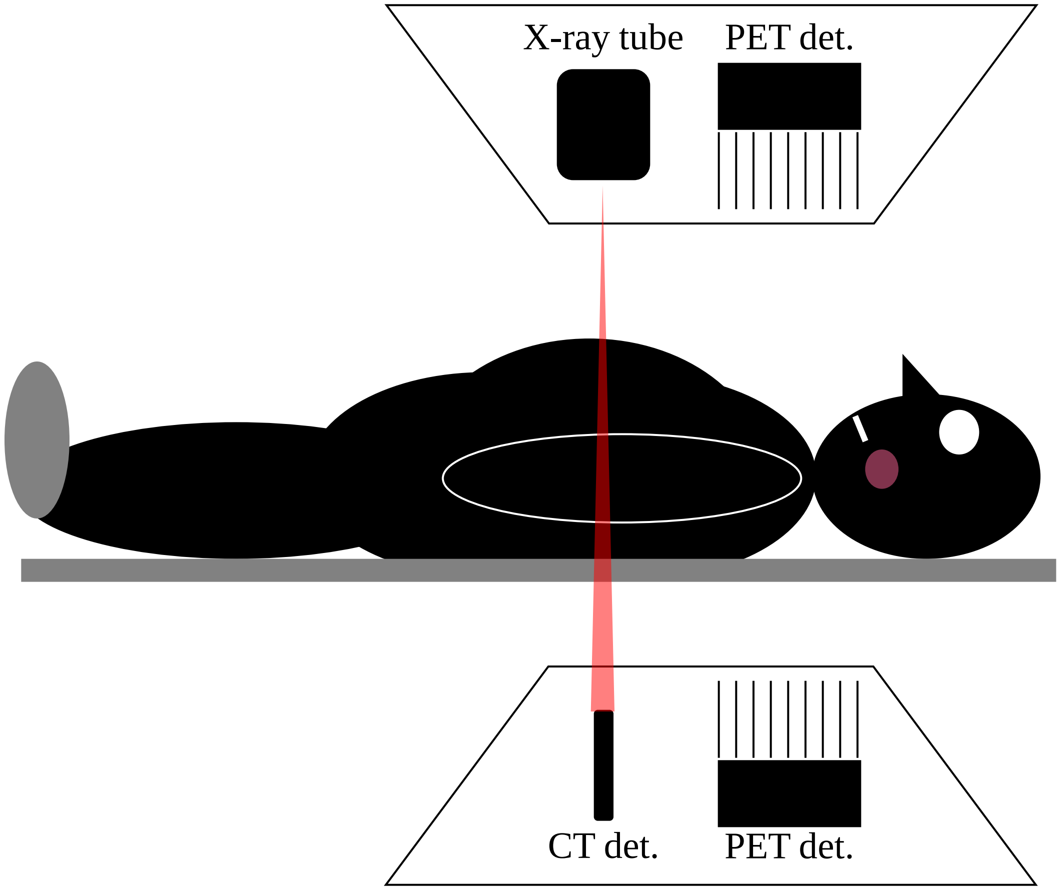
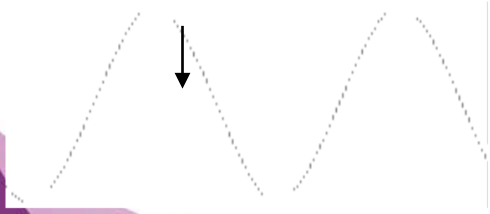
4D-CT Data Acquisition



4D-CT Data Acquisition





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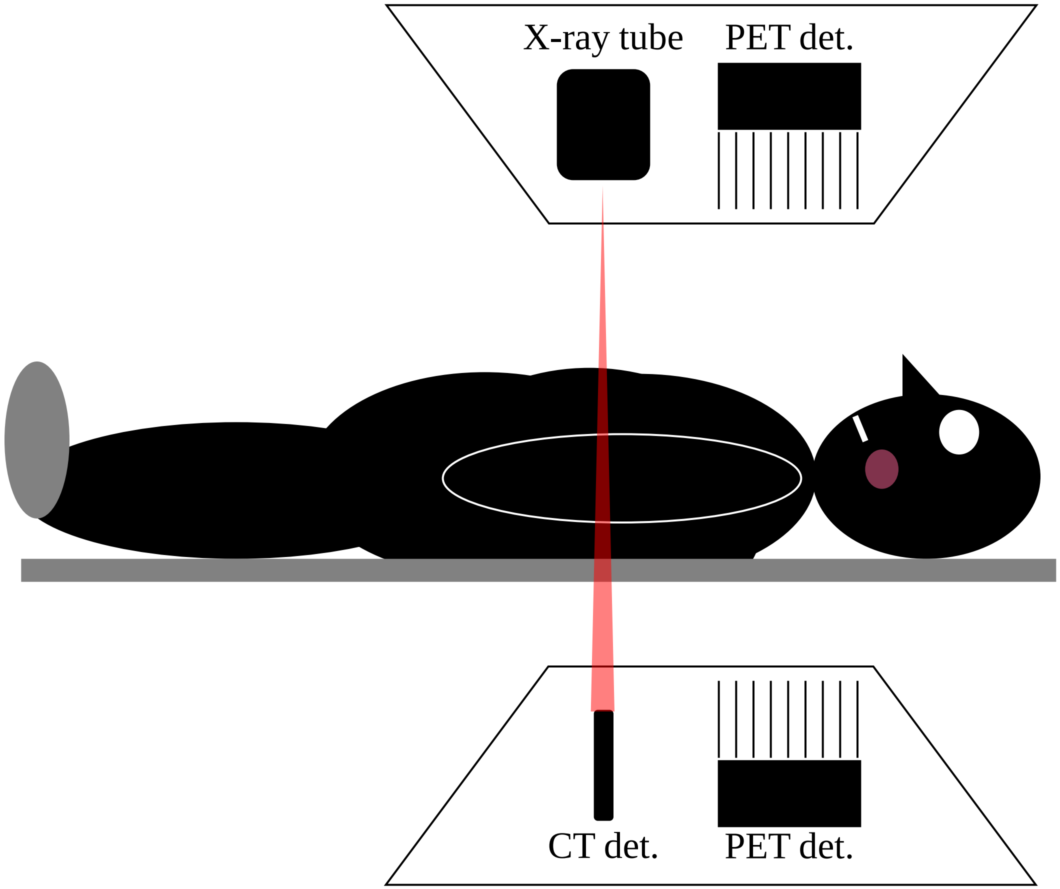
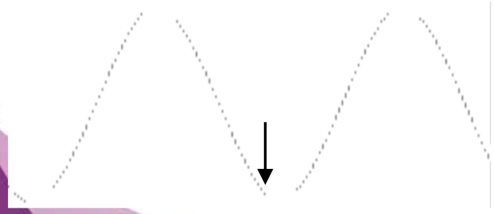
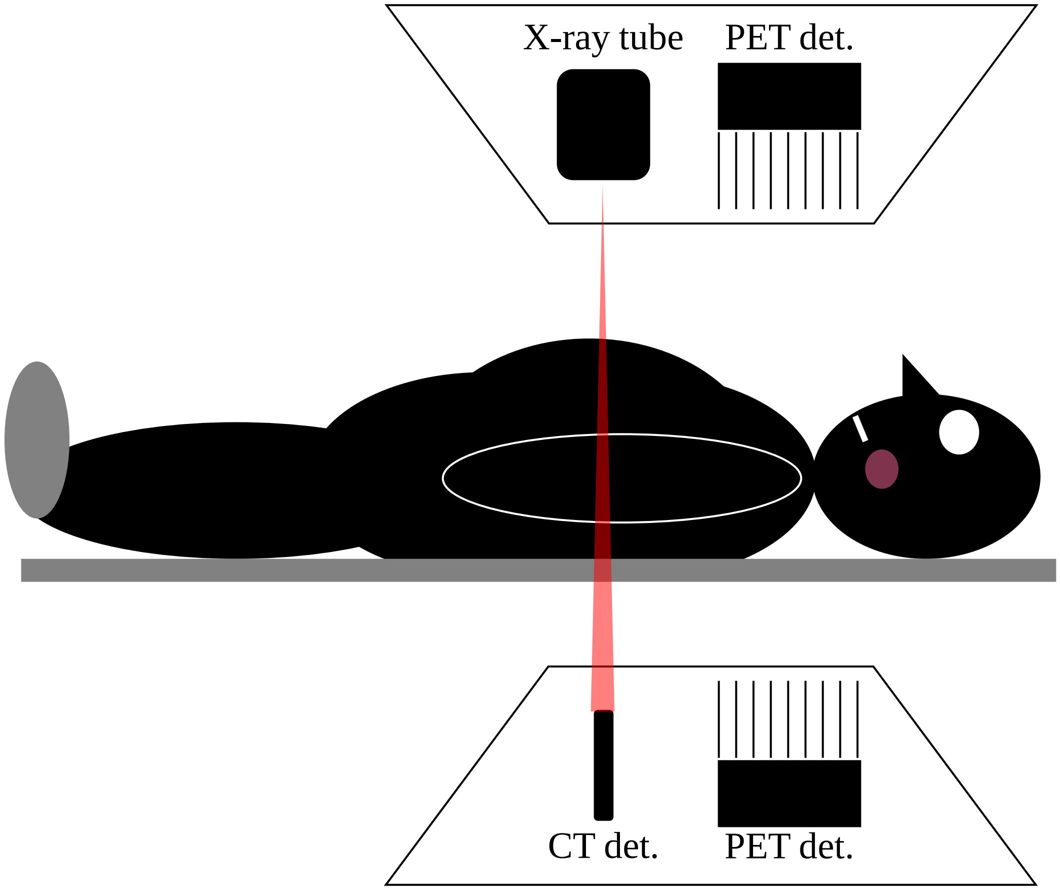
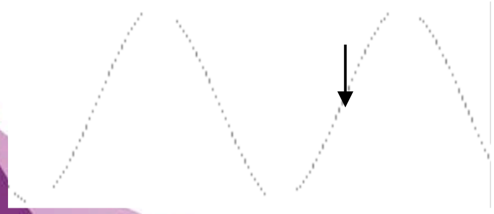


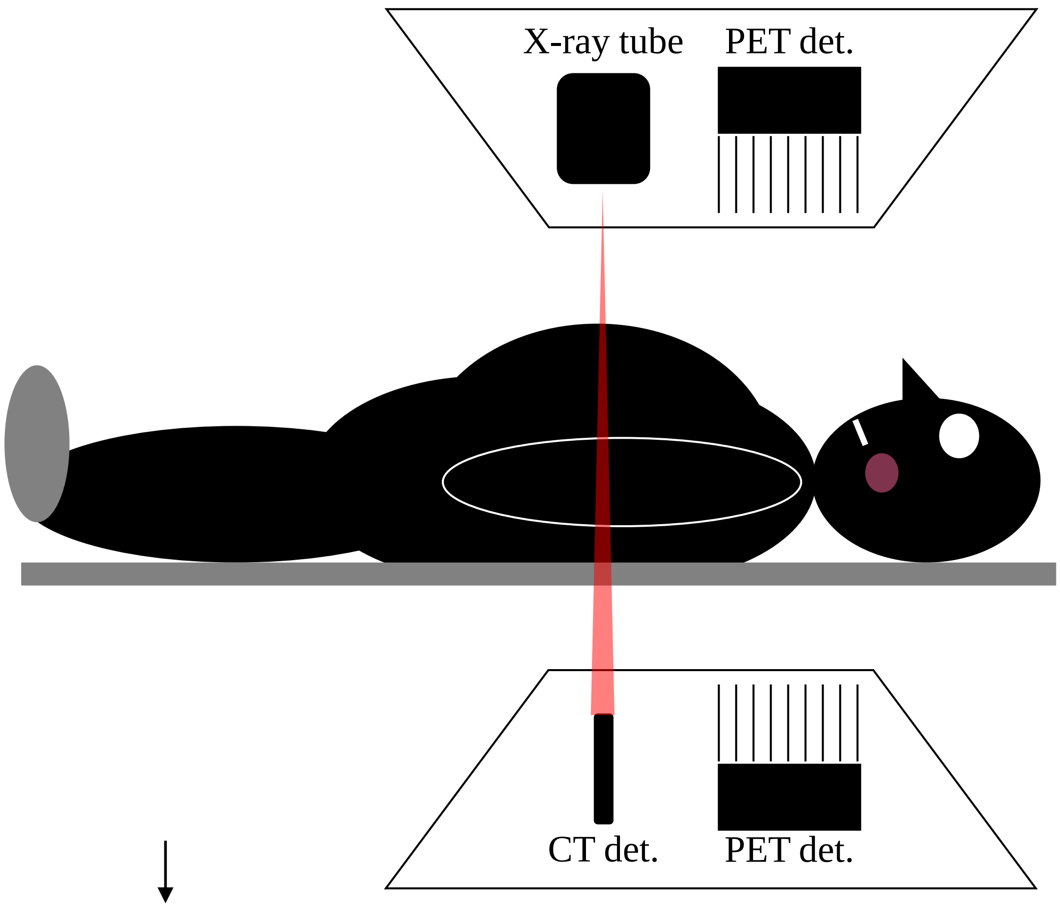


4D-CT Data Acquisition





4D-CT Data Acquisition



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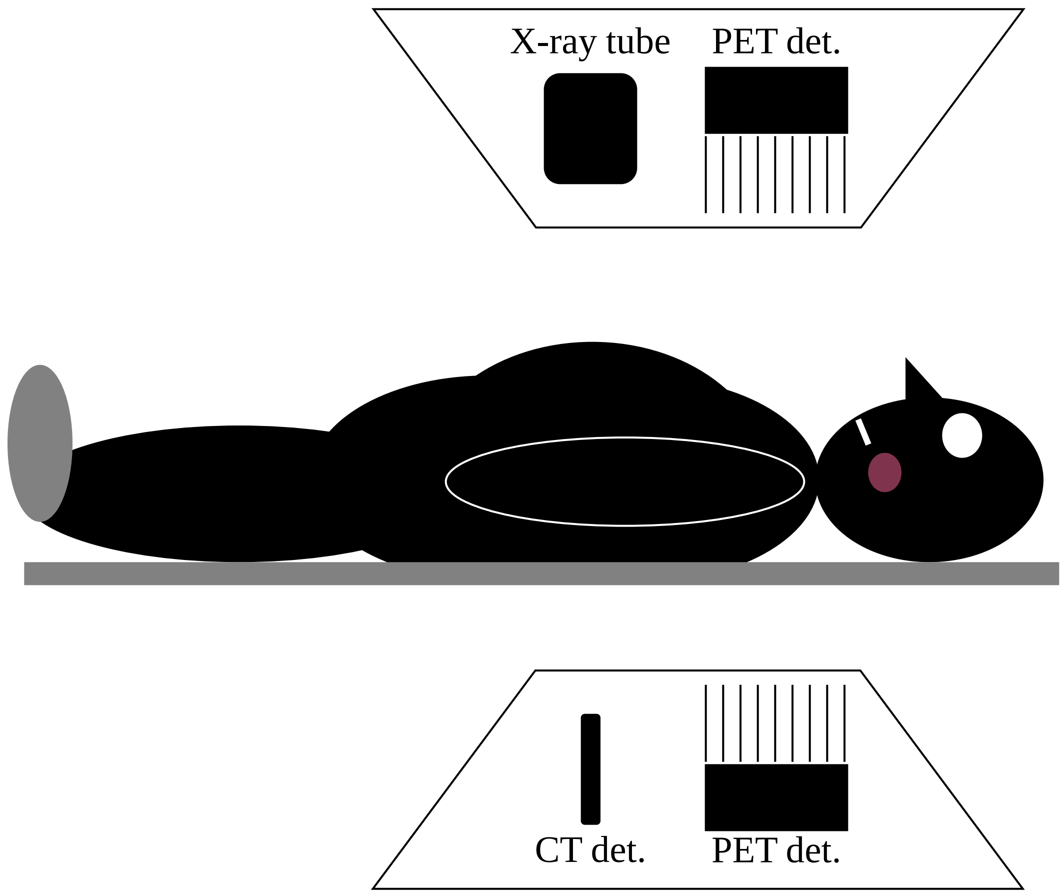

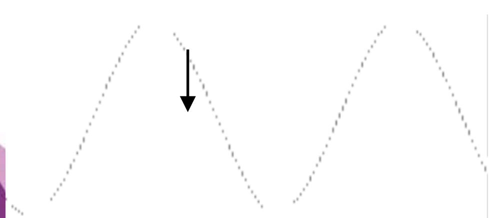

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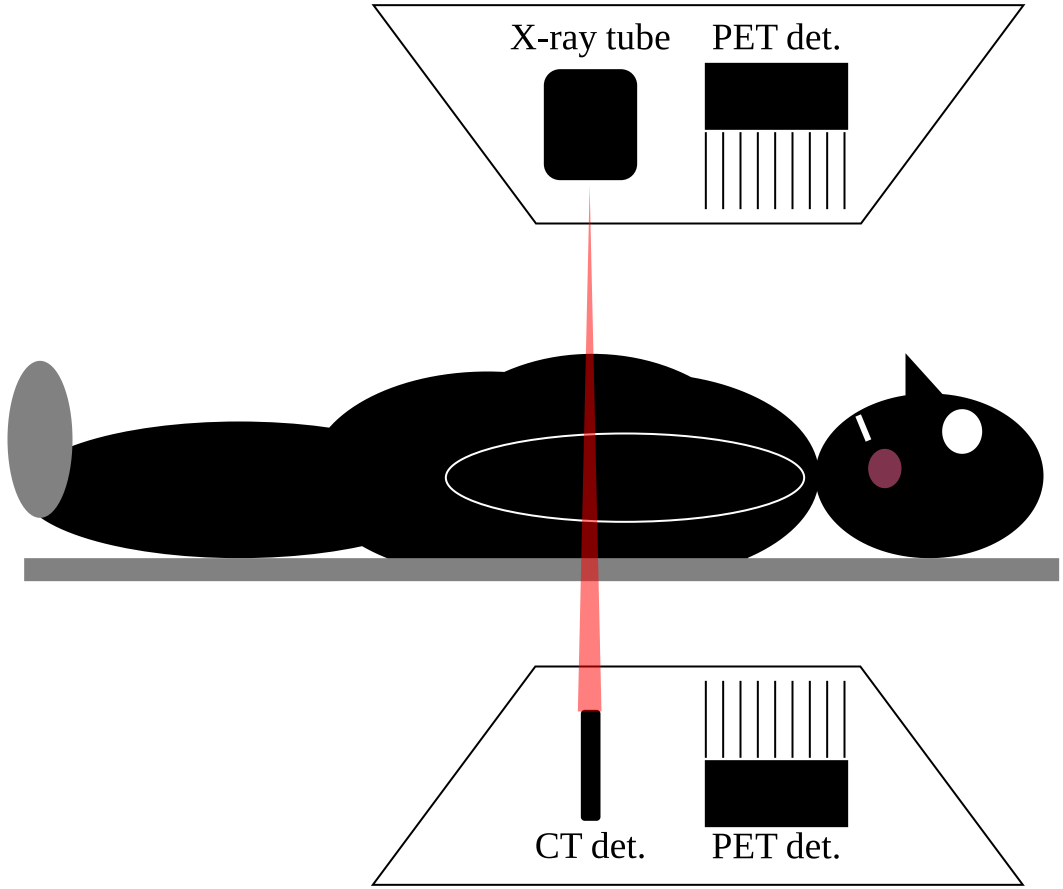
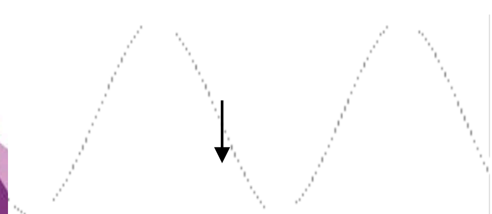
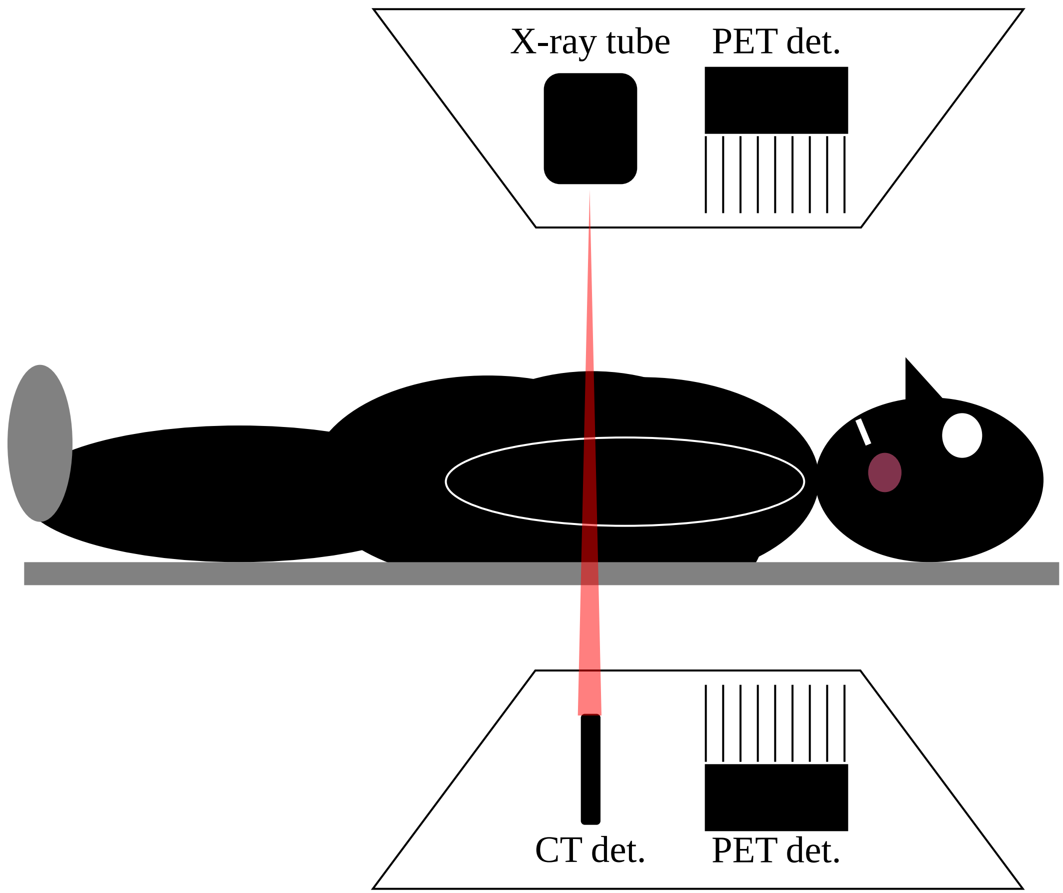
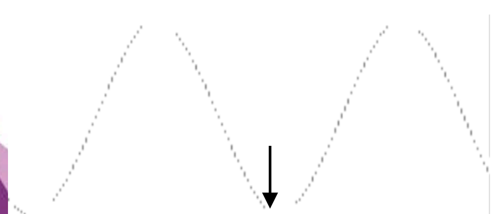


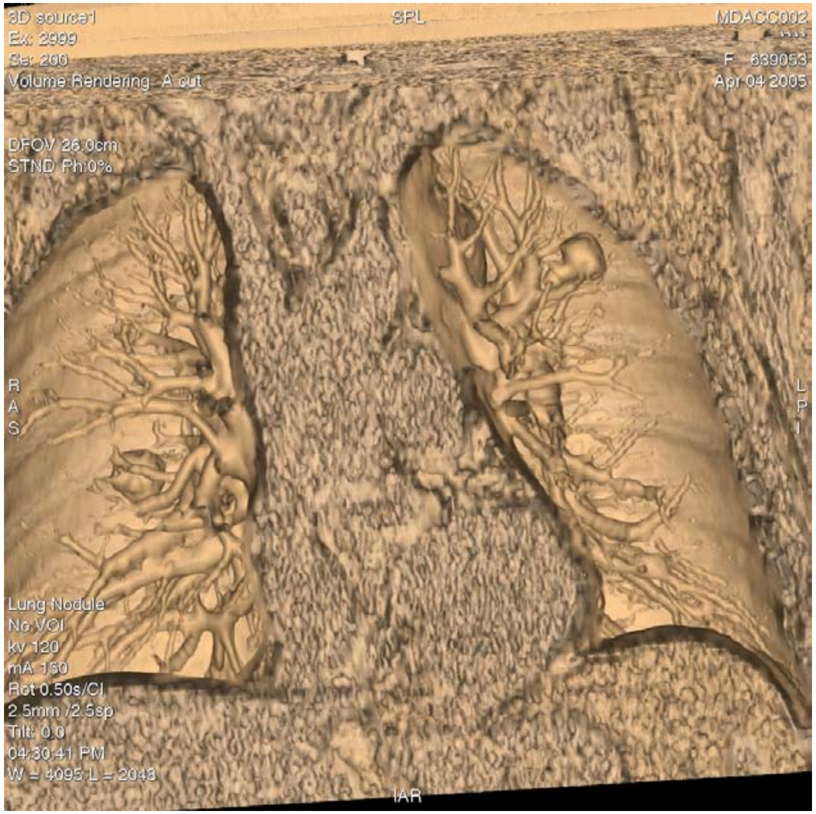


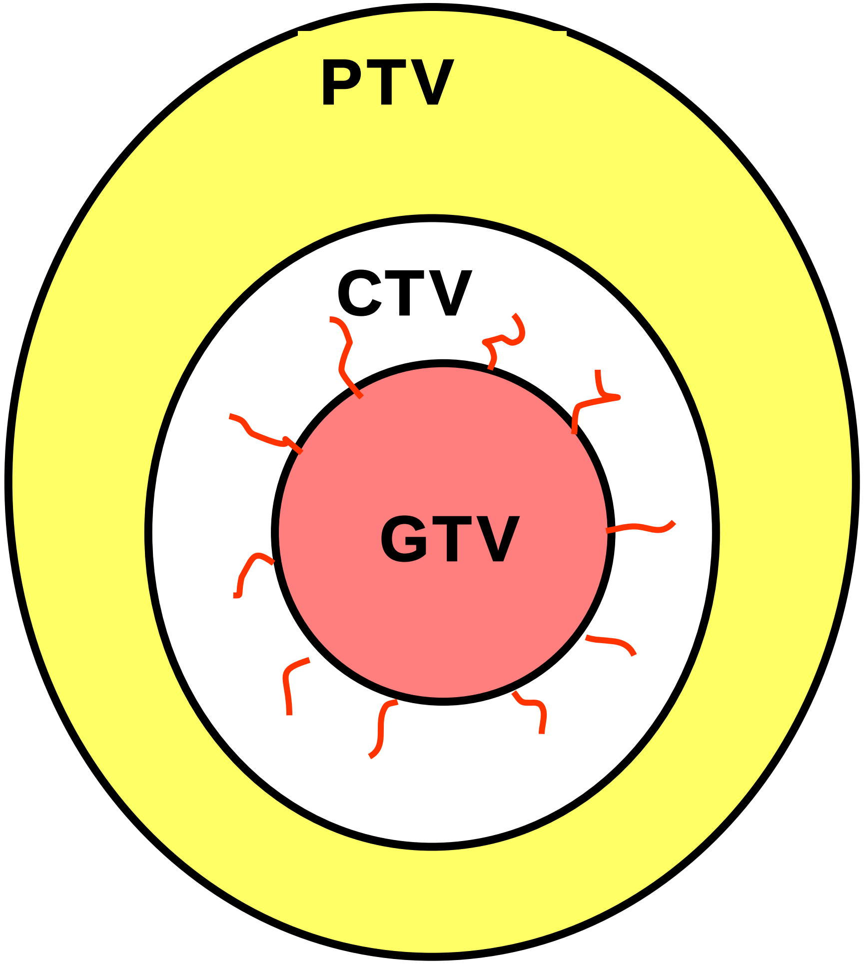
4D-CT Data Acquisition





Tumor motion





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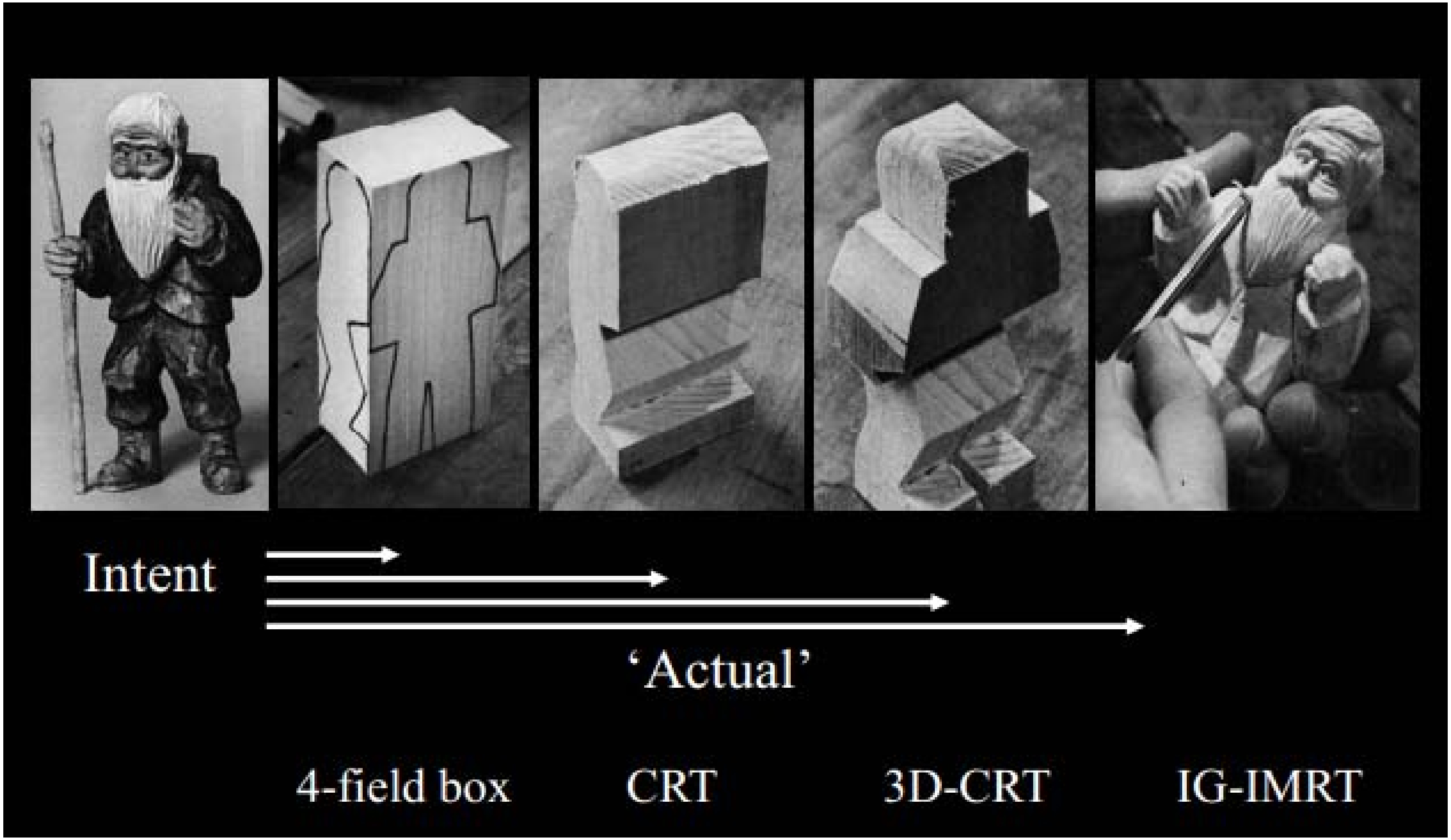
IGRT



http://www.astro.org/uploadedFiles/Main_Site/Meetings_and_Events/Spring_Refresher_Course/Meeting_Program/Jaffray%20Physics.pdf

IGRT

Radiotherapy and Oncology 78 (2006) 119-122
www.thegreenjournal.com

Special commentary

From IMRT to IGRT: Frontierland or Neverland?

C. Clifton Ling[a,*], Ellen Yorke[a], Zvi Fuks[b]

[a]*Department of Medical Physics, and* [b]*Department of Radiation Oncology, Memorial Sloan Kettering Cancer Center, New York, NY, USA*

Abstract

The recent enthusiasm for real-time image guidance in radiotherapy (IGRT) is in part due to the commercial availability of advanced on-line imaging technologies. Perhaps more important than its potential to improve conventional radiotherapy, IGRT may lead to a paradigm shift in facilitating hypo-fractionated or single-dose treatment. However, there are uncertainty regarding features and approaches of competing IGRT systems and as to whether a sub-set of the features of an ideal IGRT system would suffice for specific disease sites and clinical applications. Clinical studies are necessary for the quantification of benefit needed for evidence-based medicine (Bentzen, SM. Radiation therapy: intensity modulated, image guided, biologically optimized and evidence based. Radiat Oncol 2005;77:227-230).
© 2005 Elsevier Ireland Ltd. All rights reserved. Radiotherapy and Oncology 78 (2006) 119-122.

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IGRT

Acta Oncologica, 2008; 47: 1186–1187

informa healthcare

EDITORIAL

Will IGRT live up to its promise?

MARCEL VAN HERK

The Netherlands Cancer Institute/Antoni van Leeuwenhoek Hospital, Amsterdam, the Netherlands

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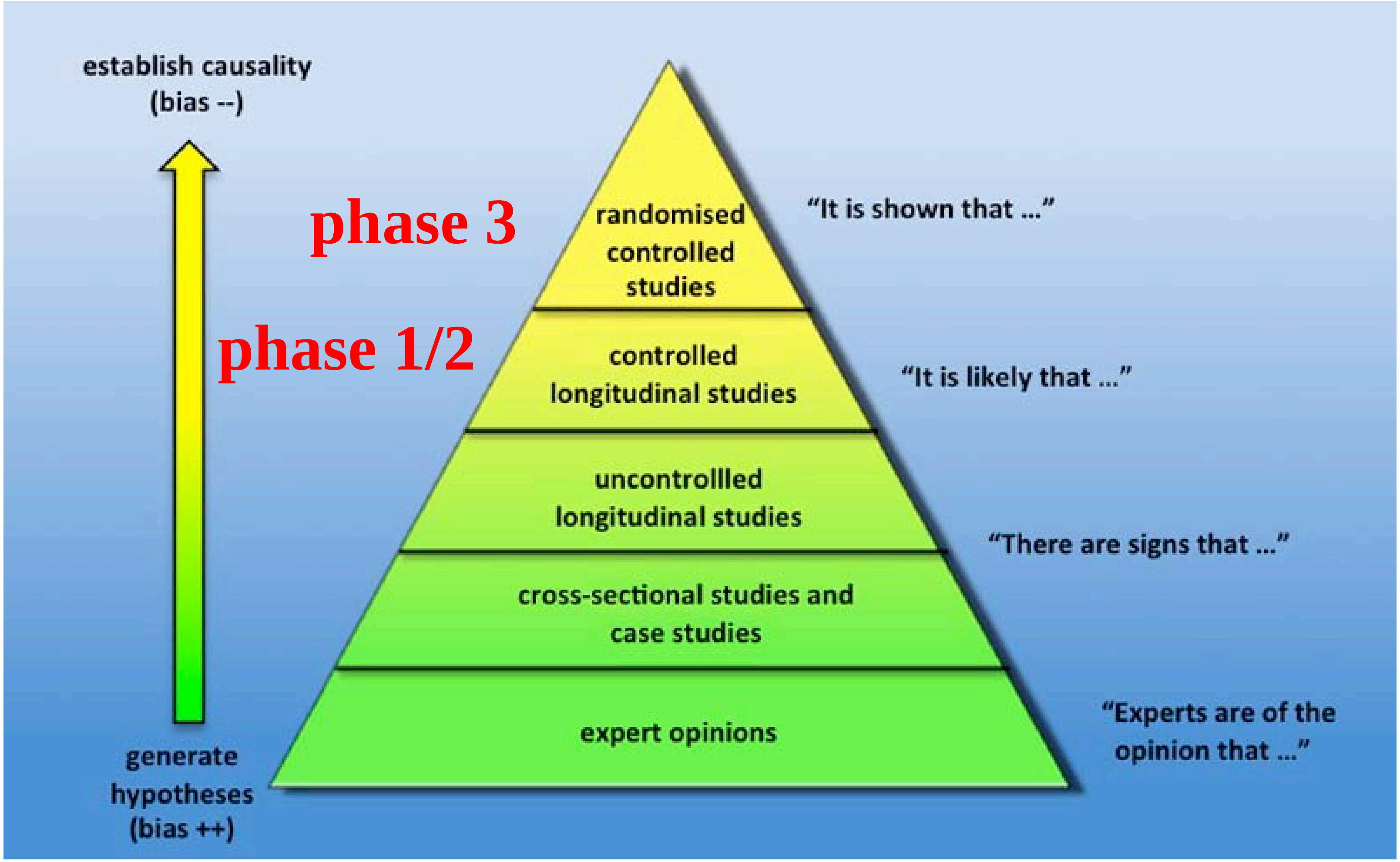
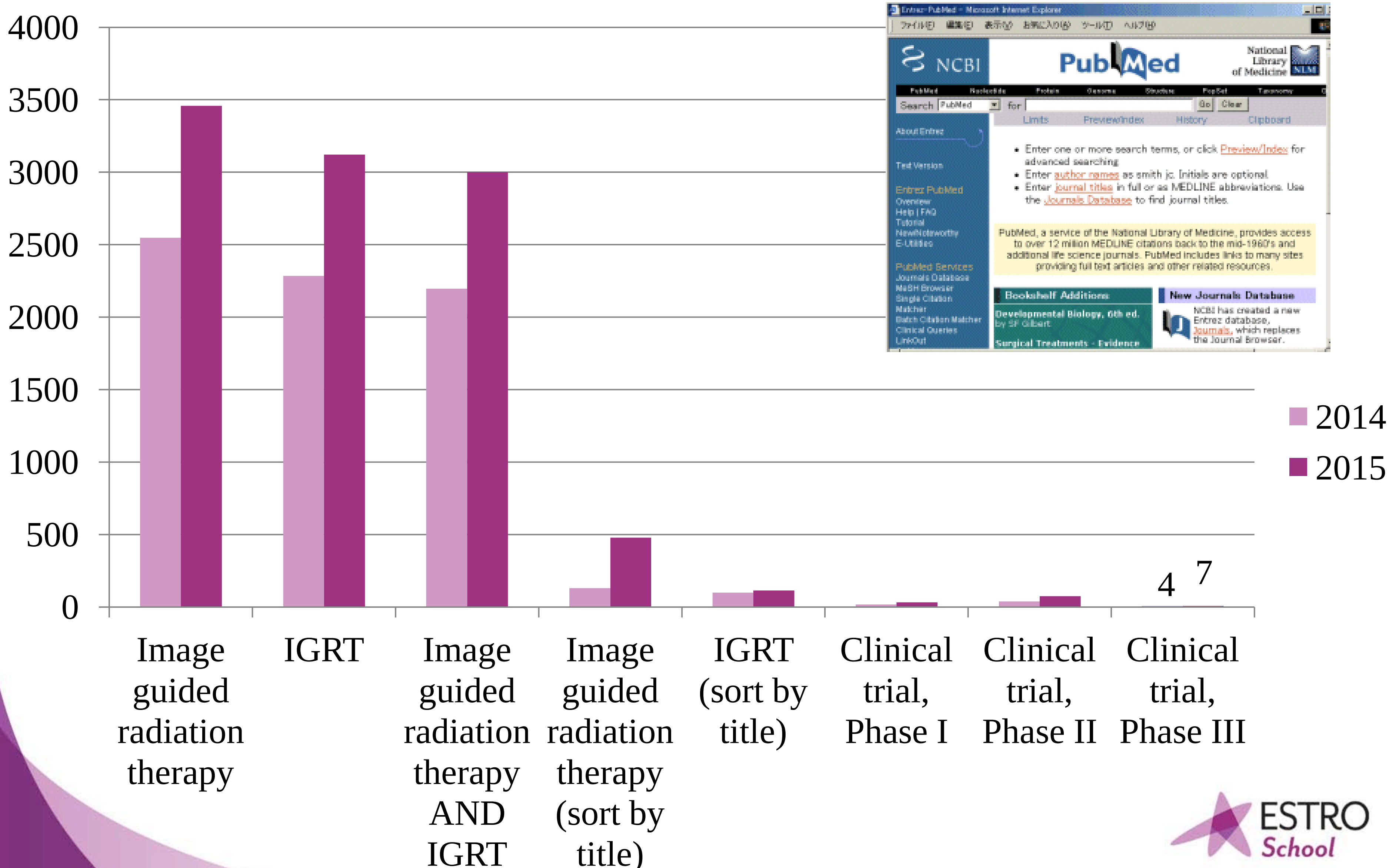
Evidence levels



Cites in Pubmed (2014-2015)



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Clinical trial, Phase III

- Standard-dose versus high-dose conformal radiotherapy with concurrent and consolidation carboplatin plus paclitaxel with or without cetuximab for patients with stage IIIA or IIIB **non-small-cell lung cancer** (RTOG 0617): a randomised, two-by-two factorial phase 3 study

- RTOG 0631 phase 2/3 study of image guided stereotactic radiosurgery for localized (1-3) **spine metastases:** phase 2 results.

- A randomized hypofractionation dose escalation trial for high risk **prostate cancer** patients: interim analysis of acute toxicity and quality of life in 124 patients.

Clinical trial, Phase III

- **Cost** of prostate image-guided radiation therapy: results of a randomized trial.

- Prognostic **impact of abdominal adiposity**, waist circumference and body mass index in patients with intermediate-risk prostate cancer treated with radiotherapy.

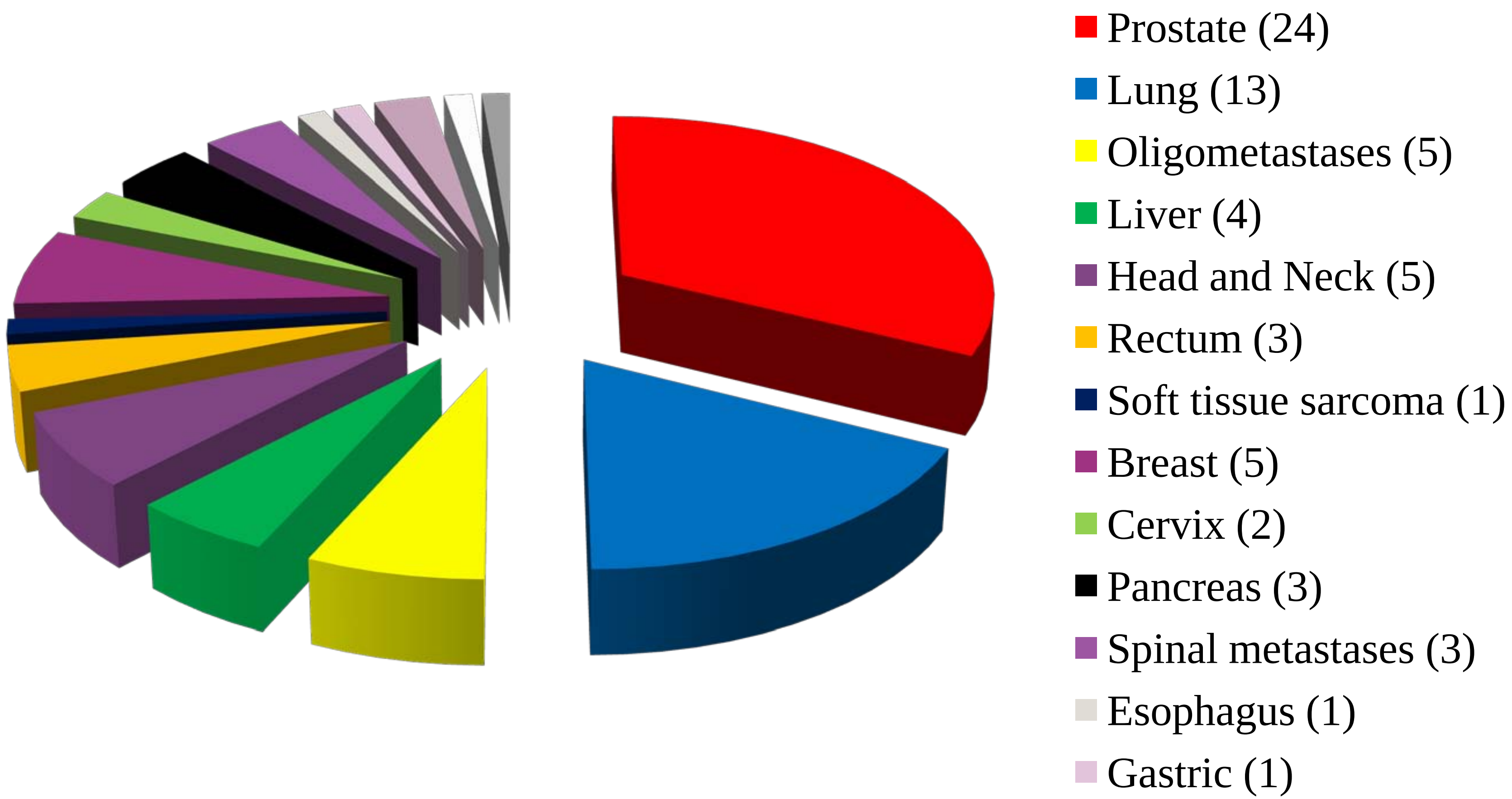
- **Recommendations** for implementing **stereotactic radiotherapy** in peripheral stage IA non-small cell lung cancer: report from the Quality Assurance Working Party of the randomised phase III ROSEL study.

- **Dosimetric experience** with accelerated partial breast irradiation using image-guided interstitial brachytherapy.

COST and TIME

- N=208 patients (France)
- Daily CBCT: 21 min
- Daily CBCT: 21.0 min. Daily EPI-FM: 18.3 min
- Increasing the control frequency from weekly to daily increased by 7.3 min **(+53%)** for CBCT and 1.7 min **(+10%)** for EPI-FM ($p \leq 0.01$).
- The additional cost per patient of daily compared with weekly controls was **€679** and **€187** for CBCT and EPI-FM, respectively ($p<0.0001$).
- Conclusions: The incremental costs due to different prostate IGRT strategies are relatively **moderate**.

Clinical trial, Phase II (N = 74)



Toxicity

Grade 0	None
Grade 1	Mild
Grade 2	Moderete
Grade 3	Severe
Grade 4	Intensive care
Grade 5	Fatal

Phase II (Prostate)

Table 1 Patient and treatment characteristics

Variable	3D-CRT (n=215)	IG-IMRT (n=260)
Mean (±SD), y	68.9 (±6.3%)	70.5 (±6.0%)
T category		
1	36 (16.7%)	40 (15.4%)
2	97 (45.1%)	89 (34.2%)
3a	53 (24.7%)	102 (39.2%)
3b	29 (13.5%)	28 (10.8%)
4	0	1 (0.4%)
Gleason score		
2-6	106 (49.3%)	75 (28.8%)
7	81 (37.7%)	119 (45.8%)
8-10	28 (13.0%)	66 (25.4%)
Median prehormone PSA concentration, Indeed "Median initial PSA concentration" µg/L (range)	11.3 (0.4-57.0)	15.0 (1.8-59.6)

SIMILAR GROUPS

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Int J Radiation Oncol Biol Phys, Vol. 91, No. 4, pp. 737–744, 2015

Treatment

	3D	IG-IMRT
Risk category		
Low	34 (15.8%)	0
Intermediate	72 (33.5%)	75 (28.8%)
High	109 (50.7%)	185 (71.2%)
Seminal vesicle dose (Gy)		
0	43 (20.0%)	50 (19.2%)
50	35 (16.3%)	0
68	101 (47.0%)	0
70	0	125 (48.1%)
78	36 (16.7%)	85 (32.7%)
Planning margins (mm)		
5	0	107 (41.3%)
6-8	0	151 (58.3%)
10	215 (100%)	1 (0.4%)
Hormone therapy	42 (19.5%)	174 (66.9%)
TURP	24 (11.2%)	28 (10.8%)
Diabetes mellitus	12 (5.6%)	29 (11.2%)
Abdominal surgery	57 (26.5%)	65 (25.0%)
Smoking	34 (15.8%)	28 (15.0%)

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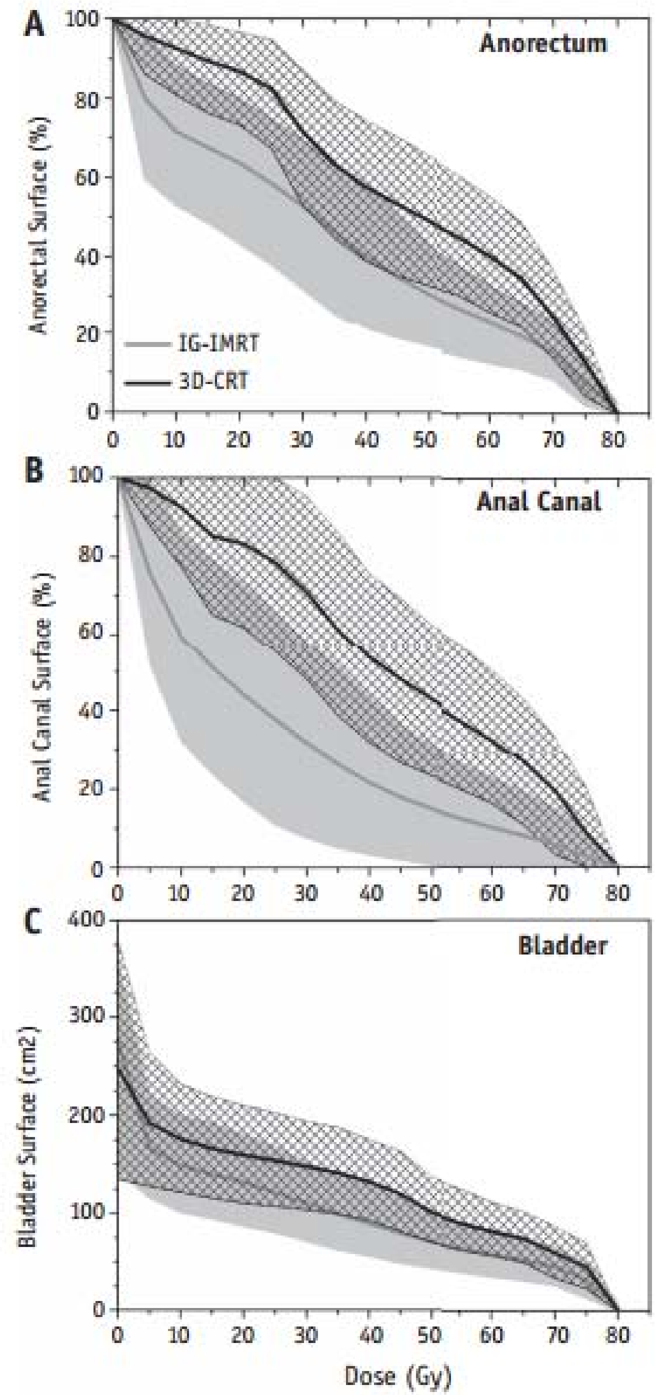
Int J Radiation Oncol Biol Phys, Vol. 91, No. 4, pp. 737–744, 2015



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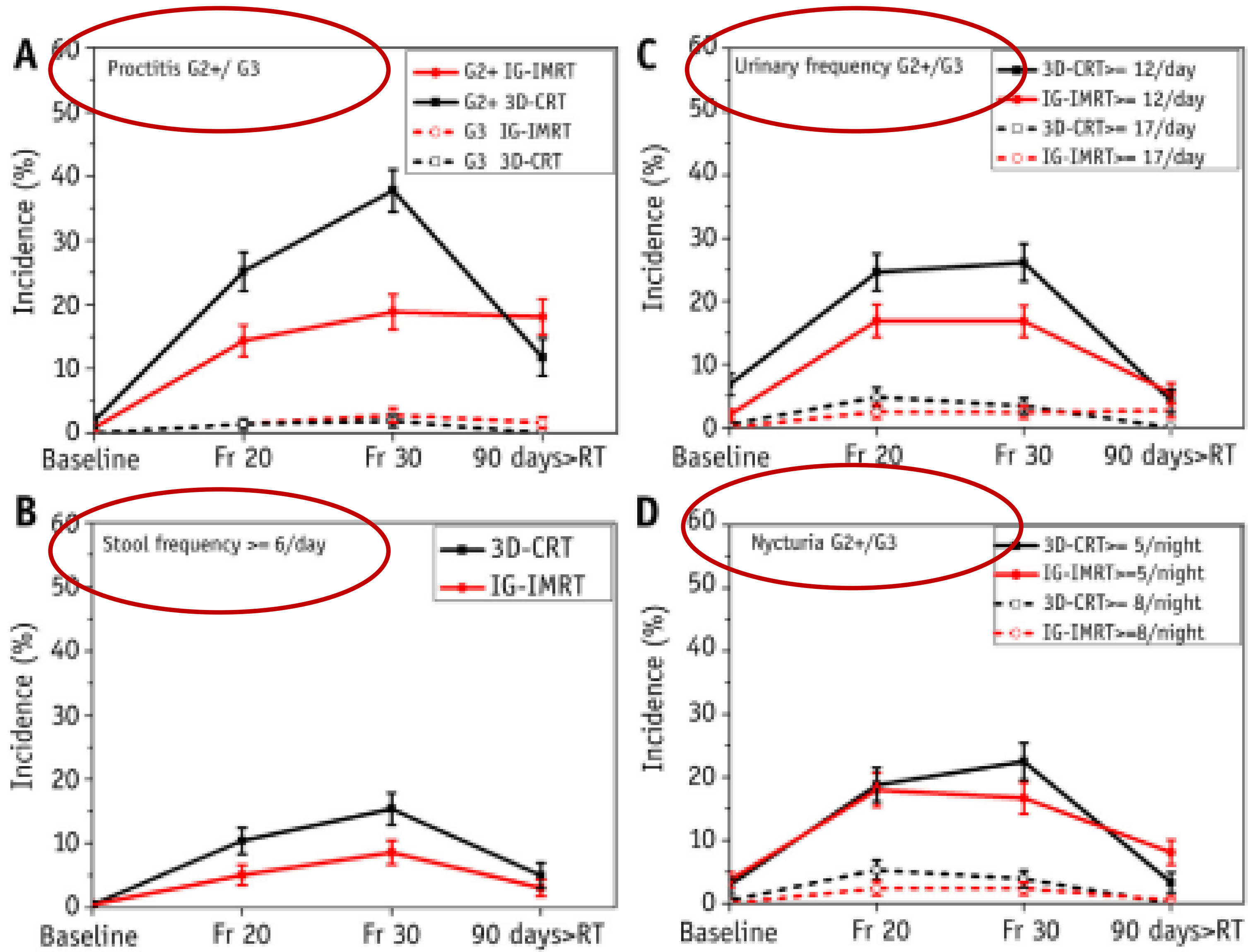
TOXICITY



Int J Radiation Oncol Biol Phys, Vol. 91, No. 4, pp. 737–744, 2015

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Prostate IGRT

ARTICLE IN PRESS

Radiotherapy and Oncology xxx (2014) xxx–xxx

ELSEVIER

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Original article

Is "pelvic radiation disease" always the cause of bowel symptoms following prostate cancer intensity-modulated radiotherapy?

Myo Min[a,*], Benjamin Chua[a], Yvonne Guttner[d], Ned Abraham[d], Noel J. Aherne[a], Matthew Hoffmann[b], Michael J. McKay[c,*,1], Thomas P. Shakespeare[a,1]

[a] North Coast Cancer Institute, Coffs Harbour; [b] North Coast Cancer Institute, Port Macquarie; [c] North Coast Cancer Institute, Lismore; [d] Coffs Harbour Hospital, Australia

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Prostate IGRT

- Multicenter study
- Postop prostate cancer
- N=102
- Bowel symptoms or positive faecal occult blood tests
- F/u: > 3 months + endoscopic examination
- IMRT-IGRT
- Dose: 74-78 Gy at 1,8-2 Gy/fx
- Endoscopy findings:

56% Polyps
49% Diverticular disease
38% Haemorrhoids
29% radiation proctopathy with associated pathology
4% radiation proctopathy alone

Myo M et al. Radiother Oncol. 2014, in press

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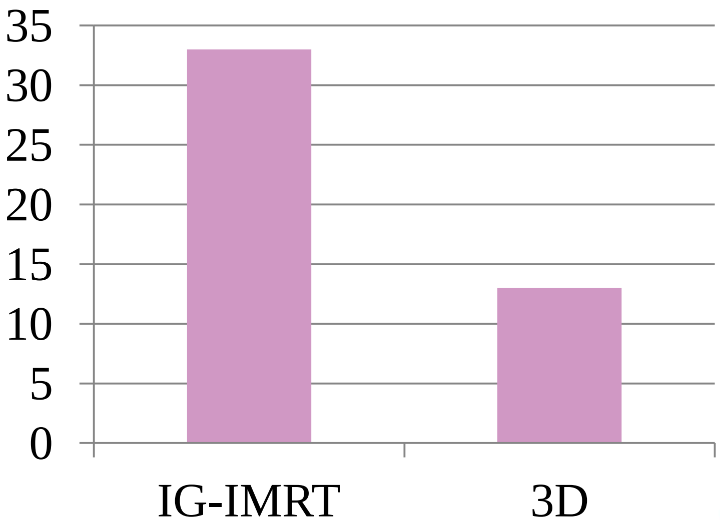
Clinical trial, Phase II (hepatocellular carcinoma)

- IG-IMRT (N=65) vs 3D (N=122)
- Stage III-IV
- Period: 2006-2011
- Dose: 62 Gy for IG-IMRT and 53 Gy for 3D

- **No differences in toxicity**
- **Survival at 3 years:**



J Cancer Res Clin Oncol. 2014 Sep;140(9):1595-605

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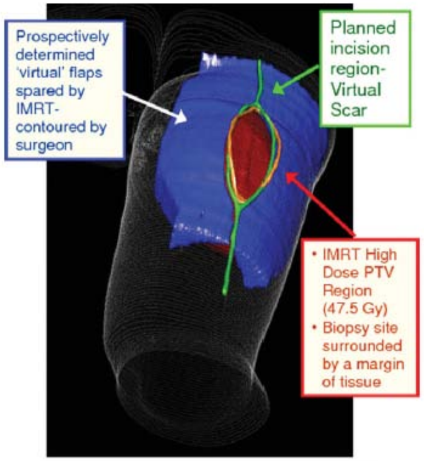
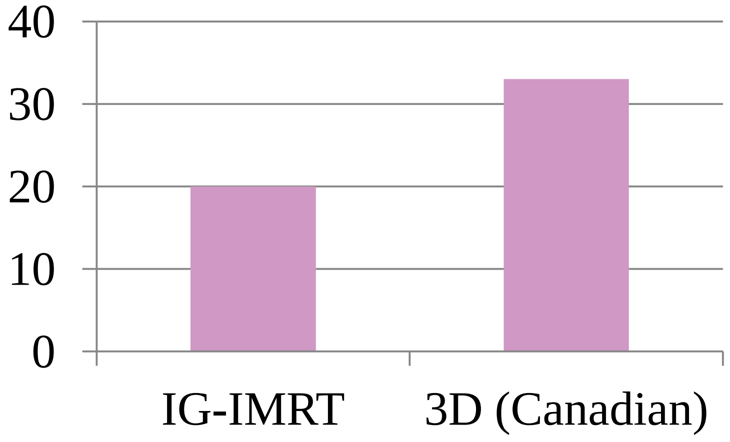
Clinical trial, Phase II (Sarcoma)

- Single Institution study
- Lower extremity soft tissue sarcoma
- N=56, mediam age 69 y.
- Period: 2005-2009
- F/u: 4 y.
- IG-IMRT
- Dose: 50 Gy at 2 Gy/fx



Multi-disciplinary STS phase II study protocol investigating high precision pre-operative IMRT to spare tissues from surgery and RT morbidity

- **Acute wound complication:**
- Local control 88%
- OS: 74%



O'Sullivan B, et al. Cancer. 2013 May 15;119(10):1878-84.

Clinical trial, Phase II (Lung)

- Multicenter study
- Inoperable T1/T2 NSCLC
- N=60, mediam age 75 y.
- Period: 2003-2005
- F/u: 2 y.

- SBRT
- Dose: 45 Gy at 15 Gy/fx
- **Grade 3 toxicity: 21%**
- Local control 96%
- OS: 65%; CSS: 80%

Table 3
Lung-related toxicity maximum grade per patient number of affected patients

Toxicity	CVD (17 patients)		COPD (40 patients)	
	Gr 1–2	Gr 3	Gr 1–2	Gr 3
Cough	4	–	11	1
Dyspnoea	2	2	8	2
Pneumonia	–	–	1	1
Pneumonitis	3	–	7	–
Fibrosis	8	1	12	1
Atelectasis	3	1	3	–
Pleural effusion	6	2	5	–
Heart disorder	1	–	–	1
Esophagitis	1	–	1	–

Toxicity grading was done according to CTC v2. Radiation-related pulmonary fibrosis >90 days post-treatment was graded according to RTOG/EORTC Late Radiation Morbidity Scoring Scheme.
Maximum grade refers to the highest degree of toxicity recorded during follow-up. CVD, cardiovascular disease; COPD, chronic obstructive pulmonary disease.

Table 4
General toxicity maximum grade per patient number of affected patients

Toxicity	CVD (17 patients)		COPD (40 patients)	
	Gr 1–2	Gr 3	Gr 1–2	Gr 3
Skin	7	–	18	–
Pain	4	2	5	–
Rib fracture	1	1	2	–
Upper airway infection	1	–	2	–
Fever	2	–	2	–
Nausea	2	–	3	–
Emesis	2	–	3	–
Fatigue	5	1	11	–

Toxicity grading was done according to CTC v2.
Maximum grade refers to the highest degree of toxicity recorded during follow-up. CVD, cardiovascular disease; COPD, chronic obstructive pulmonary disease.

Baumann et al. Radiotherapy and Oncology 88 (2008) 359–367

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Clinical trial, Phase II (oligometastases)

- Single Institution study
- Oligometastases, defined as 1–5 sites
- N=25, mediam age 69 y.
- Period: 2004-2006
- F/u: 17,5 m.
- SBRT
- Dose: 50 Gy at 5 Gy/fx + sunitinib

- **Grade 3 toxicity: 28%**
- Local control 75%
- OS: 71%; PFS: 56%

Table 2. Adverse Events.

Adverse Event	All grades	Grade 3	Grade 4	Grade 5
Anemia	18	2	0	0
Neutropenia	14	2	0	0
Fatigue	18	0	0	0
LFT abnormalities	15	1	0	0
Thrombocytopenia	15	4	0	0
Mucositis/stomatitis	8	0	0	0
Nausea/vomiting	7	0	0	0
Skin changes	4	0	0	0
Diarrhea	5	0	0	0
Hypertension	3	0	0	0
Bleeding	4	1	0	1*
Metabolic abnormalities	2	1 (PO_4)	0	0
Increased creatinine	5	0	0	0

*One case occurred after sunitinib treatment and was likely related to reirradiation performed prior to protocol therapy.
doi:10.1371/journal.pone.0036979.t002

Tong CC, et al. PLoS One. 2012;7(6):e36979.

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Clinical trial, Phase II (head and neck)

- Multicenter study
- Reirradiation (mean time 38 months)
- Recurrent head and neck cancer
- N=60, mediam age 69 y.
- Period: 2007-2010

- **Grade 3 toxicity: 18%**
- RECIST complete response 49%
- OS: 47,5%
- F/u: 11,4 m.
- SBRT
- Dose: 36 Gy at 6 Gy/fx + cetuximab

Table 1
Grade 3 toxicities and cutaneous toxicity.

Grade ⩾ 3 AE related to study treatment (*N* = 56)	*n*	Appearance of toxicity
Cutaneous		
Rash	4	<3 months
Cutaneous toxicity	1	<3 months
Fibrosis	1	3–6 months
GastroIntestinal		
Mucositis	4	<3 months
Dysphagia	3	<3 months
Xerostomia	2	3–6 months
Fistula (oral cavity)	1	>6 months
Dysgeusia	1	<3 months
Cutaneous toxicity (*N* = 56)	**Related to cetuximab and/or radiotherapy**	**Related to cetuximab**
Cutaneous toxicity, *n* (%)	47 (84)	41 (73)
NK	1 (2)	1 (2)
Grade 1	14 (25)	14 (25)
Grade 2	27 (48)	22 (39)
Grade 3	5 (9)	4 (7)

Lartigau et al. Radiotherapy and Oncology 109 (2013) 281–285

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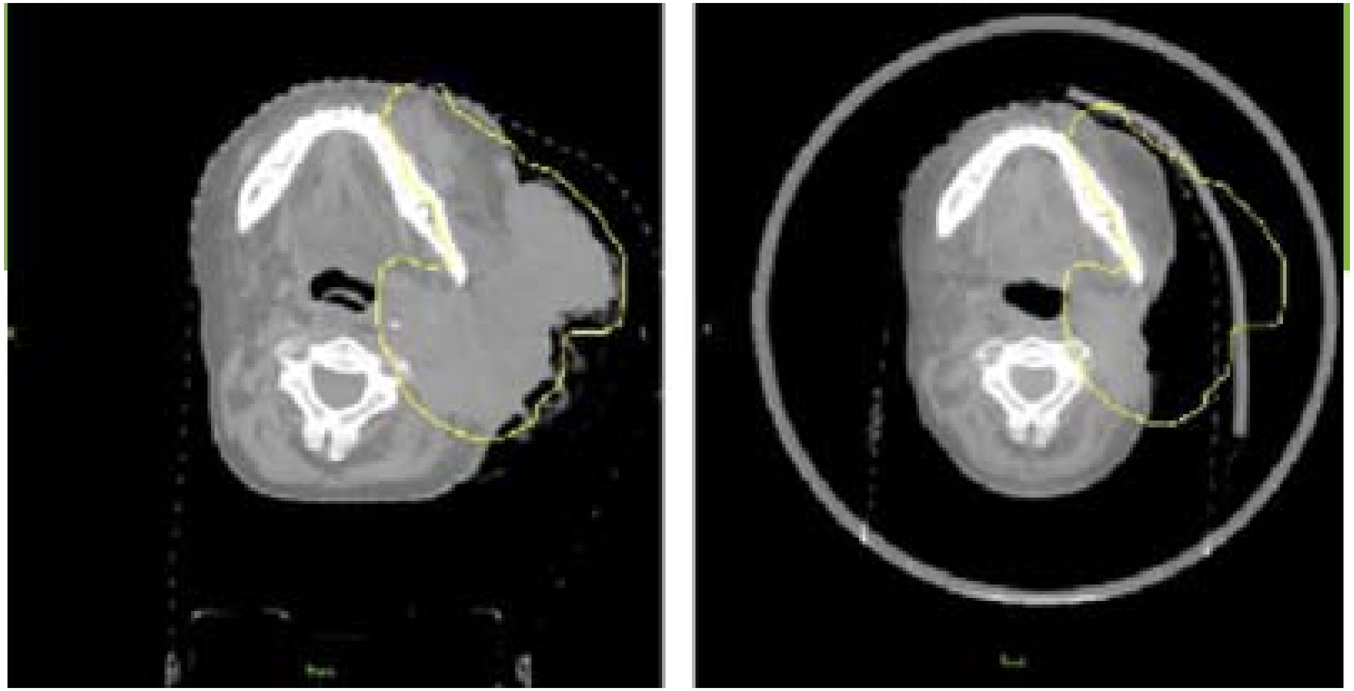


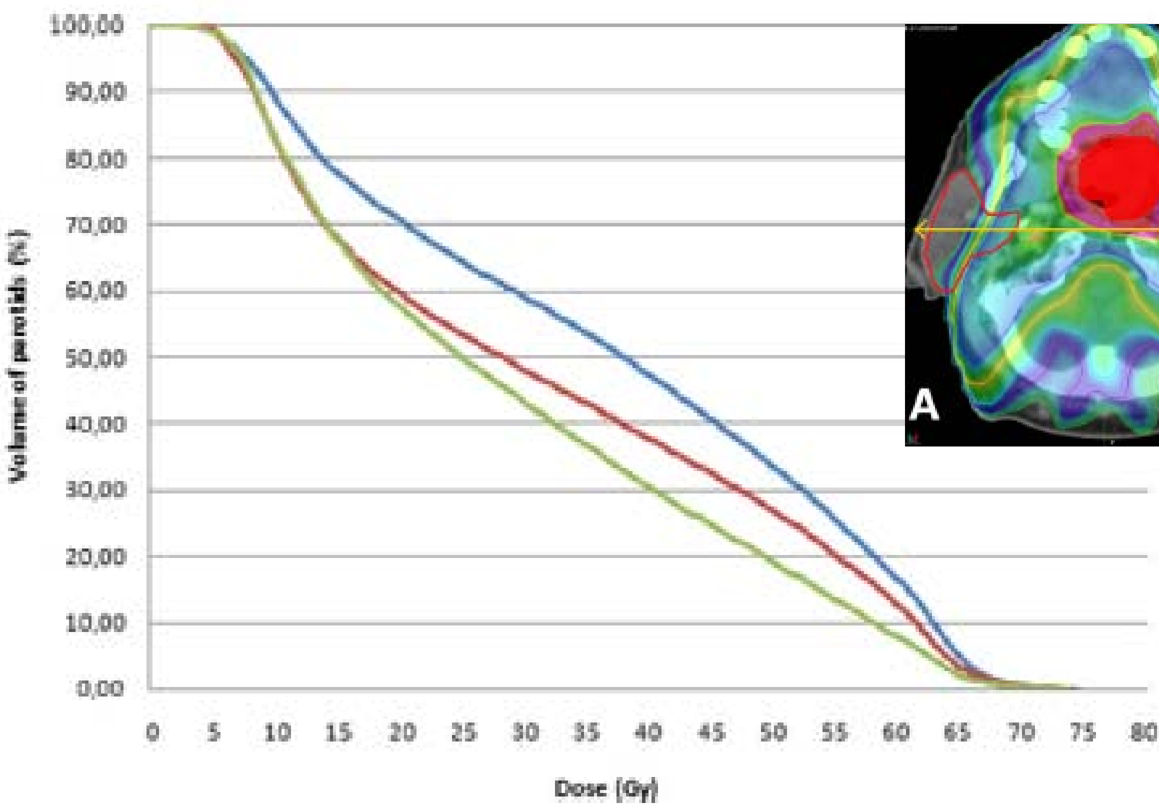
Corresponding axial CT slices from the beginning and the end of treatment.

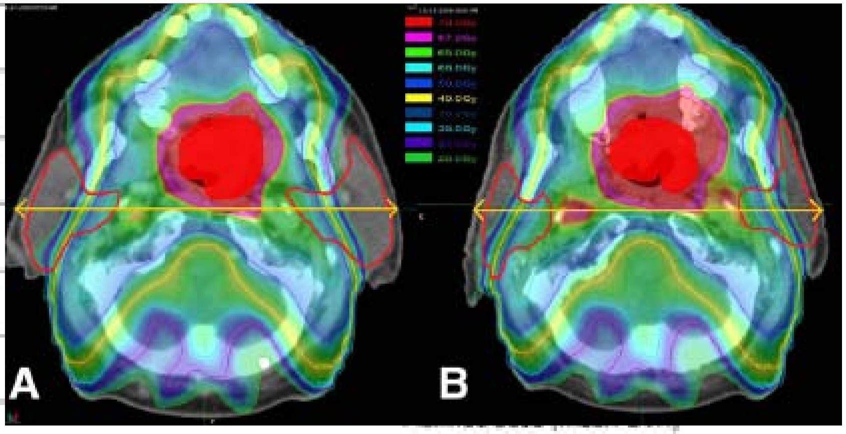
The volume of the PTV changed from 606 to 336 cm3 over treatment, a decrease of 45%.

Spinal cord D05 differed from the planned value by 3.5 +/- 9.8%

Mechalakos J et al. Med Dosim. 2009 Fall;34(3):250-5.

Adaptive radiotherapy





Head and Neck
N=15
IG-IMRT

60% of the PGs are overdosed of 4 Gy.

Replanning decreased the PG mean dose by 5 Gy, and 11% the xerostomia risk.

Castelli et al. Radiation Oncology (2015) 10:6

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CONCLUSIONS: Why IGRT?

- Security
- Precision
- Accuracy (dose escalation)
- Homogeneity
- Less toxicity
- Reliability
- Refinement of treatment
- Adapt to changes in antomy
- Shortening RT

FUTURE DIRECTIONS (phase III studies on-going)

- A Randomised, Two Centre Trial on Daily Cone-beam vs Standard Weekly Orthogonal Image Guided Radiotherapy (IGRT) for **Prostate Cancer.**
- Hypofractionated Image-Guided Radiation Therapy (IGRT) in Patients With Stage II-III Non-Small Cell **Lung Cancer**.
- Biological Image Guided Antalgic Stereotactic Body Radiotherapy of **Bone Metastases**: a Randomized Phase II/III Trial
- Evaluation of 3DCRT Versus IGRT and Analysis of Early Response in **Head and Neck Cancer**.
- Tomotherapy vs Conventional Radiation for Adjuvant Pelvic RT in **Ca Cervix.**
- **Can 3D Ultrasound Be Used Reproducibly by Radiation Therapists in Partial Breast Image-Guided Radiation Therapy?**

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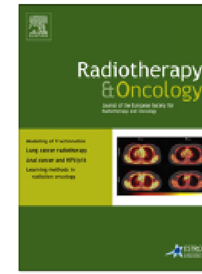
FUTURE DIRECTIONS

Radiotherapy and Oncology 109 (2013) 165–169

Contents lists available at SciVerse ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com



Learning methods in radiation oncology

The utility of e-Learning to support training for a multicentre bladder online adaptive radiotherapy trial (TROG 10.01-BOLART)

Farshad Foroudi [a,*], Daniel Pham [a], Mathias Bressel [b], David Tongs [a], Aldo Rolfo [a,1], Colin Styles [a], Suki Gill [a], Tomas Kron [a]

[a] *Division of Radiation Oncology and Cancer Imaging, Peter MacCallum Cancer Centre, Melbourne, Australia;* [b] *Centre for Biostatistics and Clinical Trials, Peter MacCallum Cancer Centre, Melbourne, Australia*

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IGRT confidence and knowledge

- To demonstrate the utility of an e-Learning programme for providing training and information regarding a multi-centre **IGRT** trial.
- Participants : **185 RTTs** from 12 centres.
- There was **an increase confidence after** completion of modules ($p < 0.001$).
- The pre **scores increased** from 67 $\pm$ 11 ⇨ 79 $\pm$ 8
- ($p < 0.001$) post
- Conclusions: **e-Learning** for a multi-centre clinical trial was feasible and **improved confidence and knowledge.**

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IGRT confidence and knowledge

Confidence questions	Pre e-Learning		Post e-Learning		p-Value
	n	Percentage	n	Percentage	
Identifying bladder on CT					<0.001
Not confident	0	0.0	0	0.0	
A little confident	20	10.8	4	2.2	
Somewhat confident	60	32.4	31	16.8	
Quite confident	69	37.3	102	55.1	
Very confident	36	19.5	48	25.9	
Identifying soft tissue anatomies on pelvic CBCT					<0.001
Not confident	13	7.0	0	0	
A little confident	49	26.5	7	3.8	
Somewhat confident	80	43.2	71	38.4	
Quite confident	39	21.1	91	49.2	
Very confident	4	2.2	16	8.6	
Implementing the BOLART at your centre					<0.001
Not confident	28	15.1	1	0.5	
A little confident	40	21.6	9	4.9	
Somewhat confident	58	31.4	48	25.9	
Quite confident	45	24.3	86	46.5	
Very confident	14	7.6	41	22.2	

- Conclusions: **e-Learning** for a multi-centre clinical trial was feasible and **improved confidence and knowledge.**

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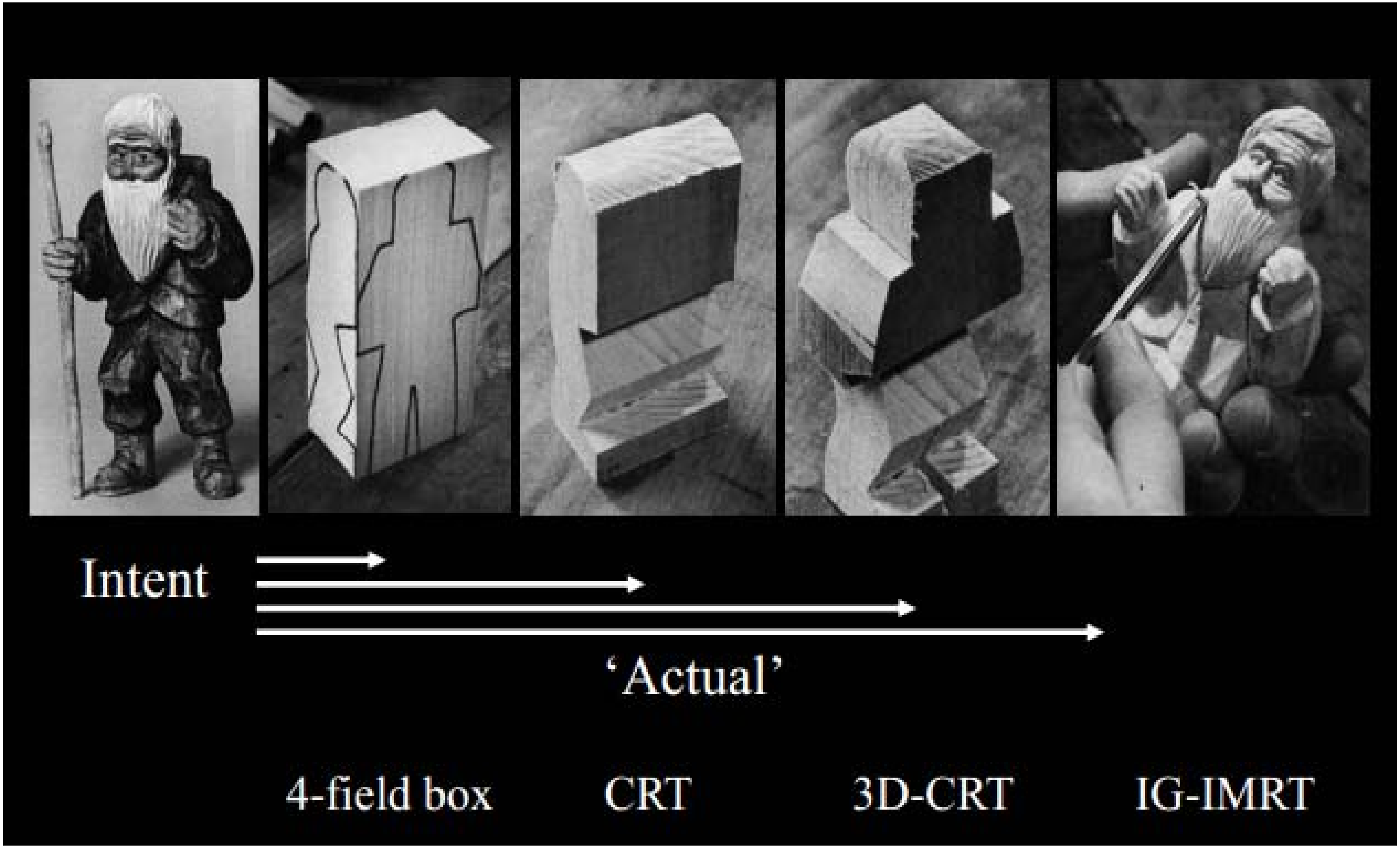

http://www.astro.org/uploadedFiles/Main_Site/Meetings_and_Events/Spring_Refresher_Course/Meeting_Program/Jaffray%20Physics.pdf

Intent

'Actual'

4-field box CRT 3D-CRT IG-IMRT

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What else ?

Triana Bridge (Sevilla, Spain)

Case report: **Prostate**

Jose Lopez, M.D., Ph.D
Radiation Oncology
University Hospital Virgen del Rocio
Seville, Spain

Advanced skills for modern radiotherapy
28 June-02 July, 2015
Copenhagen, Denmark

Outline of Talk

- Clinical data supporting benefit to local treatment in lymph node metastasized prostate cancer
- Delineation/Preparation
- Case report
- Discussion of current multidisciplinary (physician, phisyc and RTTs) management

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European Urology

Volume 58, Issue 2, August 2010, Pages 261–269

Review – Prostate Cancer

Does Local Treatment of the Prostate in Advanced and/or Lymph Node Metastatic Disease Improve Efficacy of Androgen-Deprivation Therapy? A Systematic Review

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[b] European Organisation of Research and Treatment of Cancer Headquarters, Statistics Department, Brussels, Belgium

Conclusions

The local therapy in T3 and/or lymph node–positive disease is an essential part of the optimal treatment.

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Lymph node metastasized prostate cancer

- N=80
- T1-4, N1M0
- Intensity modulated arc radiotherapy (IMAT) + androgen deprivation
- Dose: 69,3 Gy in 25 fractions; SIB (intraprostatic lesion): 72 Gy
- F/u: 3 years
- **3-year late grade 3 GI: 8%**
- **3-year late grade 3/4 GU: 6%**
- **3-year bRFS and cRFS was 81% and 89%, respectively.**

Radiotherapy and Oncology 109 (2013) 229–234

T1

T1 Clinically inapparent; tumor not palpable or visible by imaging

T1a Incidental finding during transurethral resection of prostate; < 5% of tissue resected

T1b Incidental finding during transurethral resection of prostate; > 5% of tissue resected

T1c Tumor identified by needle biopsy (e.g. because of elevated PSA)

T2

T2 Tumor confined within prostate (palpable or visible on TRUS)

T2a Involves half of a lobe or less

T2b Involves more than half of a lobe one lobe but not both lobes

T2c Tumor involves both lobes

T3

T3 Tumor extends through prostatic capsule, bladder neck or seminal capsule

T3a Unilateral extracapsular extension

T3b Bilateral extracapsular extension

T3c Tumor invades seminal vesicle(s)

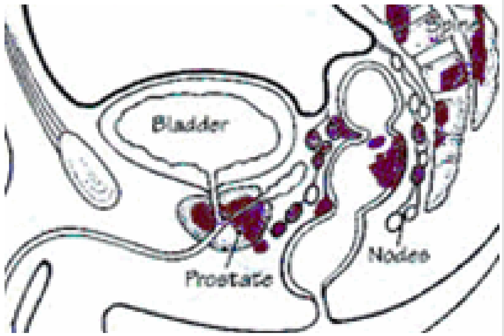
T4

T4 The tumor has spread or attached to tissues next to the prostate (other than the seminal vesicles).

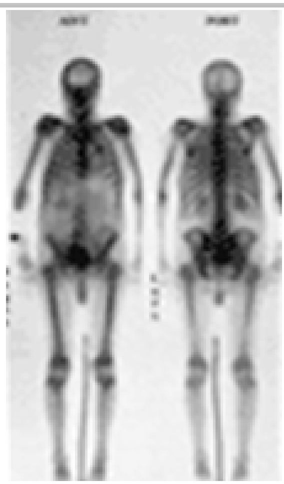
T4a The tumor has spread to the neck of the bladder, the external sphincter (muscles that help control urination), or the rectum.

T4b The tumor has spread to the floor and/or the wall of the pelvis.

N0-3



M0-1



N0 Cancer has not spread to any lymph nodes.
N1 Cancer has spread to a single regional lymph node (inside the pelvis) and is not larger than 2 centimeters
N2 Cancer has spread to one or more regional lymph nodes and is larger than 2 centimeters (¾ inch), but not larger than 5 centimeters
N3: Cancer has spread to a lymph node and is larger than 5 centimeters

M0: The cancer has not metastasized (spread) beyond the regional lymph nodes
M1: The cancer has metastasized to distant lymph nodes (outside of the pelvis), bones, or other distant organs such as lungs, liver, or brain

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Grade 1 Mild

Grade 2 Moderate

Grade 3 Severe

Grade 4 Life-threatening consequences

Grade 5 Death

Radiotherapy and Oncology 109 (2013) 229–234

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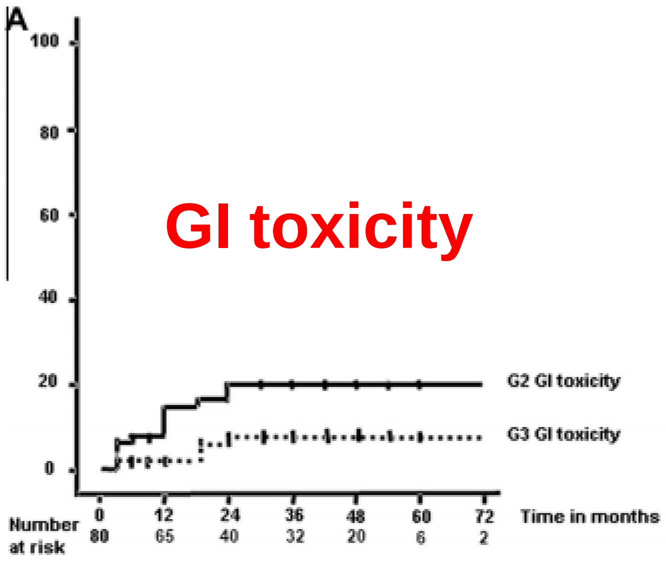
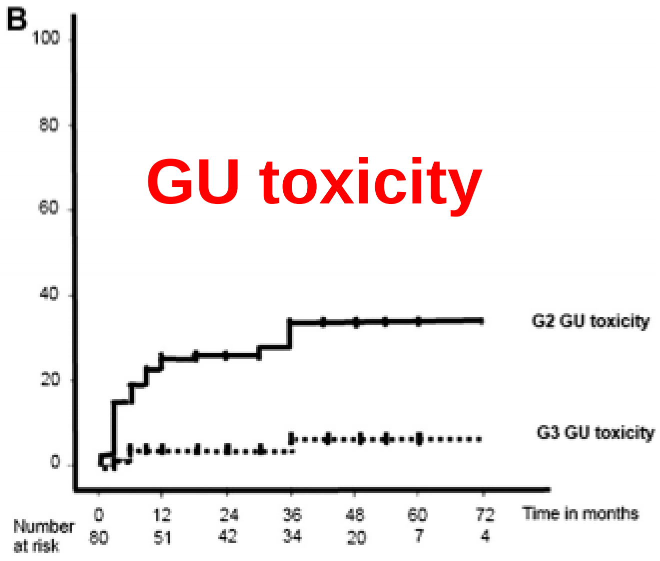
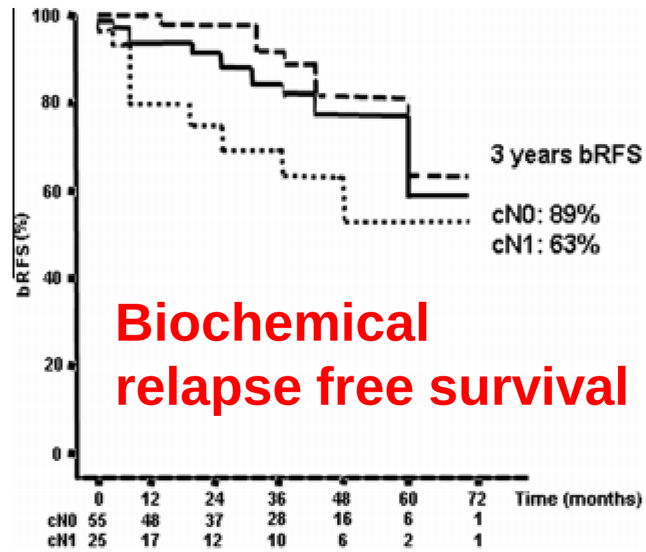
Lymph node metastasized prostate cancer







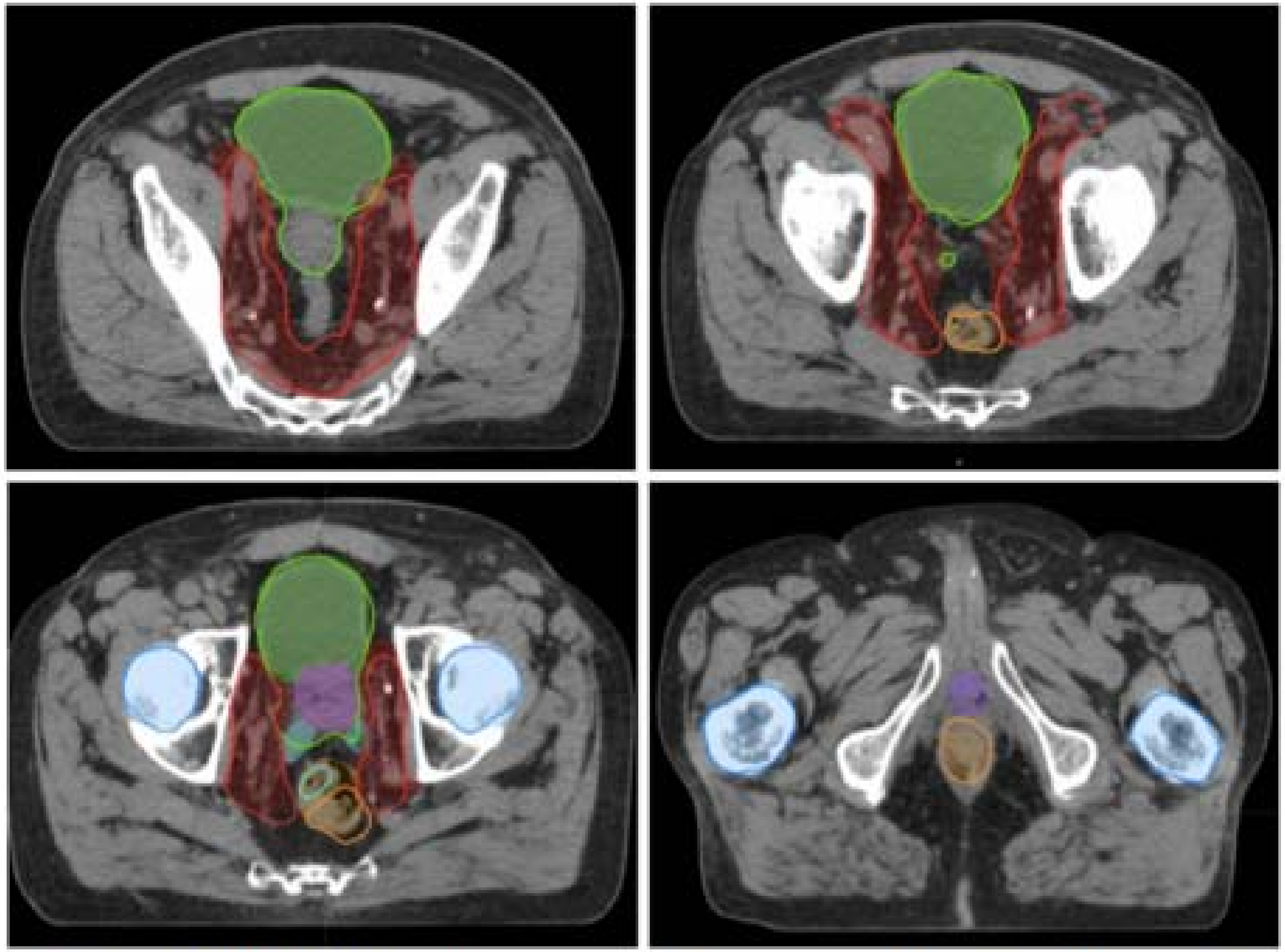


Figure 3 Atlas-predicted contouring for high risk prostate cancer. Sample slices of contoured high risk prostate cases comparing atlas predicted auto contours (bold outline) to manual contoured standard (thin outline with colourwash). ROIs demonstrated are CTV_{PROS} (purple), CTV_{NODES} (red), B (Green), R (Orange), PB (dark purple), SV (cyan), LF and RF (dark blue).

Velker et al. Radiation Oncology 2013, 8:188

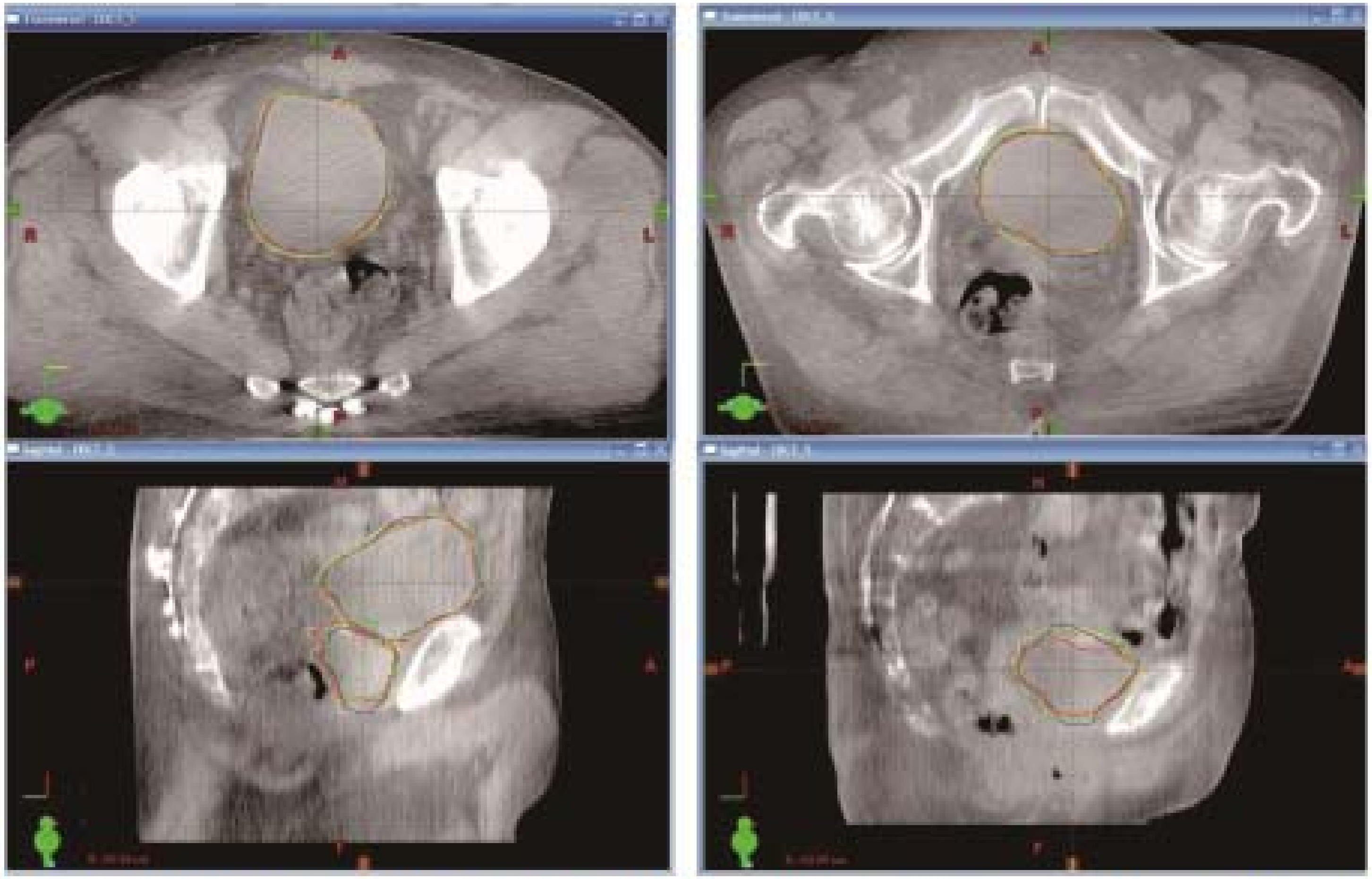


Figure 1 Example of organ boundary delineation in a male and a female. The two leftmost and two rightmost images are transaxial (upper) and sagittal (lower) images through the center of the bladder of patient H (male) and patient C (female), respectively.

Nishioka et al. Radiation Oncology 2013, 8:185

Analysis of fiducial marker-based position verification in the external beam radiotherapy of patients with prostate cancer

Uulke A. van der Heide*, Alexis N.T.J. Kotte, Homan Dehnad, Pieter Hofman, Jan J.W. Lagenijk, Marco van Vulpen

Department of Radiation Oncology, University Medical Center, CX Utrecht, The Netherlands

Abstract

Purpose: Evaluate the fiducial marker-based position verification in the external-beam radiotherapy of patients with prostate cancer.

Methods: Four hundred and fifty-three patients with prostate cancer received an IMRT treatment combined with fiducial marker-based position verification. Portal images were taken in all 35 treatment fractions. This database was used to study the accuracy of detecting the prostate position as well as the presence of time trends and the effectiveness of commonly used off-line correction protocols.

Results: The variation in inter-marker distance shows that the prostate position can be detected with an accuracy better than 0.6 mm. Significant time trends in prostate position occurred in 35%, 18% and 48% of the patients in the vertical, lateral and longitudinal directions, respectively, with 34%, 9% and 35% deviating more than 3 mm over the course of the treatment. Off-line correction protocols that estimate a deviation only in the first fractions of the treatment (shrinking action level (SAL), no action level (NAL)) are not effective in following these trends. With daily off-line position correction using an adapted SAL protocol we reduced systematic positioning errors in clinical practice to less than 0.8 mm in all directions.

Conclusion: Fiducial markers are a reliable tool for prostate position verification. Time trends occur frequently. Correction procedures must take such trends into account.
© 2006 Elsevier Ireland Ltd. All rights reserved. Radiotherapy and Oncology 82 (2007) 38–45.

Radiotherapy and Oncology 82 (2007) 38–45

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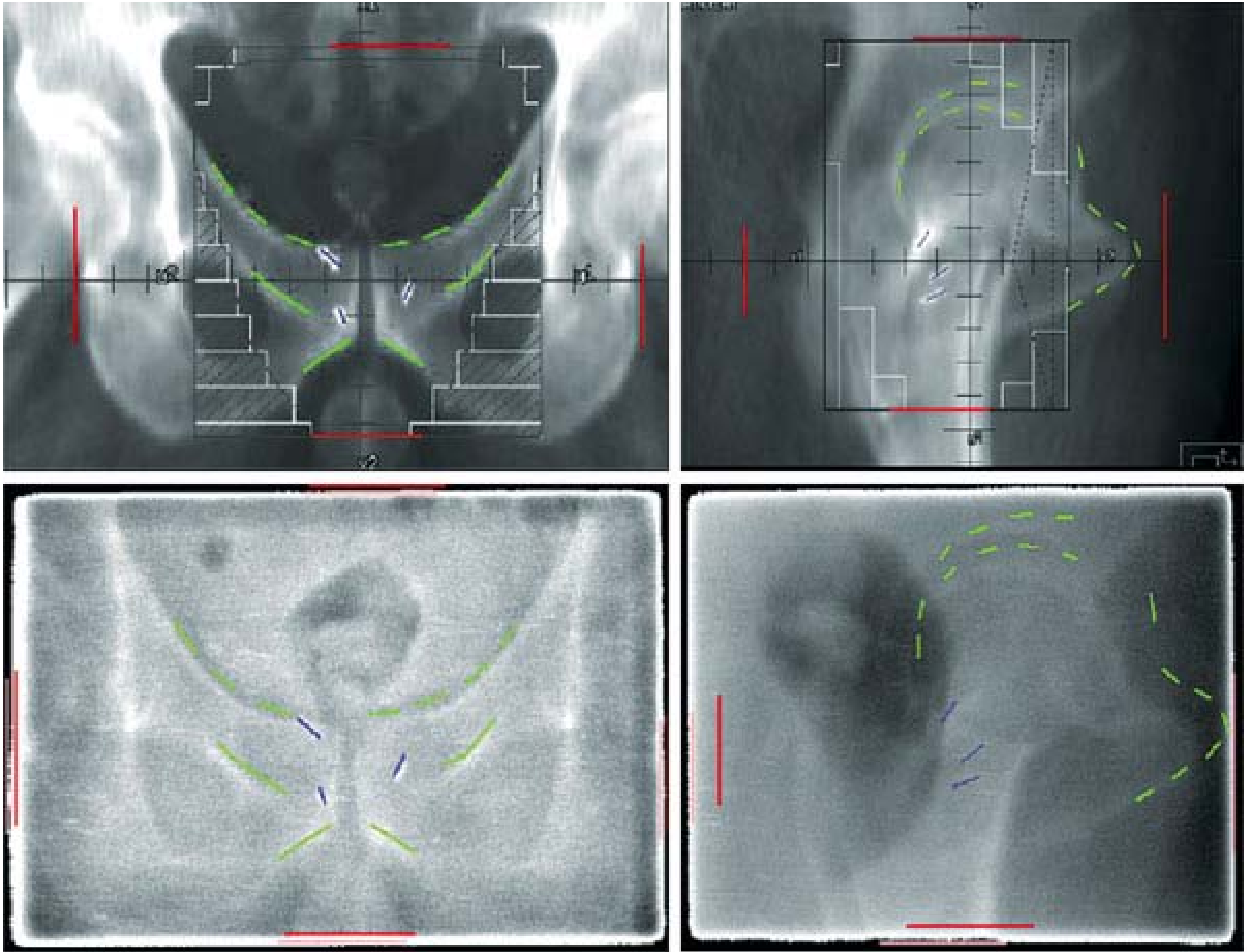

http://www.nature.com/nrclinonc/journal/v7/n10/images/nrclinonc.2010.135-f4.jpg

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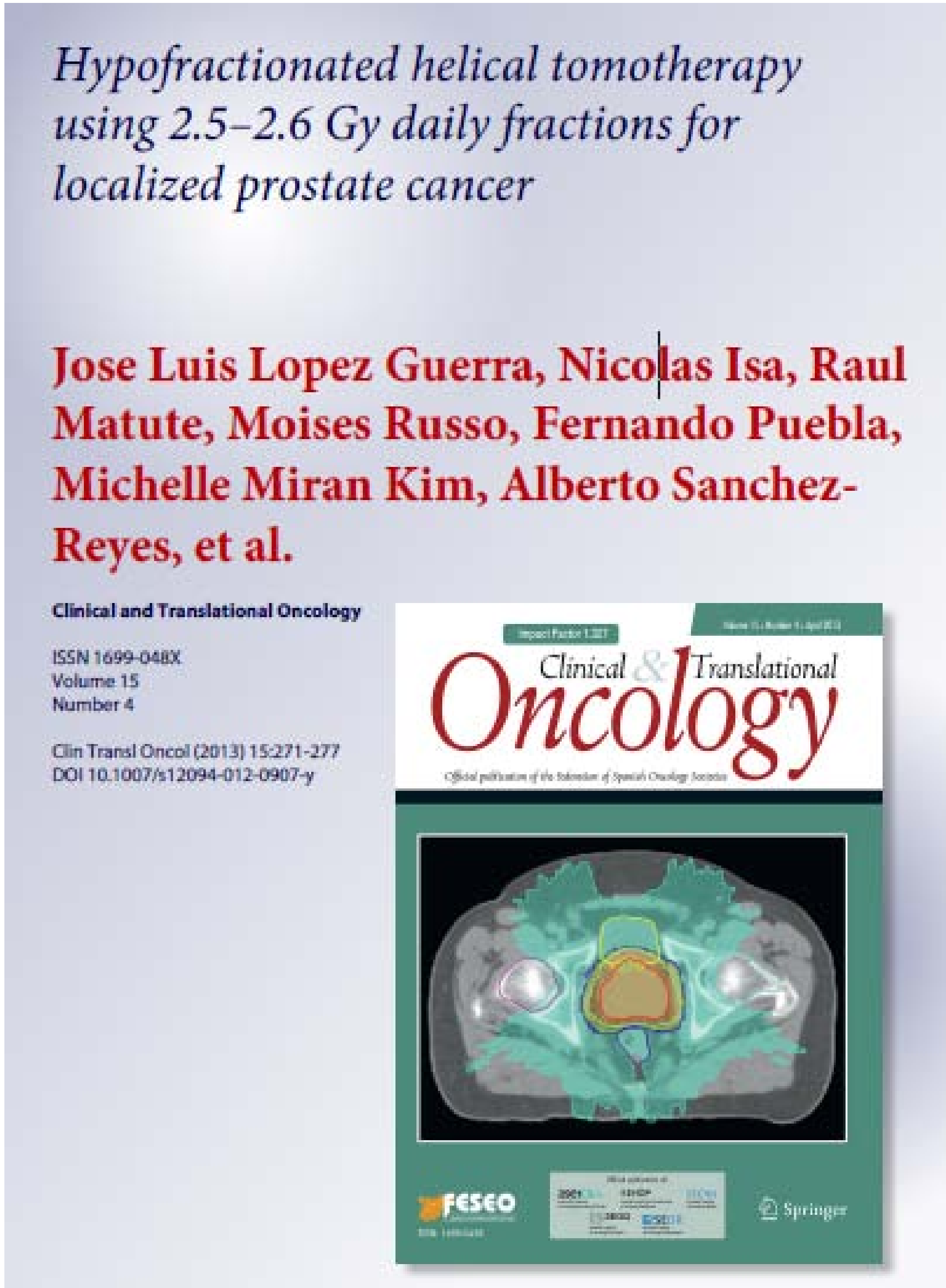


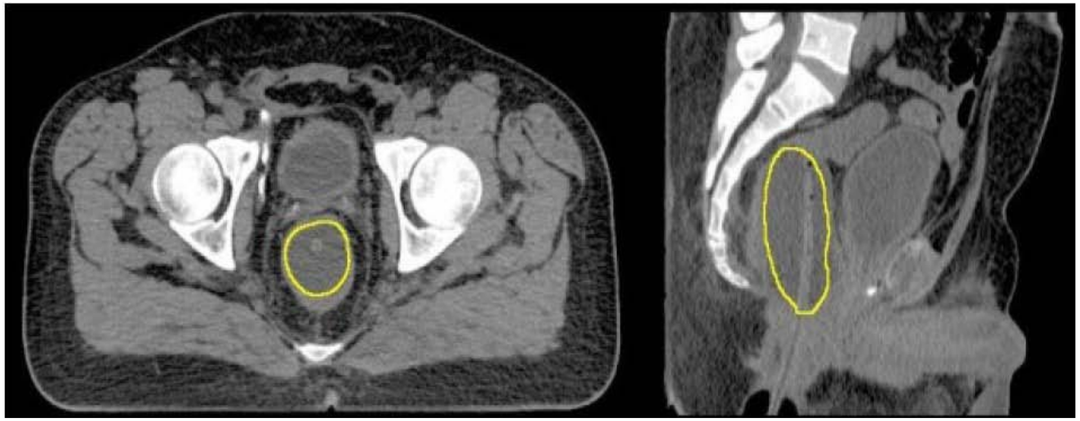
Hypofractionated helical tomotherapy using 2.5–2.6 Gy daily fractions for localized prostate cancer

Jose Luis Lopez Guerra, Nicolas Isa, Raul Matute, Moises Russo, Fernando Puebla, Michelle Miran Kim, Alberto Sanchez-Reyes, et al.

Clinical and Translational Oncology

ISSN 1699-048X
Volume 15
Number 4

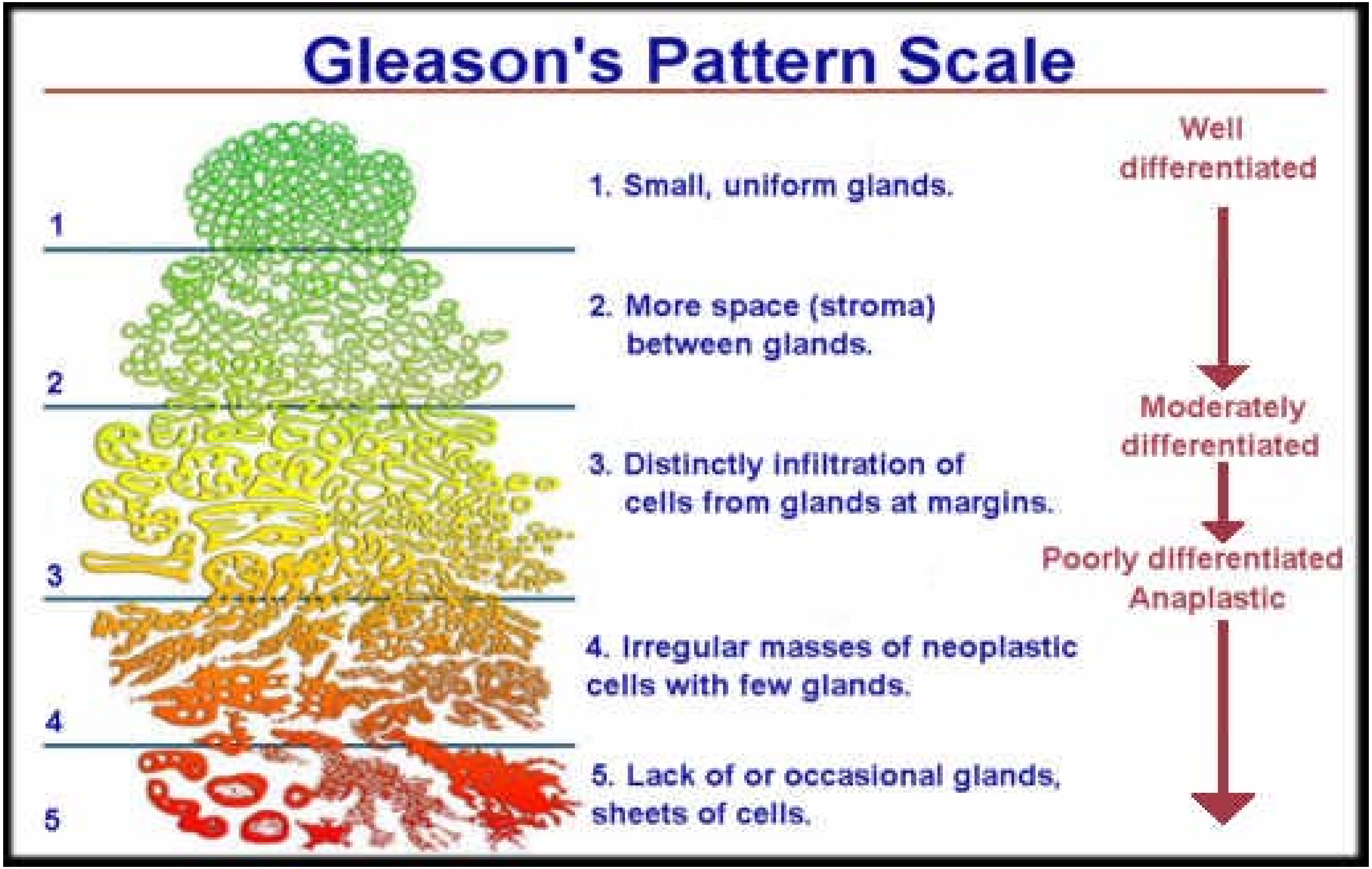
Clin Transl Oncol (2013) 15:271-277
DOI 10.1007/s12094-012-0907-y



"Various trials did not find any relation between the percentage of bladder/rectum volume receiving a certain radiation dose and urinary/rectal toxicity"

Case 1: patient with stage N+ (D1) disease

- A 78-year-old man was shown to have a prostate-specific antigen (PSA) level of 18 ng/mL in a routine evaluation.
- His physical exam was normal and the digital rectal examination revealed a slightly enlarged prostate (87 cc by transrectal ultrasound).
- Prostatic biopsy revealed a Gleason score 8 (4 + 4) adenocarcinoma in 7 of 12 specimens.
- His past medical history was significant for systemic hypertension and dyslipidemia.



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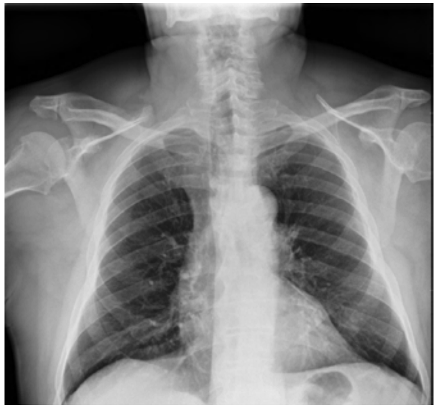
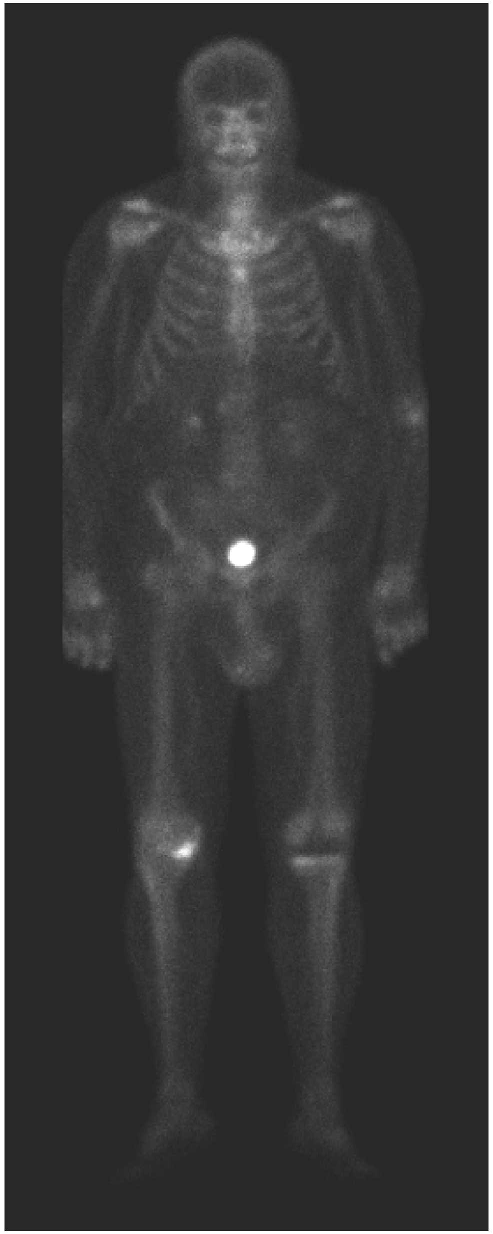
- Laboratory data: normal values

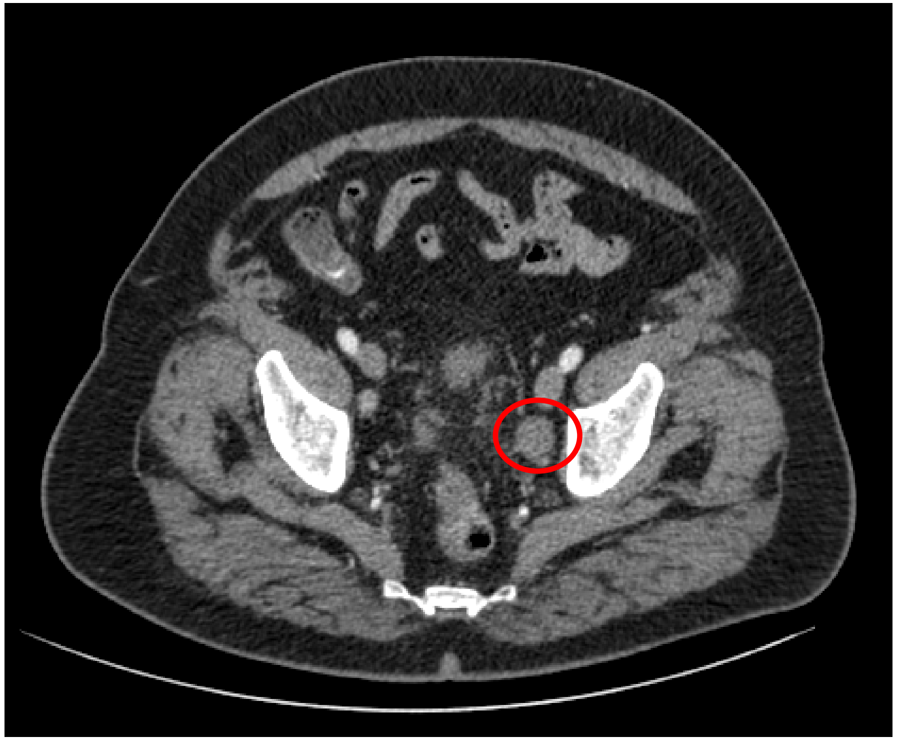
- Chest X-ray negative



- Bone scan findings suggestive of degenerative changes all over the body and no definite evidence of metastatic bone disease was noted.



- Abdominal CT scan showed enlarged pelvic lymph nodes (left obturator area, right internal iliac)



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Prostate

- **Regional lymph nodes:**
  Pelvic
  Hypogastric
  Obturador
  Iliac (internal, external)
  Sacral (lateral, presacral, promontory)

- **Distant lymph nodes:**
  Aortic (para-aortic lumbar)
  Common iliac
  Inguinal, deep
  Superficial inguinal (femoral)
  Supraclavicular
  Cervical
  Escalene
  Retroperitoneal

- Diagnosis: Stage IV Prostate Cancer (cT1cN1M0)
- Treatment: Hormonal Therapy + Radiation Therapy

Hormonal therapy:

- Neoadjuvant and Adjuvant Androgen deprivation therapy.

Radiation Therapy Dose Prescription:

- PTV (prostate gland+5mm margin): 65 Gy at 2.32 Gy/fraction
- Seminal vesicles: 60 Gy at 2.14 Gy/fraction
- Enlarged left obturator and right internal iliac lymph nodes, 60 Gy at 2.14 Gy/fraction
- Pelvic lymph nodes , 50 Gy at 1.78 Gy/fraction

Take home message

- The local therapy in lymph node metastasized prostate cancer seems to have benefit.
- Different strategies such as fiducial markers are needed for tumor location control with 2D technology
- OAR preparation is needed in order to decrease the risk of toxicity

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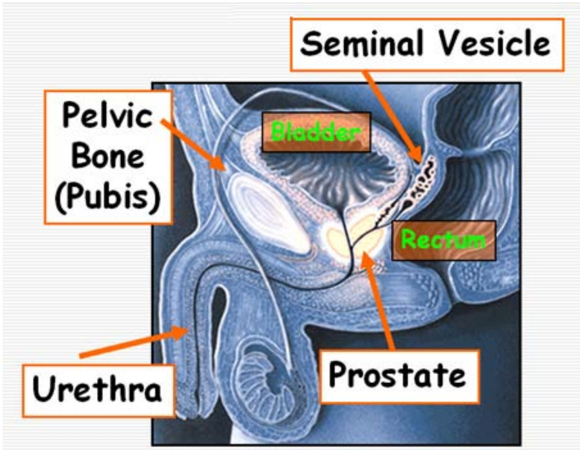

Questions:

- Preparation (bladder, rectum)
- Positioning
- Tattoos
- Organ at risk contouring
- Set-Up
- Verification
- Radiation technique

???

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Case reports: **Prostate**

Rigshospitalet

Mirjana Josipovic
Dept. of Radiation Oncology
Rigshospitalet
Copenhagen, Denmark

Advanced skills in modern radiotherapy
June 2015

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Imaging for prostate RT planning

Imaging immobilised patient in the treatment position

- CT scan
- MR scan

- Marker implantation into prostate gland

CT MR fusion


A
R
L
H
F
Y: 0.91 cm
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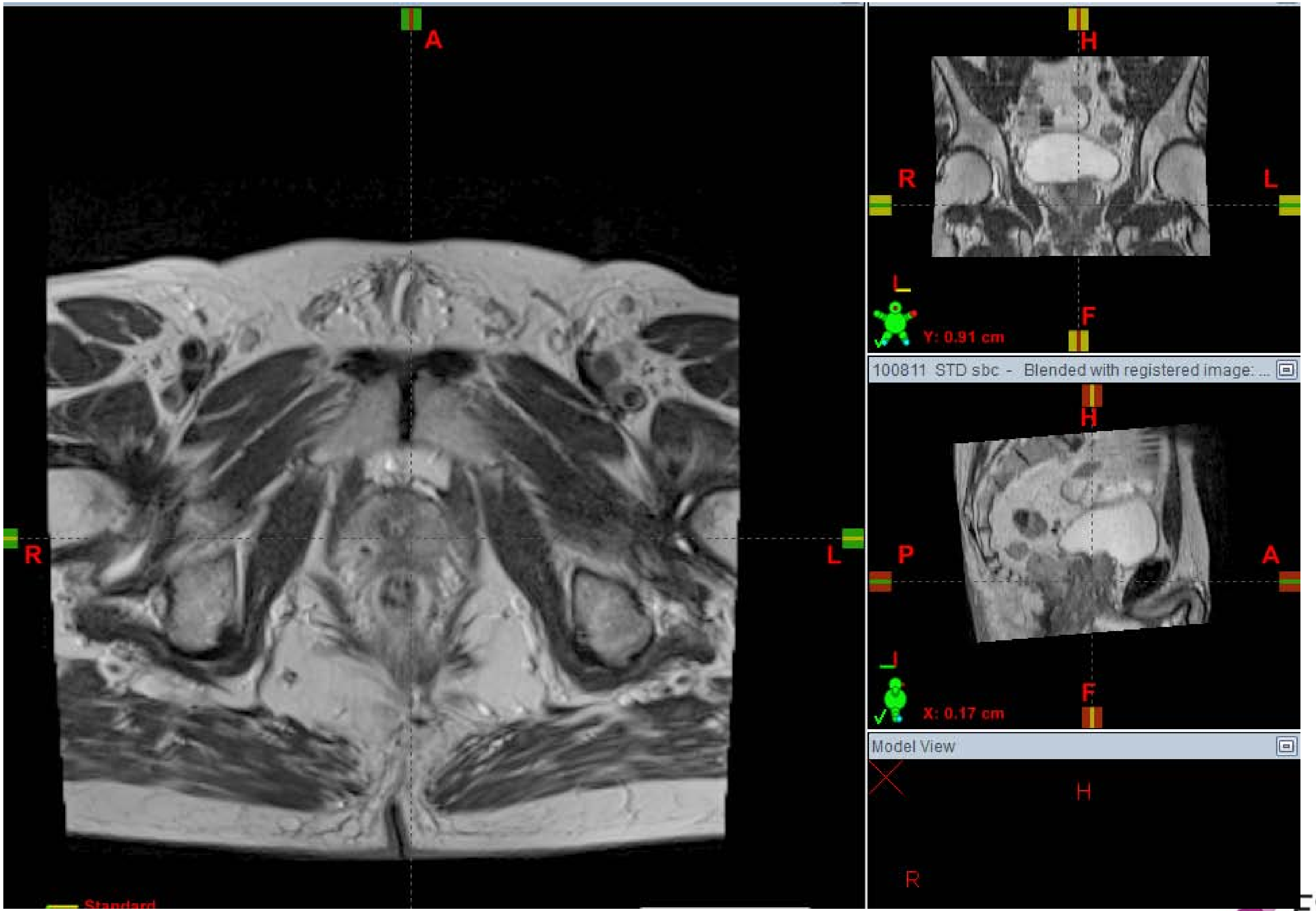
P
X: 0.17 cm
Model View
Standard

CT MR fusion



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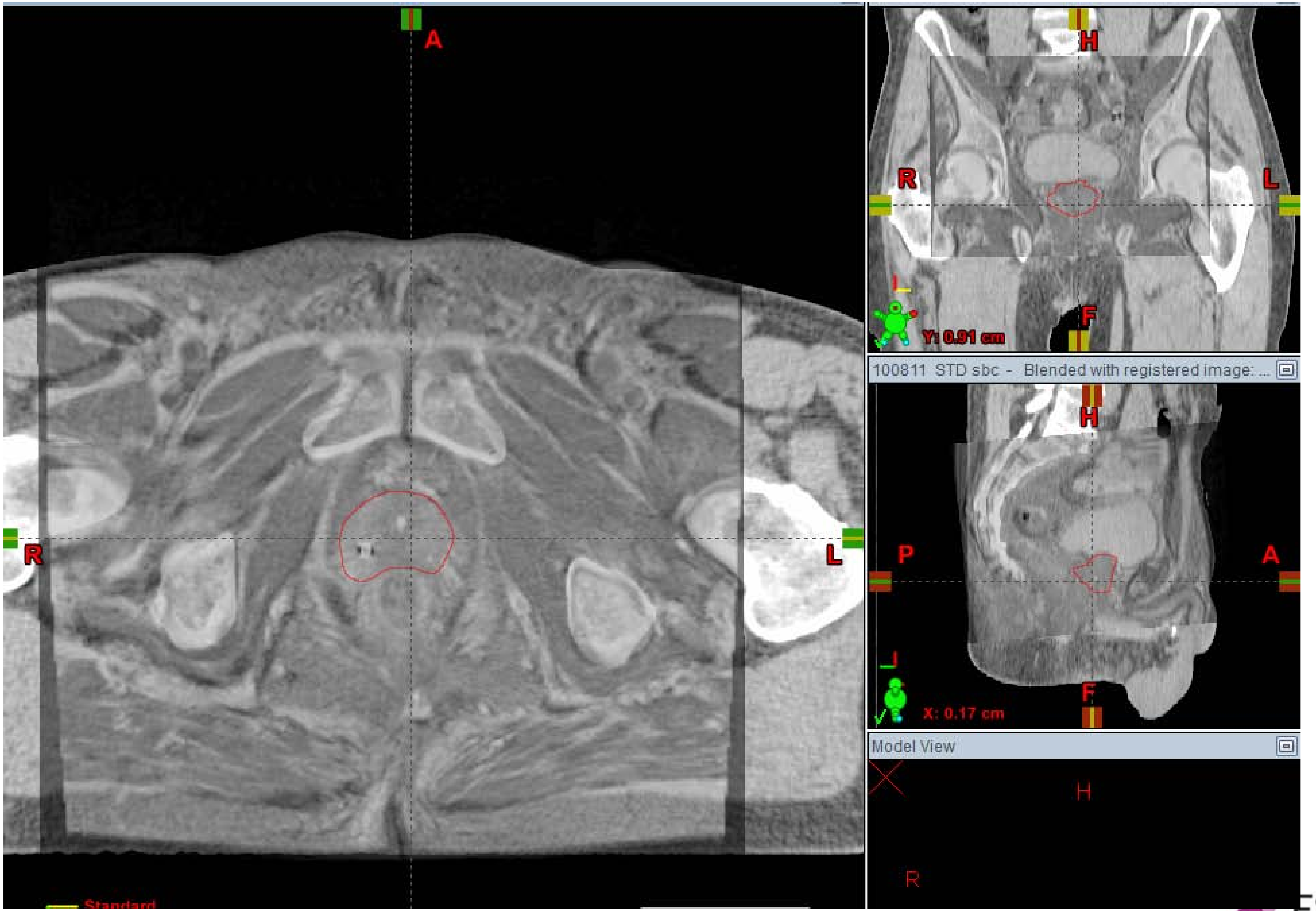
CT MR fusion


A
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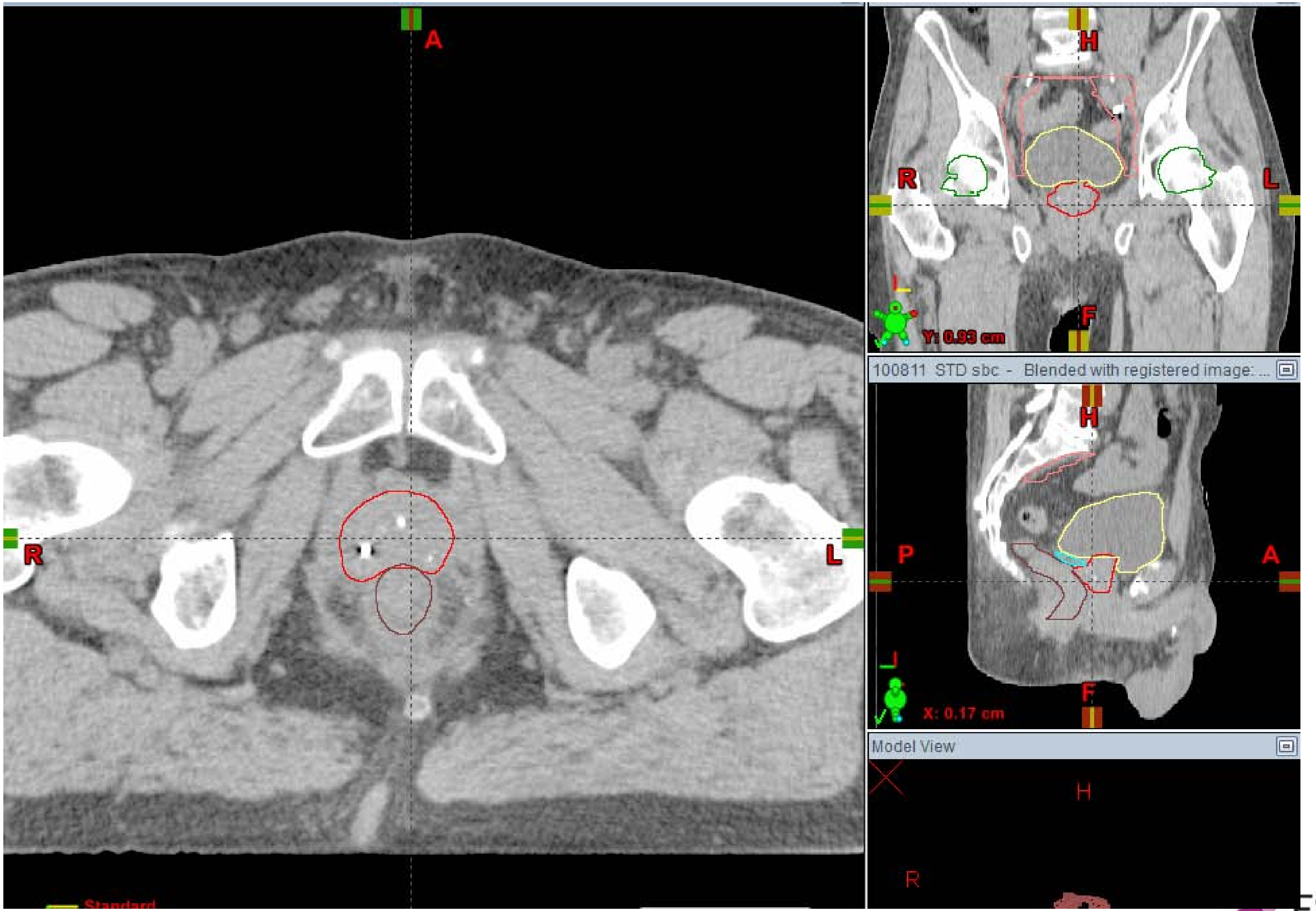
X: 0.17 cm
Model View

Target & OAR



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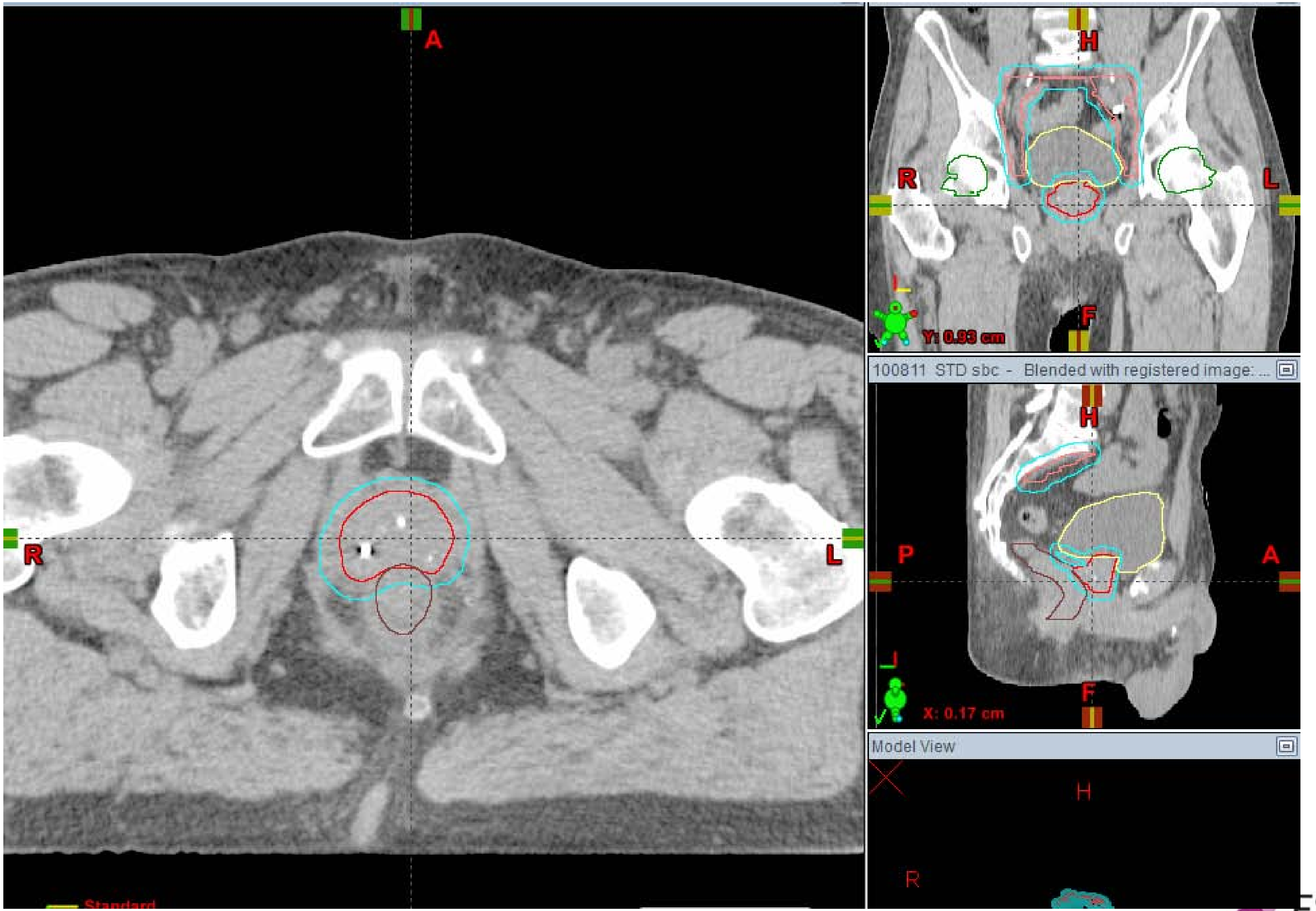
Target & OAR



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Treatment planning

Copenhagen:

- 37 or 39 fractions of 2 Gy (total 74/78 Gy) to the prostate
- 37 or 39 fractions of 1.49 Gy (total 55/58 Gy) to all nodes
  - ➢ Protocol only...

Seville:

- 28 fractions of 2.32 Gy (total 65 Gy) to the prostate
- 28 fractions of 2.14 Gy (total 60 Gy) to the sem.vessicles & inv.nodes
- 28 fractions of 1.75 Gy (total 50 Gy) profilactic to the noninv.nodes

Challenge of overlap of PTV & OAR

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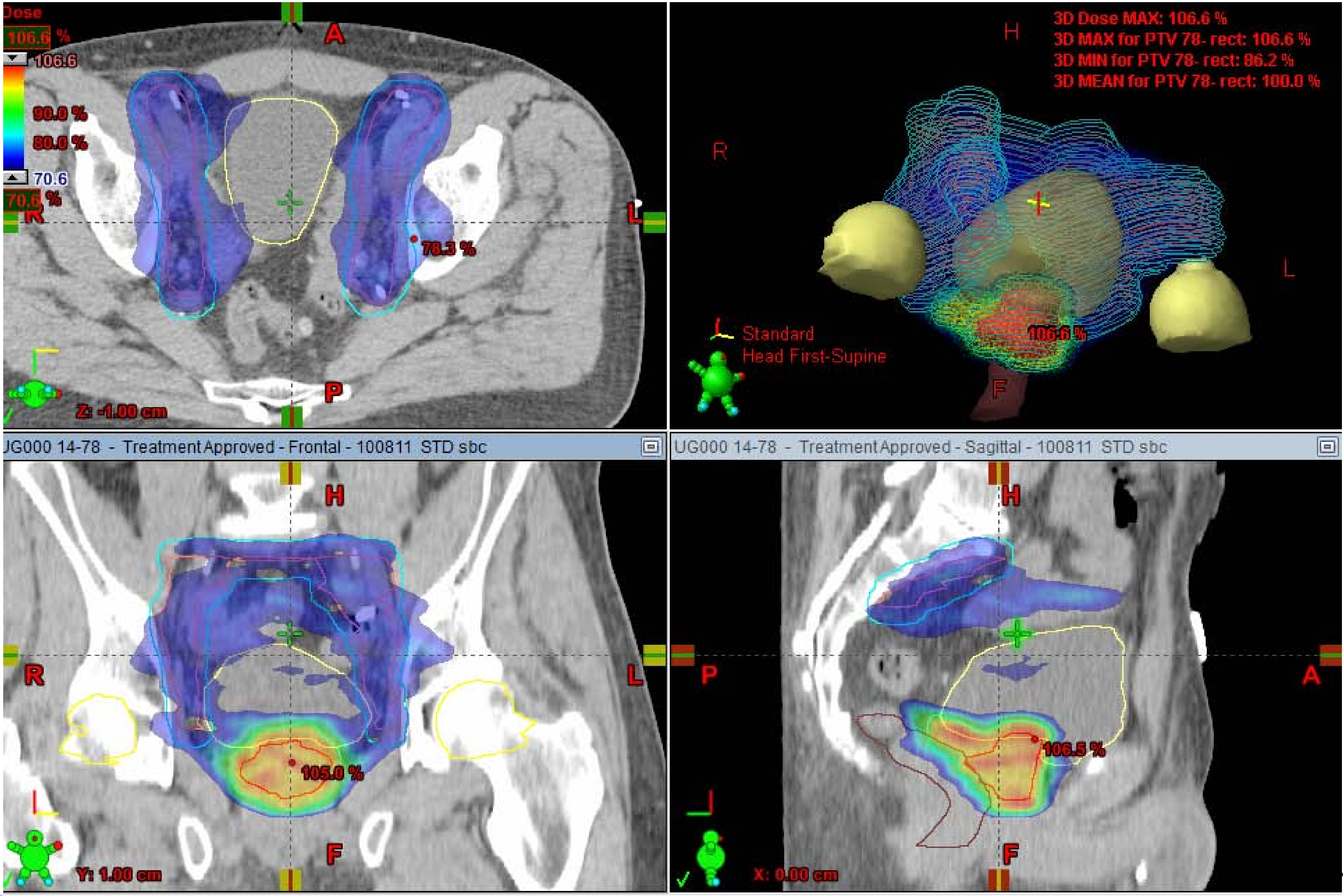
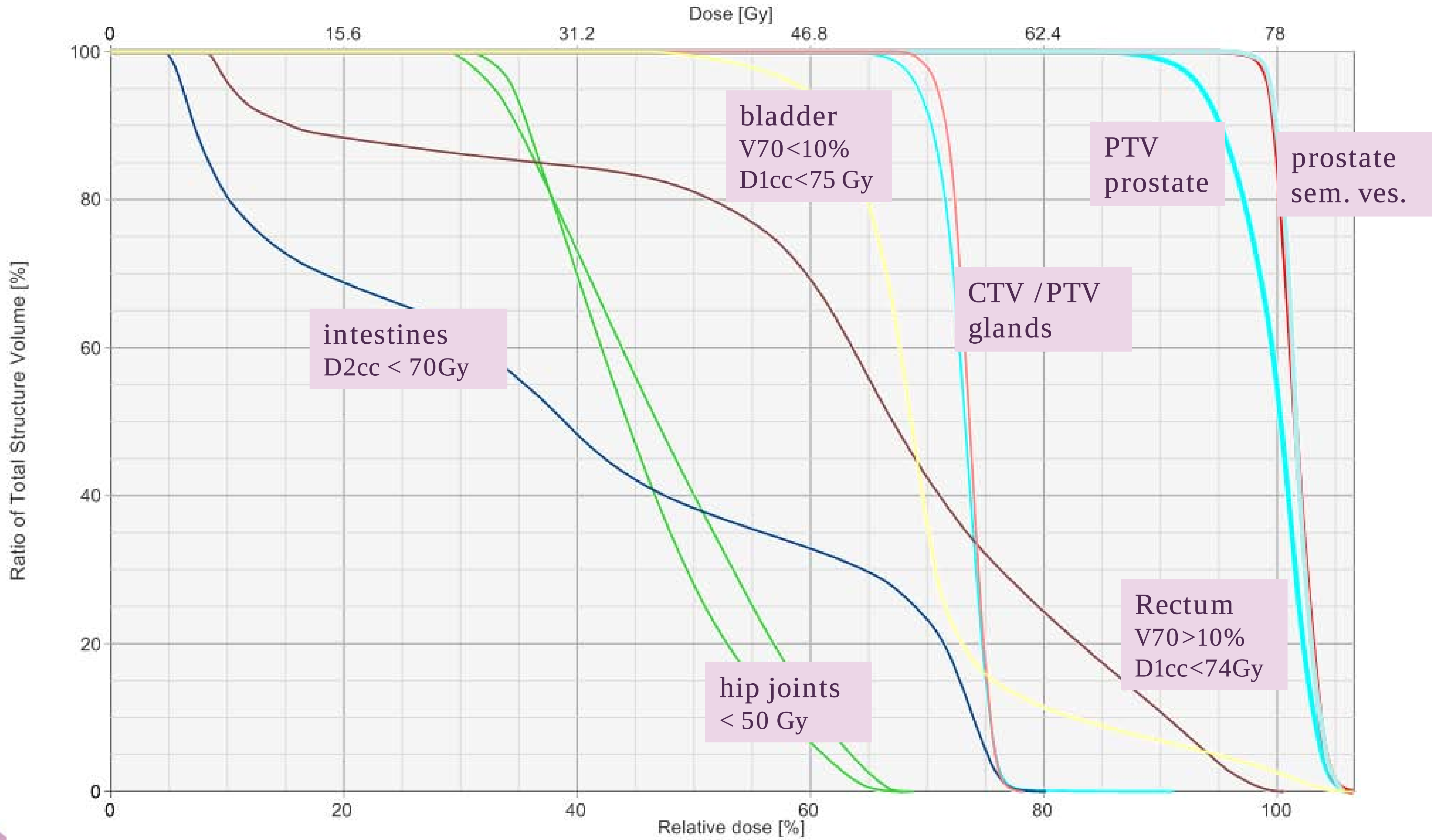
Treatment plan – VMAT with two arcs



Treatment plan – VMAT with two arcs



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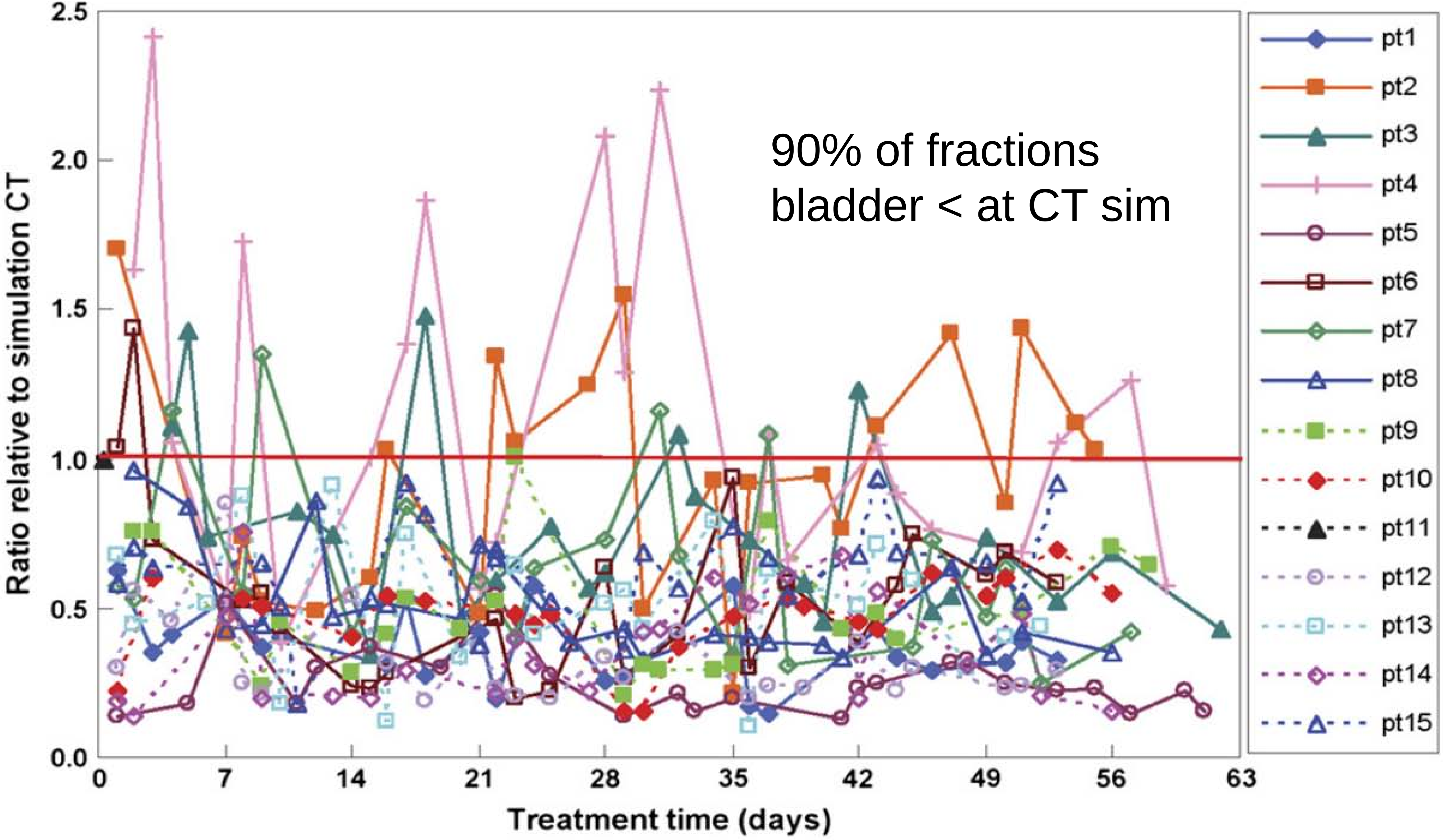
Changes in bladder volume during the RT



Frank et al. IJROBP 2007

Treatment techniques

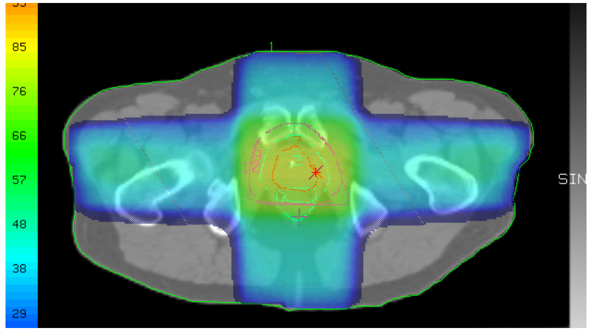
< 2005 — 3D conformal ”box” technique

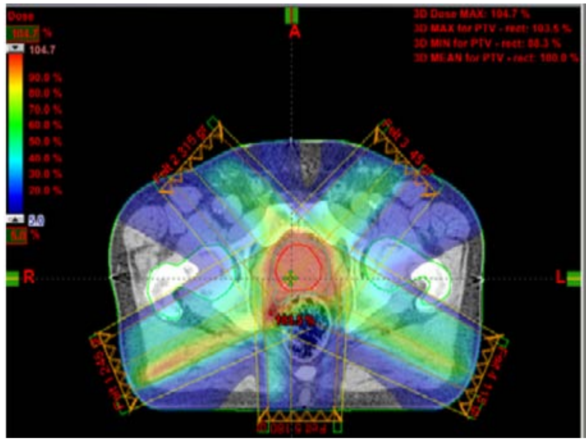
2005 — IMRT

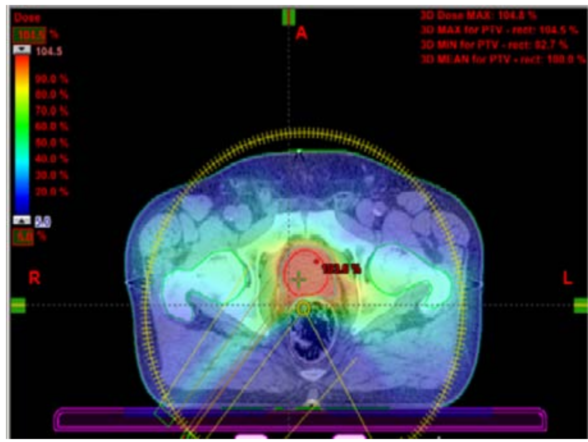
- Gold seeds & daily IGRT
- Margins ↓

2008 — VMAT

- Faster treatment (1 arc = 1 min)
- Margins ↓

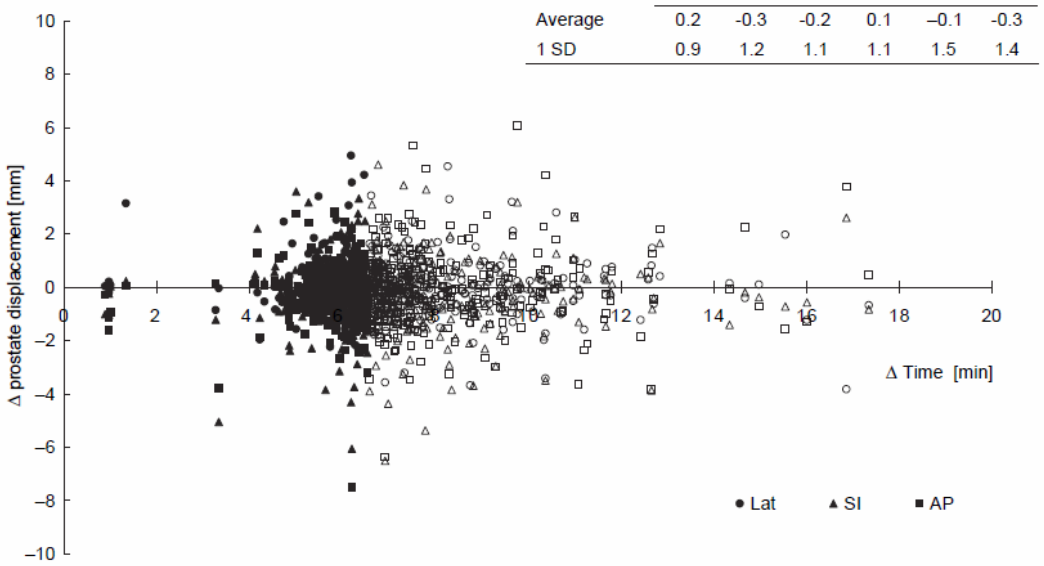






Treatment delivery time

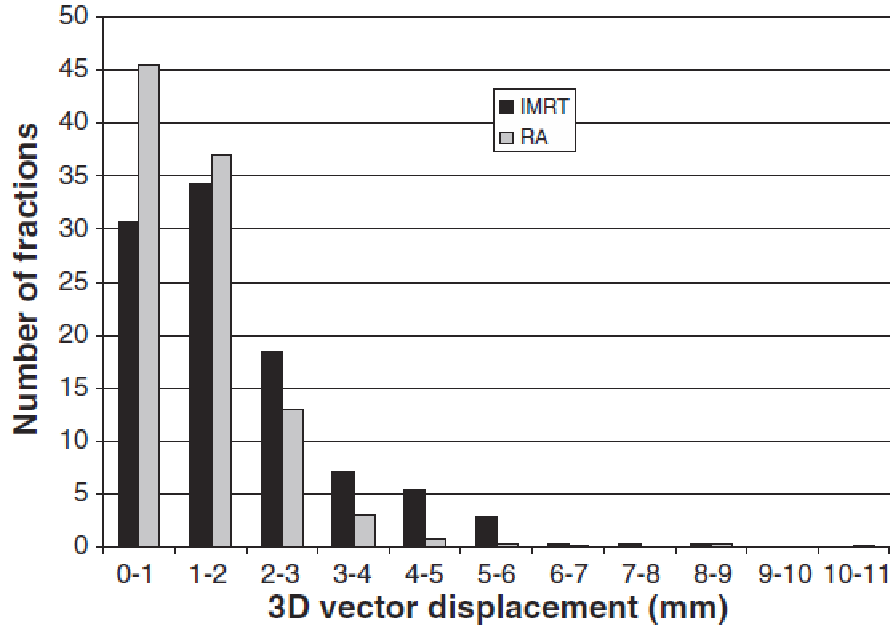
IMRT treatment



	Δ Displacement [mm]					
	Δ Time ≤ 6.55min			Δ Time ≤ 6.55min		
	Lat	SI	AP	Lat	SI	AP
Average	0.2	-0.3	-0.2	0.1	–0.1	-0.3
1 SD	0.9	1.2	1.1	1.1	1.5	1.4

Figure 3. The difference in prostate displacement before and after treatment (Δ displacement) plotted against the time span between the two positions.

M Enmark et al, Acta Oncol 2006



	IMRT	VMAT
Treatment delivery time	4.9 min	1.1 min
Intra-fractional prostate displacement > 3mm	4.7%	16.7%

M Aznar et al, Radiother Oncol 2010

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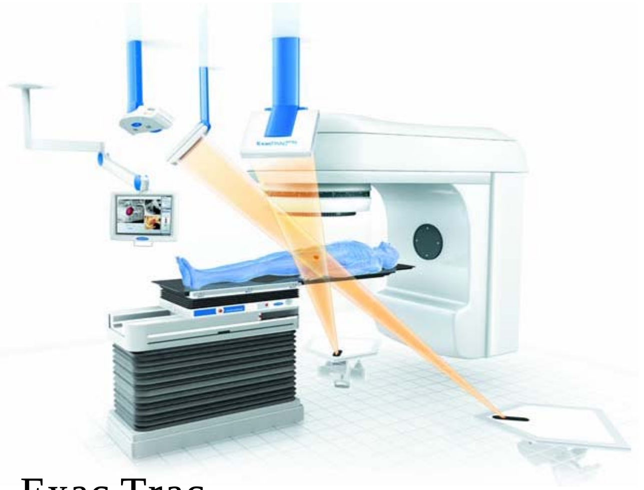
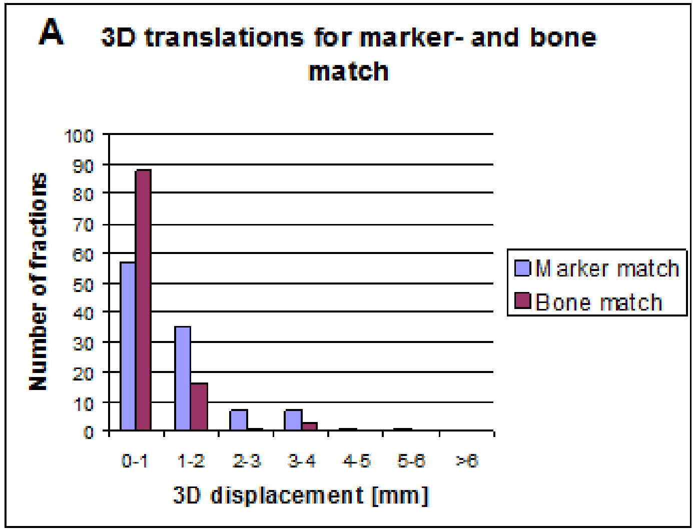
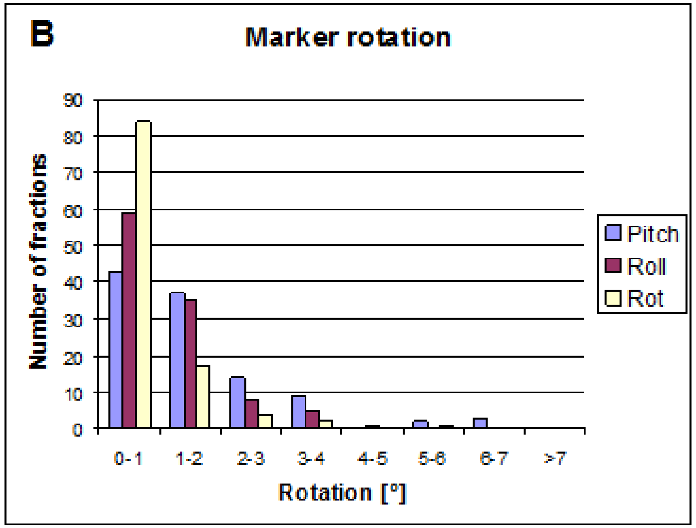
Prostate rotation

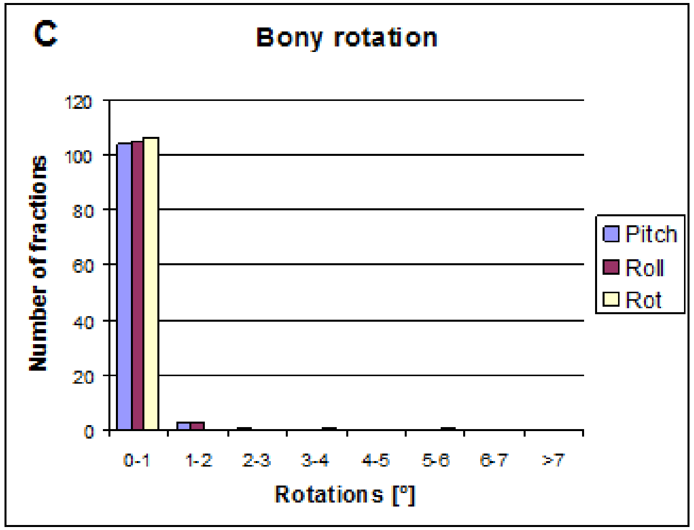
Courtesy of JB Scherman



Exac Trac
with robotic couch







After the 6D correction, the deviation in prostate is larger than deviation in patient position, for both translation and rotation

Take home messages

- Optimal imaging for RT planning
  - MR + CT
- Challenging RT planning due to overlap of OAR & PTV
- Choice of treatment techniques has an impact on margins
  - 3DC vs IMRT vs VMAT
  - The faster – the better (least chance of prostate motion)
  - Daily IGRT is optimal

IGRT for prostate cancer: RTT perspective

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Amsterdam, the Netherlands

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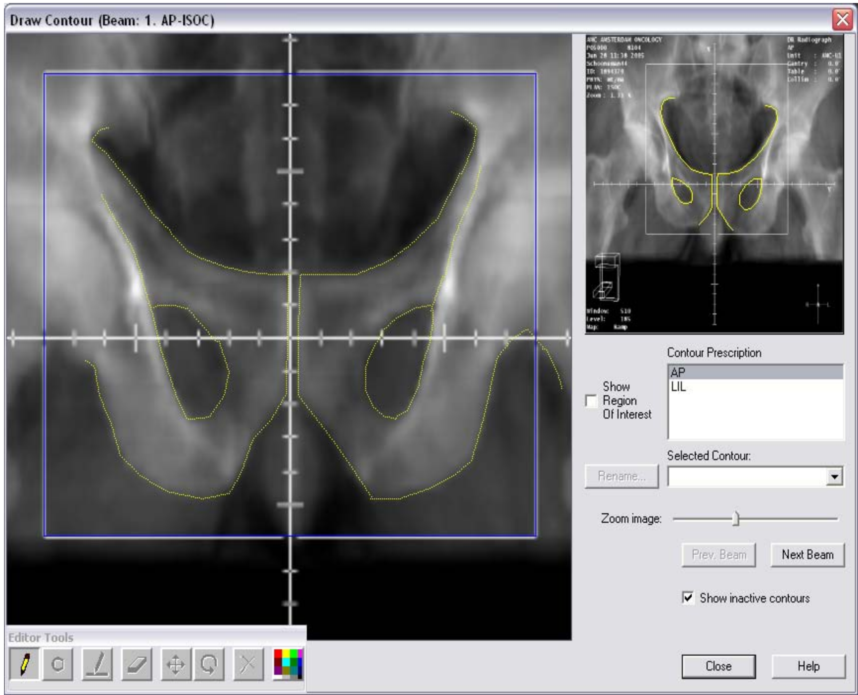
Content

- Prostate IGRT in general
  - ➢ Offline bony anatomy matching
  - ➢ Offline marker registration using fiducial markers and PI
  - ➢ Online marker registration using fiducial markers Portal or static kV imaging
  - ➢ Online marker registration using Conebeam-CT

- IGRT for this challenging case ☺

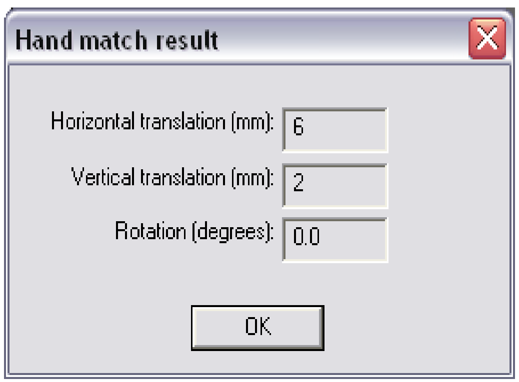
Offline/Online bony anatomy matching

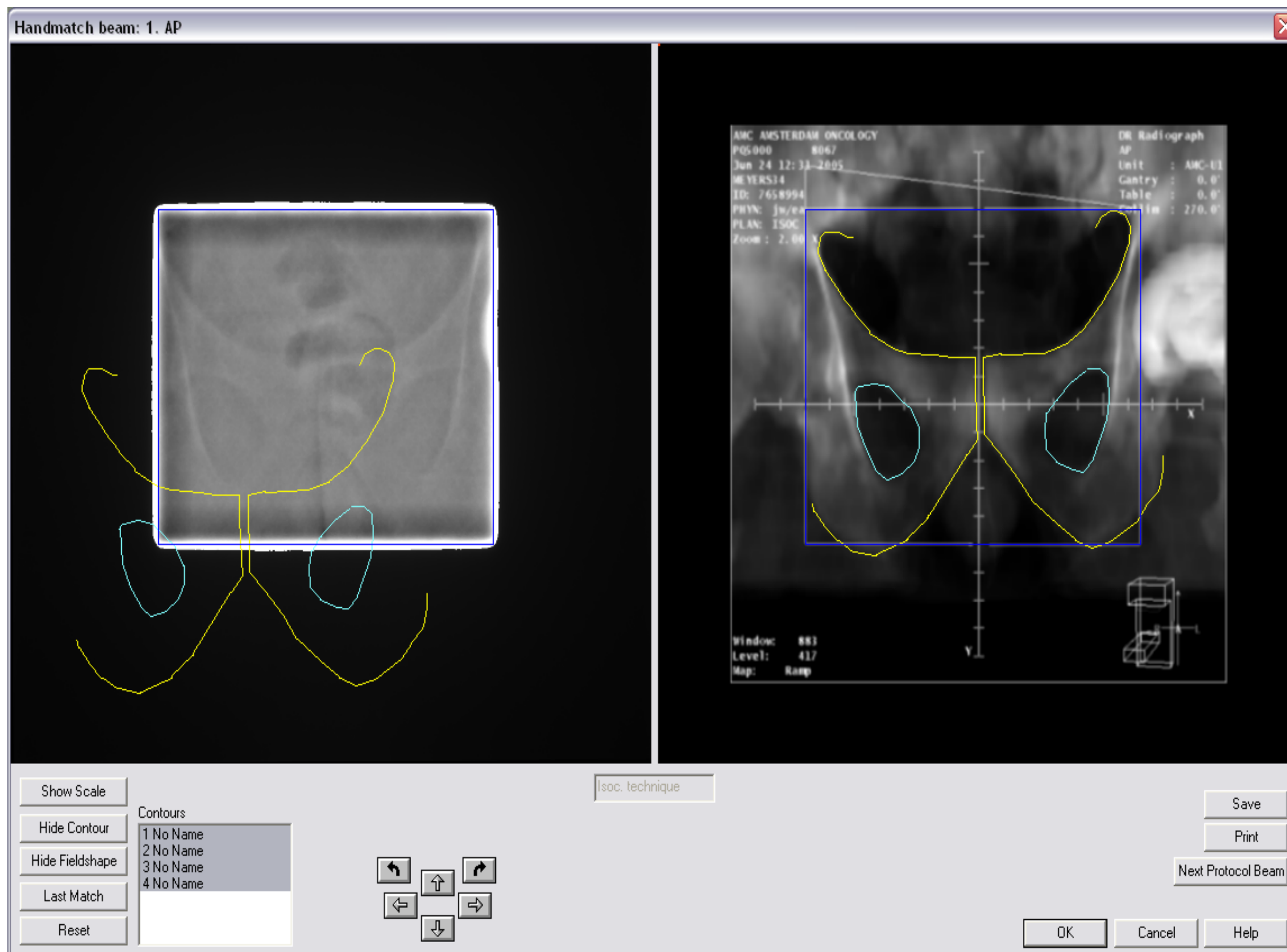
- Create an image with sufficient data
- Draw contours (templates) in reference images
- Contours should have a proper correlation with target
  - ➢ E.g. no trochantor or femur
- Produce guidelines!



Offline/Online bony anatomy matching

- Field edge match
- Match PIs

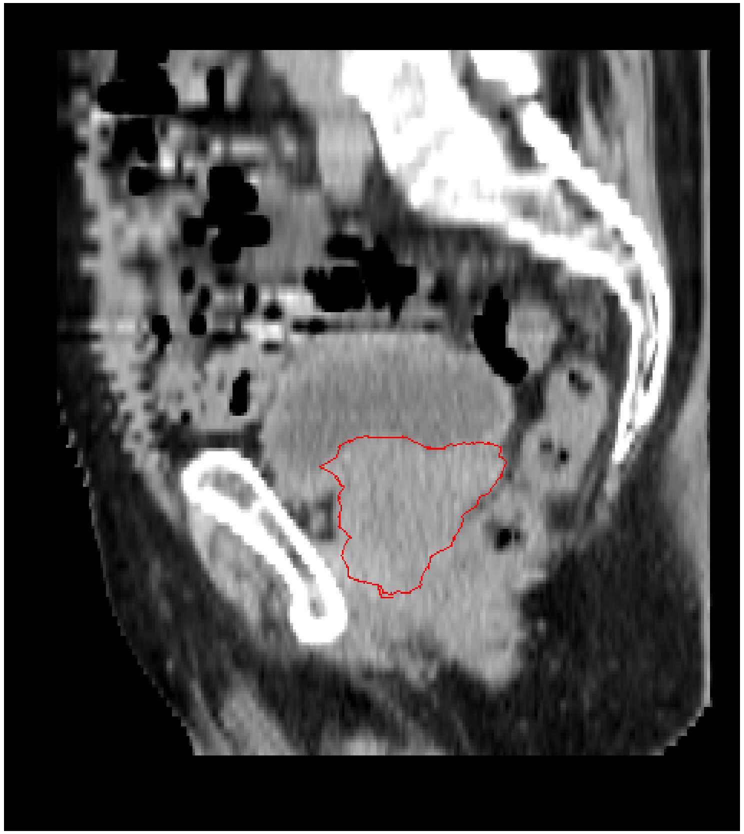




Offline marker registration using fiducial markers

Problem/challenge

- Displacement of bony anatomy does not (always) represent displacement of target



Van Herk et al.

Fiducial markers

- Displacement of bony anatomy does not (always) represent displacement of target
  - Neederveen et al. 2003: prostate cancer

	LR (mm)			AP (mm)			CC (mm)		
	marker	bone	mk. rel. bone	marker	bone	mk. rel. bone	marker	bone	mk. rel. bone
Mean	0.0	0.0	0.0	− 1.0	− 1.0	0.0	1.1	0.1	1.0
Σ	2.4	2.1	1.0	**4.4**	**4.4**	2.3	**3.7**	2.1	**4.1**
σ	2.1	1.8	0.8	**3.4**	**2.2**	2.4	**2.7**	1.7	**2.4**

Standard deviations for the systematic and random case that do differ significantly are printed in bold.

  - For 6 out of 23 patients → increase of systematic error after correction based on bony anatomy !!

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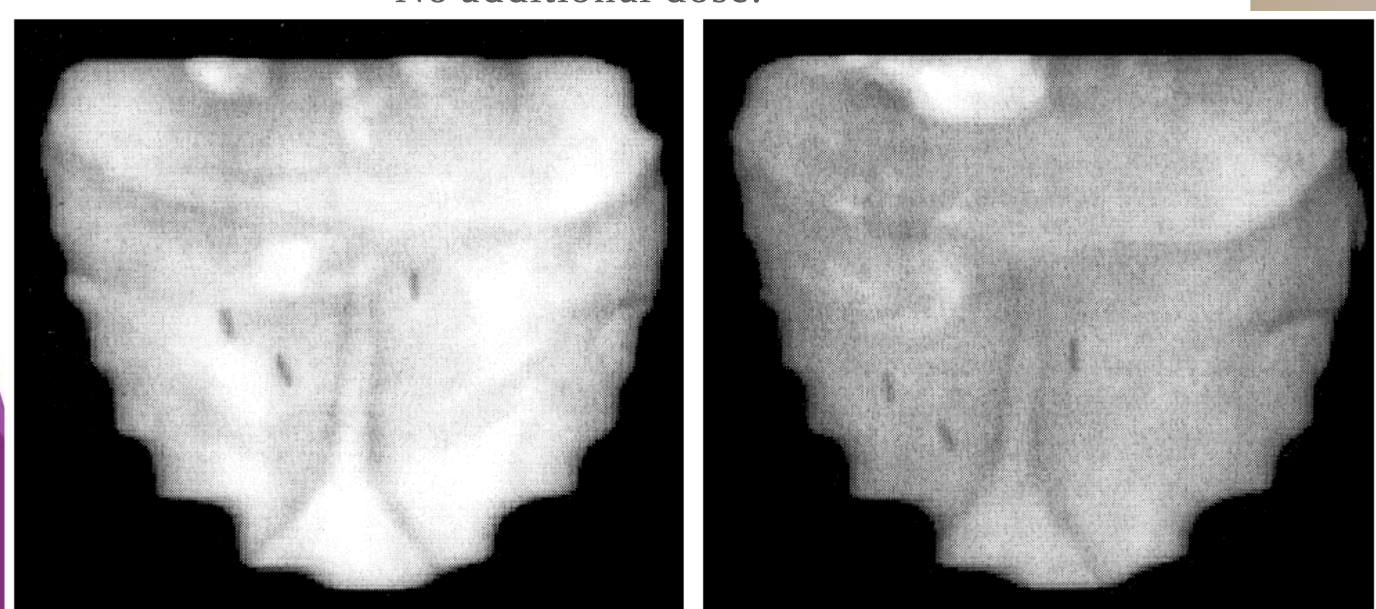
Fiducial markers: offline

Based on Van der Heide *et al.* 2007:

- 5 field IMRT treatment
- Daily offline imaging:
  - Treatment field: 40, 180 and 320 degrees
  - SAL (α=8, N=4)
  - Threshold SAL= $\alpha/\sqrt{N}$
- Limited (radiation) fields adequate
  - No additional dose!

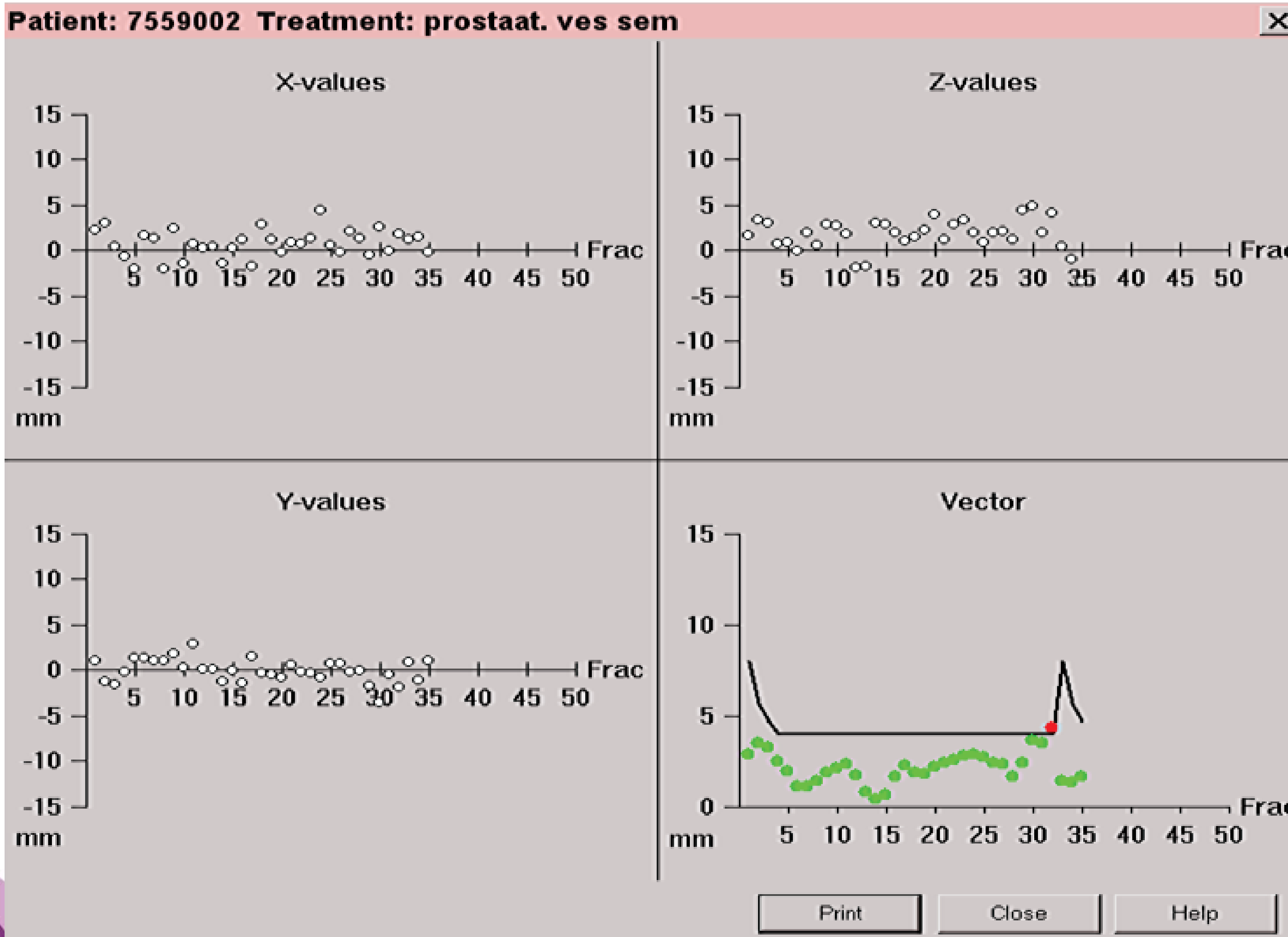


Fiducial markers: offline

- Succesfull reduction of systematic error!
  - Without applying a correction protocol, the systematic errors (*Σ)* are:
    - 4.8, 2.2 and 2.9 mm in the vertical, lateral and longitudinal directions
  - The SAL protocol
    - 0.7, 0.8 and 0.8 mm, respectively.
  - Random position variations are not reduced in an off-line correction protocol

Online fiducial marker registration

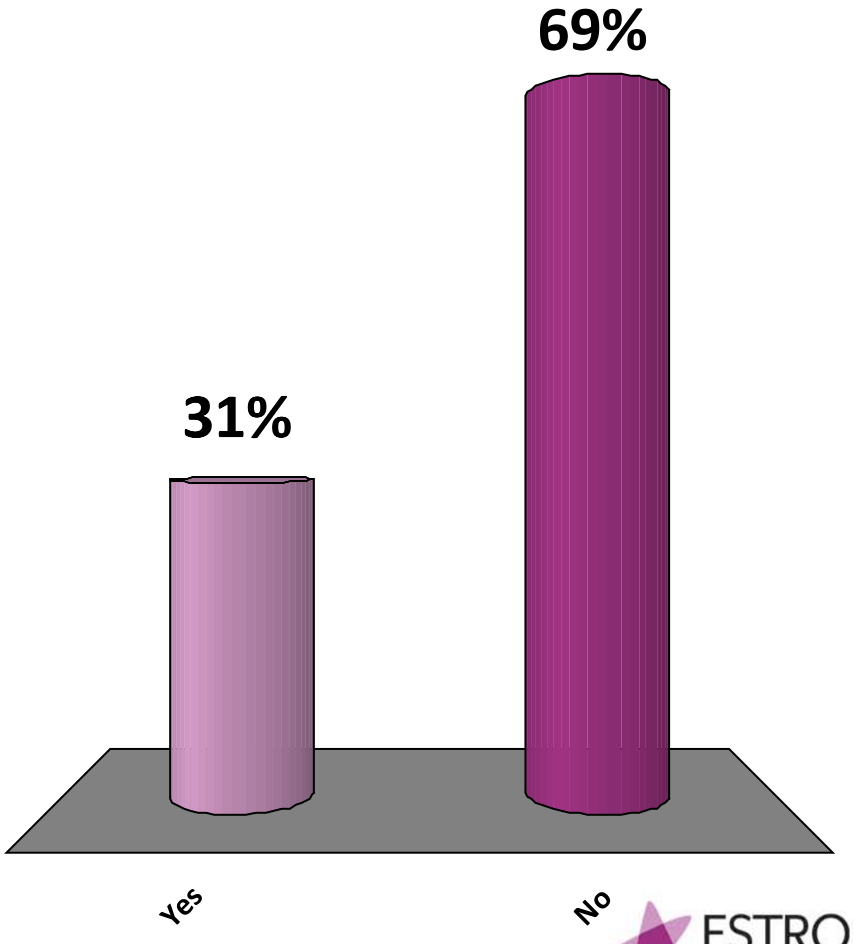
Food for thought!



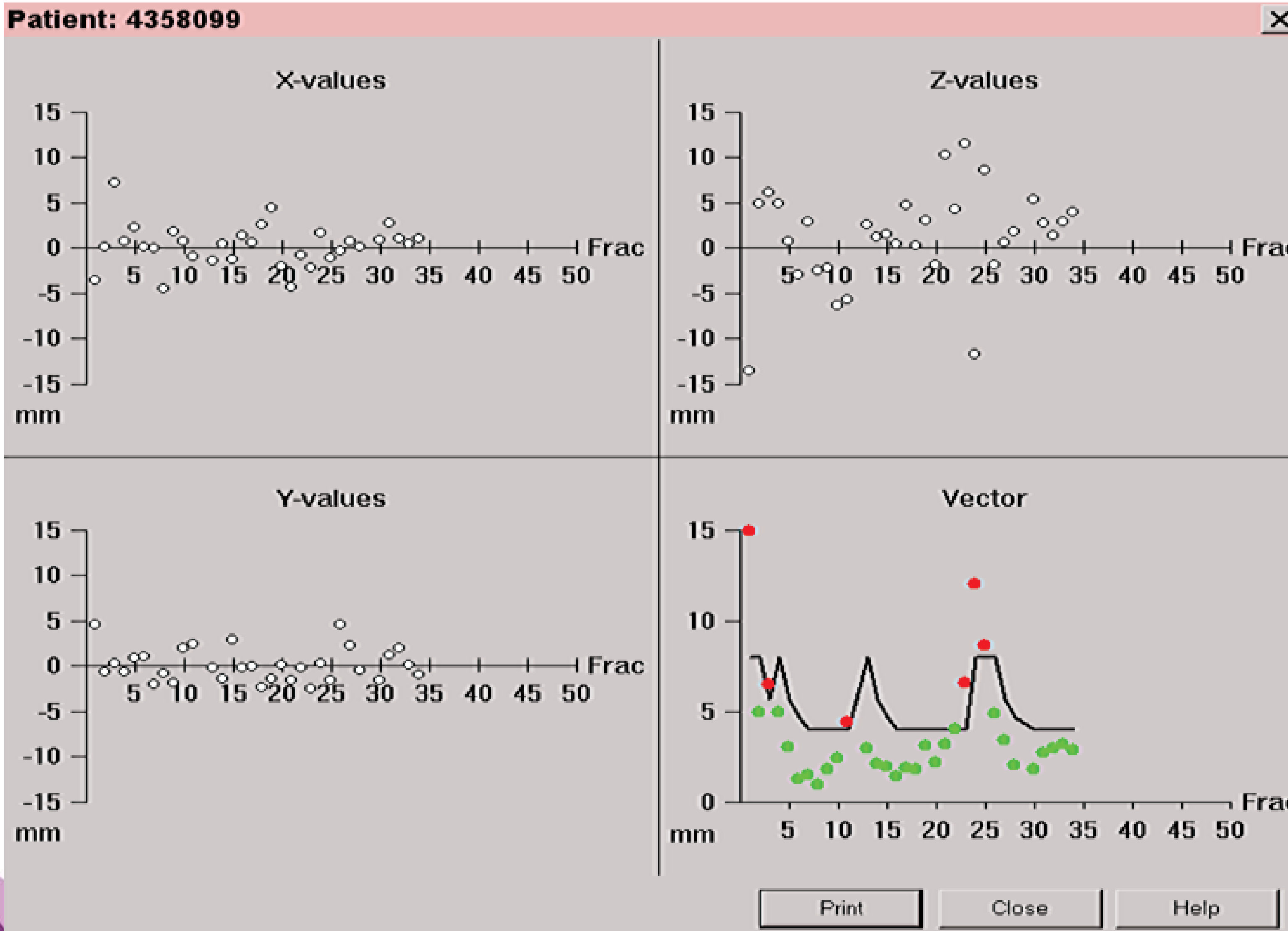
Would you like to treat a patient like this offline?

A. Yes

B. No



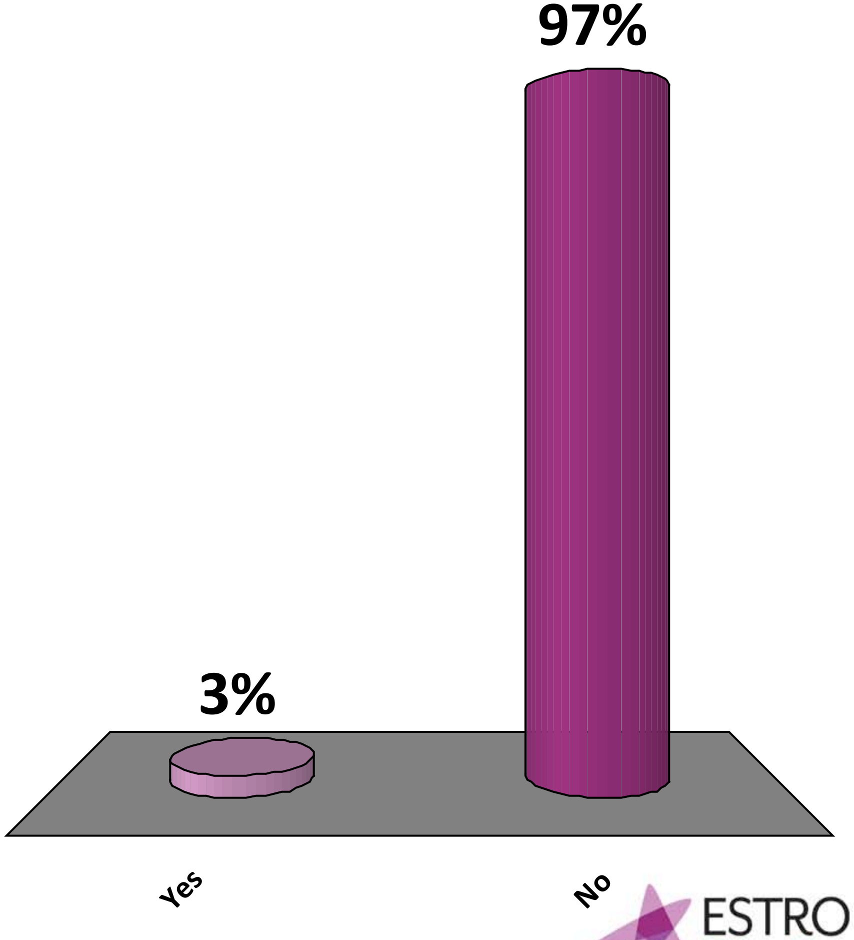
Food for thought!



Would you like to treat a patient like this offline?

A. Yes

B. No



Online Position Verification

- To reduce random error:
  - Online position verification is needed

- Different methods available
  - Two dedicated EPI field, e.g. 40 and 320 degrees
    - Correction for imaging dose necessary
  - Stereo Graphic Targeting
    - MV and kV together
    - Correction for imaging dose necessary
  - Two kV images
    - With CBCT or OBI
    - With ExacTrack system

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Offline vs Online

		Results (mm)		
		X	Y	Z
Offline	Sys. error	0.8	0.8	0.7
	Random error	2.3	2.5	4.0
Online	Sys. error	0.8	0.6	0.9
	Random error	1.0	1.0	1.2

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Online Position Verification

Online procedure

- Random error minimalized

Enables **limited** margin reduction!

treatment execution	β * σ	3.3	7.7	3.6
breathing	b	0.0	0.0	0.0
scalar	a – β * σ_p	-2.7	-6.6	-2.7
CTV-PTV marge (mm)		6.6	7.2	7.1
Eenvoudige formule van Herk: 2.5*SIGMA+0.7*sigma		8.0	7.8	8.7
Formule Stroom: 2.0*SIGMA+0.7*sigma		6.8	6.6	7.5

breathing	b	0.0	0.0	0.0
scalar	a – β * σ_p	-2.7	-6.6	-2.7
CTV-PTV marge (mm)		6.2	6.2	6.1
Eenvoudige formule van Herk: 2.5*SIGMA+0.7*sigma		7.1	6.8	7.0
Formule Stroom: 2.0*SIGMA+0.7*sigma		5.9	5.6	5.8

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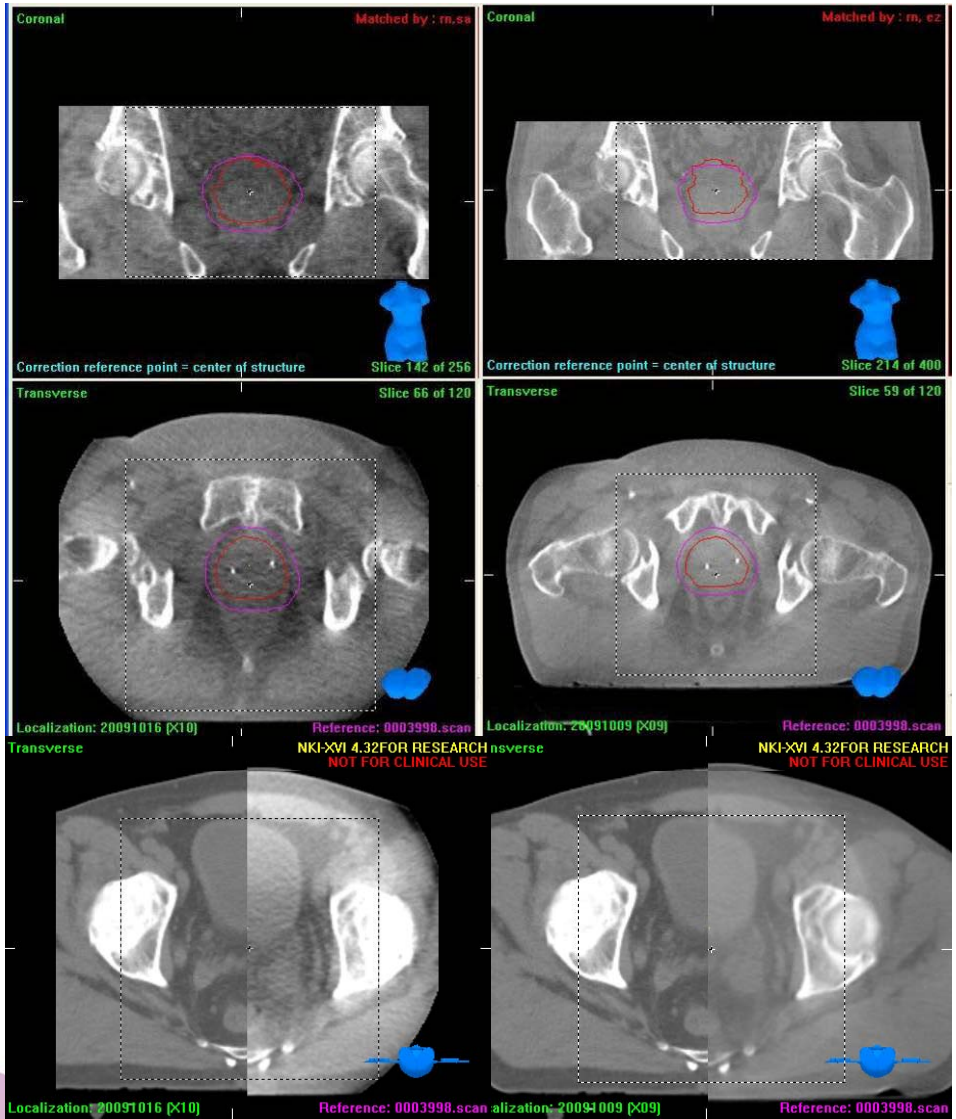
Online marker registration using CBCT

0.4 cGy 3 cGy



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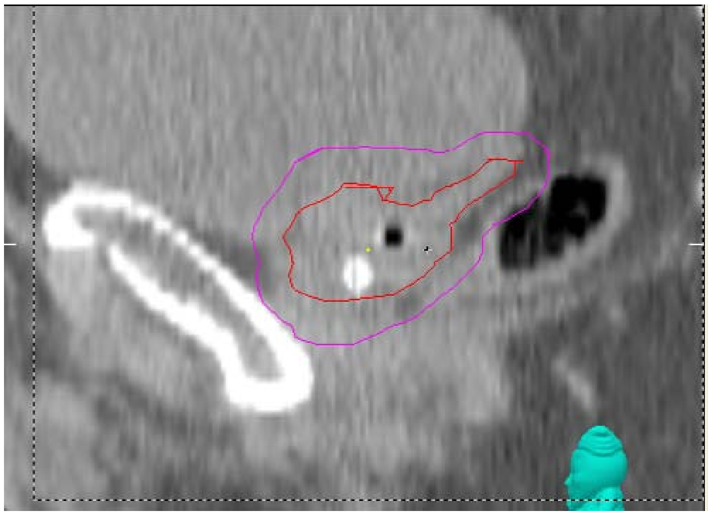
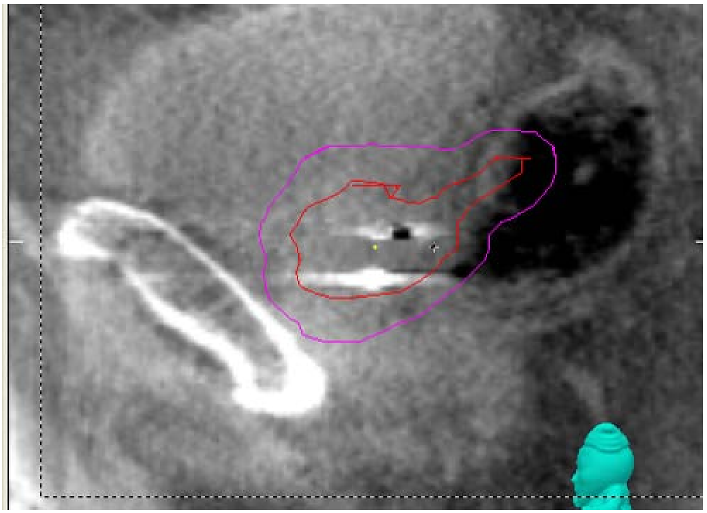
ConeBeam CT: soft tissue information





Red = Prostate + sem.ves.

Purple = PTV

CBCT : sem.ves outside PTV

Acknowledgements NKI/AvL

Many ways to Rome!

Method	Margin (AMC)	Extra treatment time	Imaging dose	Corretable?	Relevant anatomical information
Bone match	10 mm	2-3 minutes	(3cGY*2) High	Possible	-
Offline fiducial PI	8 mm	0 minutes	No	-	+
Online fiducial PI	7 mm	1-3 minutes	Very low (kV) to high (MV)	Correctable in case of PI	+
Online CBCT	7 mm	1-3 minutes	0.4-3.5 cGy/scan	Partly	+++

If there is a balance with the used margin:

1. LC is about the same for the all different procedures
2. Toxicity probably lowest with online IGRT

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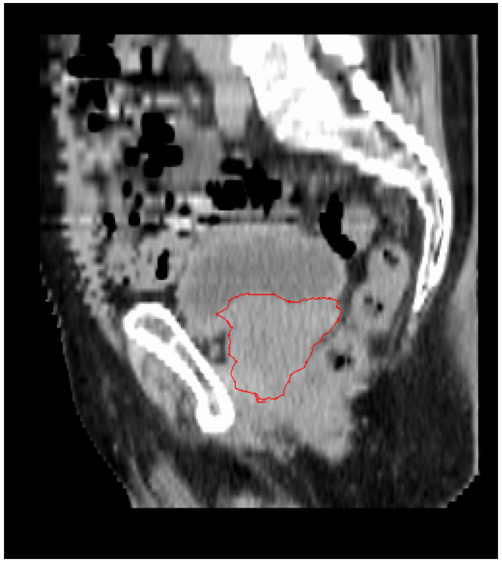
The N1 case

Challenge: Independent moving targets

- Lymph nodes
  - Correlate nicely with bony anatomy
- Prostate
  - Doesn't correlate with bony anatomy



Van Herk *et al.*

Option 1: solved by margins (AMC)

- Use guidelines for delineation: e.g.Taylor
- Depending on correction protocol calculate optimal margins
    - ➢ E.g. AMC offline eNAL correction protocol 8 mm, 7 mm and 10mm for X, Y and Z direction respectively

- If ,for the prostate, no fiducials are used
    - ➢ AMC would use 1 cm isotropic margin

- Available for everybody
- Not optimal concerning toxicity

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Option 2: MAP IMRT (P.Xia *et al.* 2010)

Multiple Adaptive Plans IMRT (MAP-IMRT)

- Fiducial markers
- Library of plans:
  - ➢ Select plan with prostate position for that day
  - ➢ Plans were created with fictitious prostate positions

- Labor intensive
- Realistic? E.g. rotational errors are neglected

Option 3: MLC optimization (Ludlem *et al.* 2007)

Difference in position between bones and prostate is corrected by MLC adjustment:

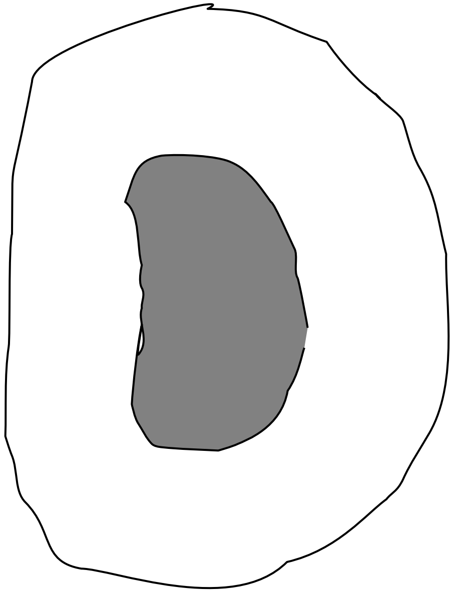
- Online recalculation

- Labour intensive
- Intra fraction motion?
- Dose study
- Not commercially available

Option 4: Adaptive procedure

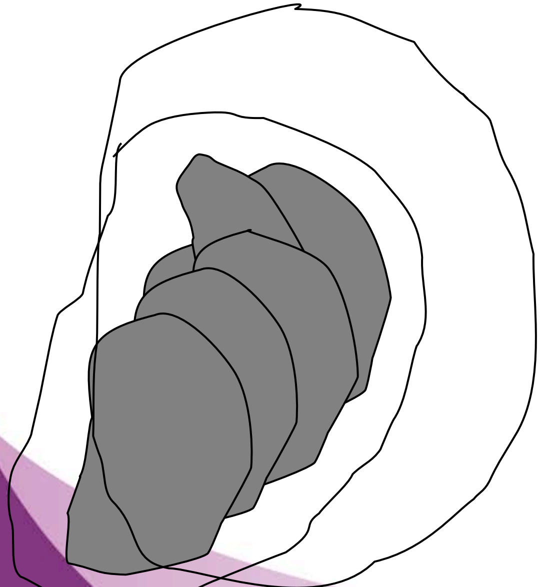
- Major problem:
  - “uncorrectable” systematic error between lymph nodes and prostate match
  - Peter’s rules: deformations can not be corrected with table corrections

Bladder: Focal adaptive margin strategy



Conventional focal boost technique:

one initial tumor position plus 2 cm margin



<u>Adaptive margin strategy</u>:

5 CT scans during first week of RT

Delineate 6 tumor positions plus 1 cm margin

- 40% boostvolume reduction *(pos et al 06)*
- less geografical missers

Thank you for your attention!

Case report: **Cervix**

Sofia Rivera, Gustave Roussy, Villejuif, France

Case from the Gyn GEC ESTRO Network / FALCON WS
Courtesy of Pr Pötter

Advanced skills in modern radiotherapy
June 2015

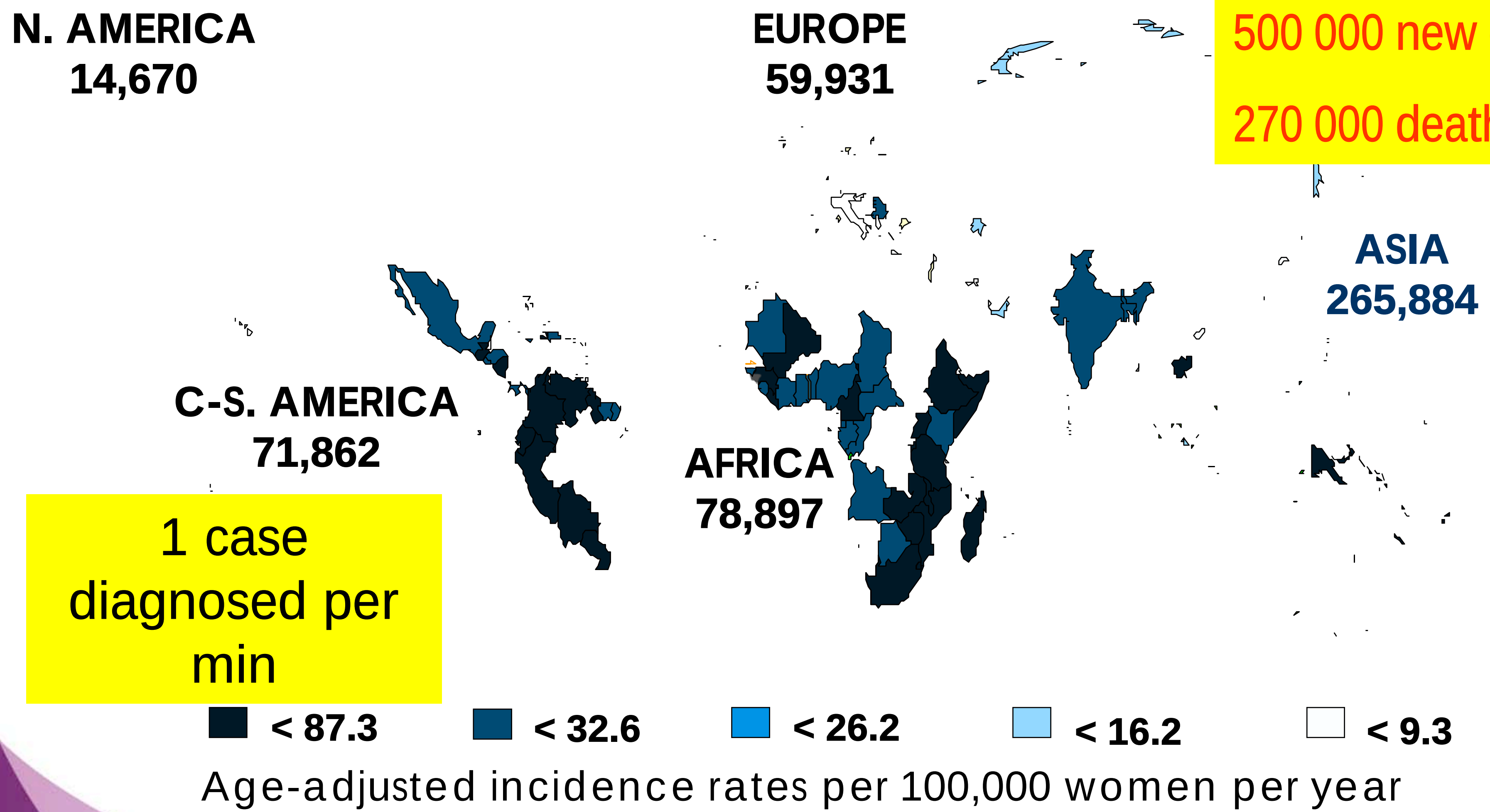
WWW.ESTRO.ORG/SCHOOL

Cervix cancer diagnosis OMS

1,4 Million cases

500 000 new cases/ year

270 000 death / year



1 case diagnosed per min

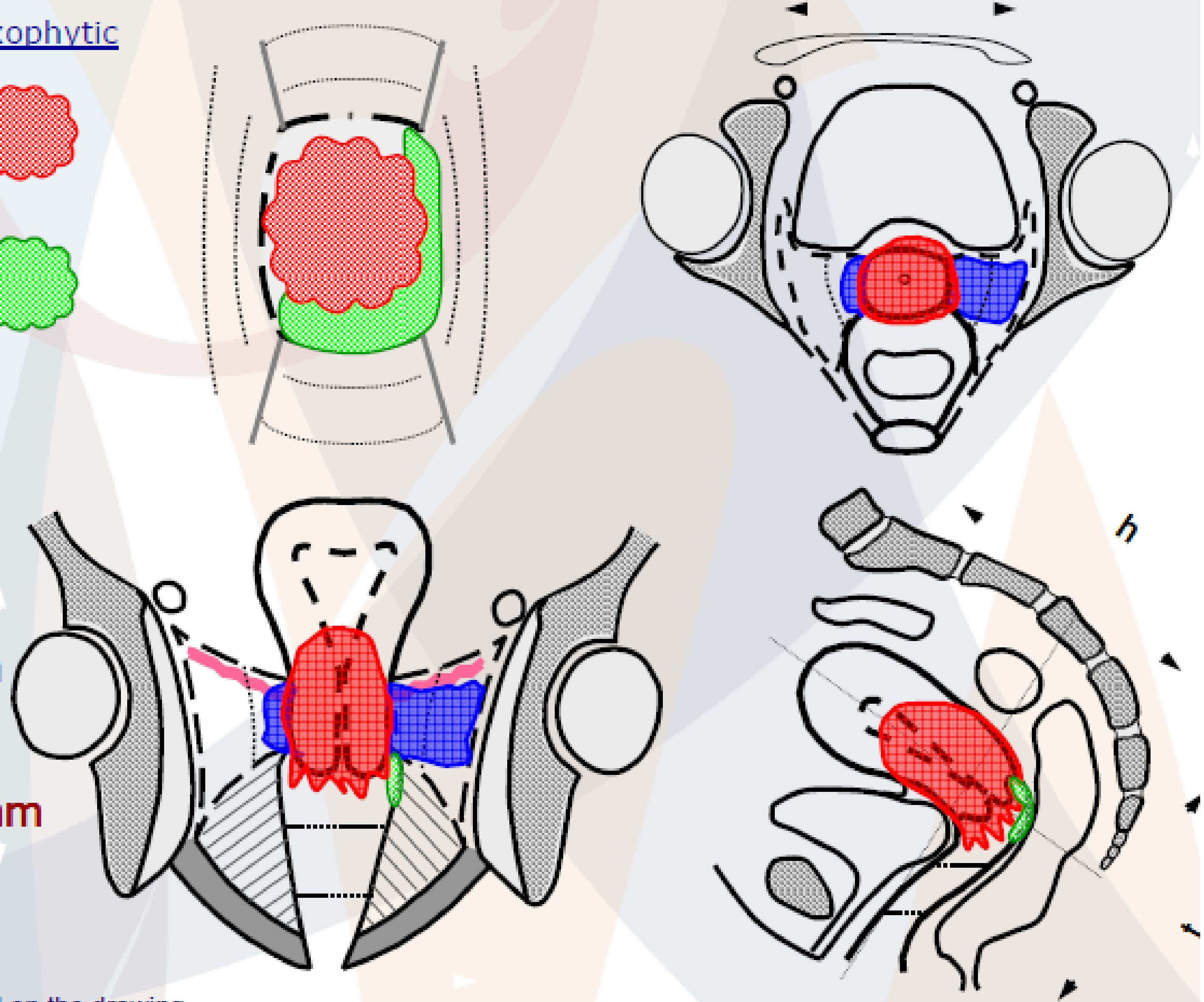
Whosis Statistical Database, 2002.

Patient History

- 72-year old woman.
- WHO performance status=1
- No palpable node
- Squamous cell carcinoma, grade 3
- TNM: T3b N1 M0

Clinical findings of gyn. examination: at DIAGNOSIS

	Infiltrative	Exophytic
Cervix		
Vagina		
Parametria		



Dimensions:

Width: 90 mm

Thickness: 50 mm

Height: 60 mm

Vaginal inv.: 20 mm

ESTRO
Gyn contouring workshop
Barcelona, May 2012

*Radiological findings integrated on the drawing

Clinical findings of gyn. examination: SUMMARY

FIGO stage: IIIB

	At diagnosis	At brachytherapy
Width	90 mm	
Thickness	50 mm	
Height*	60 mm	
Left parametrium	Infiltration to pelvic wall	
Right parametrium	Proximal infiltration	
Vagina	20 mm: left & posterior wall	
Bladder**	Not infiltrated	
Rectum**	Not infiltrated	

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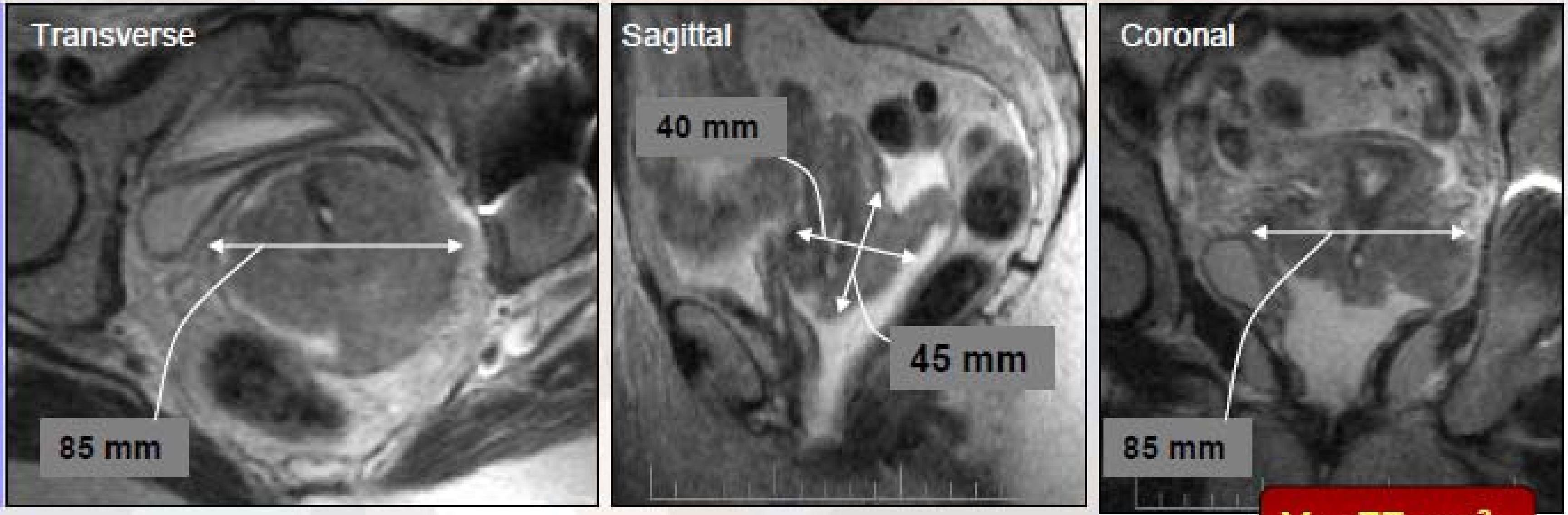
Gyn contouring workshop
Barcelona, May 2012

*Some uncertainty in assessment of height

**Endoscopy at diagnosis

MRI findings

At diagnosis

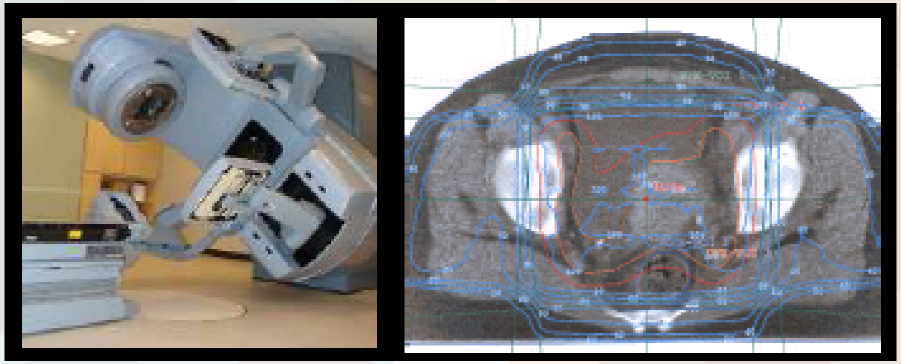


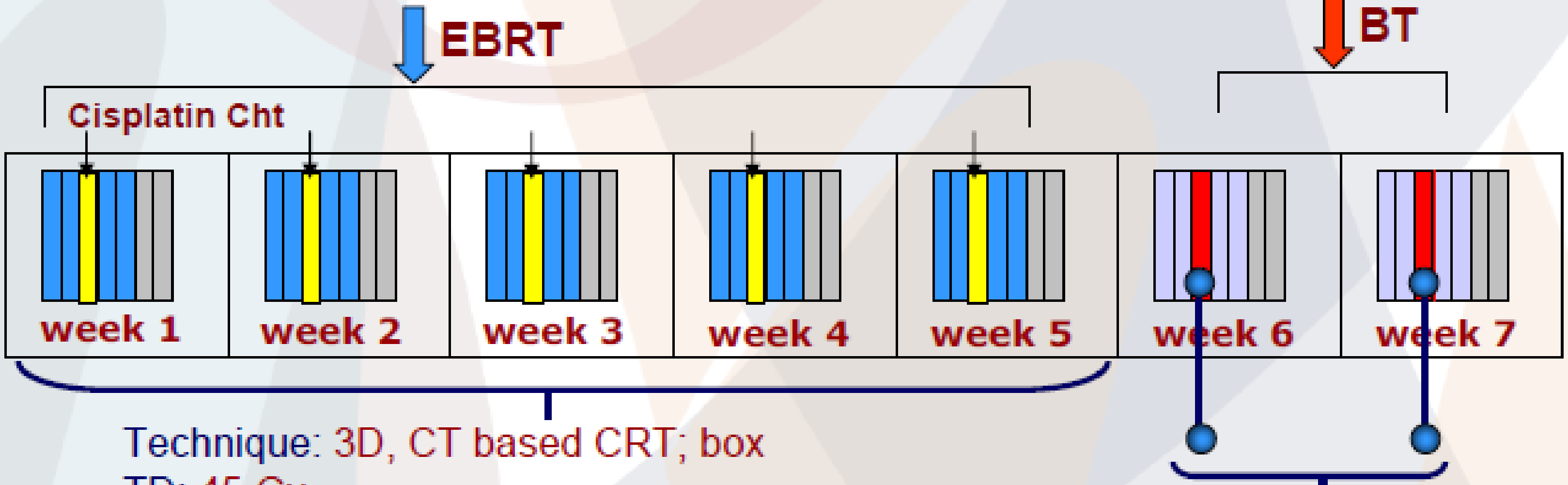
V ≈ 77 cm^3

Comment:

Only the representative slices are shown here. Use the information from complete initial MRI data set to fully understand the extent and topography of the tumour.

EBRT, Chemotherapy & timing of BT





Technique: 3D, CT based CRT; box
TD: 45 Gy
Dose per fraction: 1,8 Gy

Concomitant chemotherapy:
Cisplatin 40 mg/m2 weekly, 5 cycles

2 x 7 Gy 2 x 7 Gy

Prescribed to HR CTV

High Dose Rate

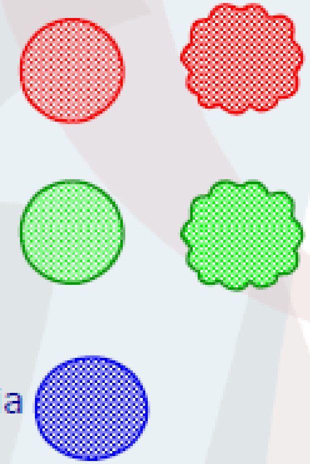
Clinical findings of gyn. examination: at Brachytherapy

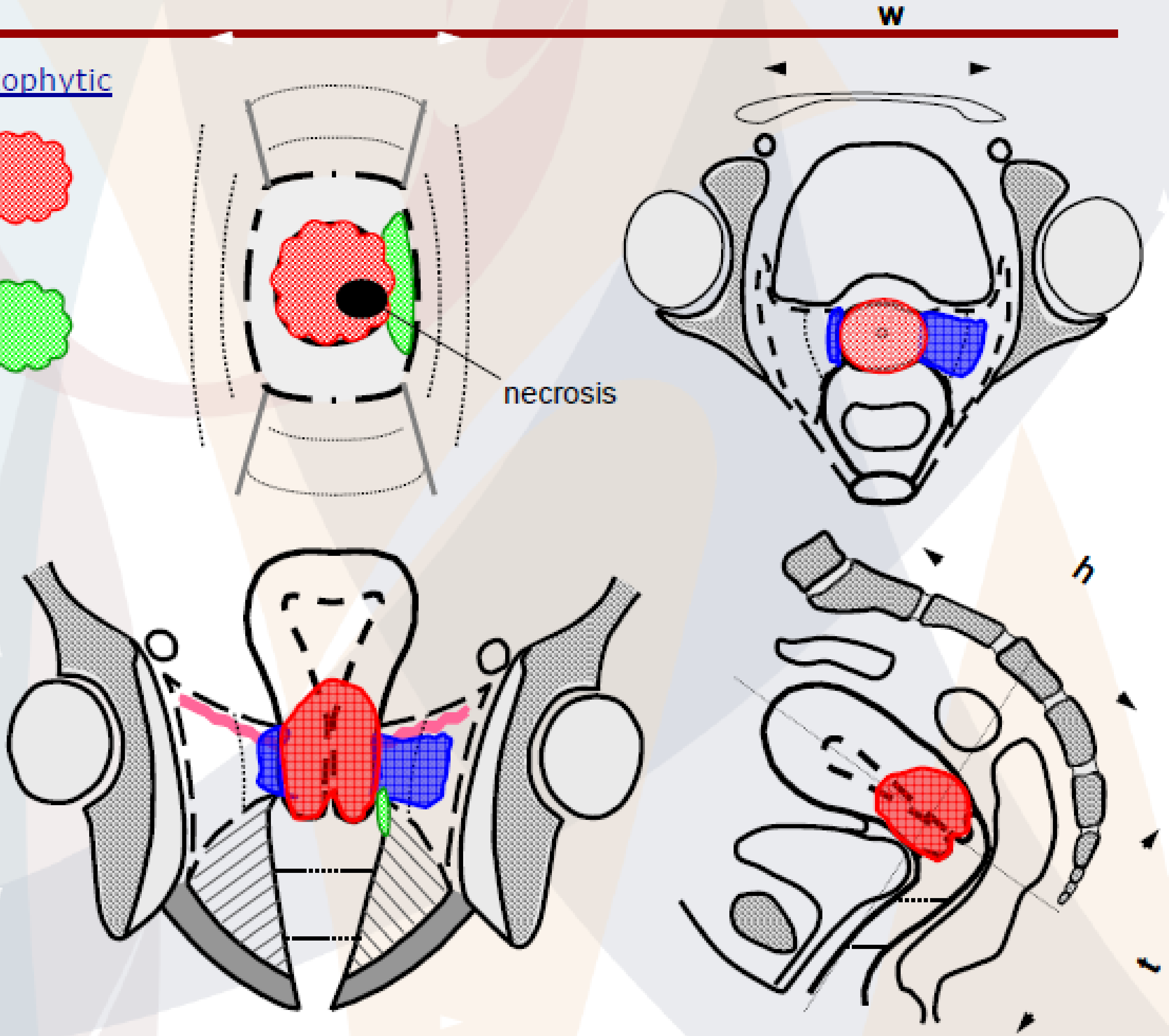
Infiltrative   Exophytic

Cervix

Vagina

Parametria





Dimensions:

Width: 70 m

Thickness: 40

Height: 40

Vaginal inv.: 10

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Gyn contouring workshop
Barcelona, May 2012

Clinical findings of gyn. examination: SUMMARY

FIGO stage: IIIB

	At diagnosis	At brachytherapy
Width	90 mm	70 mm
Thickness	50 mm	40 mm
Height*	60 mm	40 mm
Left parametrium	Infiltration to pelvic wall	Distal infiltration (≈ 30 mm)
Right parametrium	Proximal infiltration	Proximal infiltration (≈ 10 mm)
Vagina	20 mm: left & posterior wall	10 mm: left fornix
Bladder**	Not infiltrated	NA
Rectum**	Not infiltrated	NA

*Some uncertainty in assessment of height

**Endoscopy at diagnosis

Brachytherapy application

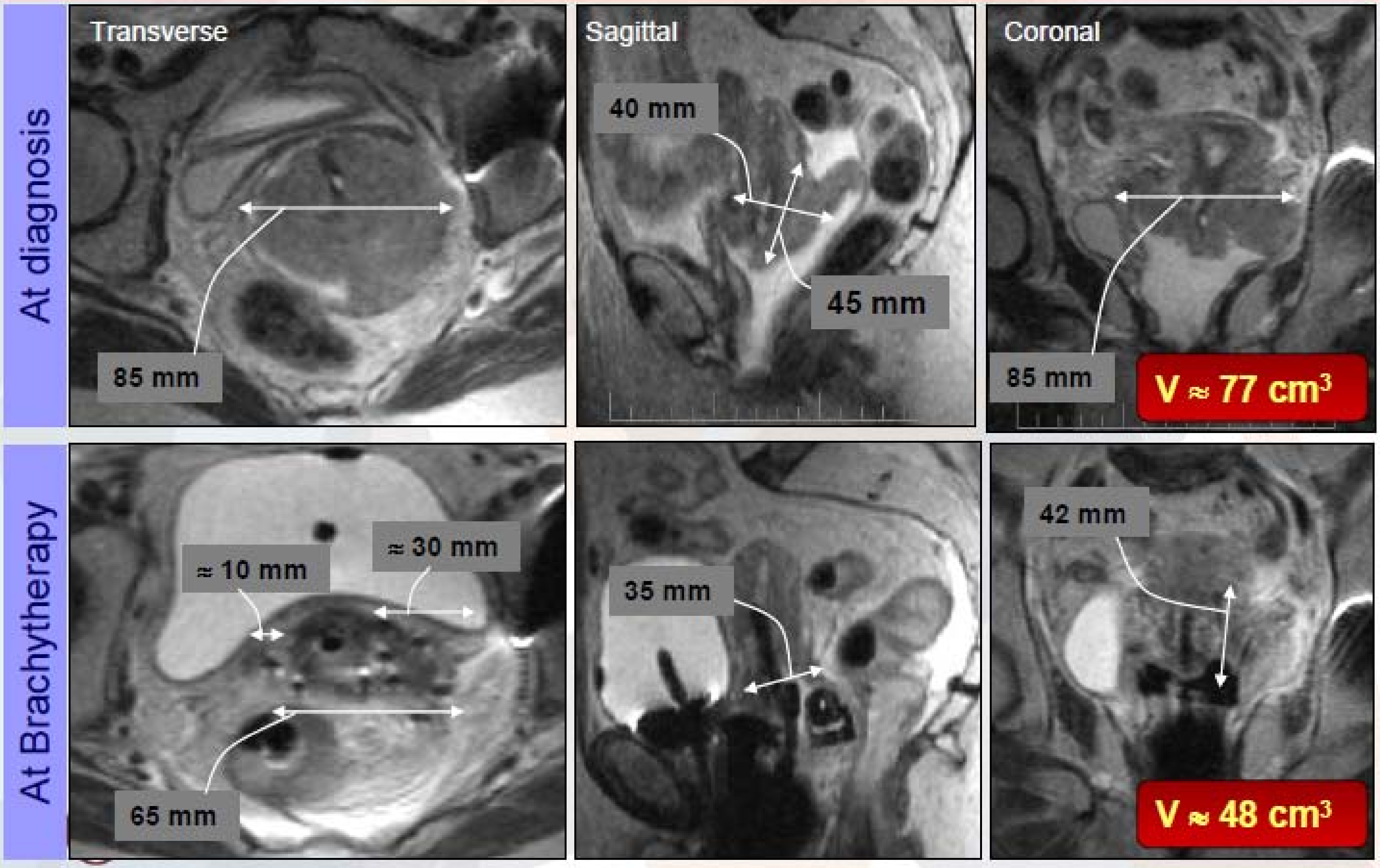
Tandem & Ring

Interstitial parametrial needles according to tumour spread

Following applicator insertion:

pelvic MRI with the applicator in place

MRI findings



Radiotherapy and Oncology 78 (2006) 67–77
www.thegreenjournal.com

ESTRO project

Recommendations from gynaecological (GYN) GEC ESTRO working group (II): Concepts and terms in 3D image-based treatment planning in cervix cancer brachytherapy—3D dose volume parameters and aspects of 3D image-based anatomy, radiation physics, radiobiology

Richard Pötter[a,*], Christine Haie-Meder[b], Erik Van Limbergen[c], Isabelle Barillot[d], Marisol De Brabandere[c], Johannes Dimopoulos[a], Isabelle Dumas[b], Beth Erickson[e], Stefan Lang[a], An Nulens[c], Peter Petrow[f], Jason Rownd[e], Christian Kirisits[a]

[a]Department of Radiotherapy and Radiobiology, Medical University of Vienna, Austria, [b]Department of Radiotherapy, Brachytherapy Unit, Institut Gustave Roussy, Villejuif, France, [c]Department of Radiotherapy, University Hospital Gasthuisberg, Leuven, Belgium, [d]Department of Radiation Oncology, Centre George-Francois Leclerc, Dijon, France, [e]Department of Radiation Oncology, Medical College of Wisconsin, Milwaukee, WI, USA, [f]Service de Radiodiagnostic, Institut Curie, Paris, France

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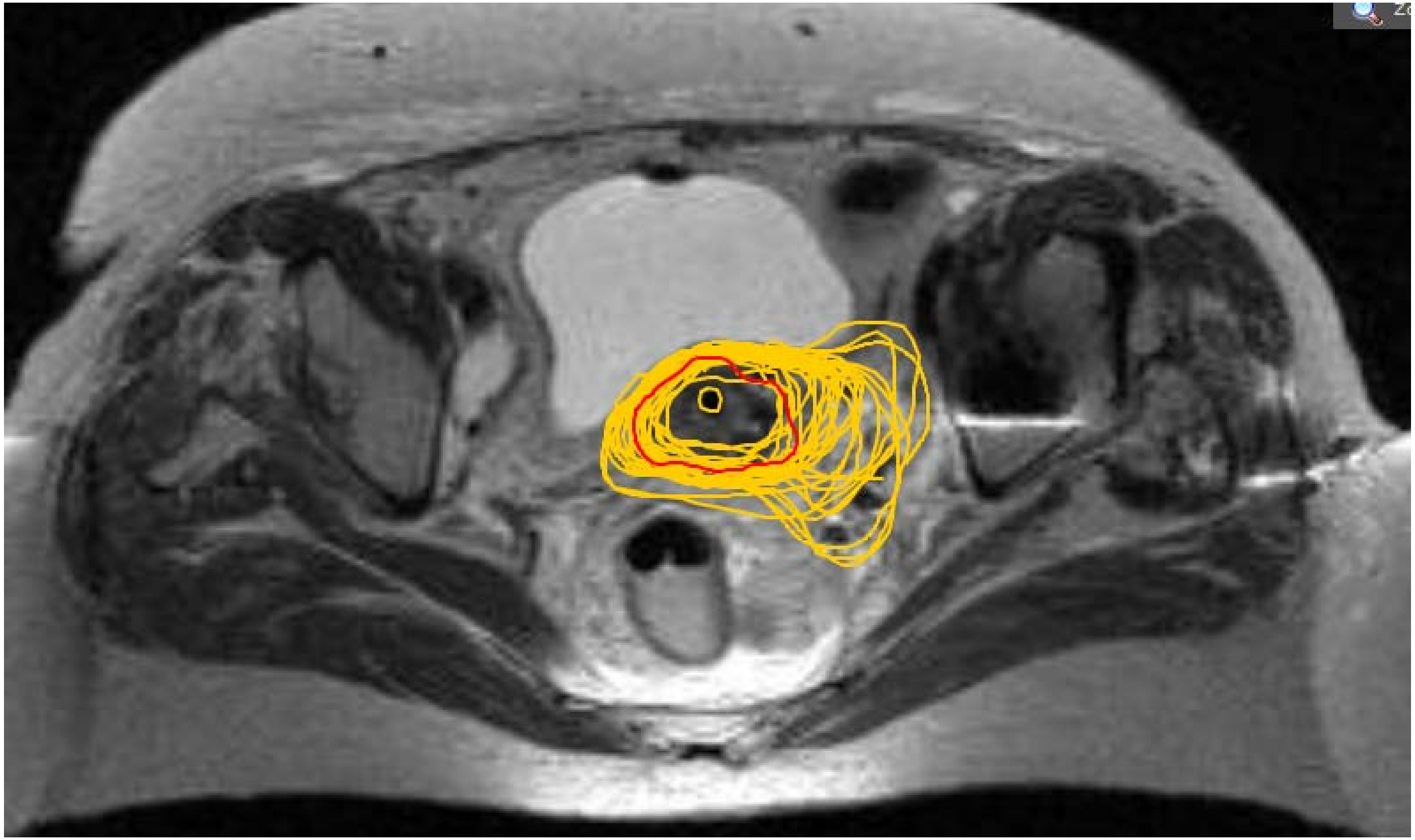
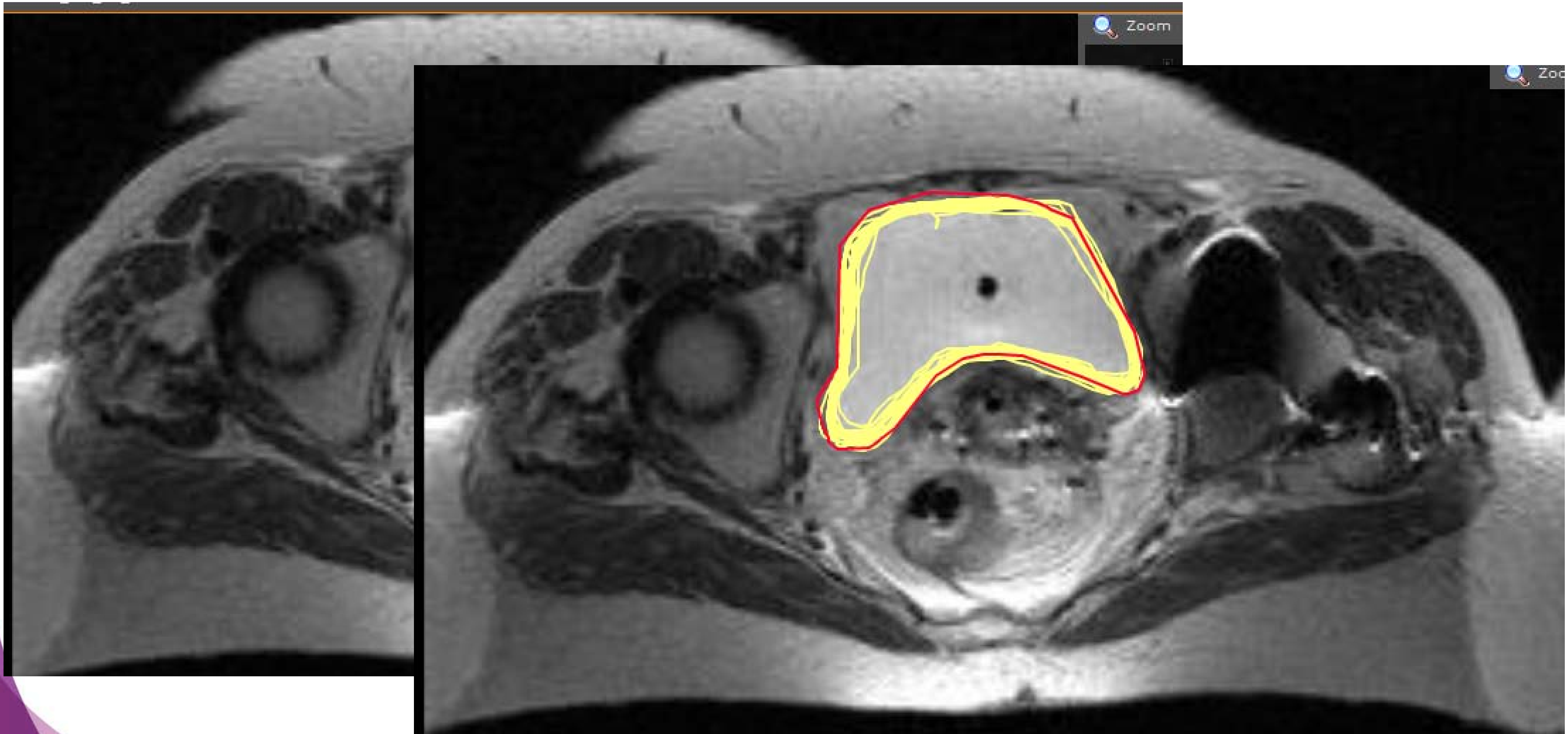
Heterogeneity in contouring target volumes besides the use of guidelines

- High Risk CTV

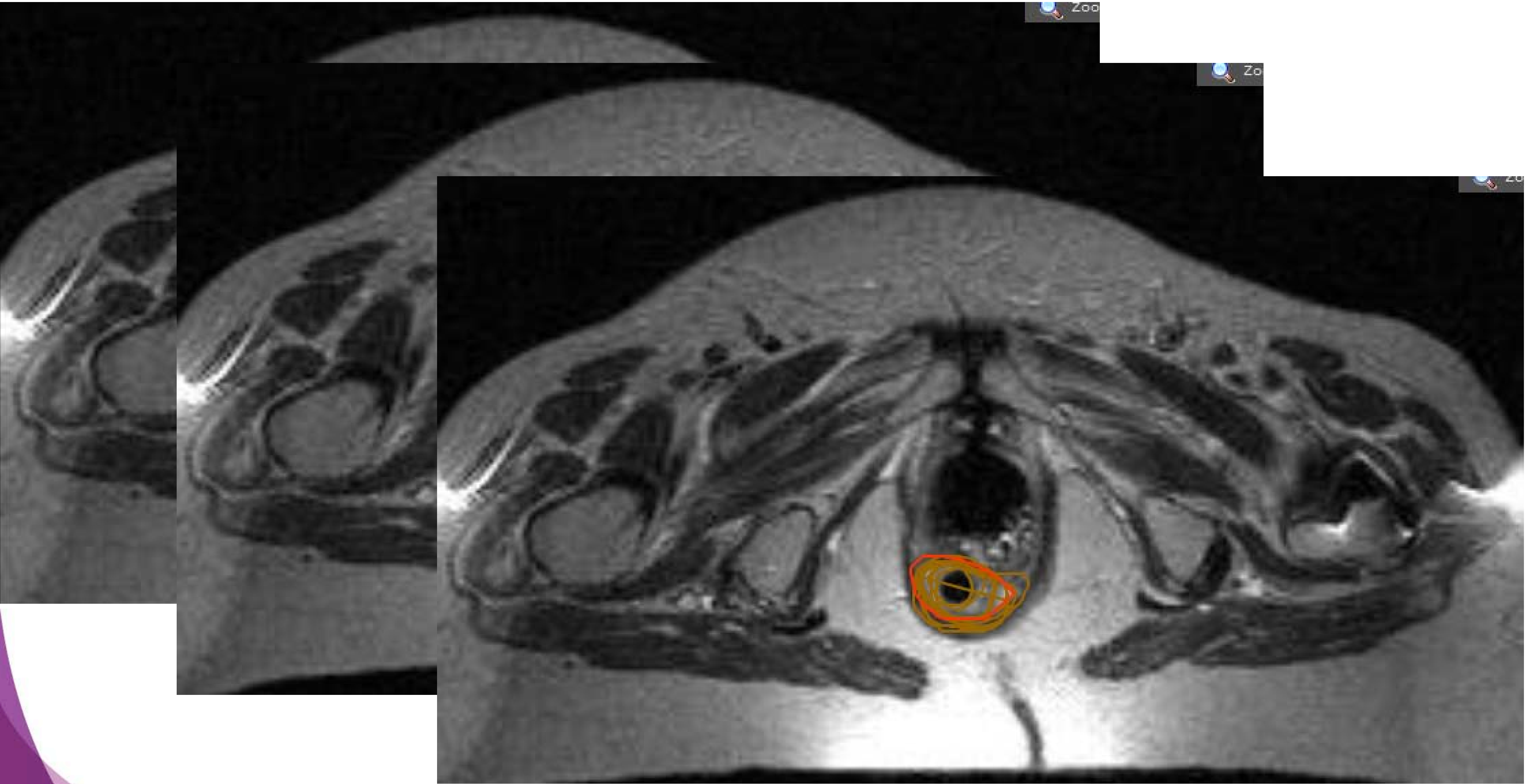


Quite good homogeneity in some OAR contouring

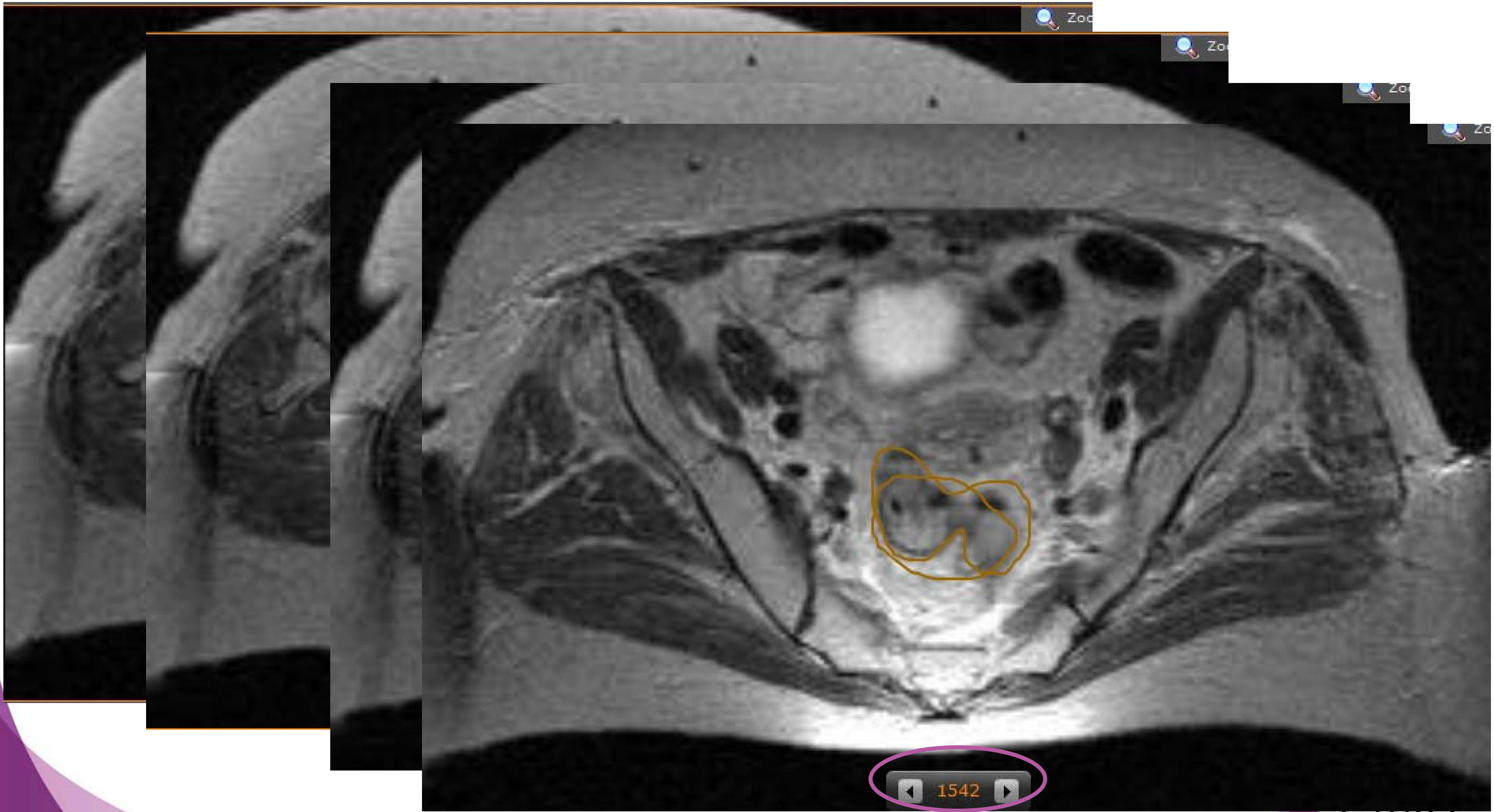
- Where anatomical bundaries are well visible



But it's not always the case!



Upper and lower limits are a source of heterogeneity in contouring as well



5 slices = 1,5cm difference in the upper limit of the rectum

Take home messages:

- High quality CT and MR imaging is crucial for contouring targets and OAR in the pelvic region

- High quality re-imaging is a key point in cervical cancer to adapt contours for brachytherapy dosimetry

- MR is a key imaging modality in gynecology

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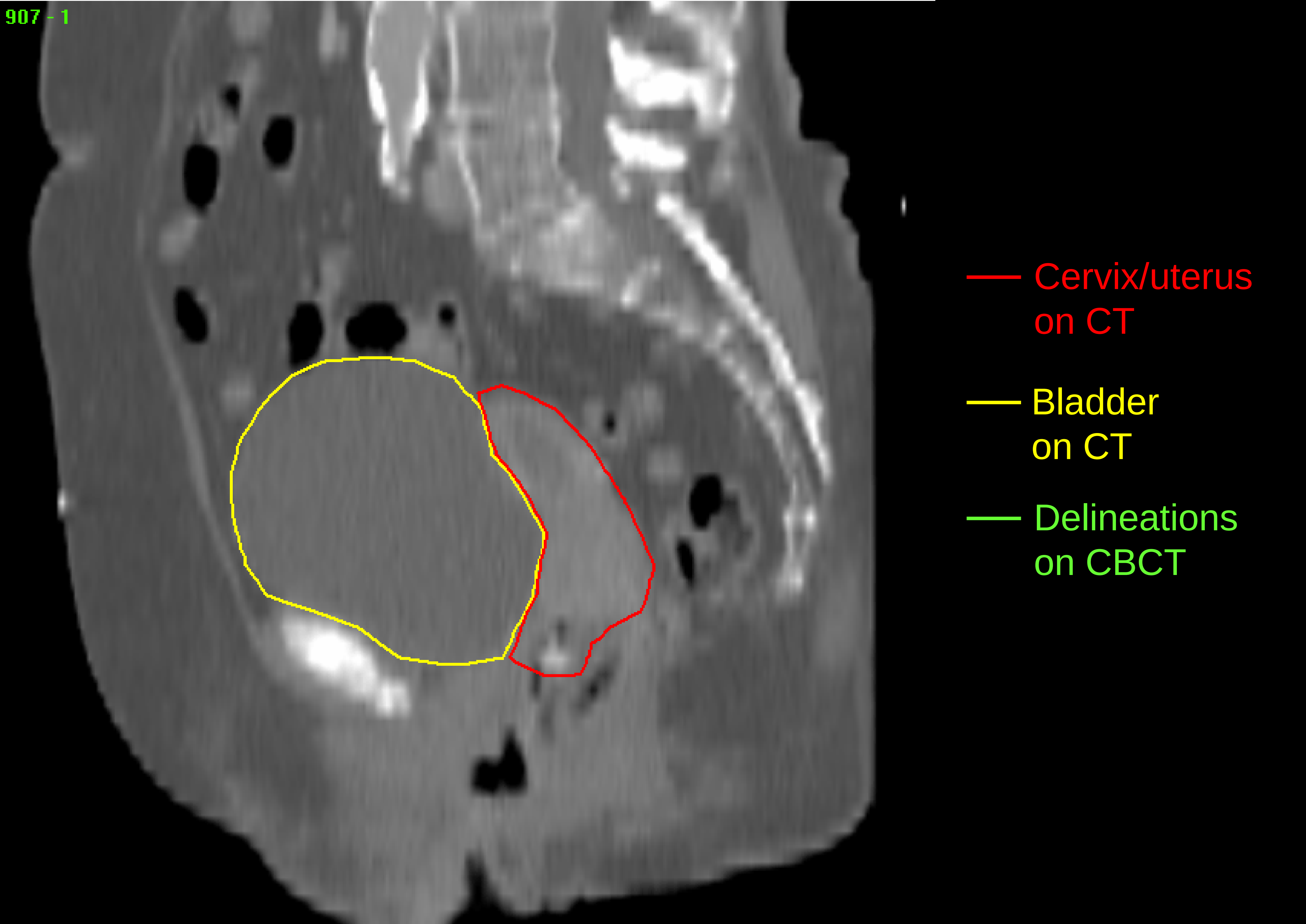
Cervix case – Physics aspects

Peter Remeijer


907 - 1
Cervix/uterus on CT
Bladder on CT
Delineations on CBCT

The main issue

- Very large movement
- Clinically a margin of 2 cm is used
- Probably too small

Can online corrections using couch shifts solve this?

A. True

B. False

Options

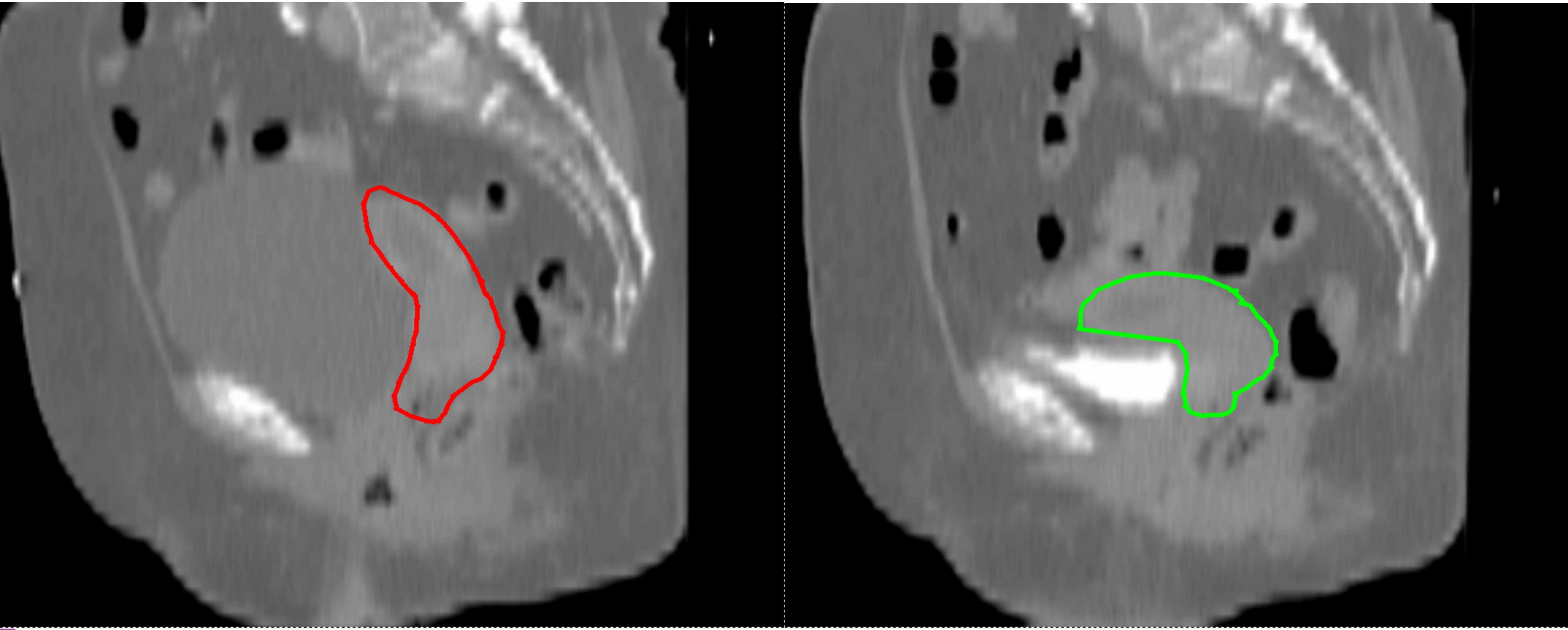
- Drinking protocol
  - ➢ Does it work?
- Scan and postpone treatment if not ok
  - ➢ Ask patient to empty bladder or drink and wait
  - ➢ Not very efficient
- Adapt the plan
  - ➢ Fast planning and delineation not readily available
  - ➢ A-priori plans – select the right one at treatment


hey, i had a full bladder

Options

- Drinking protocol
  - Does it work?
- Scan and postpone treatment if not ok
  - Ask patient to empty bladder or drink and wait
  - Not very efficient
- Adapt the plan
  - Fast planning and delineation not readily available
  - A-priori plans – select the right one at treatment

Full/empty bladder CT

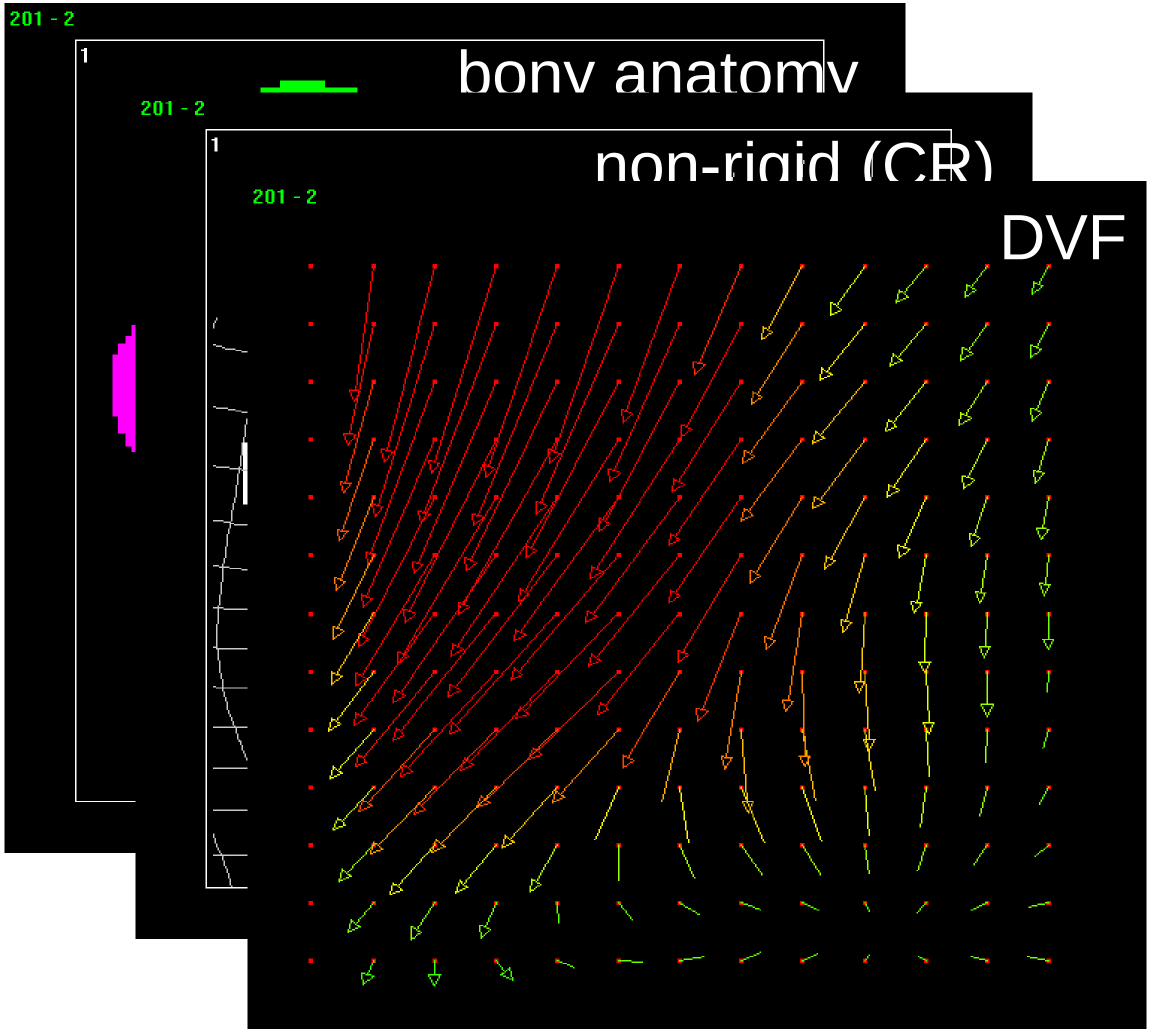


Generate uterus motion model

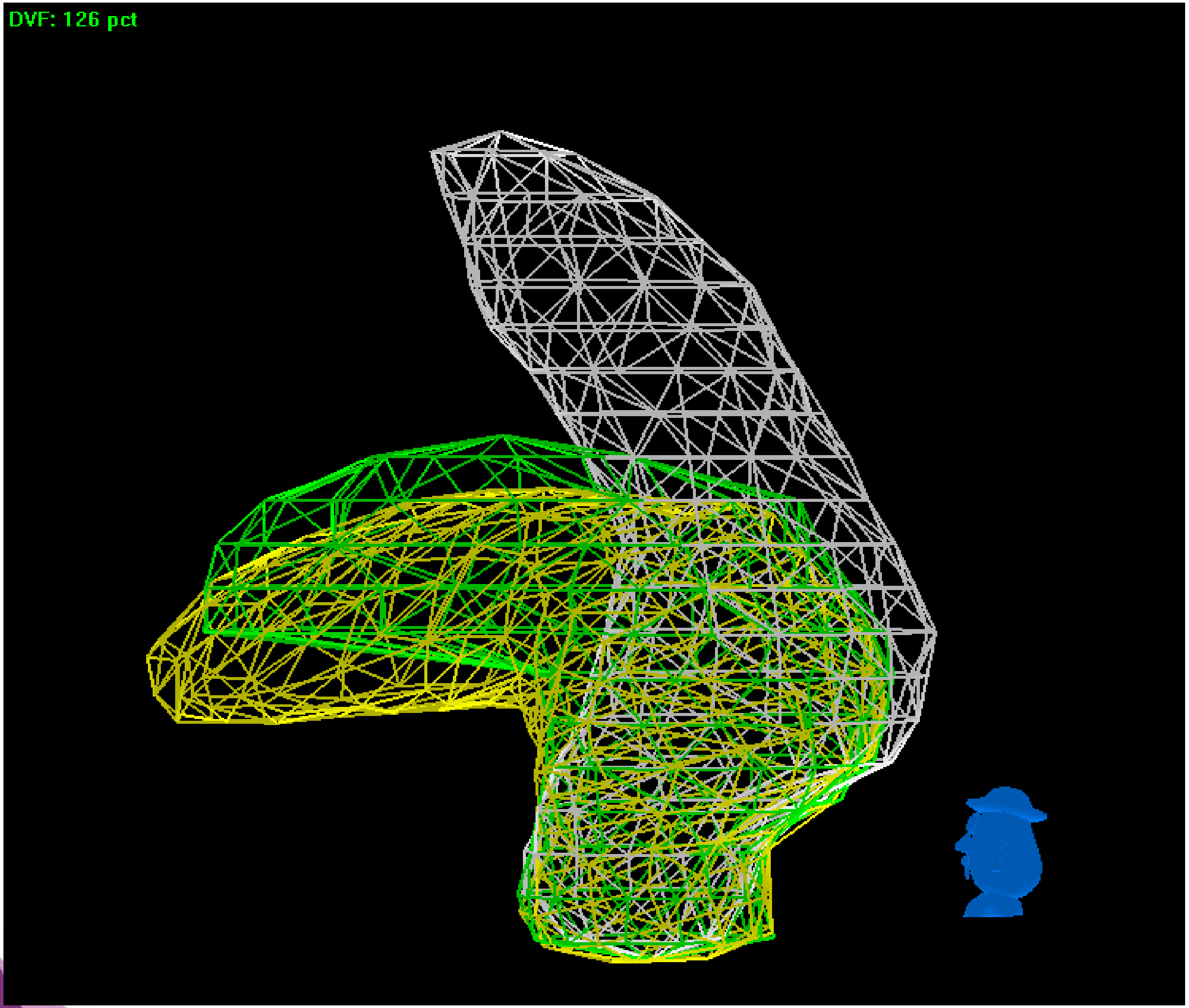
Delineate on full and empty bladder CT

Deform full bladder contour

Generated warp field is model for organ motion



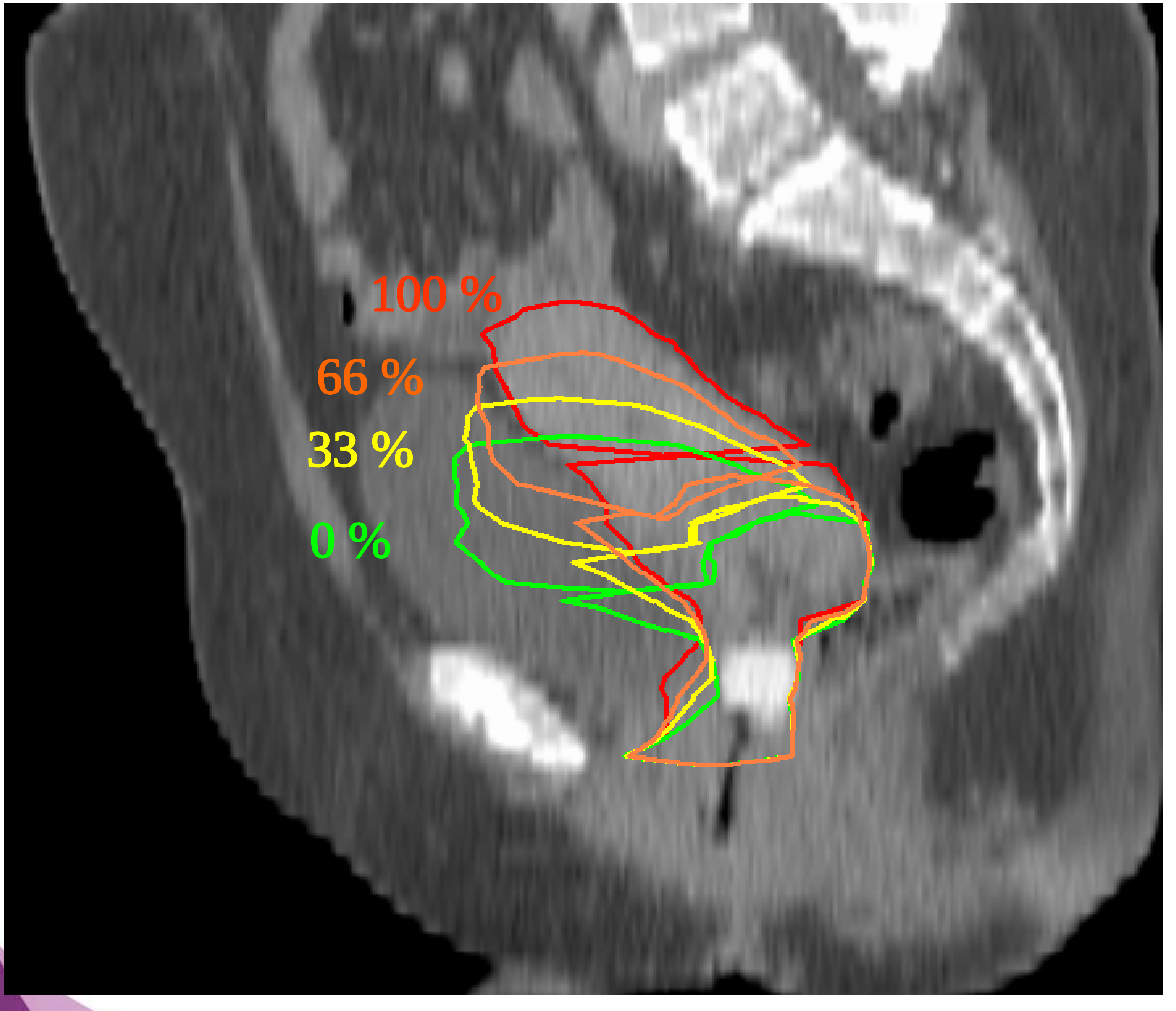
Uterus motion model



Select 4 bladder fillings based on this model:

- 0 %
- 33 %
- 66 %
- 100 %

Generated CTVs



Select 4 bladder fillings based on this model:

- 0 %
- 33 %
- 66 %
- 100 %

Planning

Planning

- 1 VMAT plan created manually (66%, LP2)

- Used as starting point to create three plans automatically (Pinnacle scripting)

- All plans based on full bladder CT scan
  - ➢ Dosimetrically not correct
  - ➢ Small deviations (1-2 %)

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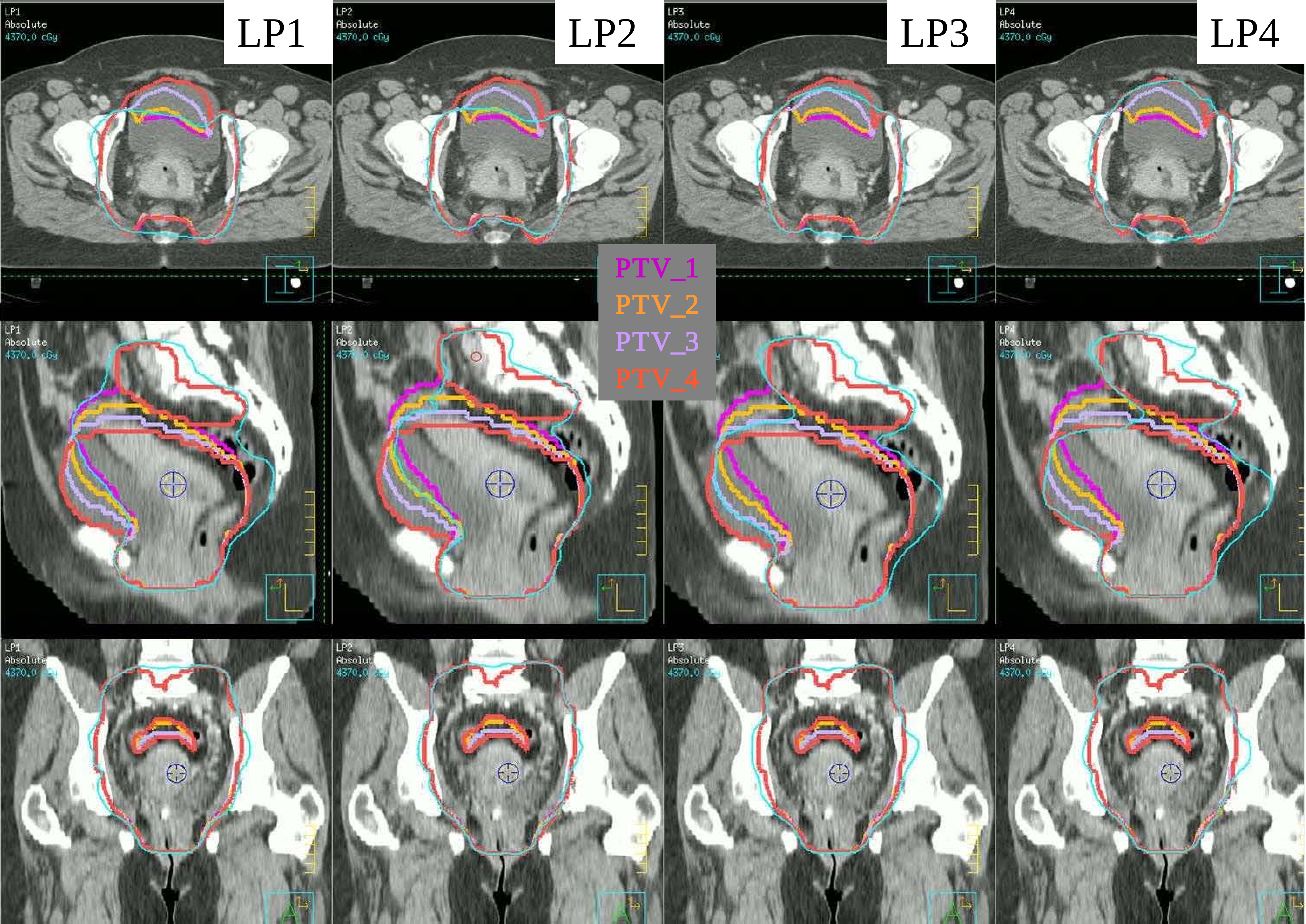
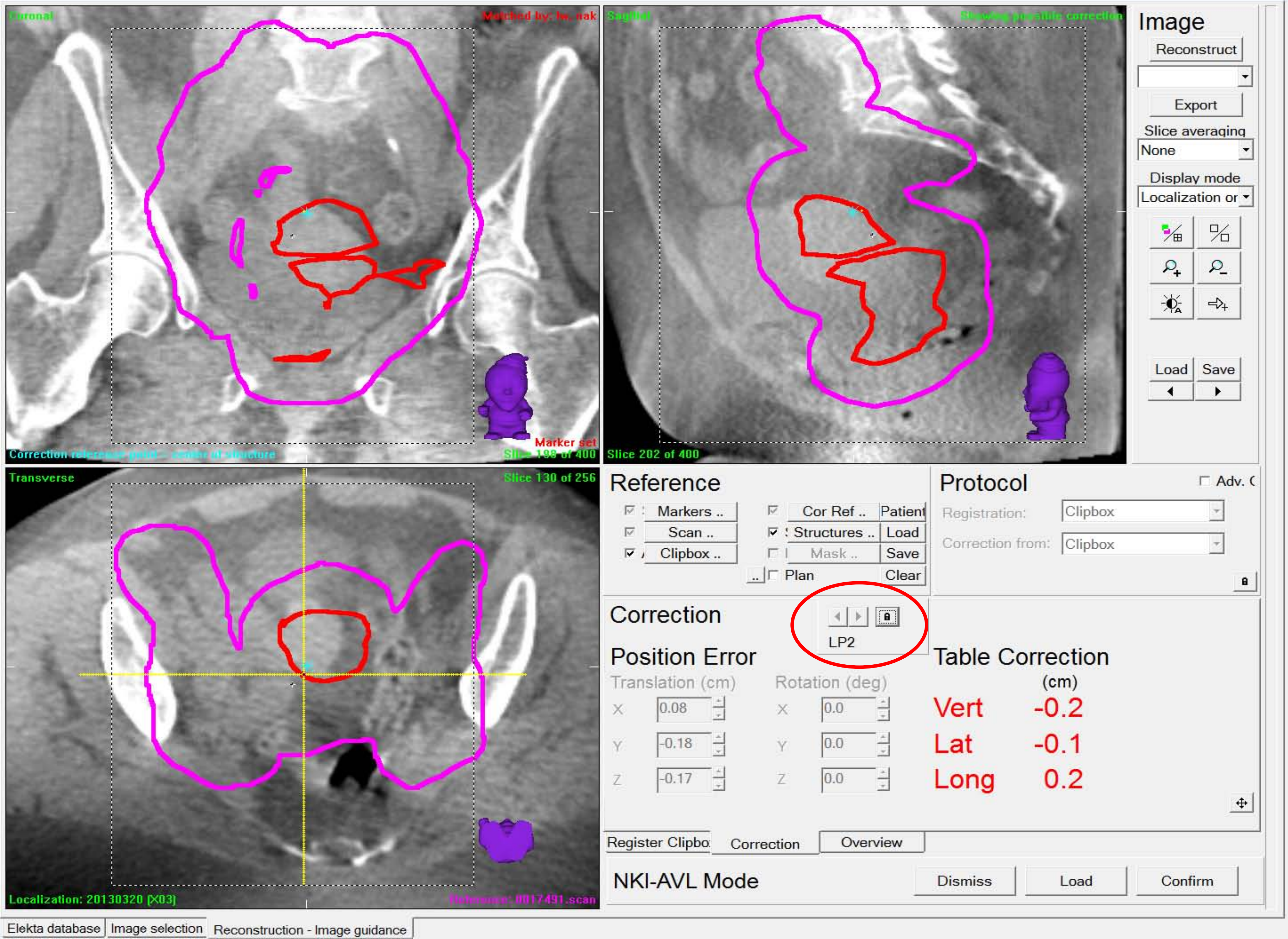

LP1
LP2
LP3
LP4
Absolute
4370.0 cGy
PTV_1
PTV_2
PTV_3
PTV_4

Treatment

- CBCT scan prior to treatment
- Select the ‘best fitting structure’
- Select corresponding plan on the linac
- Treat
- All steps are checked/interlocked using in-house software



LP1 = full bladder LP4 = empty bladder

Slide Nelly Kager, ESTRO 2014

Alternatives?

- Only use full/empty scan
  - ➢ Margin about half the motion
  - ➢ Other errors small compared to motion

- Use CBCT data from the first week
  - ➢ Import CBCT data in planning/delineation system
  - ➢ Delineate on scans, using planning scan as template
  - ➢ Create plan library

- Protocolize everything. It is easy to make mistakes when doing planselection on the linac!

Take home messages

- Drinking protocols are usually not very effective
- Multiple scans to estimate the range of motion are
- Large improvements in geometrical accuracy can be achieved with simple methods
- Protocolize the plan selection process (error prone!)
- Planning and dosimetry is the least of your problems!





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Cervix
ART Library of Plans

Rianne de Jong *RTT*,
Academic Medical Centre, Amsterdam
Copenhagen 2015

m.a.j.dejong@amc.uva.nl

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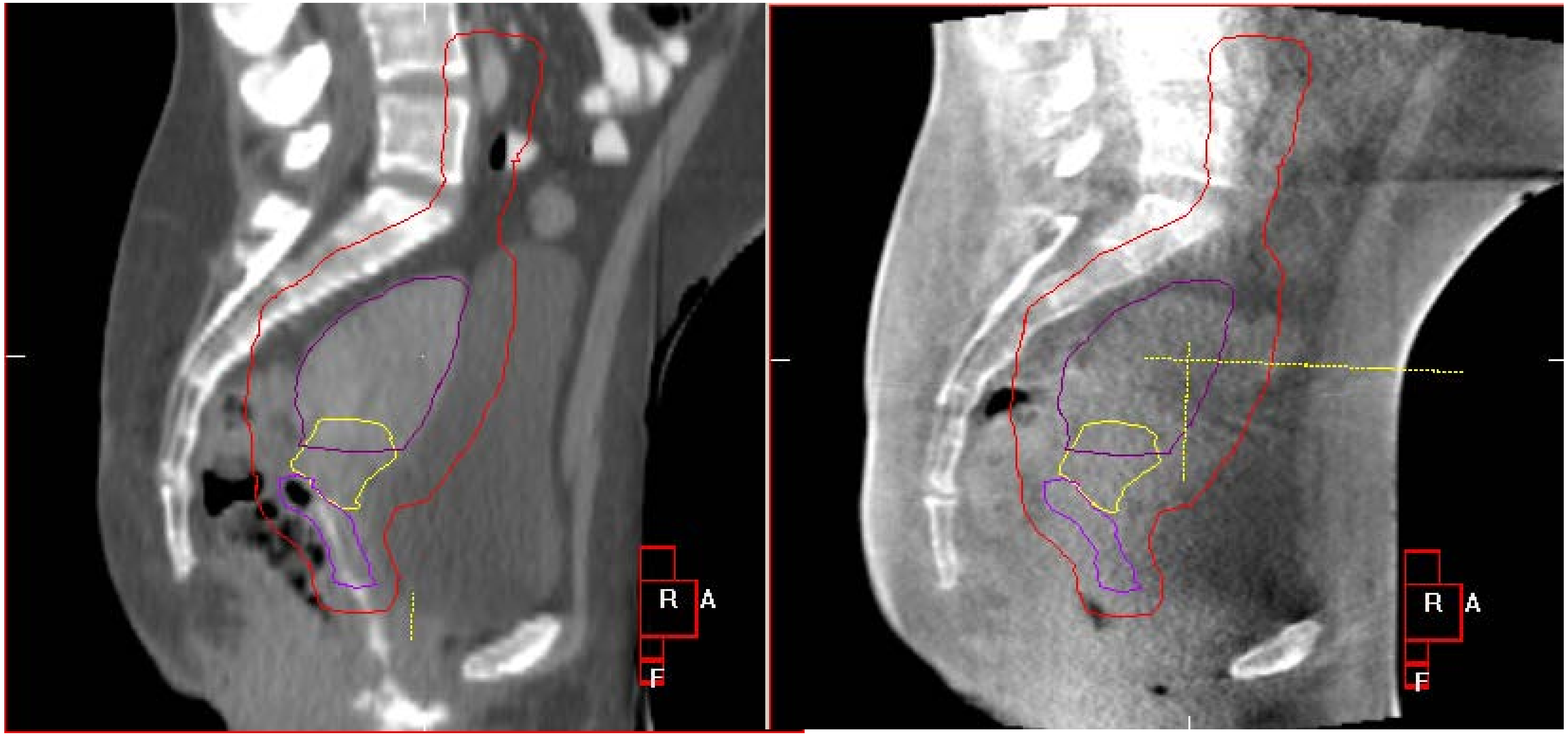

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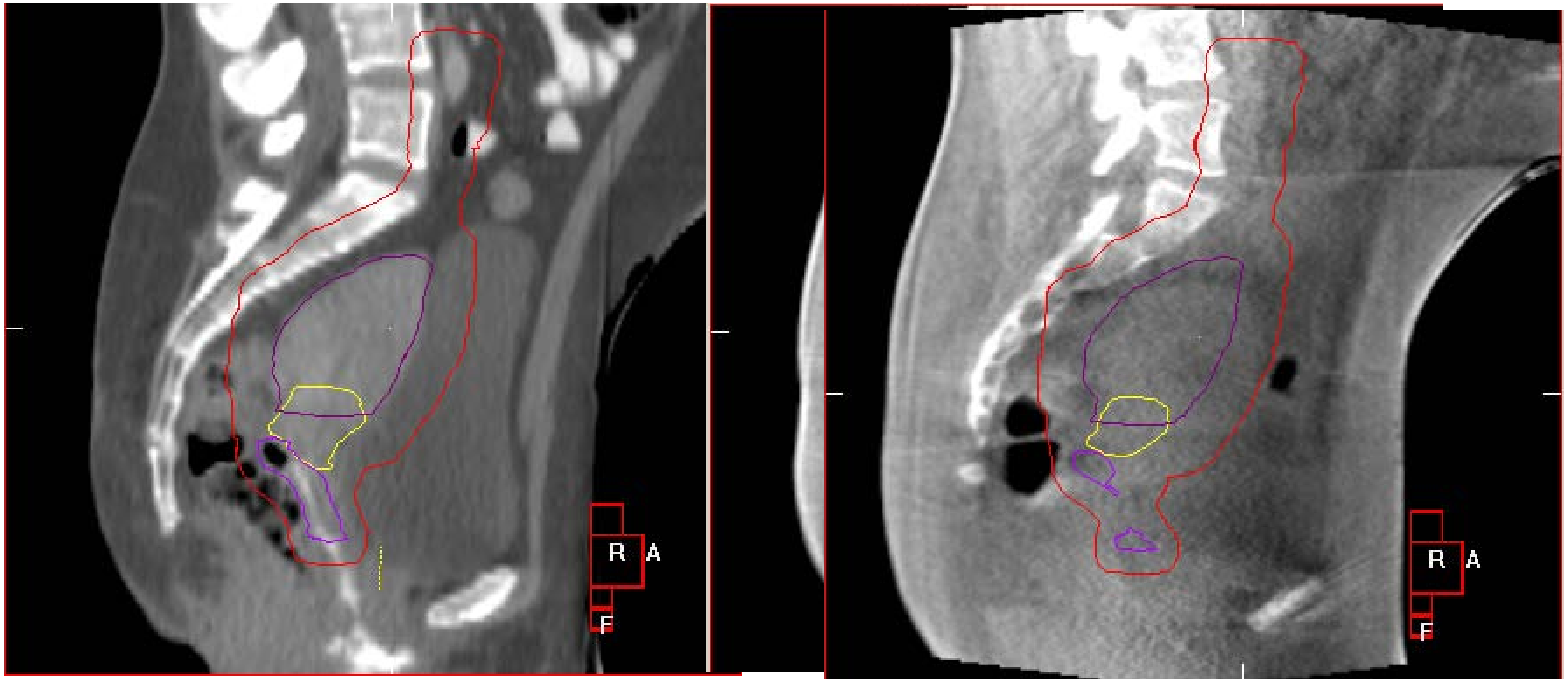

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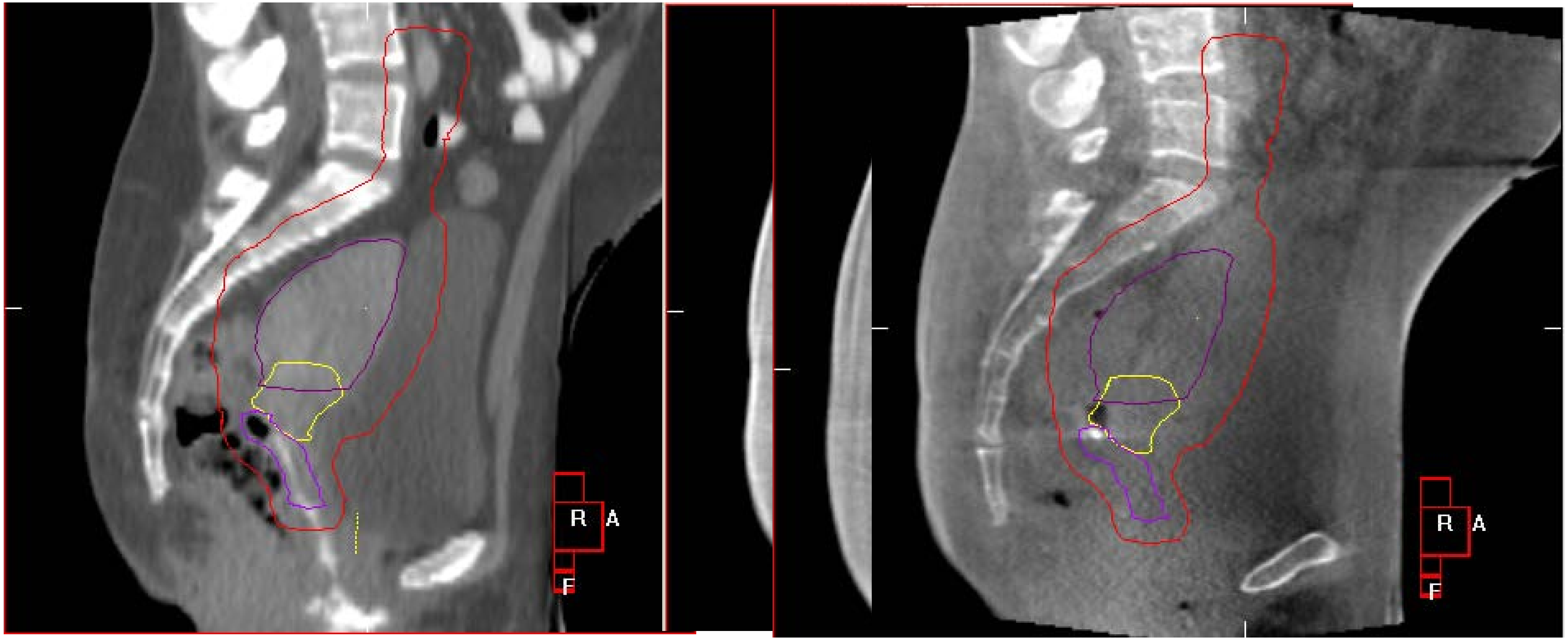

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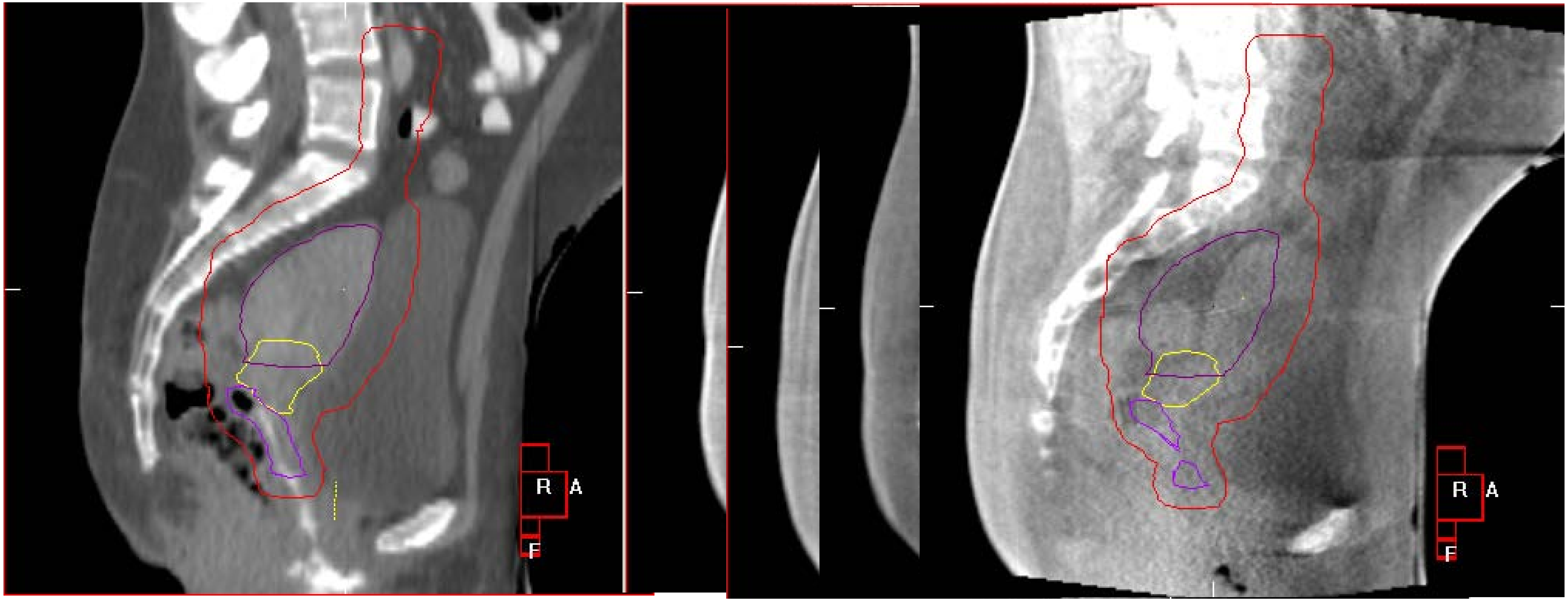
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F
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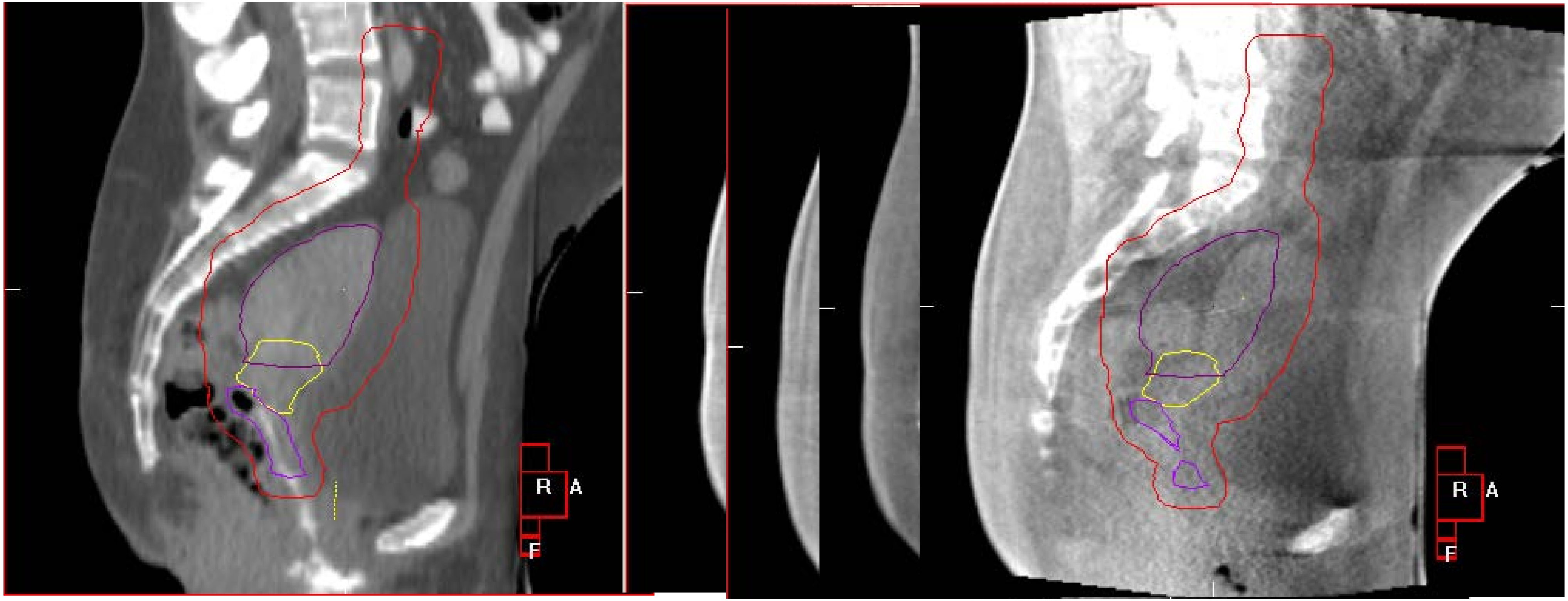

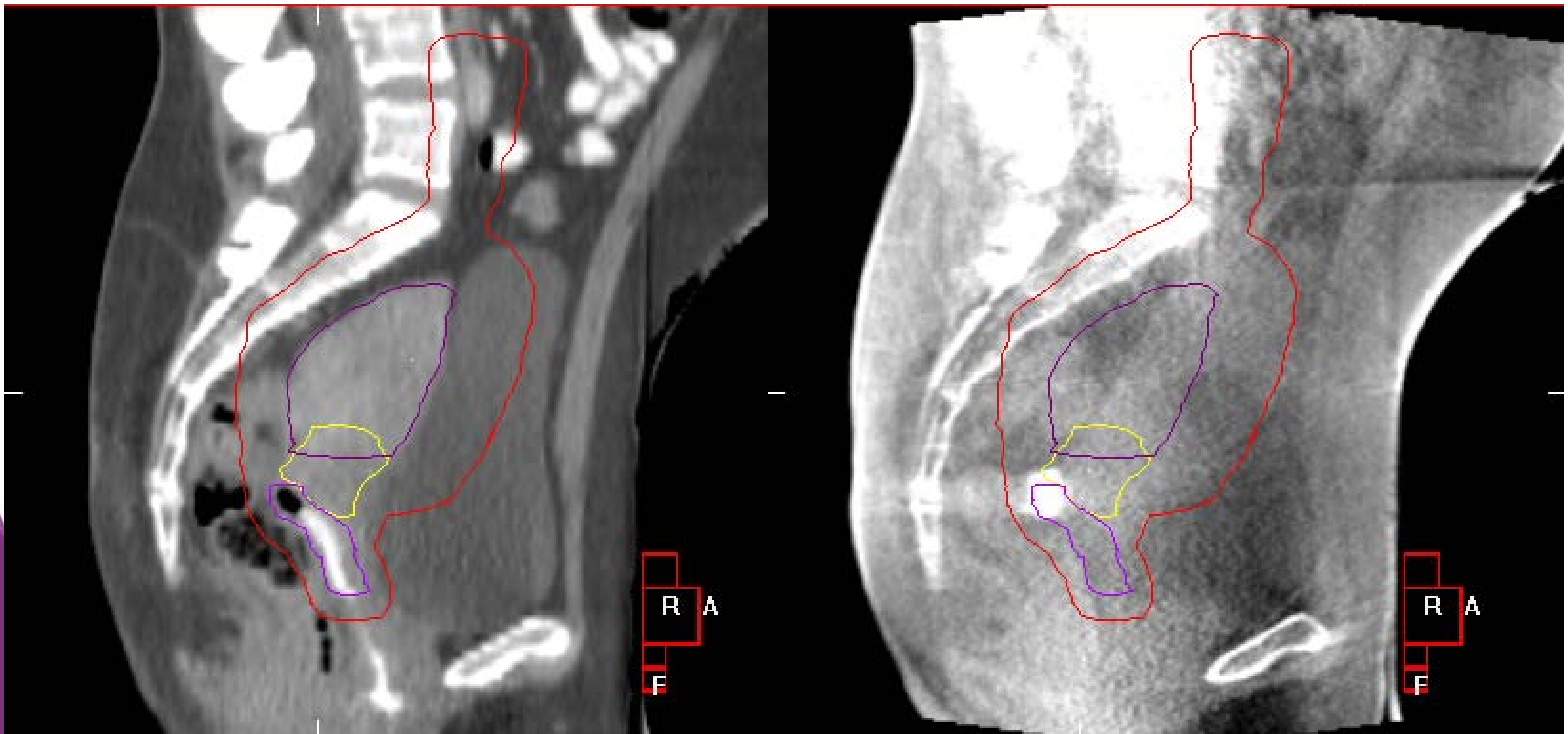

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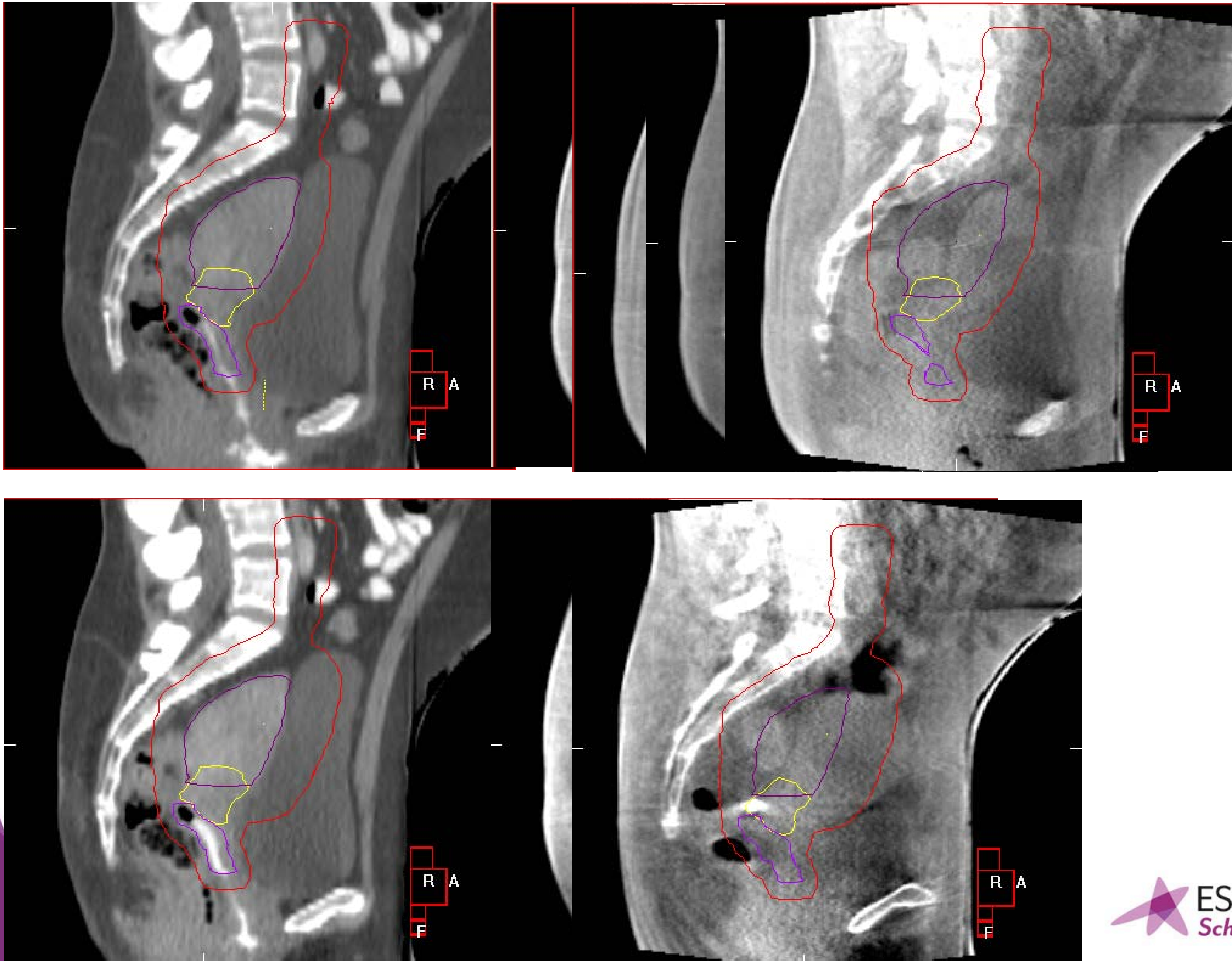

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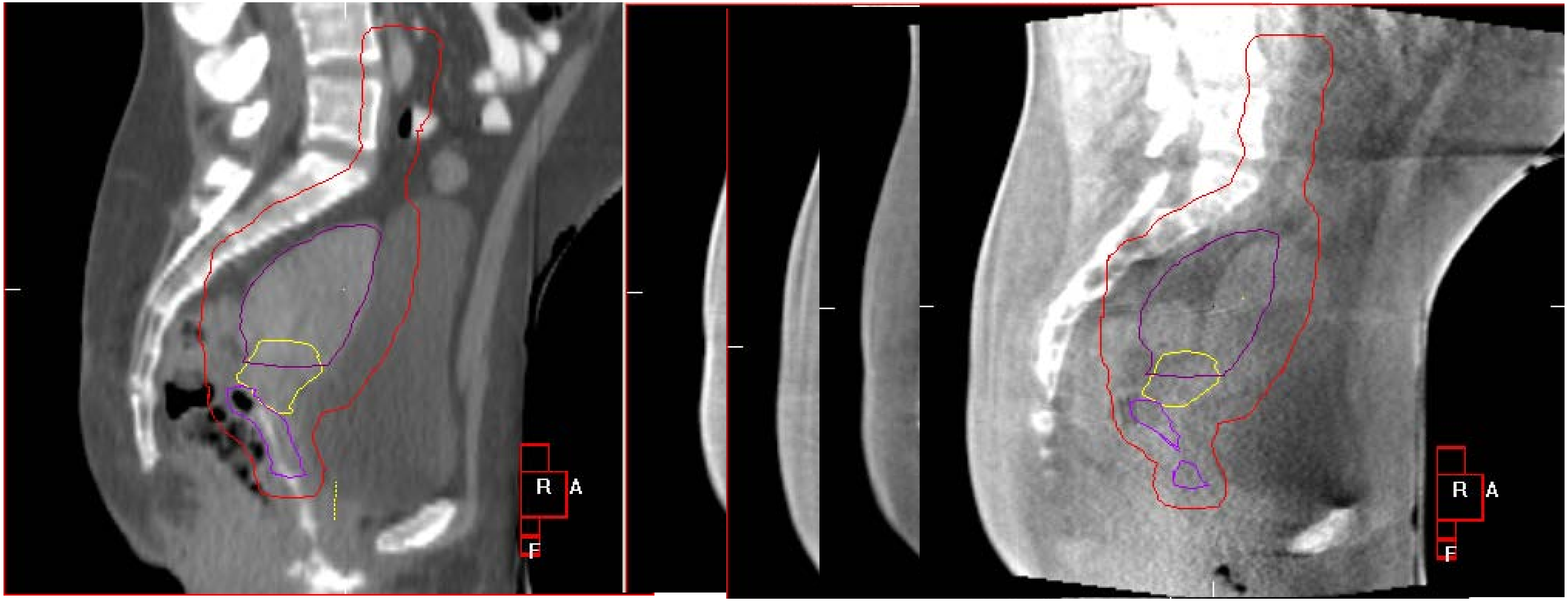
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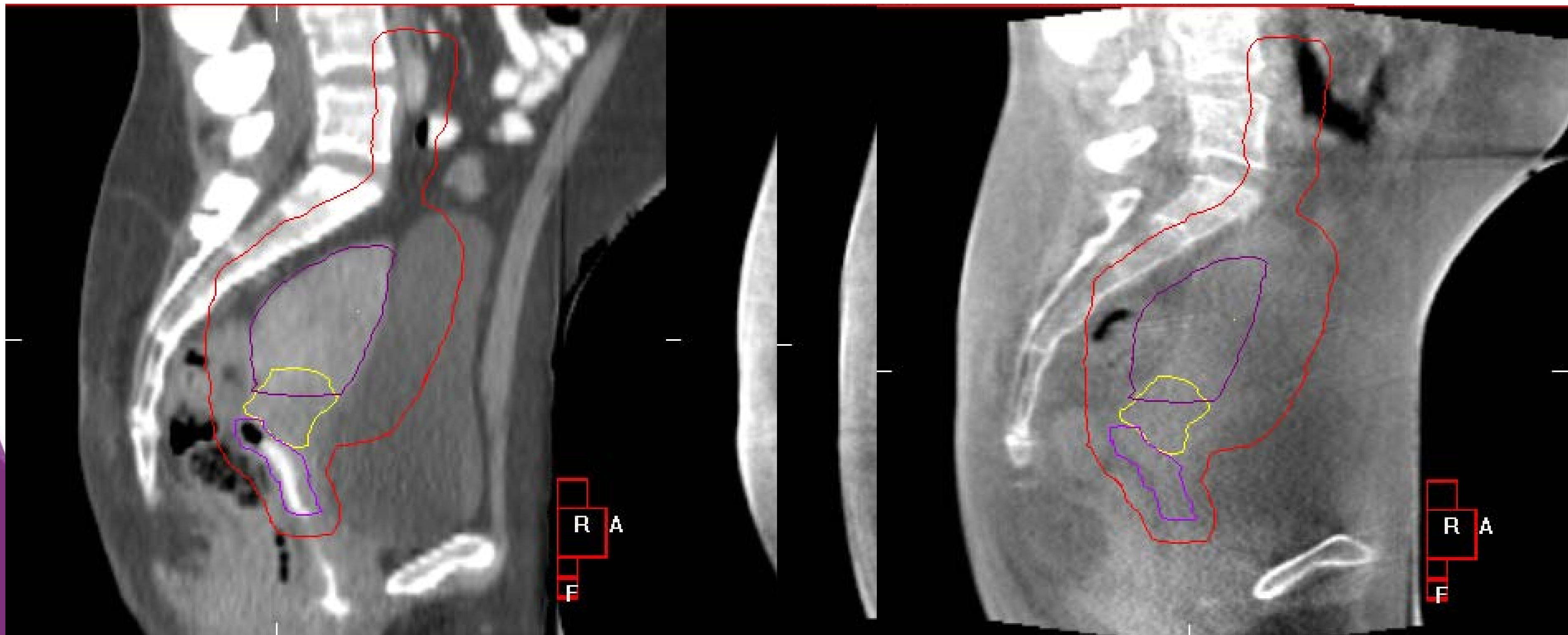
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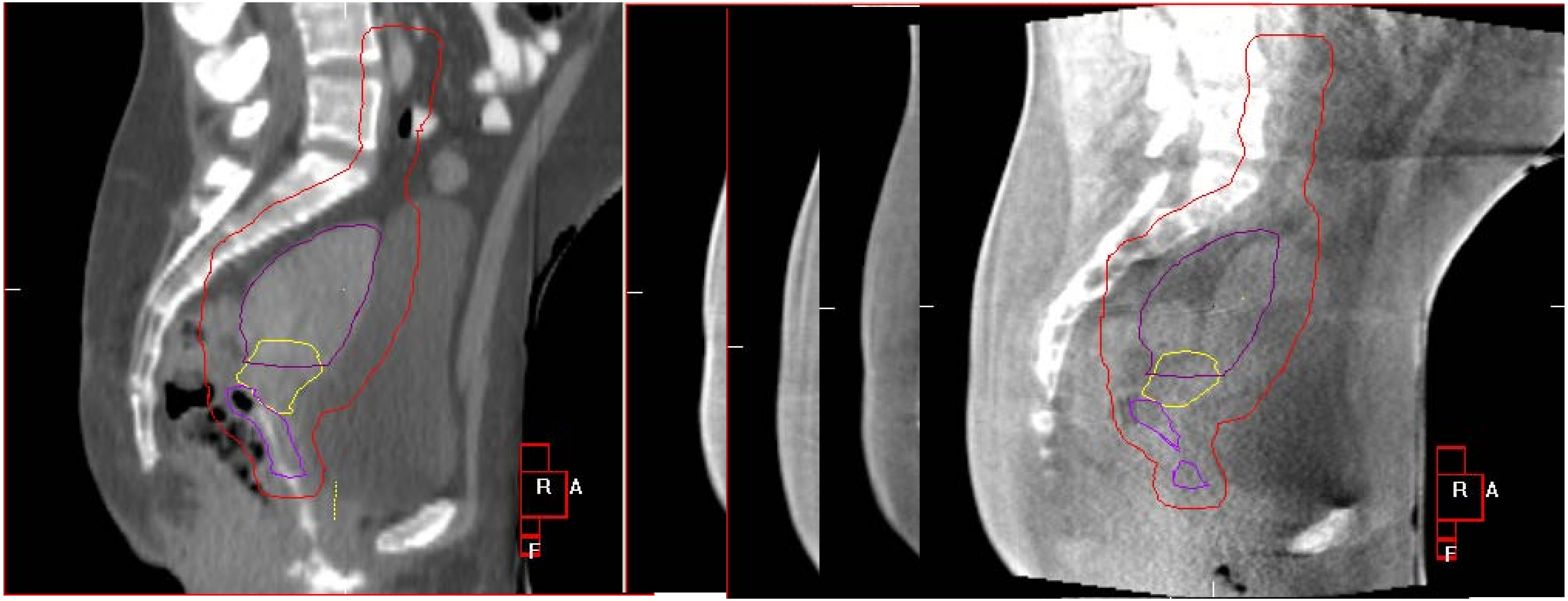
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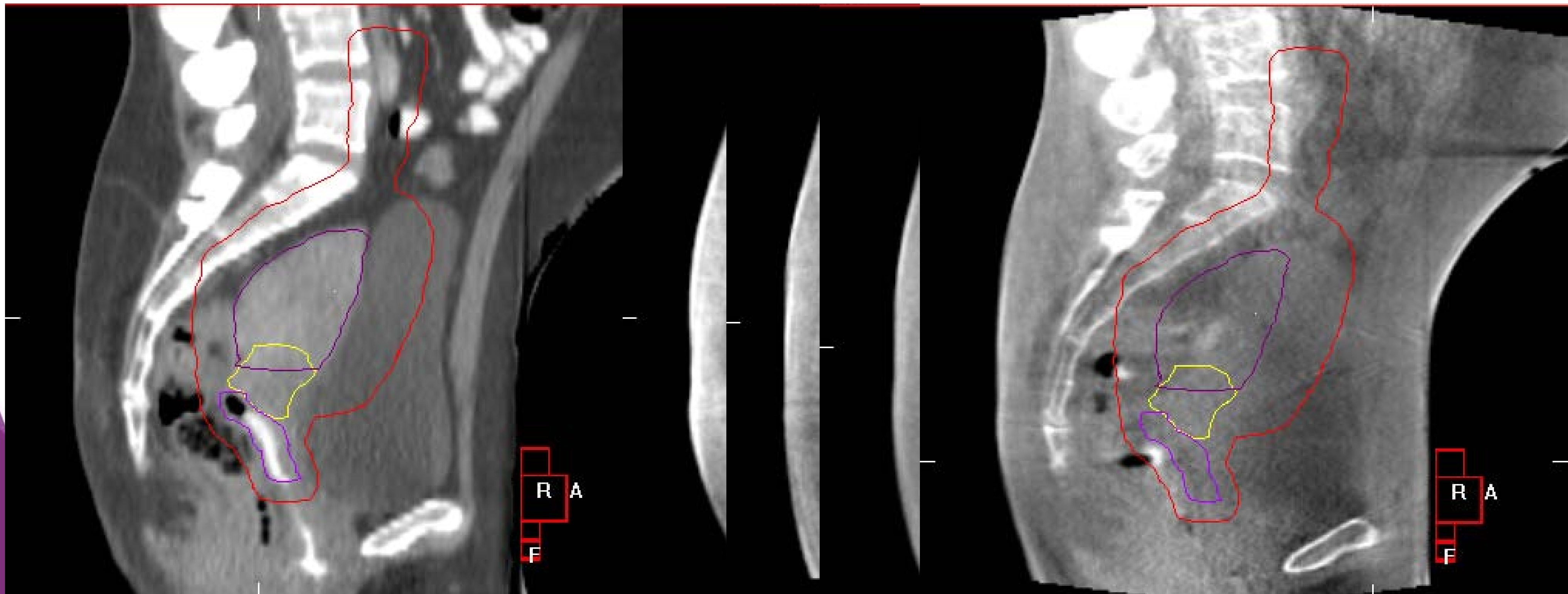
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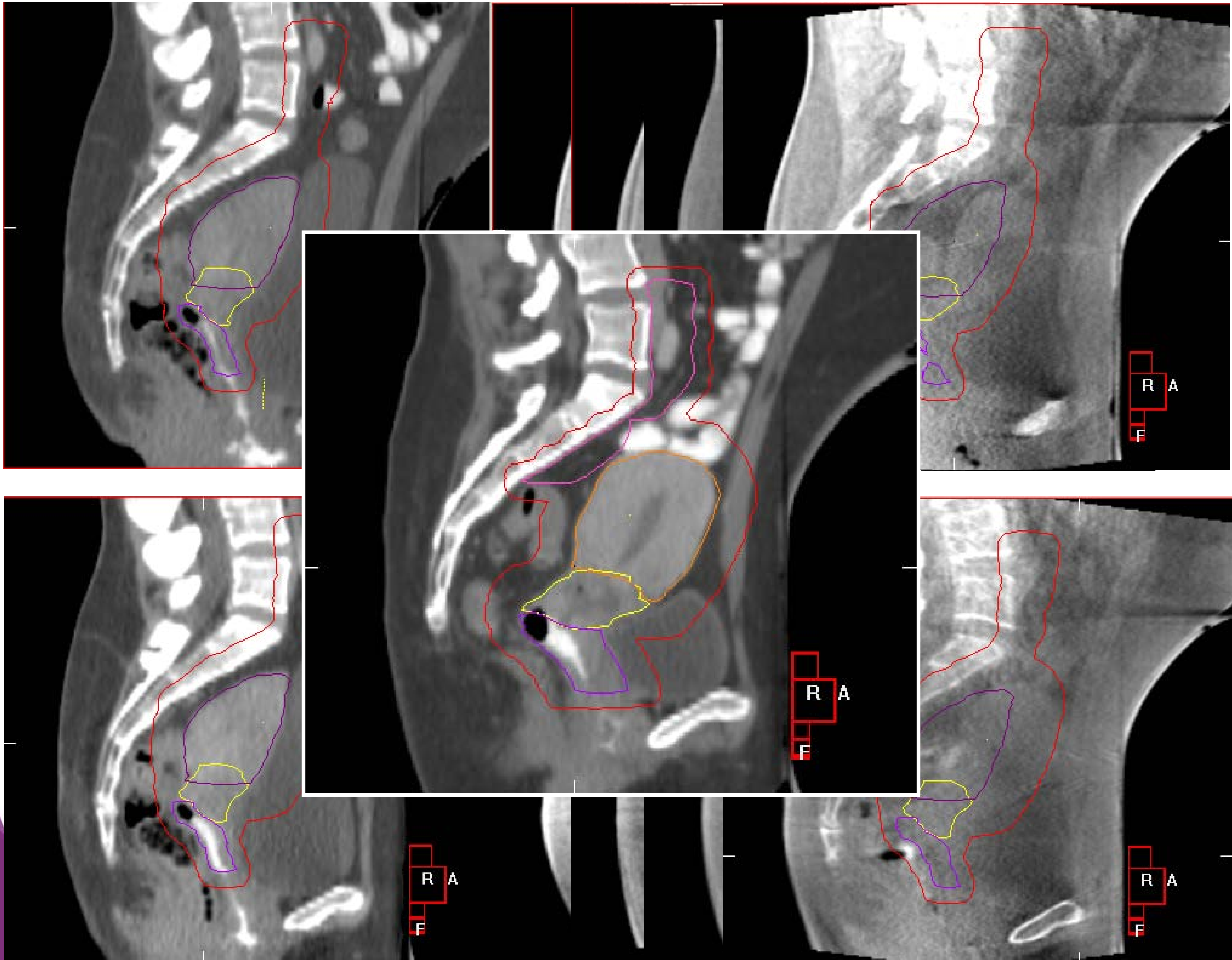
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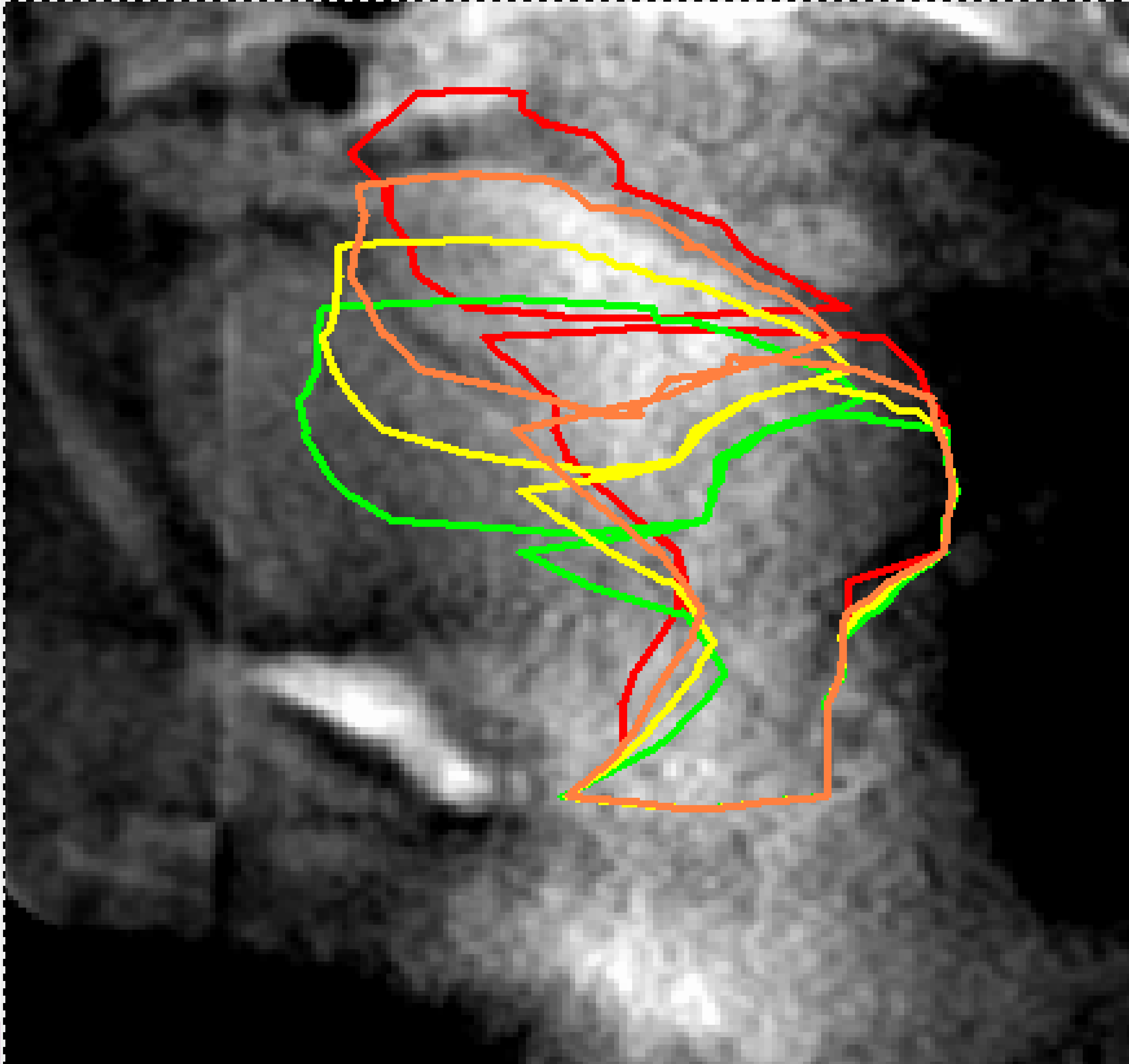

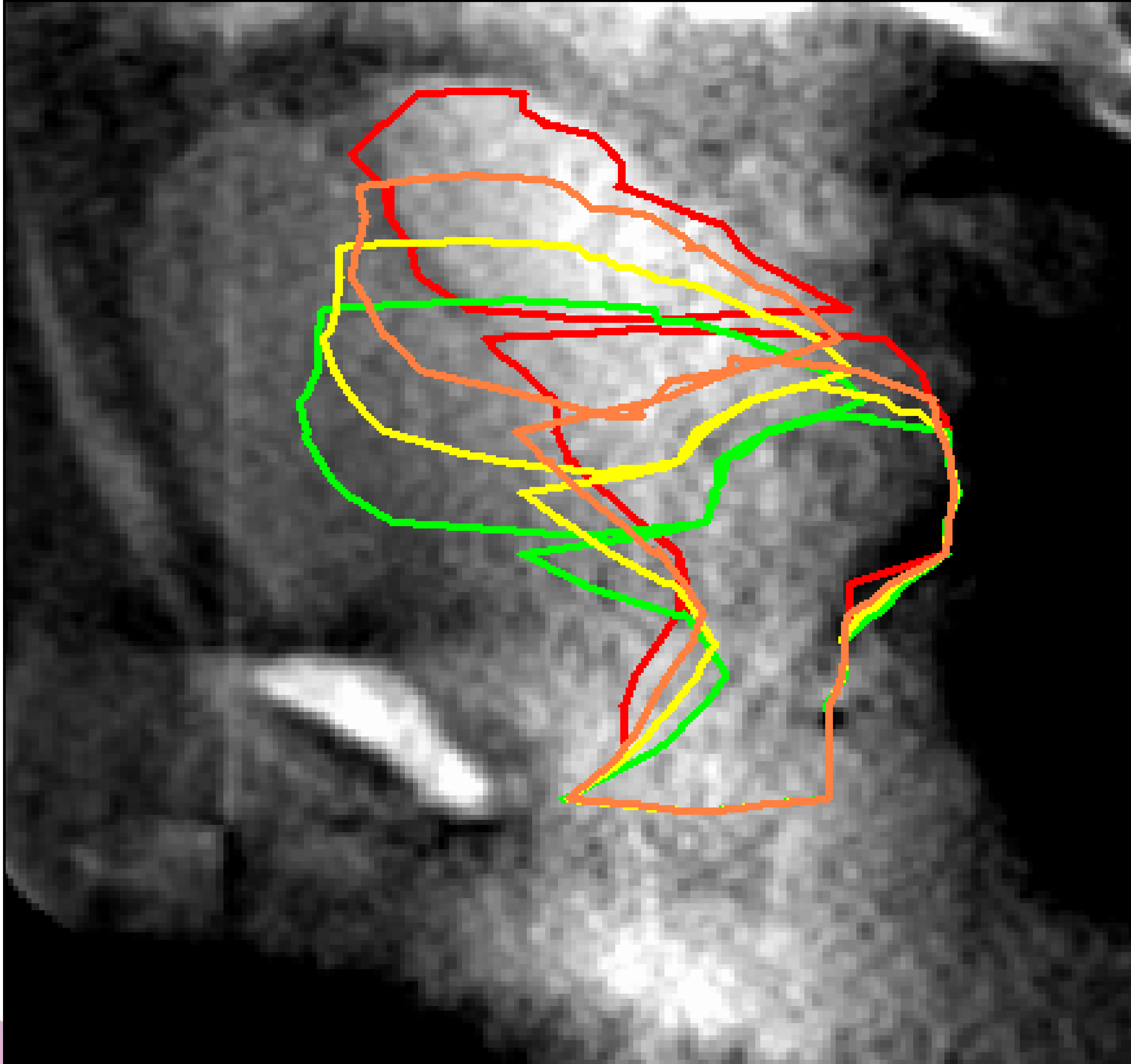

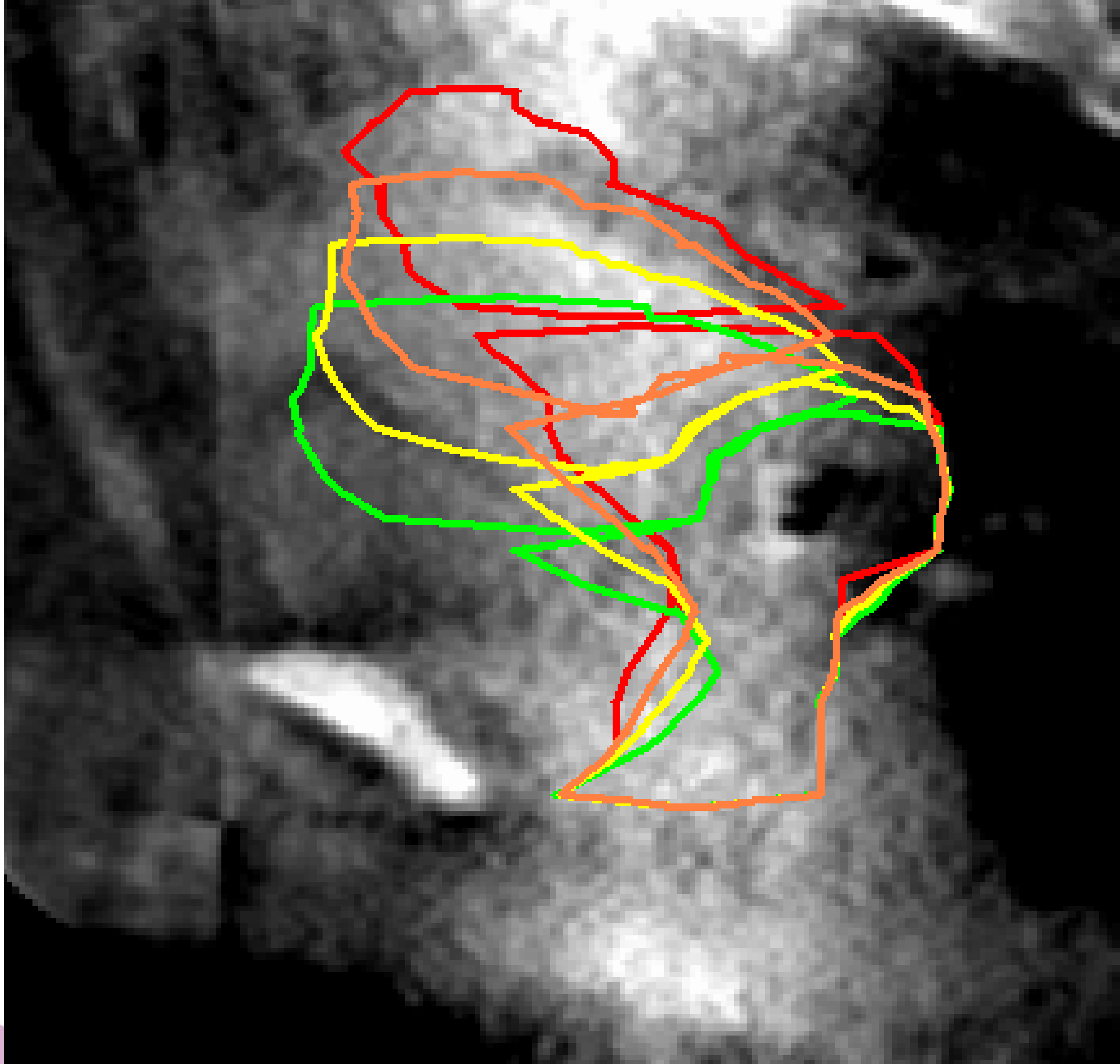

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Question

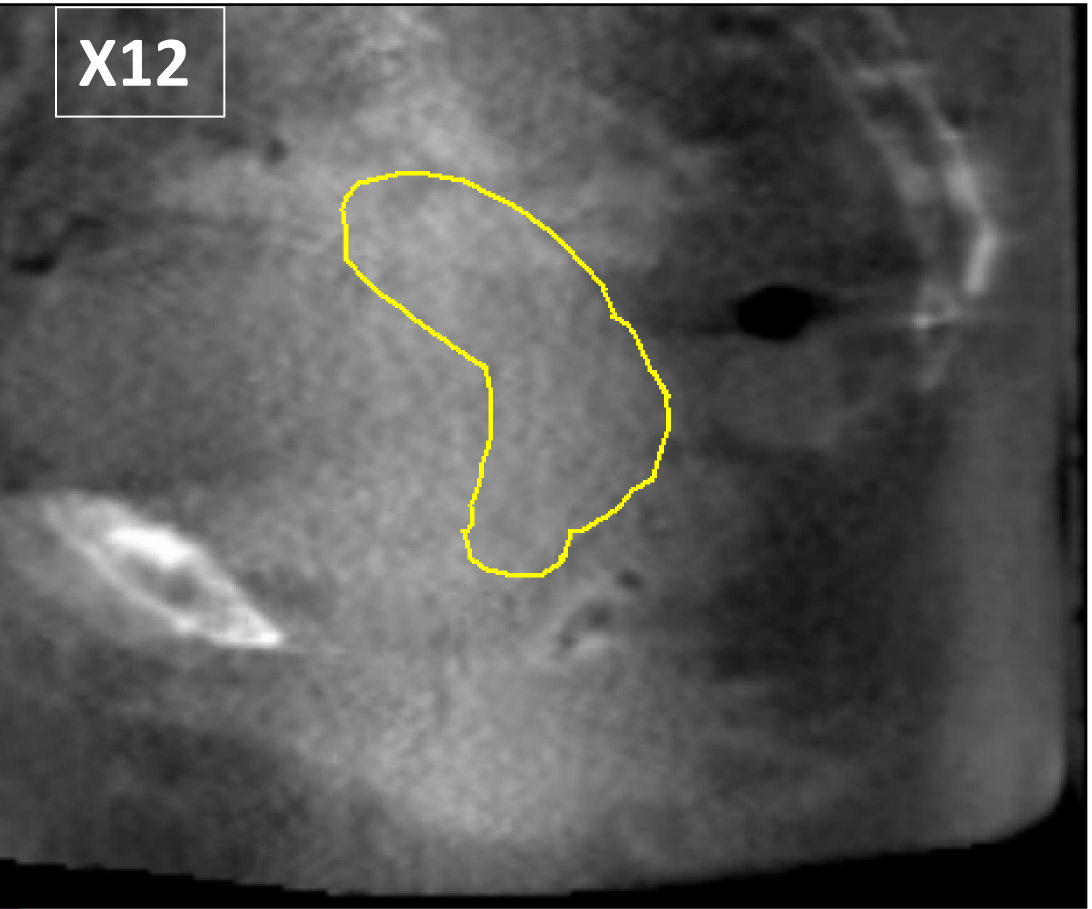
Is it possible to consistently select a best fitting CTV based on CBCT scans?

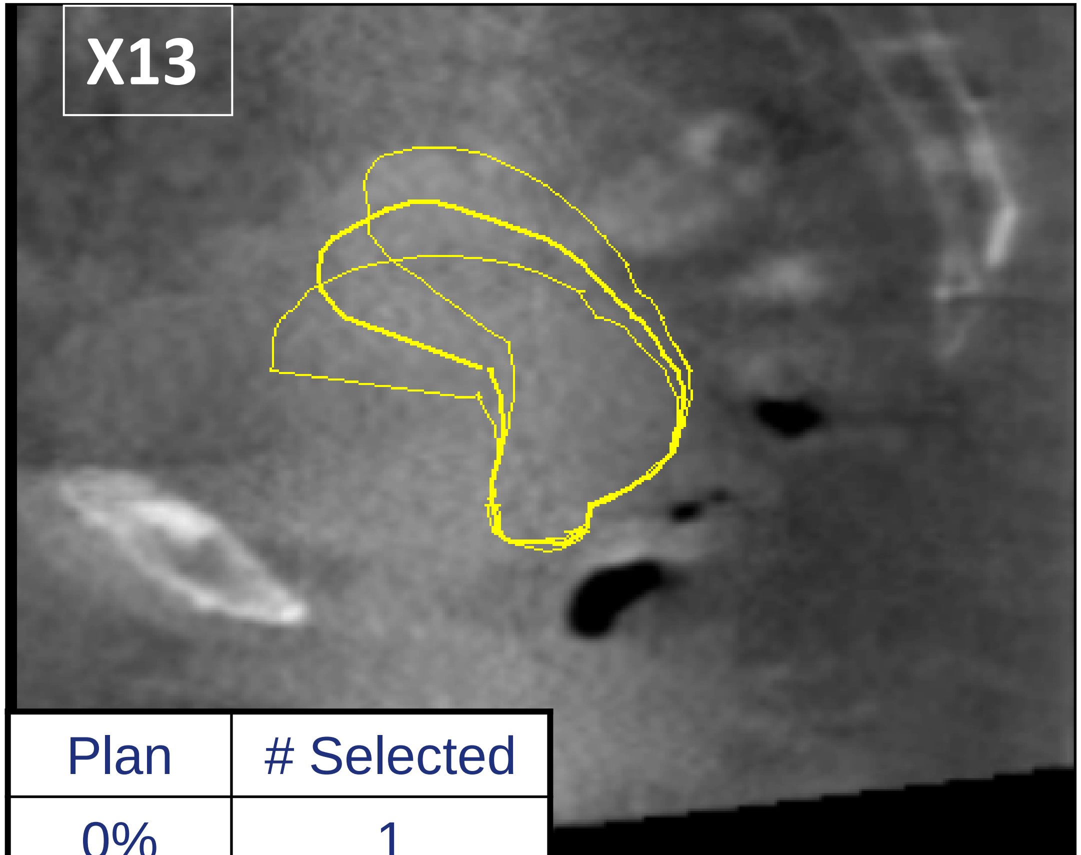
Observer study setup

- 5 patients, 23 scans per patient (1 scan missing)
- Per patient 6 structures

  -20, 0, 33, 66, 100, 120%
- 9 observers (experienced RTTs)
- 2 sessions
- Workshop in between sessions to determine Golden Standard with observers (RTT), physicians and physicists

Patient 1





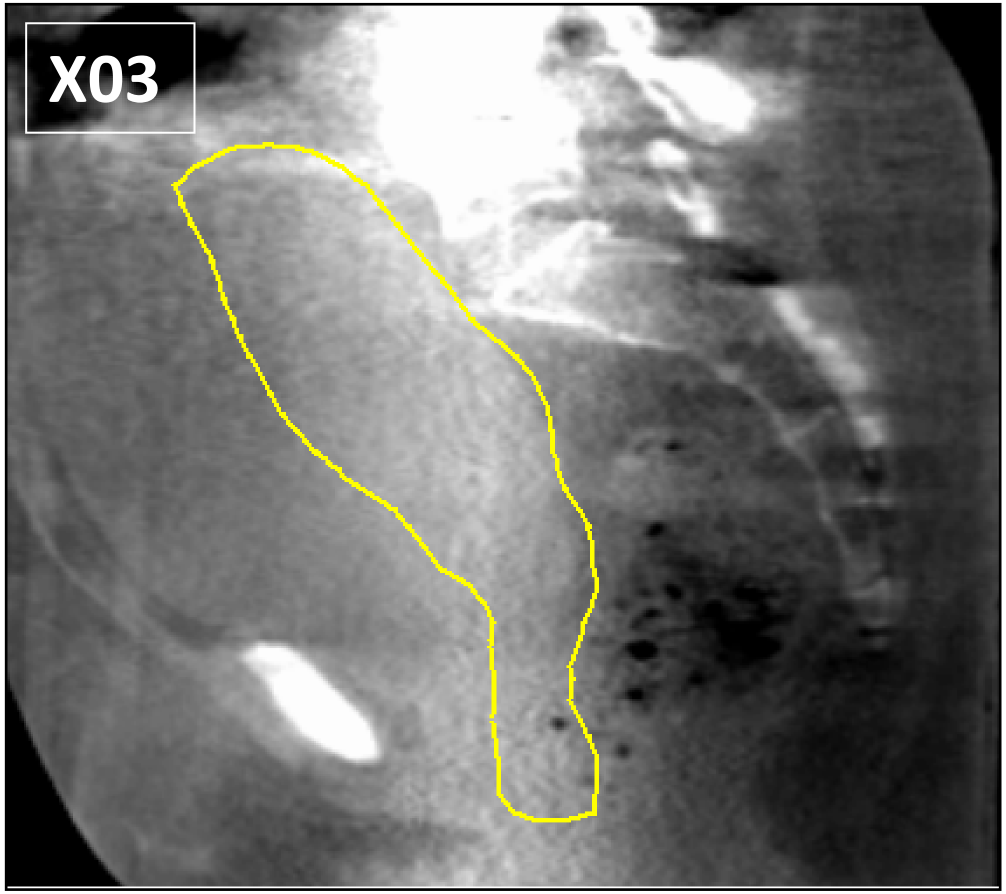
Plan	# Selected
0%	1
33%	4
66%	4

100% agreement

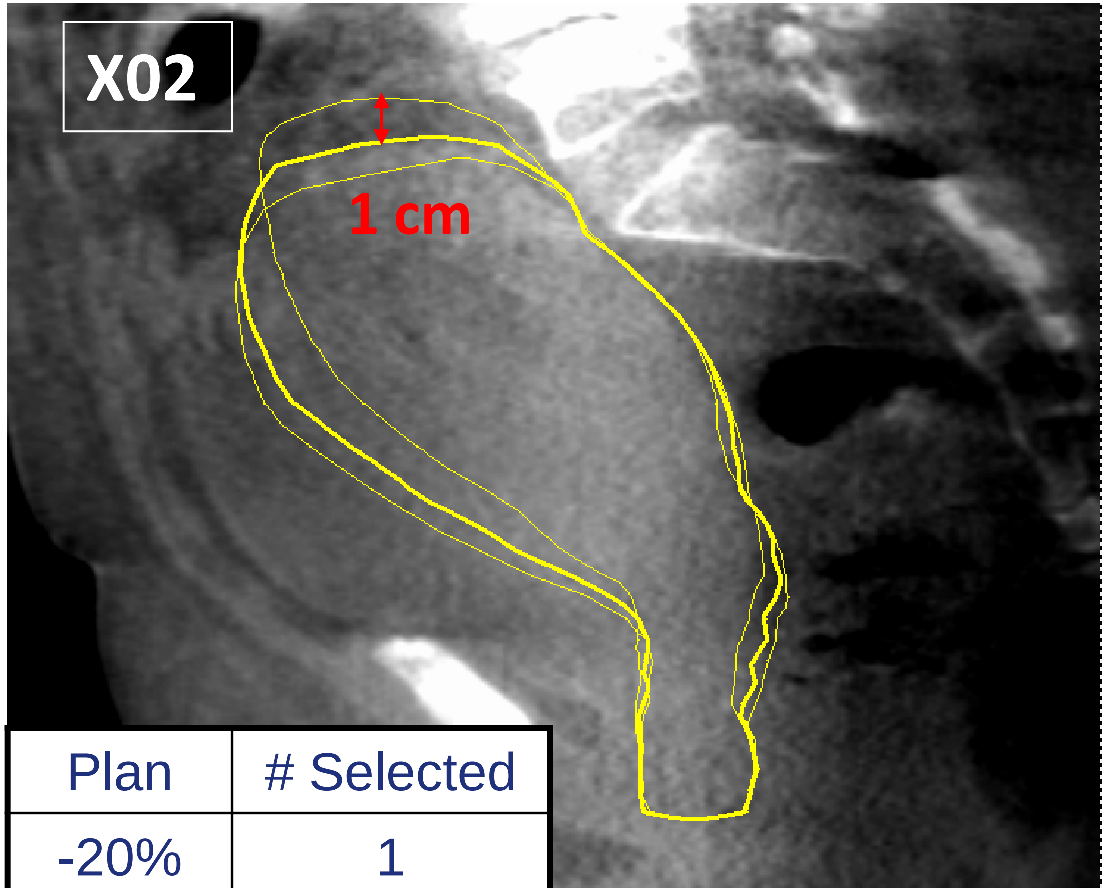
Golden star 3 %

NKI-AVL
Het Nederlands Kanker Instituut
Antoni van Leeuwenhoek Ziekenhuis

Patient 2



100% agreement

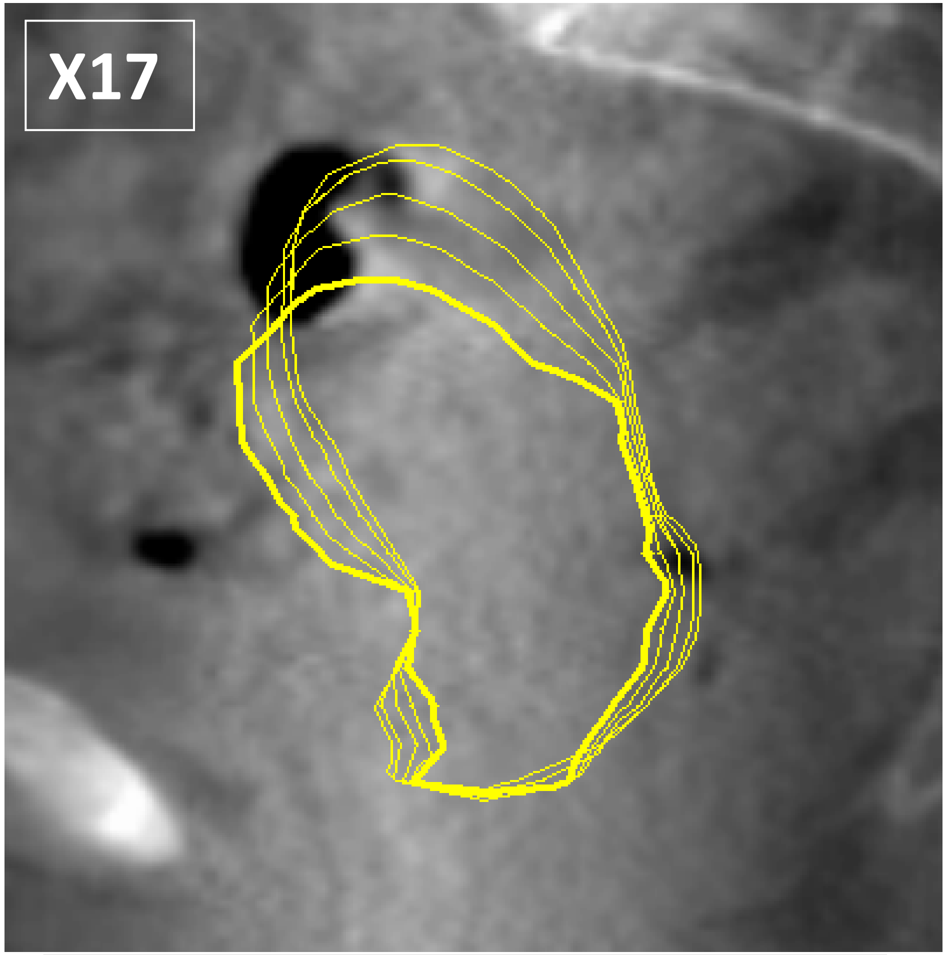


Plan	# Selected
-20%	1
0%	6
33%	2

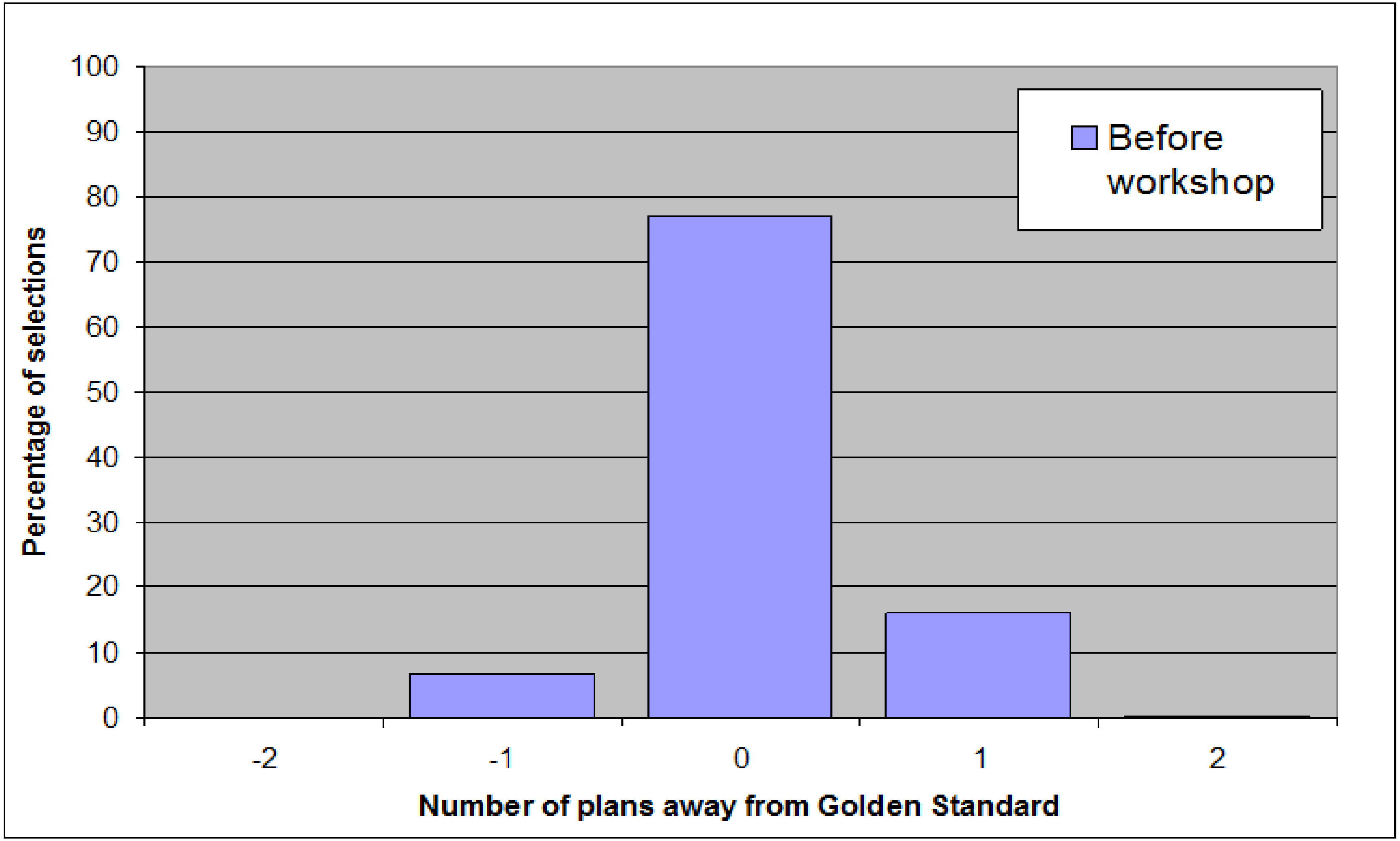
Golden star %

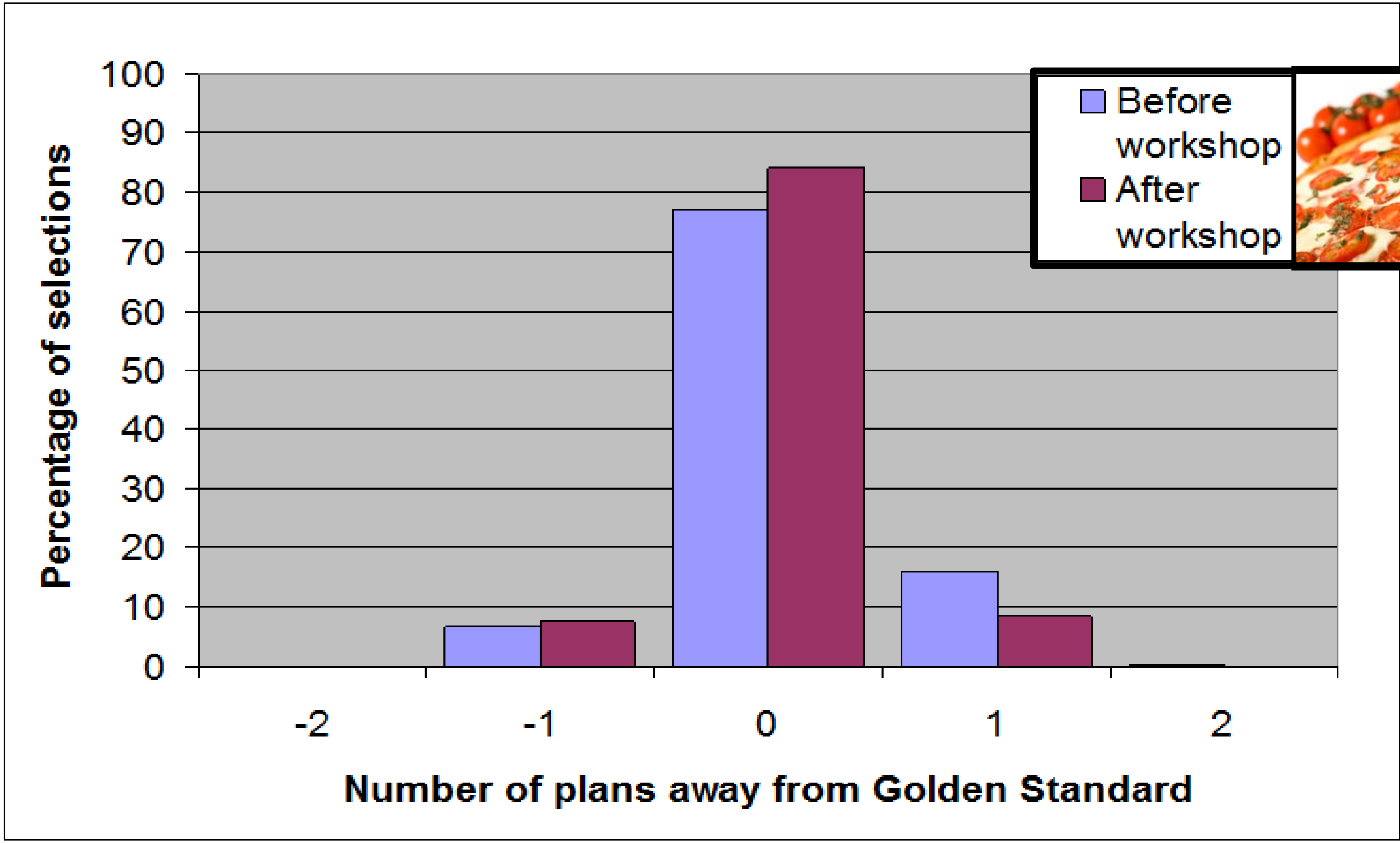
Patient 5

100% agreement

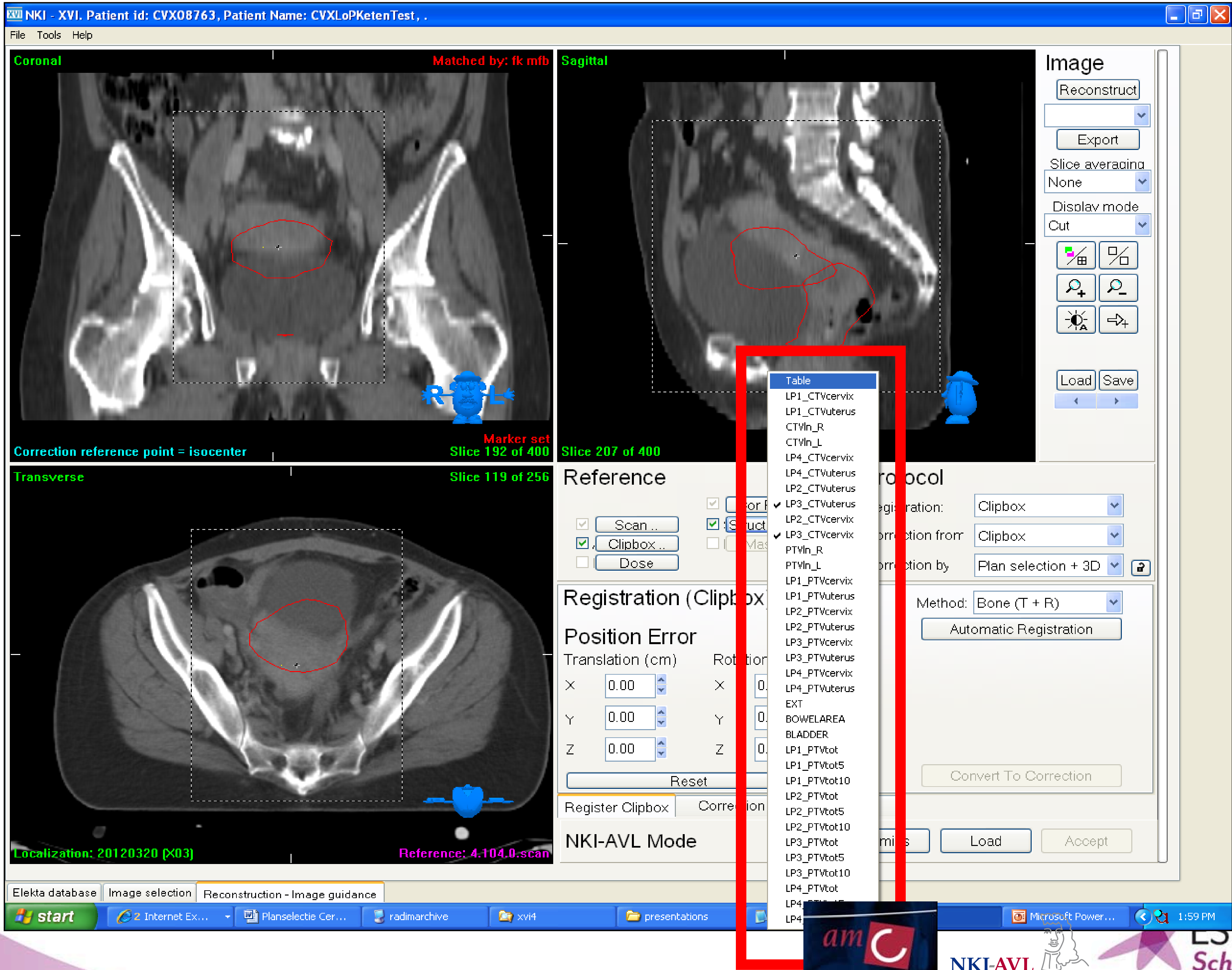


No agreement. Large anatomical change wrt planning CT


100
90
80
70
60
50
40
30
20
10
0
Percentage of selections
Before workshop
-2
-1
0
1
2
Number of plans away from Golden Standard



100
90
80
70
60
50
40
30
20
10
0
Percentage of selections
-2
-1
0
1
2
Number of plans away from Golden Standard
Before workshop
After workshop



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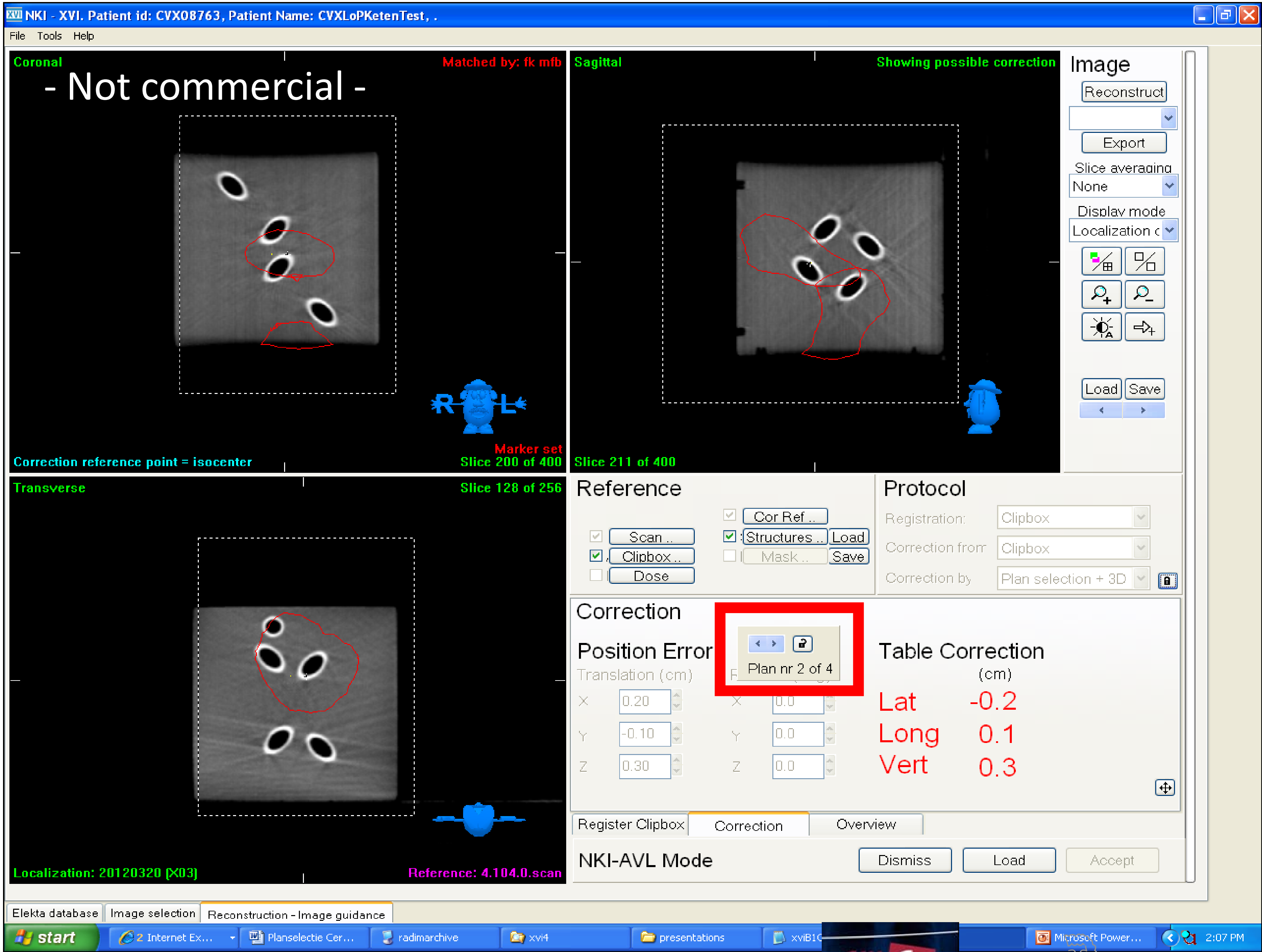

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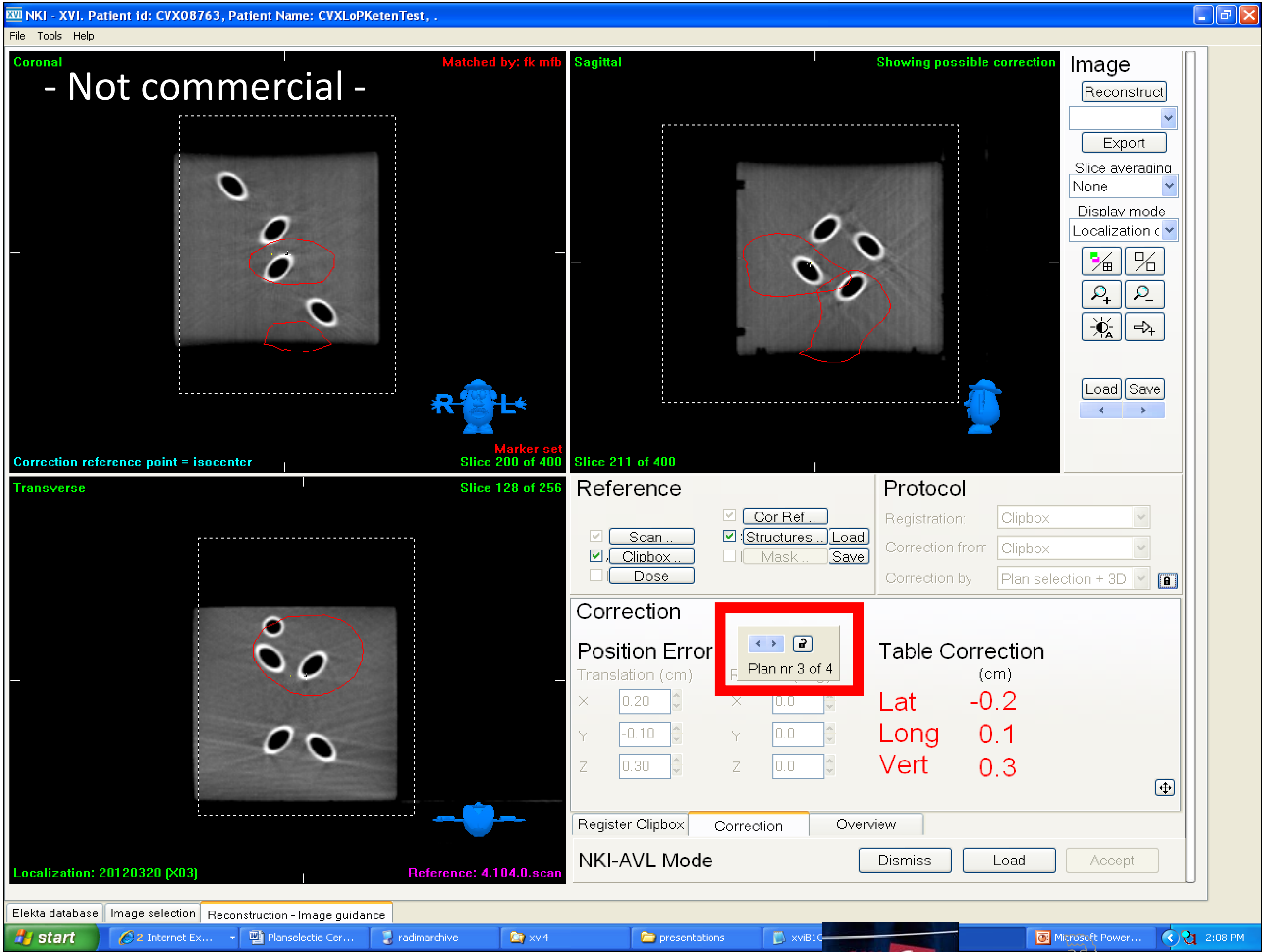

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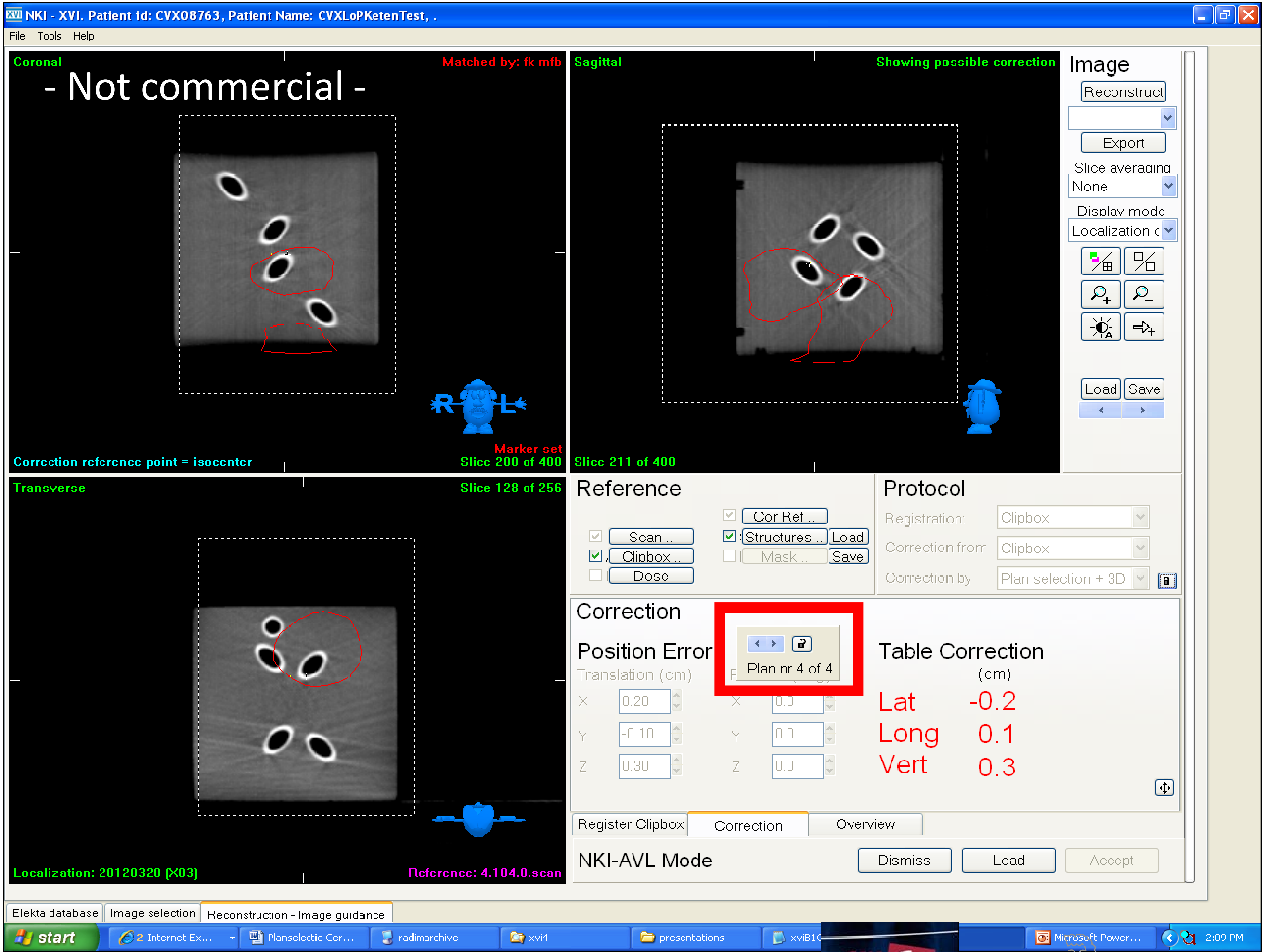
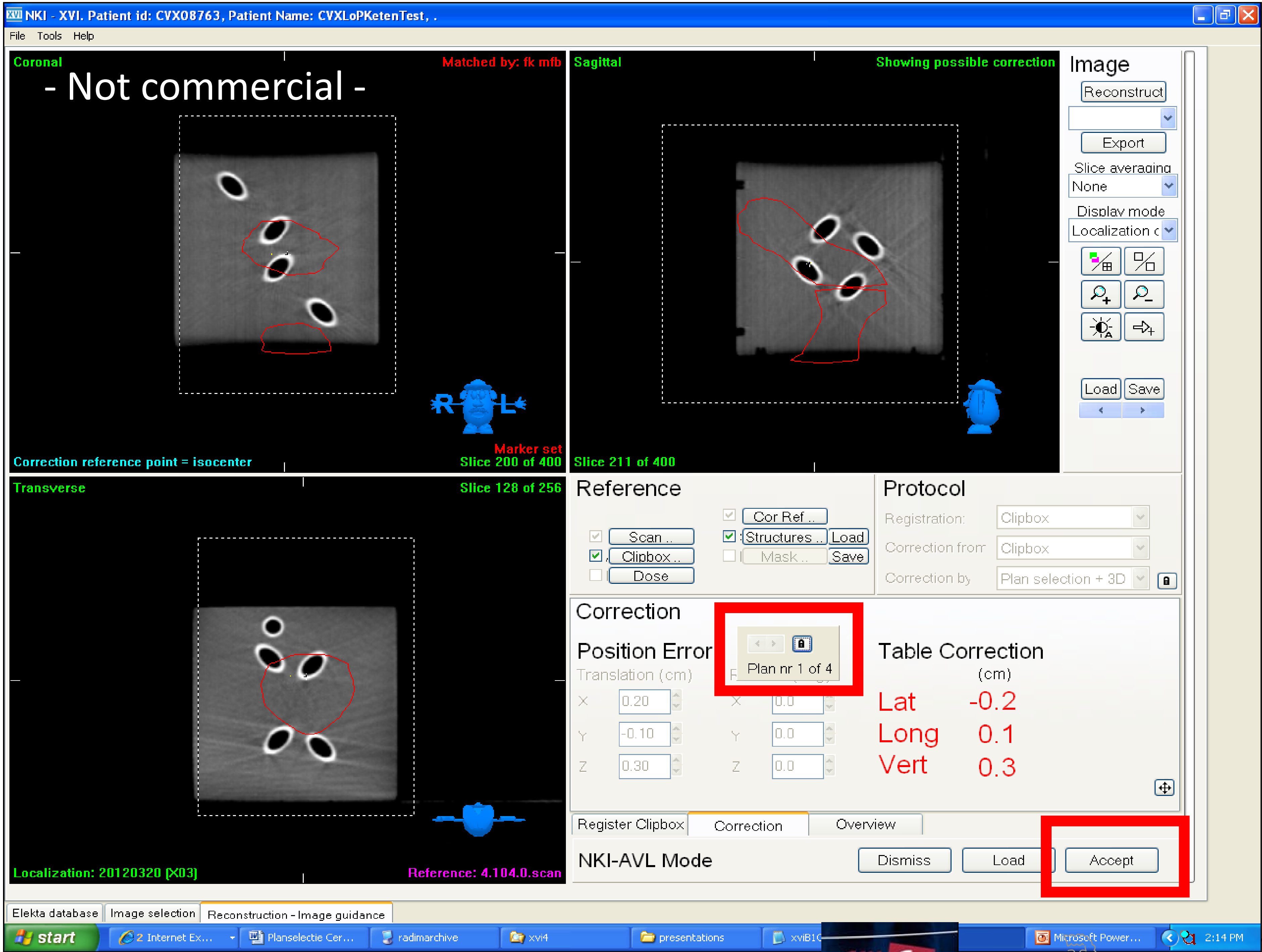


amc NKI-AVL ESTRO School



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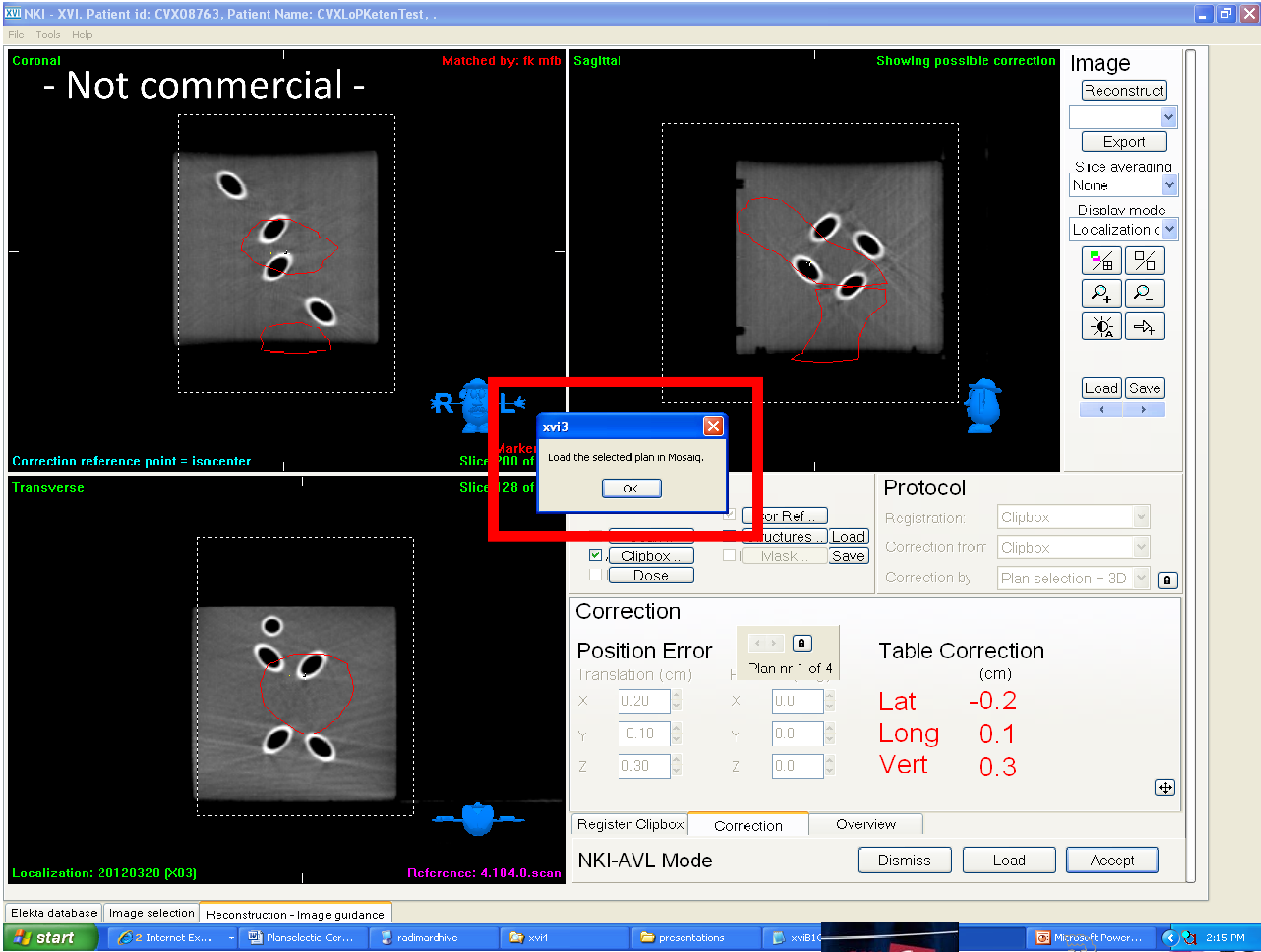

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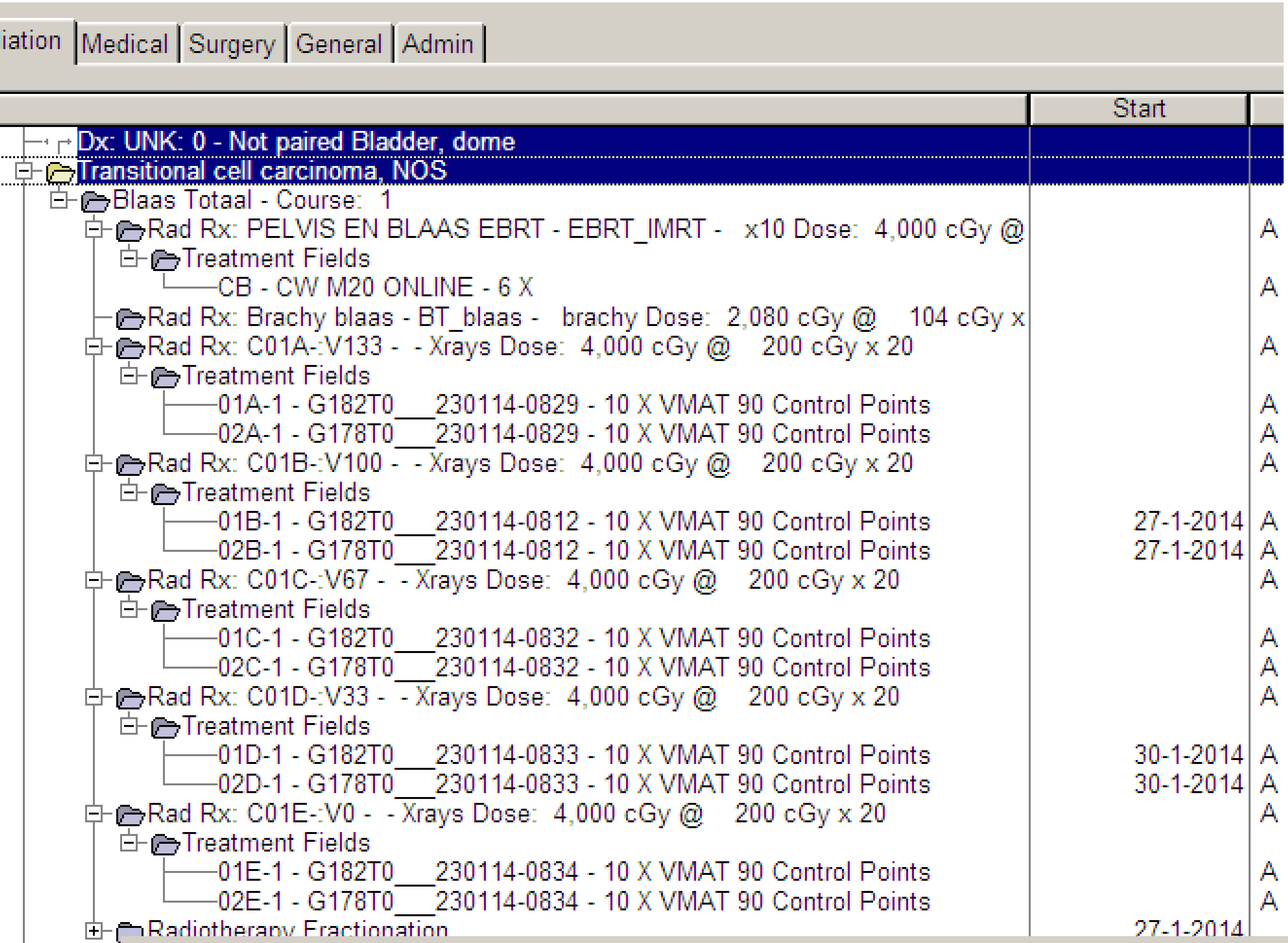
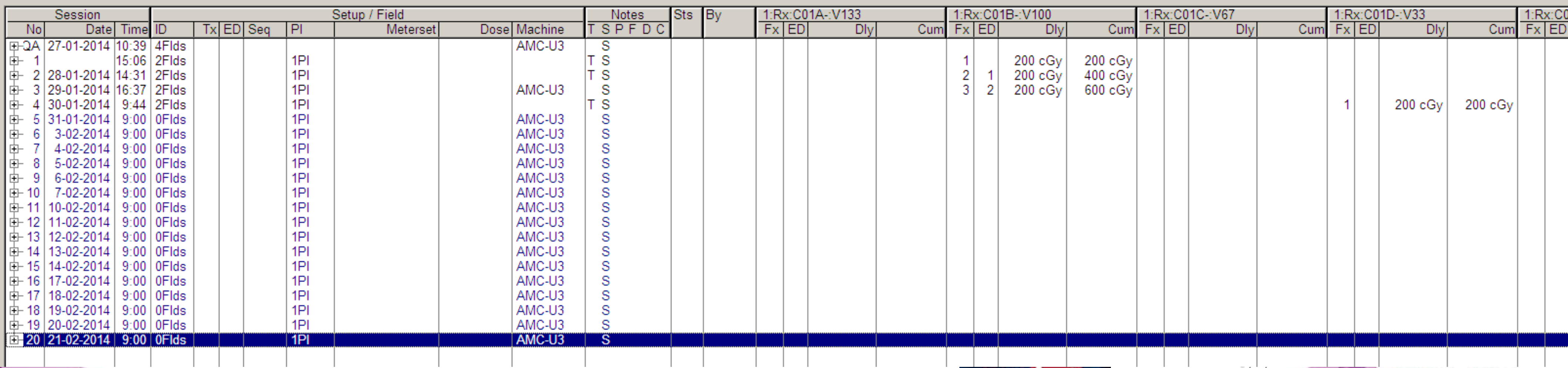
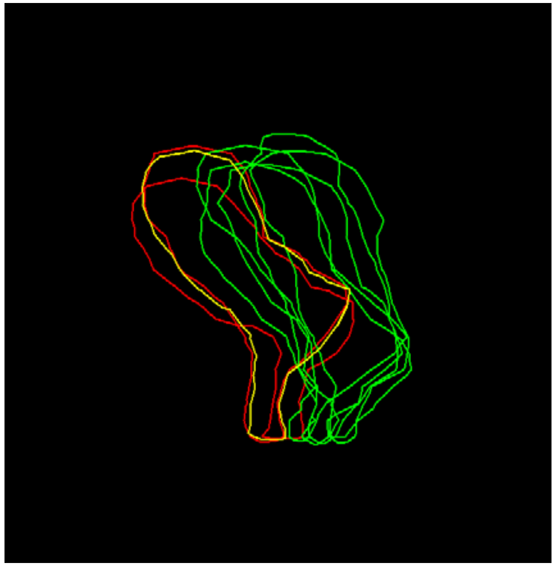
Not optimized for library of plans

1. Empty session
2. Session with all plans available

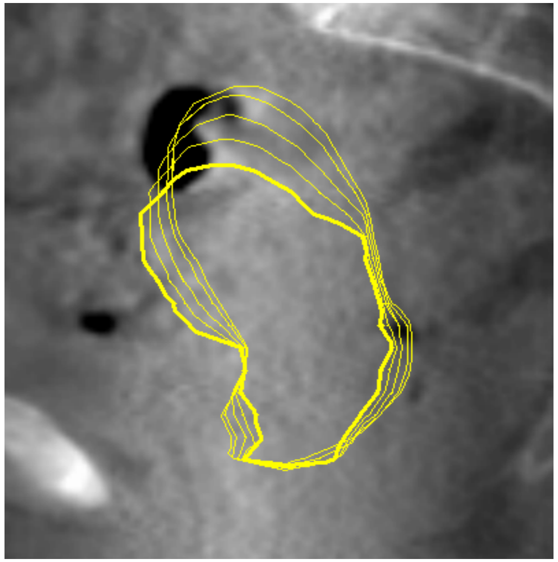




Session			Setup / Field								Notes	Sts	By	1:Rx:C01A-:V133				1:Rx:C01B-:V100				1:Rx:C01C-:V67				1:Rx:C01D-:V33				1:Rx:C0	
No	Date	Time	ID	Tx	ED	Seq	Pl	Meterset	Dose	Machine	T S P F D C			Fx	ED	Dly	Cum	Fx	ED	Dly	Cum	Fx	ED	Dly	Cum	Fx	ED	Dly	Cum	Fx	ED
QA	27-01-2014	10:39	4Flds							AMC-U3	S																				
1		15:06	2Flds				1Pl				T S							1		200 cGy	200 cGy										
2	28-01-2014	14:31	2Flds				1Pl				T S							2	1	200 cGy	400 cGy										
3	29-01-2014	16:37	2Flds				1Pl			AMC-U3	S							3	2	200 cGy	600 cGy										
4	30-01-2014	9:44	2Flds				1Pl				T S															1		200 cGy	200 cGy		
5	31-01-2014	9:00	0Flds				1Pl			AMC-U3	S																				
6	3-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
7	4-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
8	5-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
9	6-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
10	7-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
11	10-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
12	11-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
13	12-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
14	13-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
15	14-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
16	17-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
17	18-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
18	19-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
19	20-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				
20	21-02-2014	9:00	0Flds				1Pl			AMC-U3	S																				



Not all anatomy change is due to bladder filling
~30% rectum filling



Anatomy change over course of treatment due to regression

8890230_1.xlsm - Microsoft Excel

ART - Cervix

Patiënt naam:	
Patiënt nummer:	8890230
Course:	1
Aantal plannen	3

Gegevens opslaan

Fractie	IGRT-laborant(en)	Datum	Plan	Opmerkingen
1		10 juni 2015	66-100%	
2		11 juni 2015	66-100%	
3		12 juni 2015	66-100%	
4		15 juni 2015	33-66%	krap
5		16 juni 2015	66-100%	
6		17 juni 2015	33-66%	buiten PTV
7		18 juni 2015	33-66%	op PTV
8		19 juni 2015	66-100%	krap
9		22 juni 2015	66-100%	op PTV
10	mka/jvr	23 juni 2015	33-66%	op PTV, bekkenkanteling, klieren gecovered
11	rjg/kgl/jvr	24 juni 2015	66-100%	krap binnen PTV craniaal
12	dwl mos ahk	25 juni 2015	66-100%	craniaal buiten PTV
13				
14				
15				
16				
17				
18				
19				
20				

Week	Eval.	Door	Opmerkingen
1	☑	rjg	
2	☑	rjg	iom LSS en EPQ volume vergroting akkoord
3	☐		
4	☐		

Per 13 april 2015 zijn we begonnen met planselectie voor cervixpatiënten: ART cervix. Zie voor complete werkinstructie Kwadraet 'Cervix ART'. Iedere dag moet er iemand van de IGART-groep aanwezig zijn bij planselectie.

Om inzichtelijk te maken voor het toestel welke plannen er worden gekozen graag bovenstaande tabel invullen. Als er vroeg in de behandeling 3 keer achter elkaar voor plan 0% - 33% wordt gekozen, graag in gesprek gaan met de patiënt of hierin verbetering kan worden aangebracht door meer te drinken of eerder uit te plassen. Dit graag noteren bij 'opmerkingen'.

NB: In tegenstelling tot ART-Blaas mag er bij ART-Cervix NOOIT getweakt worden!

Vragen en/of opmerkingen horen wij graag. Alvast dank.

Jorrit (62594)
Rianne (66857)

Sessies | Bestralingsoverzicht

CT scans full and empty bladder

1 full bladder CT

1 empty bladder CT

Judgement call of the RTT at CT simulation whether bladder is “full”

If not, patient needs to wait extra time and rescan.

			CBCT	
			>1.0 cm	<1.0 cm
		15 pts	12	3
pre-RT	>1.0 cm	7	**6**	**1**
	<1.0 cm	8	**6**	**2**

library possible

library beneficial

tip uterus CC motion

CT scans full and empty bladder

- RTT registers CT scans and determines movement:
  - <1 cm no planselection
  - Between 1 en 2 cm: 2 plans
  - 2 cm < 4 plans
- Physician delineates target volumes on full bladder CT scan
- Physician delineates bladder and uterus on empty bladder CT scan
- Physician generates intermediate structures
- RTT creates PTV margins and delineates OAR.

CT scans full and empty bladder

IMRT or VMAT on full bladder CT scan.

→ Intermediate plans are automatically generated using scripting.

CT scans full and empty bladder

Workflow:

1. Registration bones
2. Selection of plan
3. Marker check
   - Trained RTTs

Demo database for training of RTTs

Workshop

Big Brother software checks consistency of selected plan in XVI and Mosaiq plan!

Big Brother software prohibits delivery of more than 1 plan!

Evaluation / safety procedures

1 x week by IGRT-groep (RTT/physician)

- Selection as discussed in workshop?
- Is uterus moving as predicted on full/empty bladder CT scan (mover/non-mover)?
  - Including those patients that had no planselection due to no movement at full/empty bladder CT scans
- Are the anatomy changes still valid? Think regression

Documents…

- *Patient letters for bladder instructions*
- CT
- Physician: delineation instructions and interpolations
- *Mosaiq*
- *Treatment Planning scripting*
- *IGRT*

Discussion

Cervix planselection: a RTTs job?

(Almost) every step of the way

Summary

- Development and implementation of ART (library of plans) is
  - Departement specific
  - Protocol specific
- Development and implementation of ART is a multi-diciplinairy effort
- Because of the multi-disciplinairy character one needs to be creative, like pizza meetings

- Training is key. Invest in training as it will improve quality, but also raises awareness as to the importance of IGRT/ART!

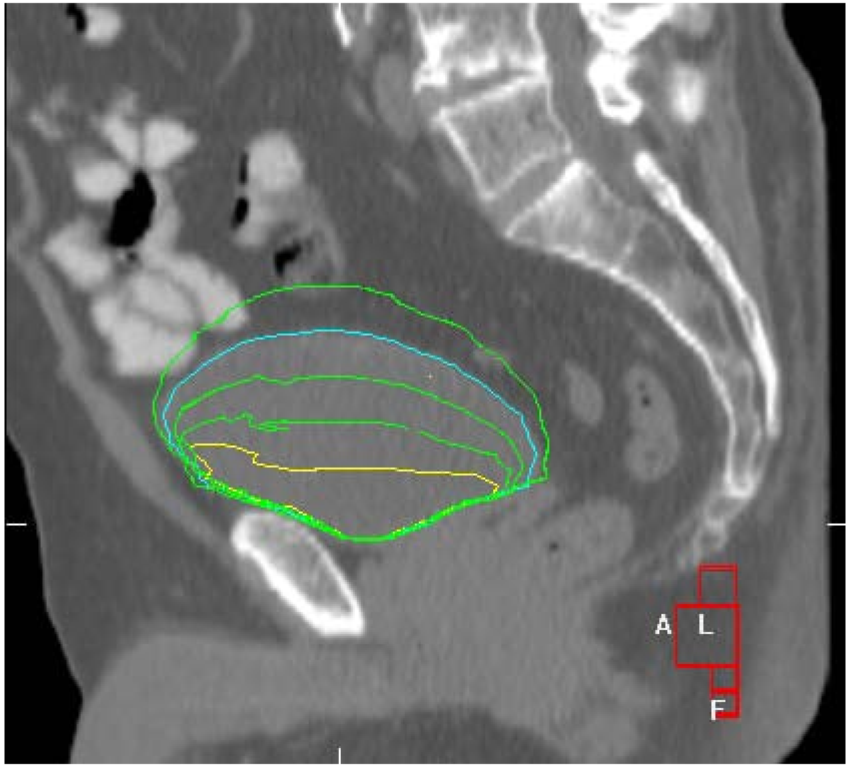
Special thanks to

AvL/NKI

Folkert Koetsveld

Simon van Kranen

Peter Remeijer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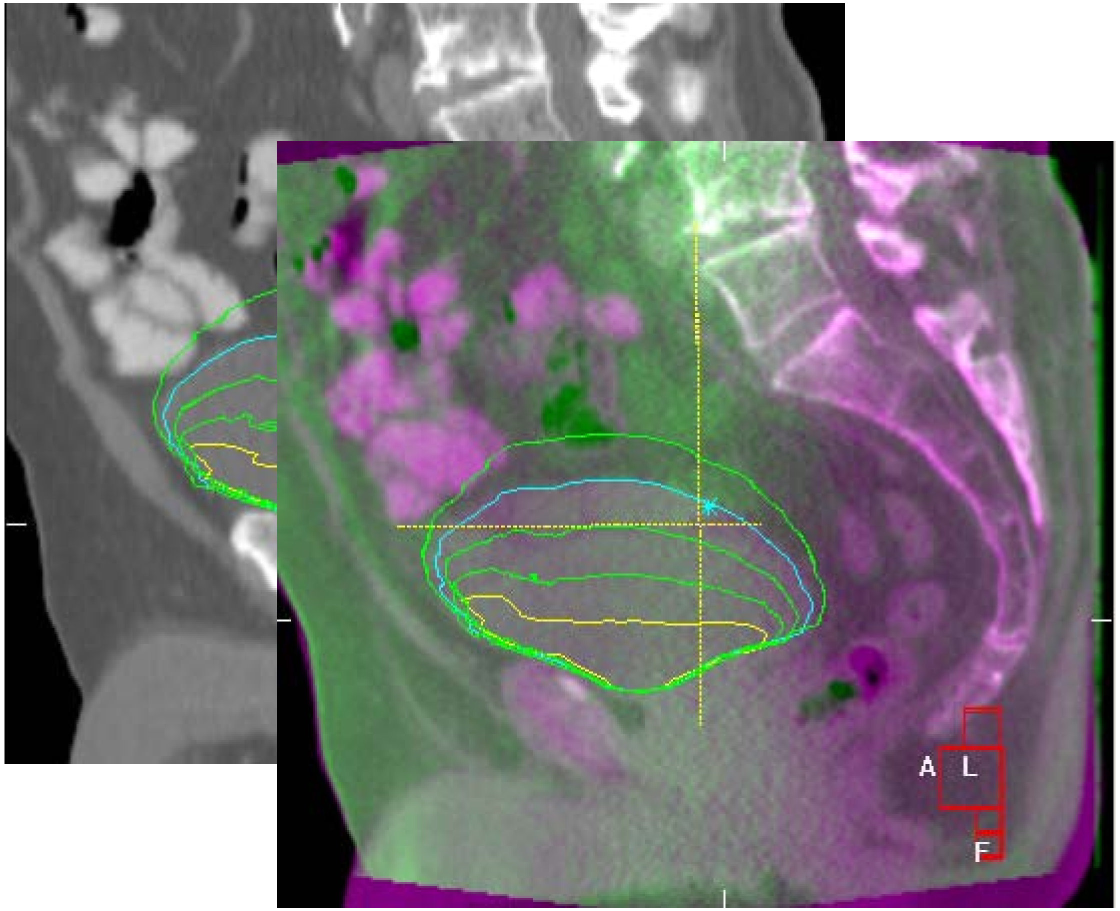
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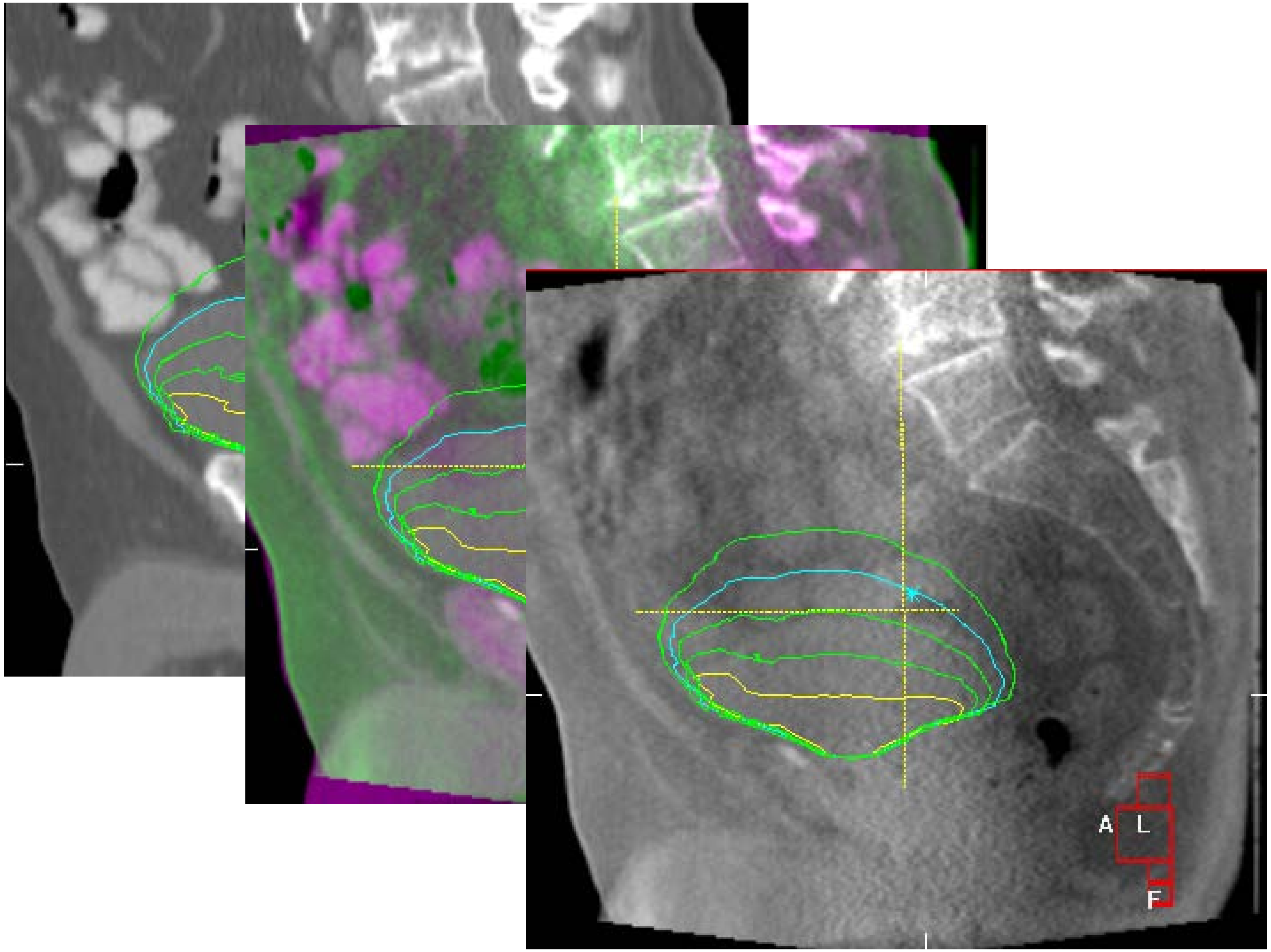
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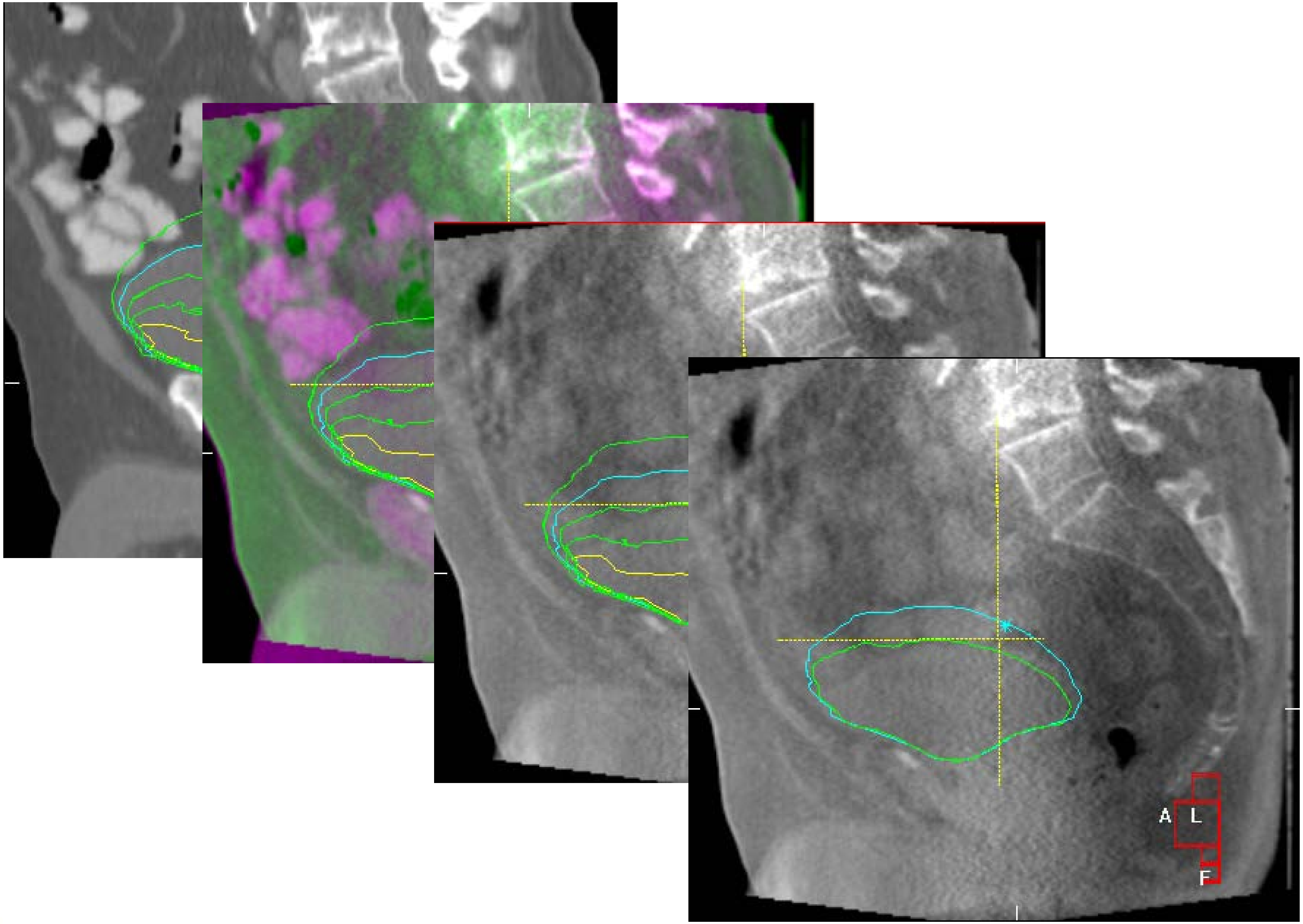
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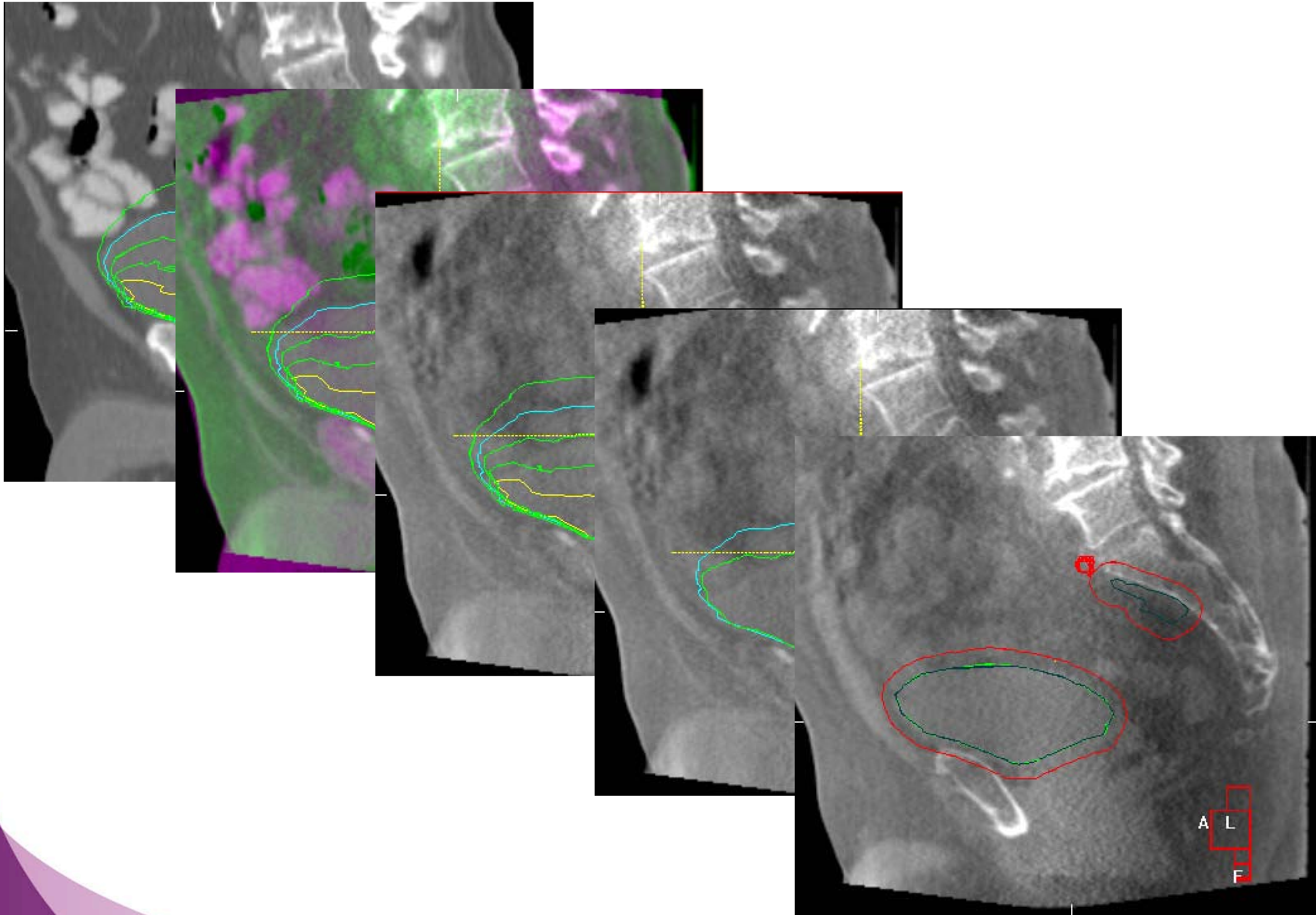
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Case reports: **Lung**

ESTRO School

Jose Lopez, M.D., Ph.D
Radiation Oncology
University Hospital Virgen del Rocio
Seville, Spain

Advanced skills for modern radiotherapy
28 June-02 July, 2015
Copenhagen, Denmark

WWW.ESTRO.ORG/SCHOOL

Outline of Talk

- Preclinical rationale behind oligometastatic state
- Clinical data supporting benefit to local treatment in oligometastatic NSCLC
- Case report
- Discussion of current multidisciplinary (physician, phisyc and RTTs) management

Introduction

- Definitive radiotherapy has historically been reserved for patients with stage I-III disease, and the most common indication for radiation therapy to the primary site for patients with metastatic NSCLC)has been palliation for pain or other symptoms directly resulting from tumor.

- However, stage IV NSCLC is a very broad category , and prior studies have suggested that some patients with stage IV NSCLC and only a few distant metastases (‘oligometastasis’) may benefit from local therapy to both the primary tumor and the distant sites of disease .

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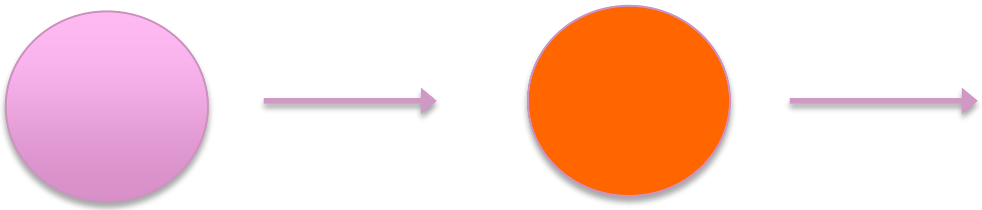
Introduction

- Spectrum of metastatic patients exists
  - Indolent vs. aggressive course
- In-between locoregionally confined and true metastatic state, there appears to exist intermediate state of low disease burden systemically=oligometastasis
  - Can these patients be “cured”?

“Oligo” means “having few, having little.”

Studies with lung cancer have defined oligometastatic disease as up to 5 metastatic lesions.



"Oligo" means "having few, having little."

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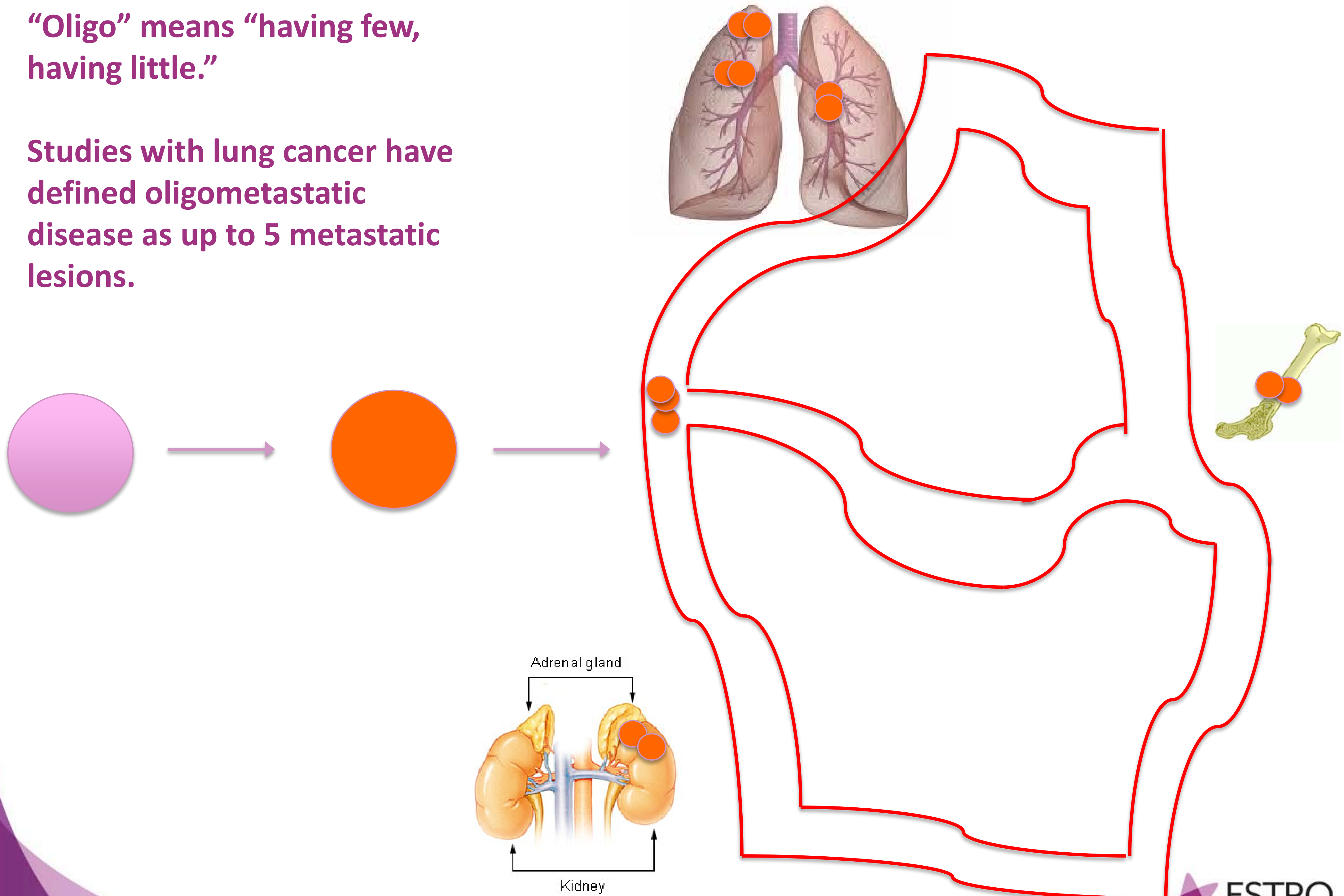

Dr Daniel Gomez. MD Anderson Cancer Center

Recent Trials Addressing Management of Oligometastatic NSCLC

- Recent developments
  - Targeted agents
  - Maintenance chemotherapy
  - Technologic advances permitting ablative doses of radiation therapy

Clinical Data Supporting Local Treatment in Oligometastatic Setting

Author	Year	n	Timespan (years)	Single institution
Twomey	1982	2	14	Yes
Reyes	1990	5	4	Yes
Raviv	1990	3	nr	Yes
Kirsch	1993	1	6	Yes
Higashiyama	1994	5	12	Yes
Ayabe	1995	3	9	Yes
Urschel	1997	1	9	Yes
Bendinelli	1998	4	4	Yes
Tsuji	1998	1	2	Yes
Linos	1998	1	1	Yes
Porte	1998	11	8	Yes
Wade	1998	14	7	No (159 centers)
de Perrot	1999	1	5	Yes
Bretcha-Boix	2000	5	nr	Yes
Ambrogi	2000	5	7	Yes
Porte	2001	43	12	No (8 centers)
Mercier	2004	23	14	Yes
Lucchi	2005	11	10	Yes
Pfannschmidt	2005	11	7	Yes
Sebag	2006	9	9	Yes
Munoz	2006	1	5	Yes
Strong	2007	29	11	Yes

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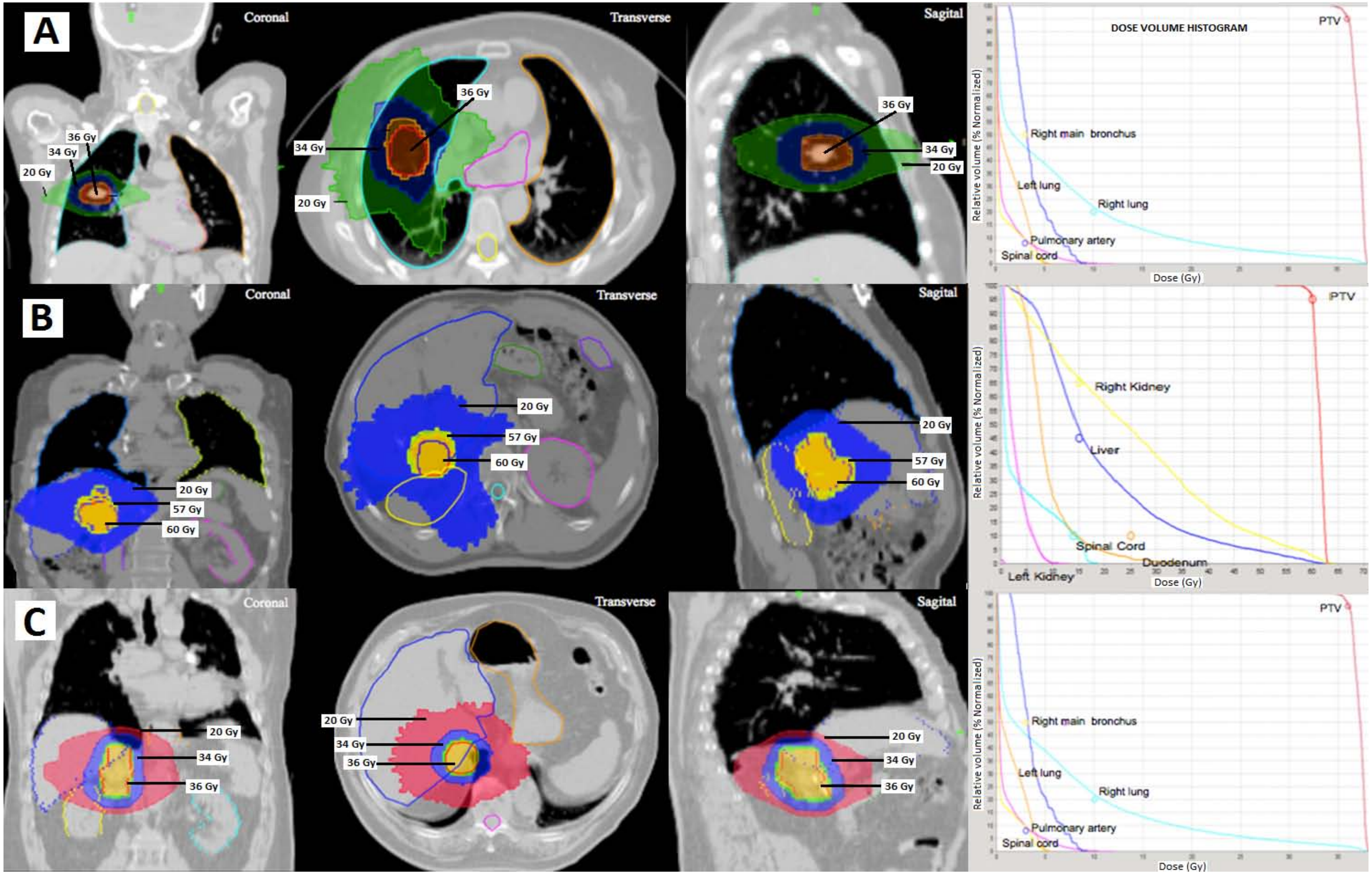
STEREOTACTIC ABLATIVE RADIOTHERAPY DELIVERED BY HELICAL TOMOTHERAPY FOR EXTRACRANEAL OLIGOMETASTASIS



Sole CV, Lopez Guerra JL, et al. Clin Transl Oncol. 2013

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STEREOTACTIC ABLATIVE RADIOTHERAPY DELIVERED BY HELICAL TOMOTHERAPY FOR EXTRACRANEAL OLIGOMETASTASIS

CONTOURS

- GTV: defined only as the solid abnormality on CT + PET
- ITV: using a multiple CT scan (free breathing, maximal inspiration, and maximal expiration)
- PTV: 0.5 cm in the axial plane and 1.0 cm in the craneocaudal plane

DOSE PRESCRIPTION

- Lung (not chest wall): 3 fractions of 20 Gy
- Lung (chest wall): 3-5 fractions of 12 Gy for lesions
- Lung (central): 8 fractions of 7.5 Gy

CHEMOTHERAPY (90%)

- FOLFOX/FOLFIRI

Sole CV, Lopez Guerra JL, et al. Clin Transl Oncol. 2013

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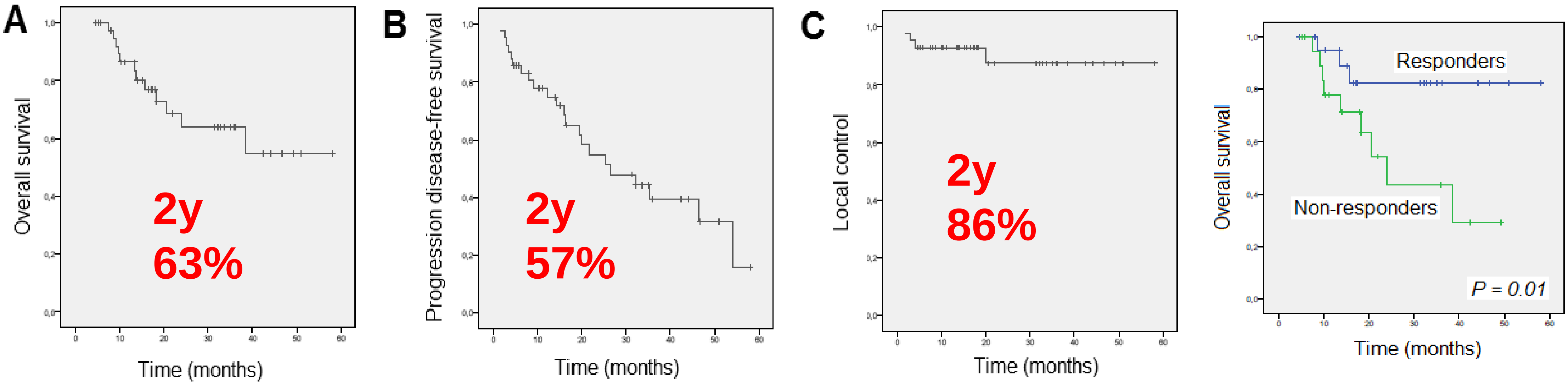
DOSE CONSTRAINTS

THORAX

- Chronic lung disease: 70% of the lung <17 Gy.
- Healthy lungs: 60 % of the <20 Gy.
- Esophagus: Dmax < was 4.0 Gy per fraction.
- Chest wall: <30 Gy to 30 cc and <60 Gy to 3 cc.
- Spinal cord: <2 Gy per fraction and <45 Gy total.



Toxicity (N=28)	Grade I	Grade II	Grade III
Pneumonitis	11	3	1
Chest wall pain	6		
Skin	6		
Esophagitis	3		

Select group of patients that benefit from aggressive local treatment for oligometastatic disease

Sole CV, Lopez Guerra JL, et al. Clin Transl Oncol. 2013

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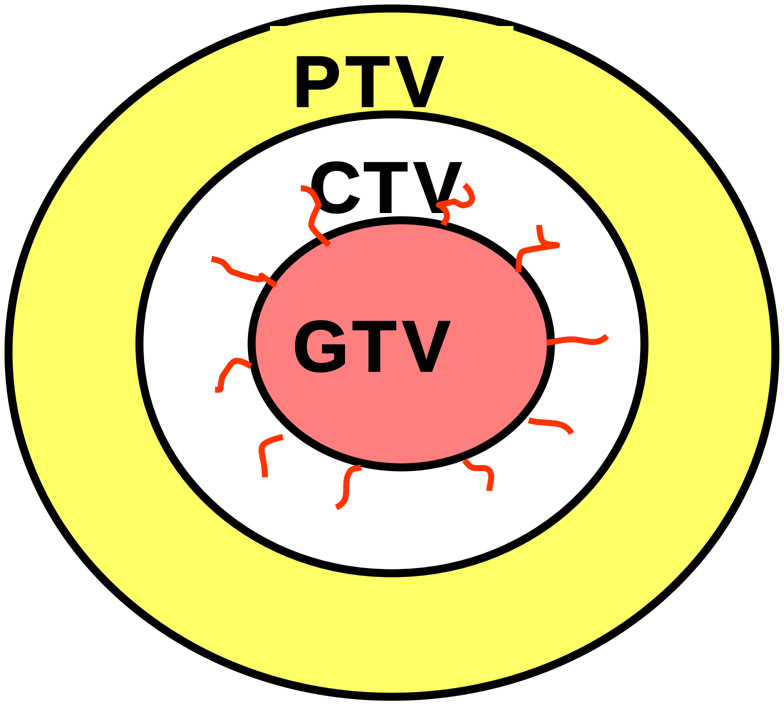
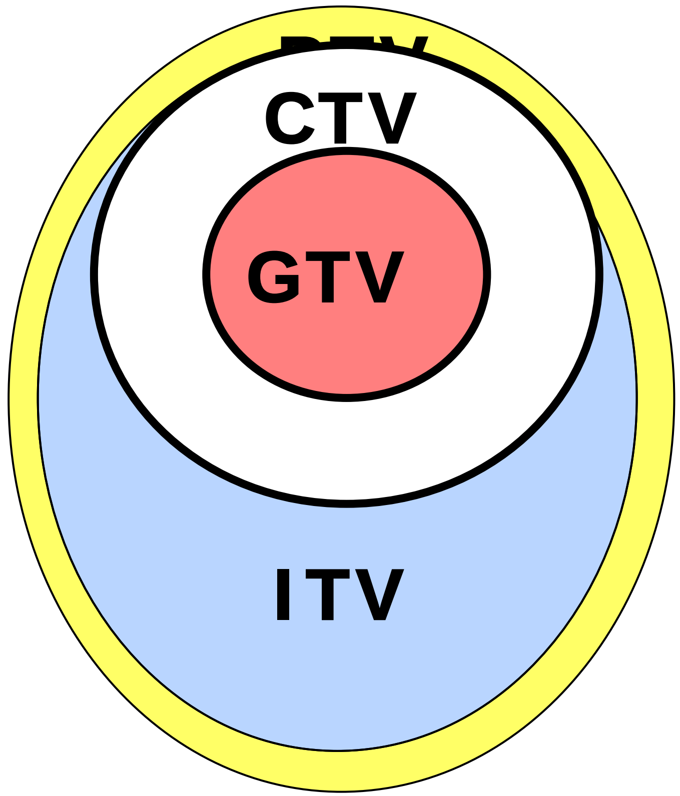
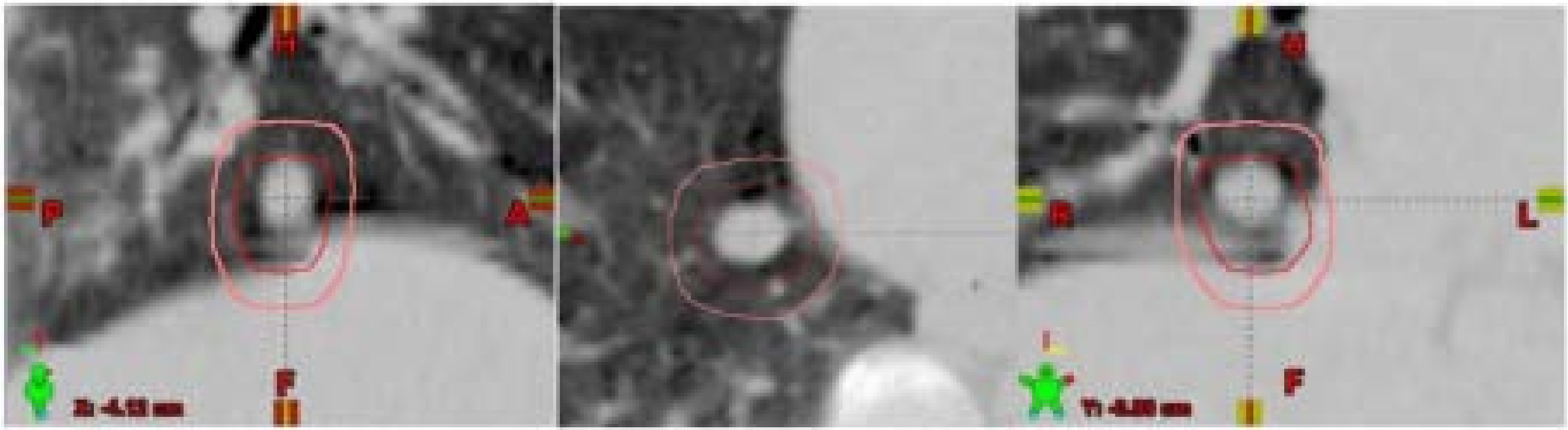
ICRU 50



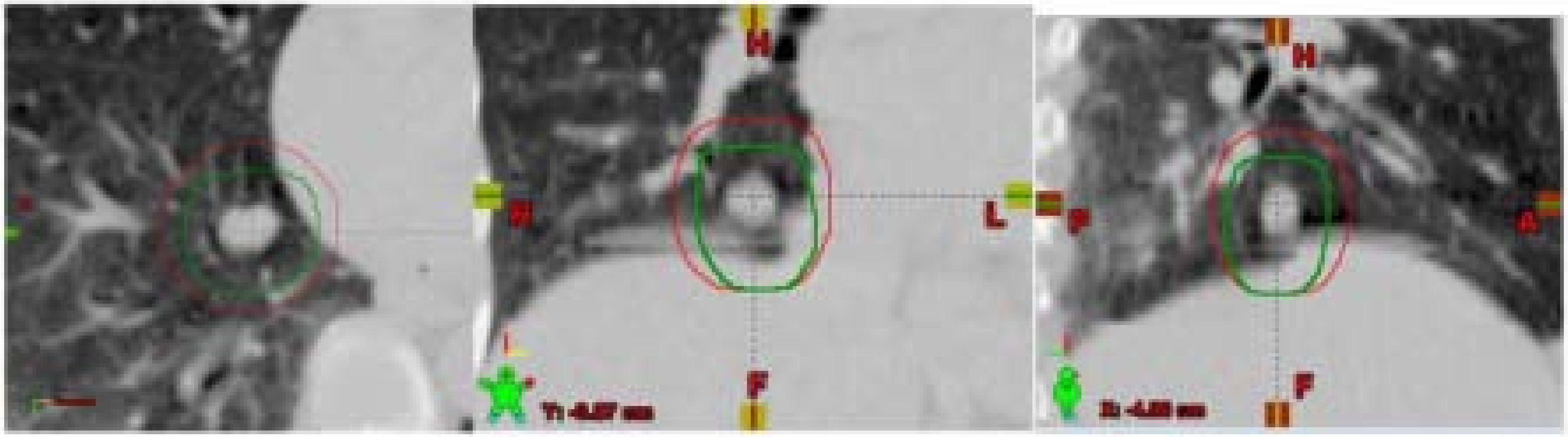
ICRU 62



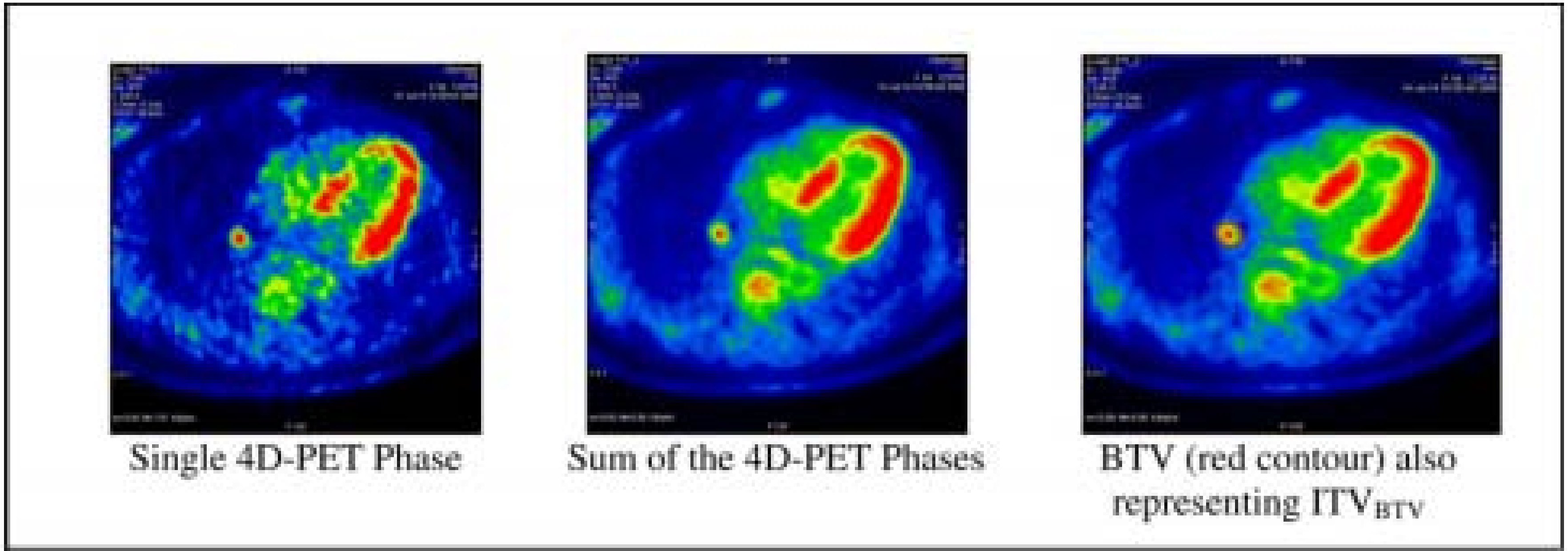
GTV= Gross Tumor Volume, CTV=Clinical Target Volume, PTV=Planning Target Volume, ITV=Internal Target Volume

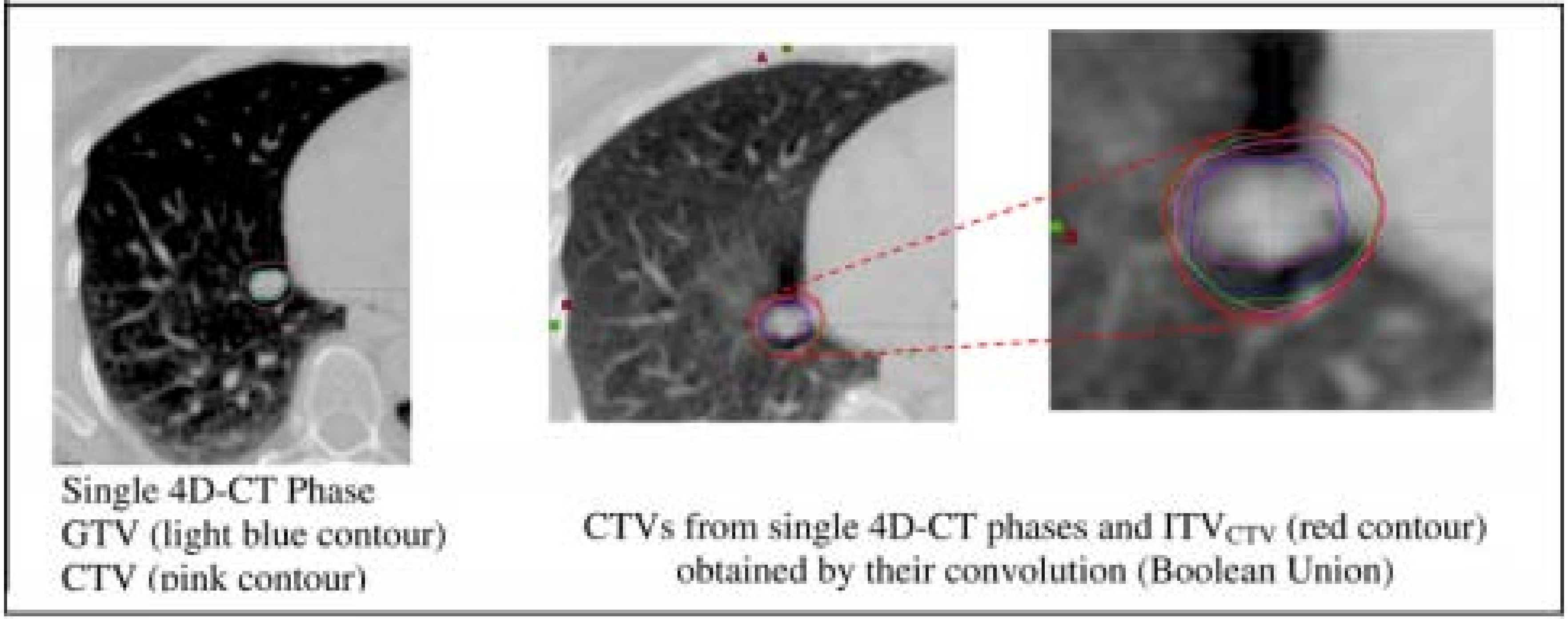


CT Image (Left: Transaxial, Center: Coronal, Right: Sagittal).
ITV (red contour) obtained by the convolution (Boolean Union) of ITV_{CTV} and ITV_{BTV} and PTV_{4D} (pink contour) obtained by the expansion of the ITV for the set-up margins



CT Image (Left Transaxial, Center: Coronal, Right: Sagittal).Comparison between PTV_{4D} (green contour) and PTV obtained by standard expansions (red contour)





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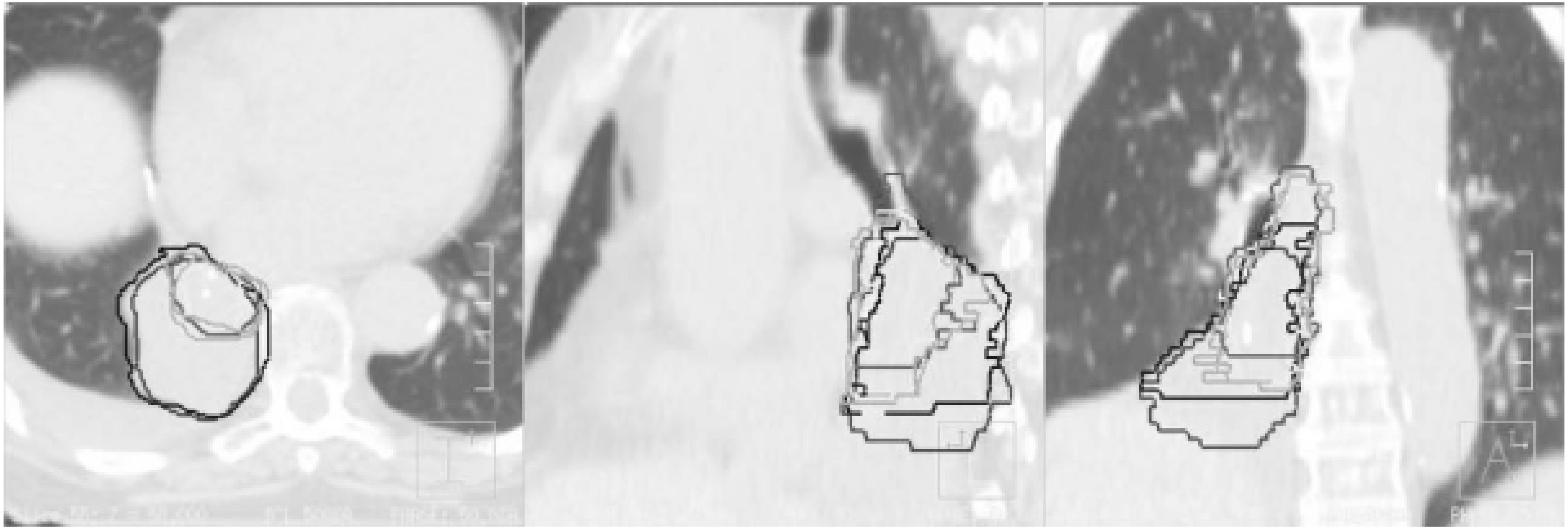

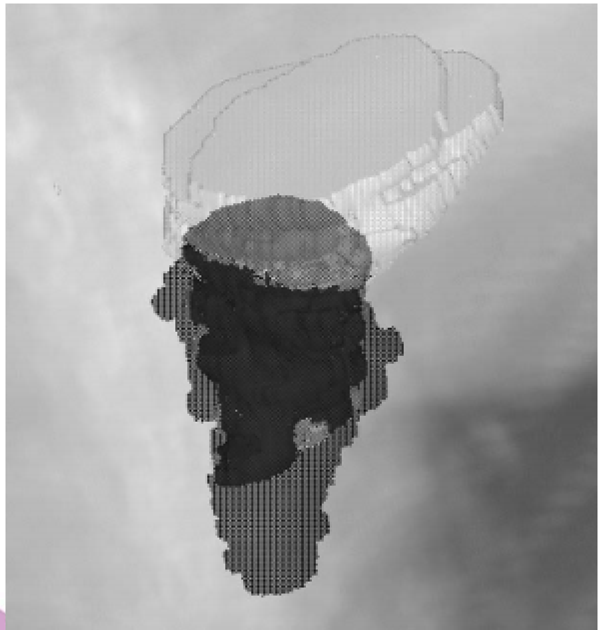

Inter-observer and intra-observer reliability for lung cancer target volume delineation in the 4D-CT era

Radiotherapy and Oncology 95 (2010) 166–171

Radiotherapy and Oncology 101 (2011) 322–328

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Radiotherapy and Oncology

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Lung cancer radiotherapy

An evaluation of an automated 4D-CT contour propagation tool to define an internal gross tumour volume for lung cancer radiotherapy

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Conclusions: Automated 4D-CT propagation tools can significantly decrease the IGTV delineation time without significantly decreasing the inter- and intra-physician variability.

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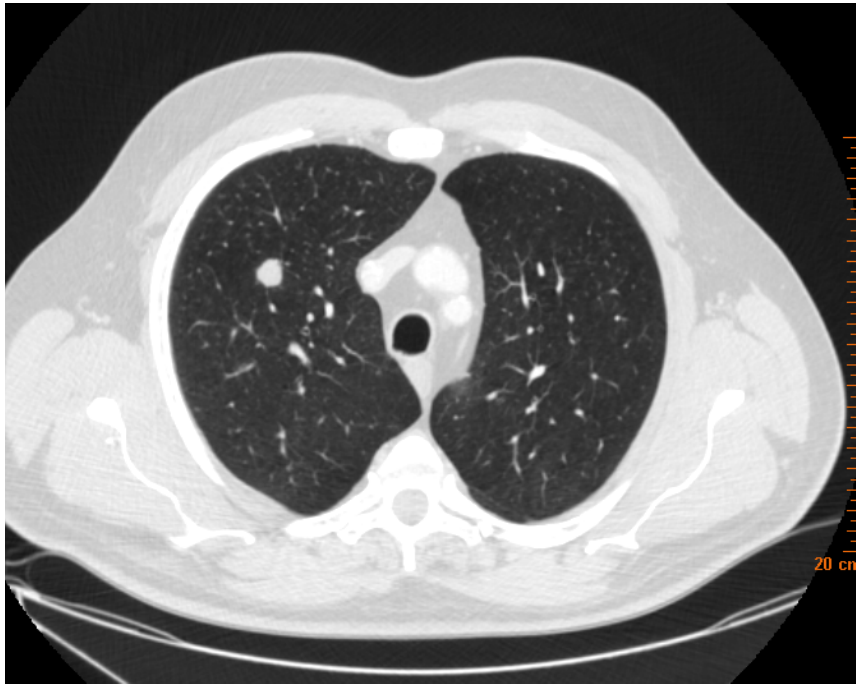
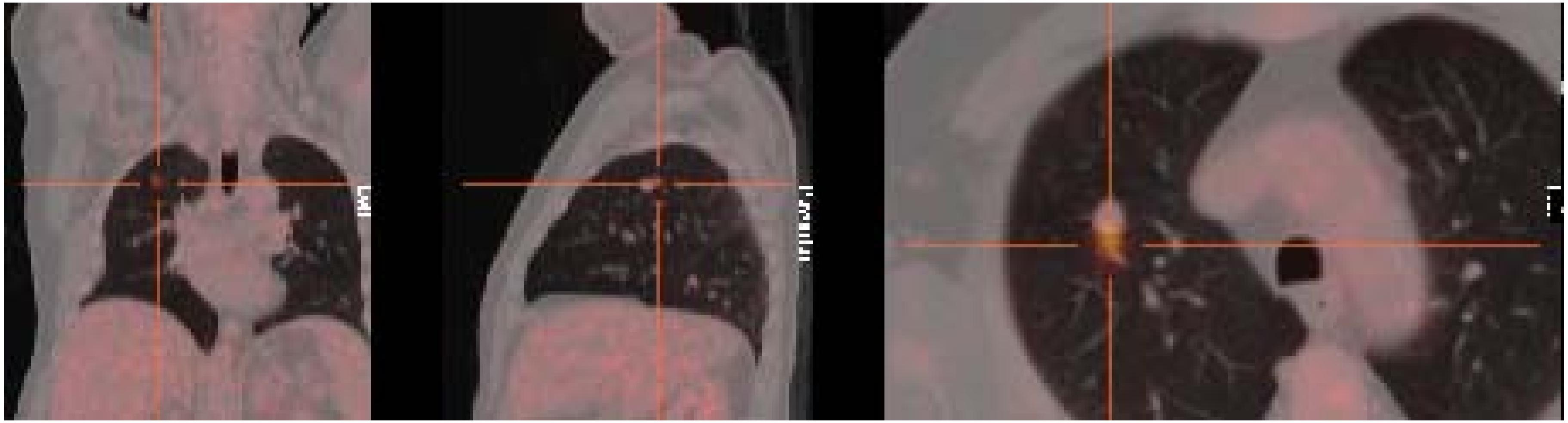
Case 1: Oligorecurrence of lung cancer

- A 65-year-old male presented to the emergency department with a two-week history of upper back pain
- Pertinent social history includes a 34-pack year history of tobacco smoking, as well as history of heavy alcohol consumption in the past.
- Chest X-ray and CT scan showed a RUL nodule (14 mm)

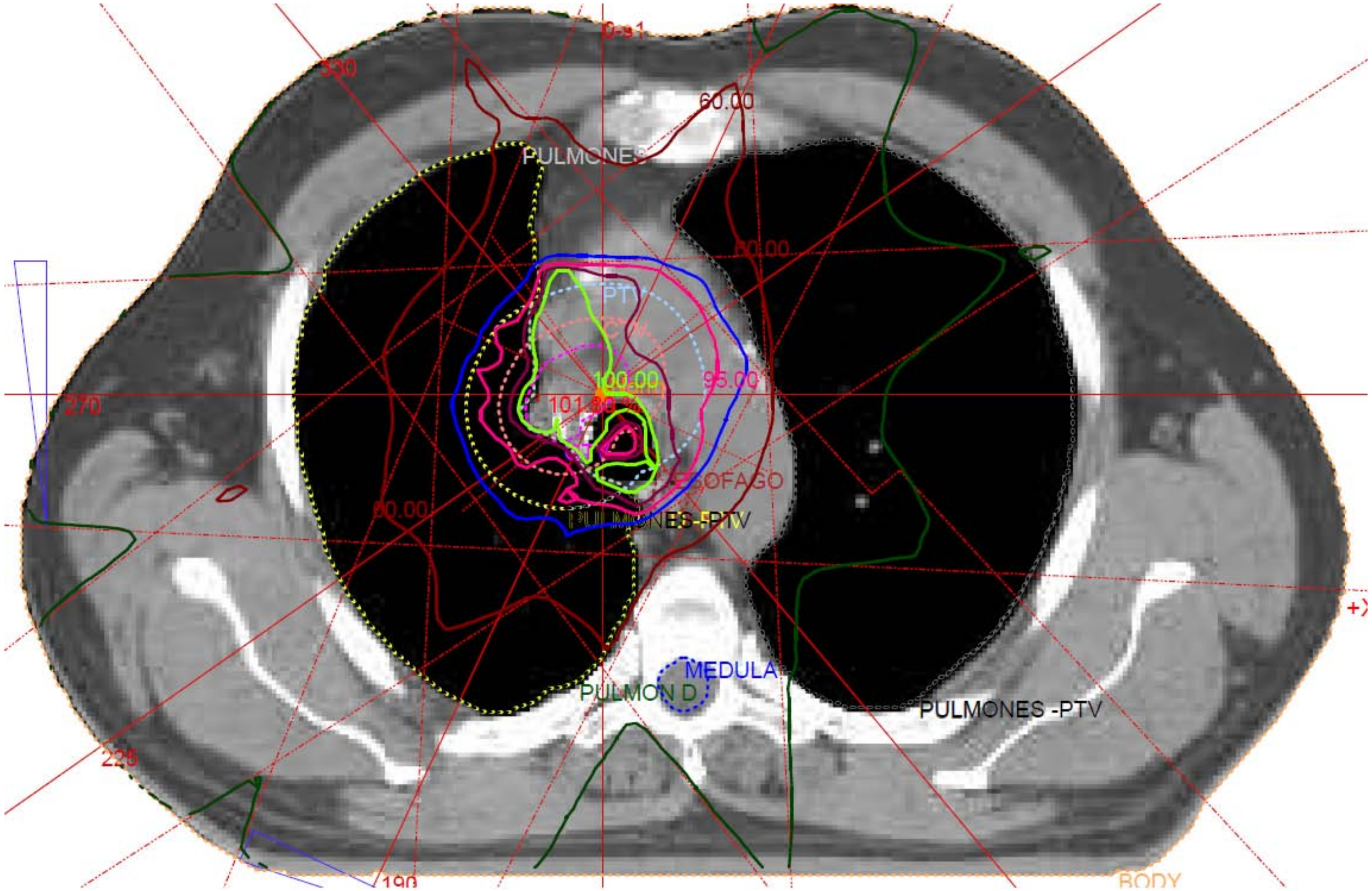


- PET/CT: SUVmax 5,1



- The patient underwent RUL lobectomy and mediastinal lymph node dissection.
- Final pathology report was consistent with high-grade large cell neuroendocrine carcinoma.

- At 2 years follow up , the CT scan showed mediastinal recurrence that was treated with concomitant radiochemotherapy (total radiation dose 66 Gy at 2 Gy/fraction).



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- At 3 years follow up , the CT scan showed a RML recurrence (15 mm nodule).

IMG_4190 (1).MOV

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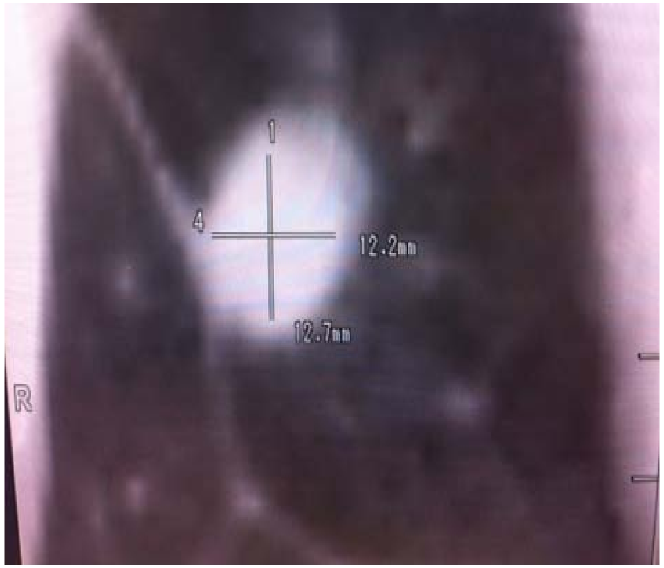
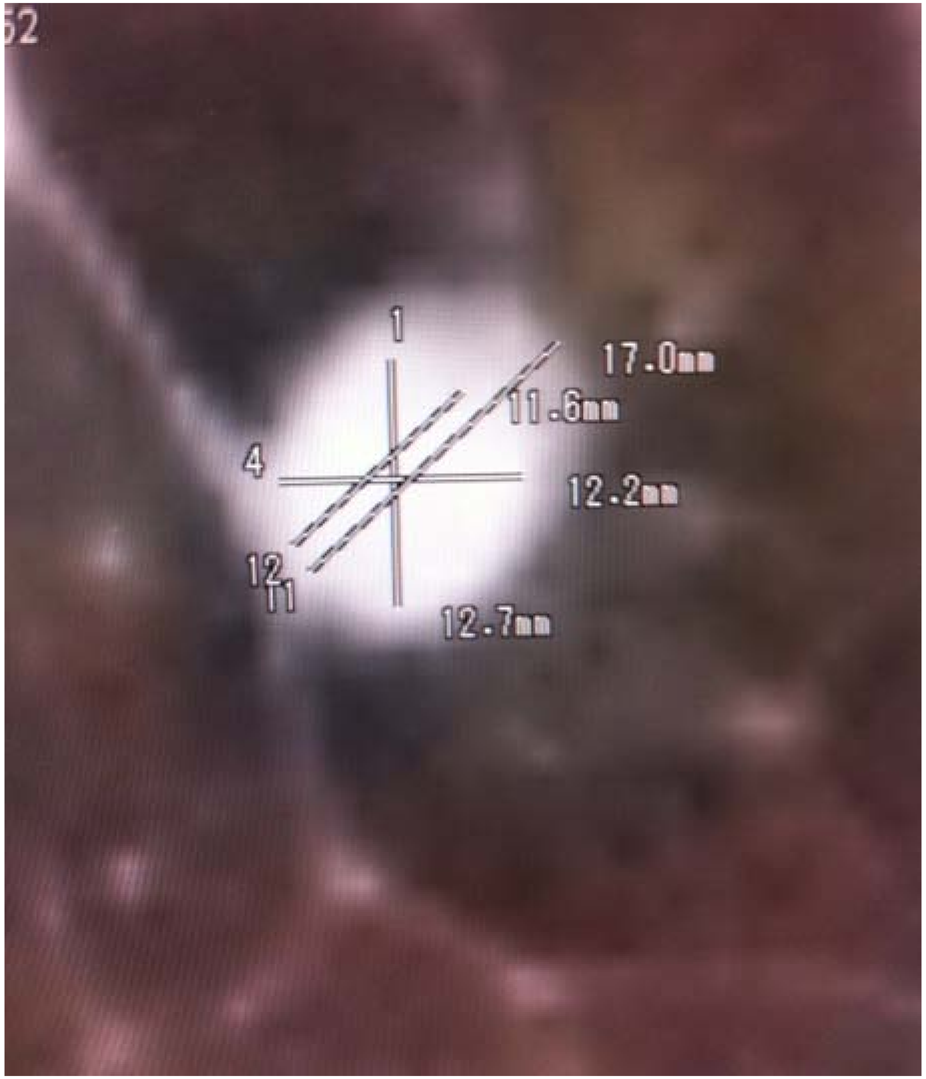
Motion artifacts are commonly seen with thoracic CT images

Motion artifacts



Tumor movement



- Diagnosis
- Oligorecurrence of lung cancer

- Treatment

- Radiation Therapy (SBRT)

- Radiation Therapy Dose Prescription:

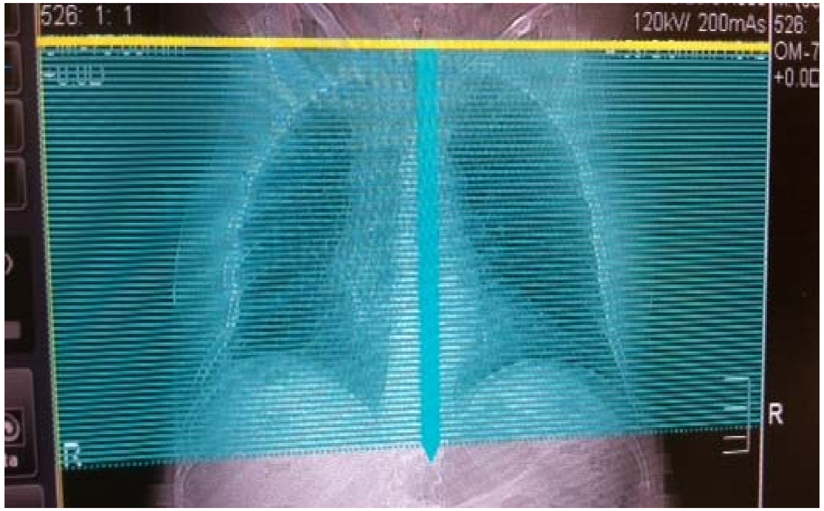
- PTV (RML nodule): 50 Gy at 12,5 Gy/fraction

Take home message

- Further research is necessary to assess the survival outcome and late toxicity with a longer follow-up for oligometastatic NSCLC

- Different strategies such as 4D repiratory gated acquisition techniques are needed for tumor motion control

- The consecuences of lower doses (“bath dose”) in the OAR is still unknown



Questions:

- Immobilization
- Positioning
- Organ at risk contouring
- Set-Up
- Verification
- Radiation technique

???

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Case reports: **Lung**

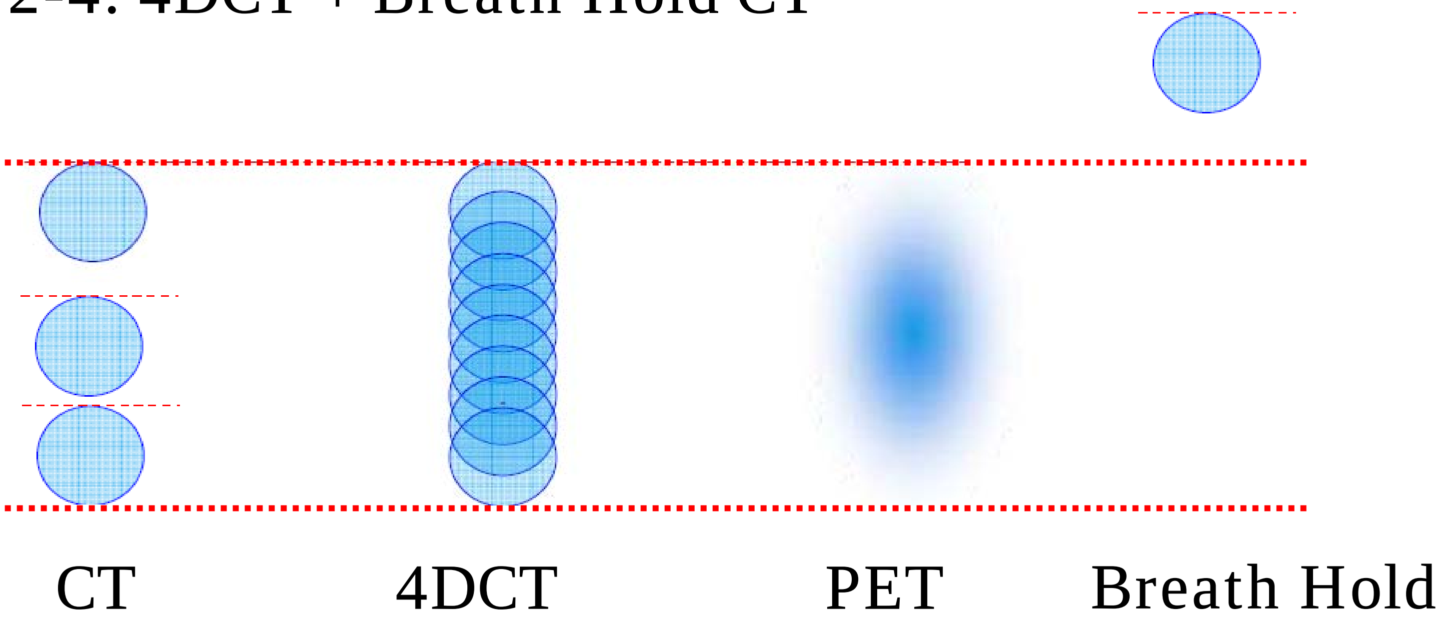
Mirjana Josipovic
Dept. of Radiation Oncology
Rigshospitalet
Copenhagen, Denmark

Advanced skills in modern radiotherapy
June 2015

Imaging for treatment planning of lung cancer

Rigs:

- Day 1: PET/CT
- Day 2-4: 4DCT + Breath Hold CT



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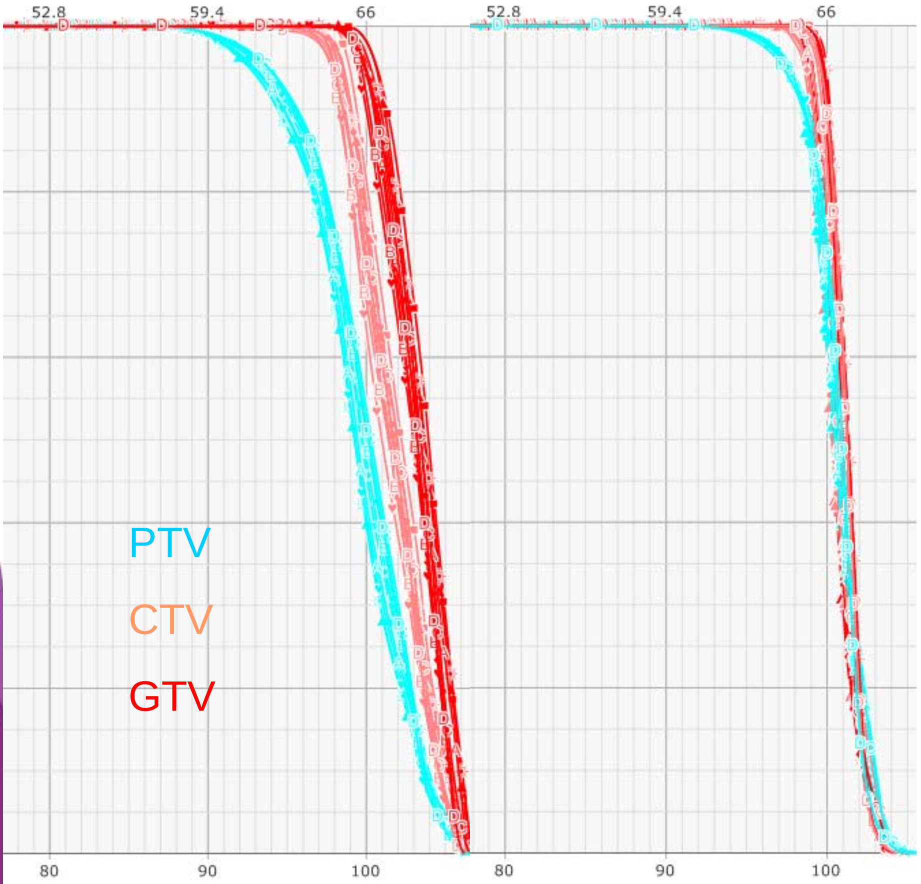
Treatment planning – PTV coverage

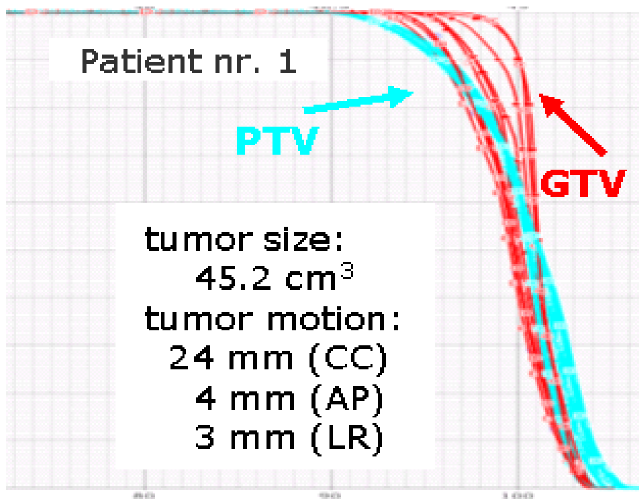
Advanced dose calculation algorithm

- PTV covered by 90% isodose

DVH for 10 respiration phases



- mean PTV ± 1.2%
- min PTV – 2.5%
- mean CTV > 99.2%



Room for improvement in case of large target motion!

STD margins!

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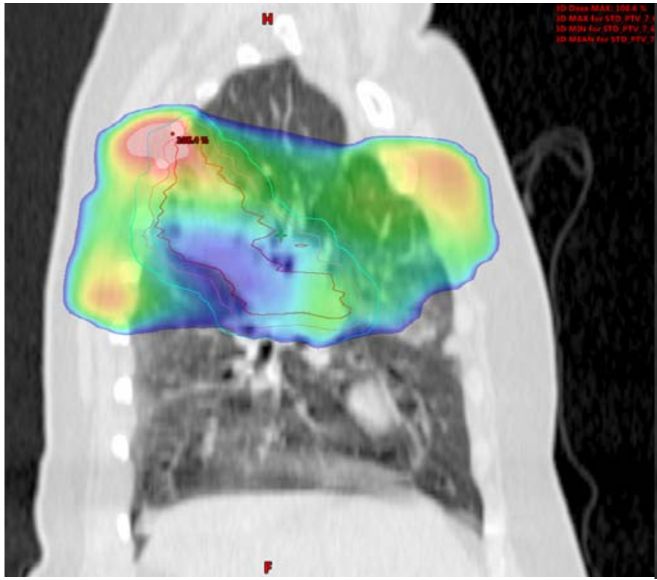
Individual margins

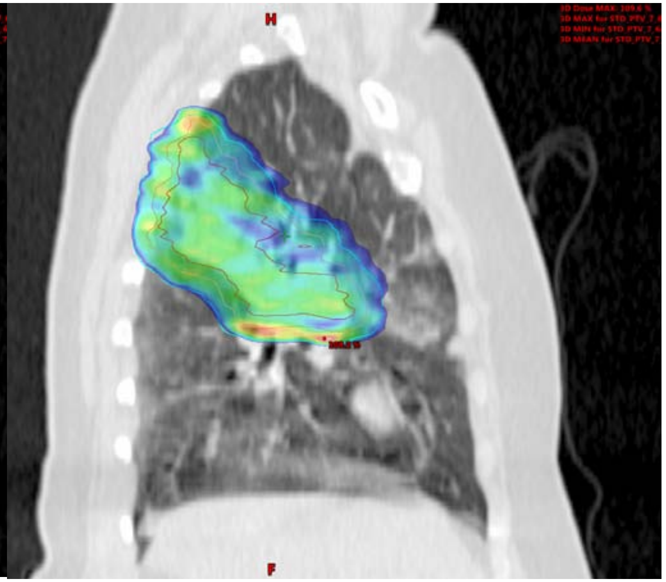
Based on van Herk’s margin formula

- Uncertainties evaluated base on our own data
  - ➢ Baseline shift
  - ➢ 3D instead of 6D match
  - ➢ Delineation uncertainty (for lung SBRT)
- Respiration amplitude
- No. of fractions
  - ➢ 3, 8, 24 -33
- Penumbra width
  - ➢ Lung/bone/softtissue

3D vs. VMAT

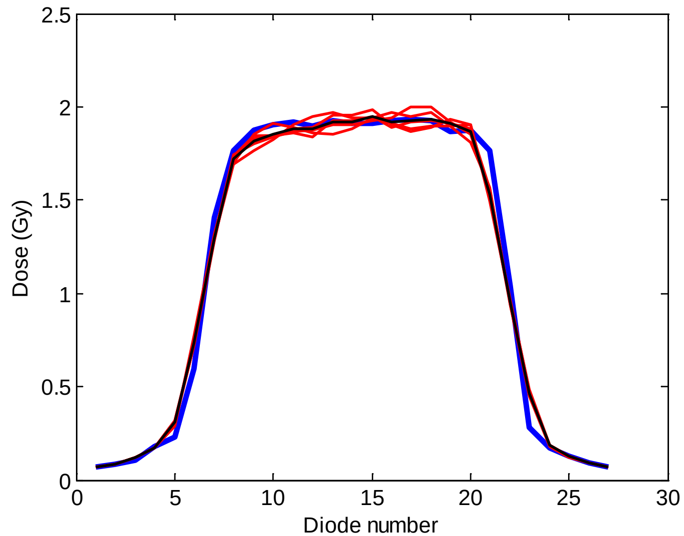


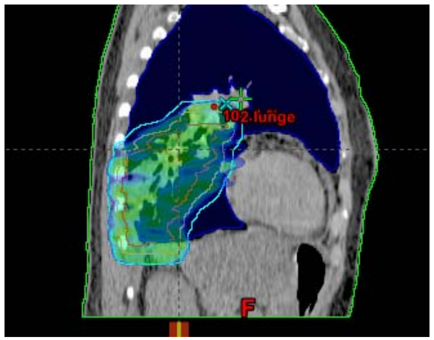
3DC

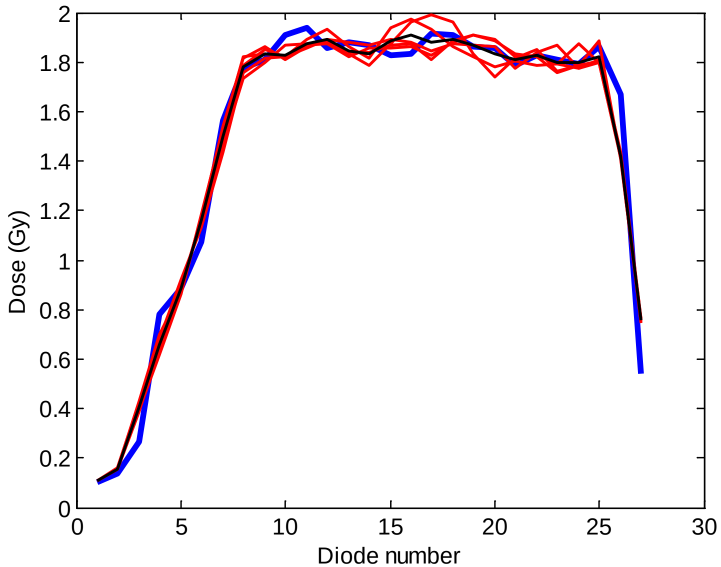


VMAT

Interplay effect?



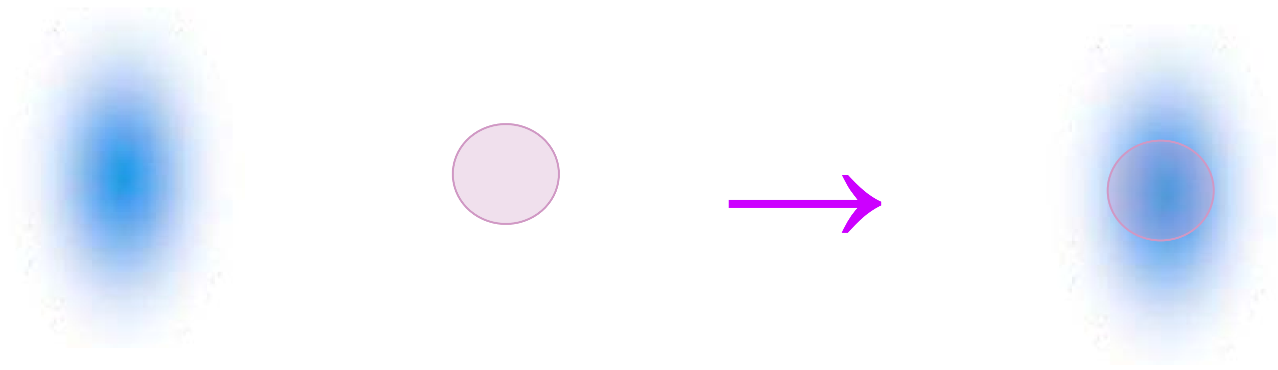




2 cm respiration amplitude

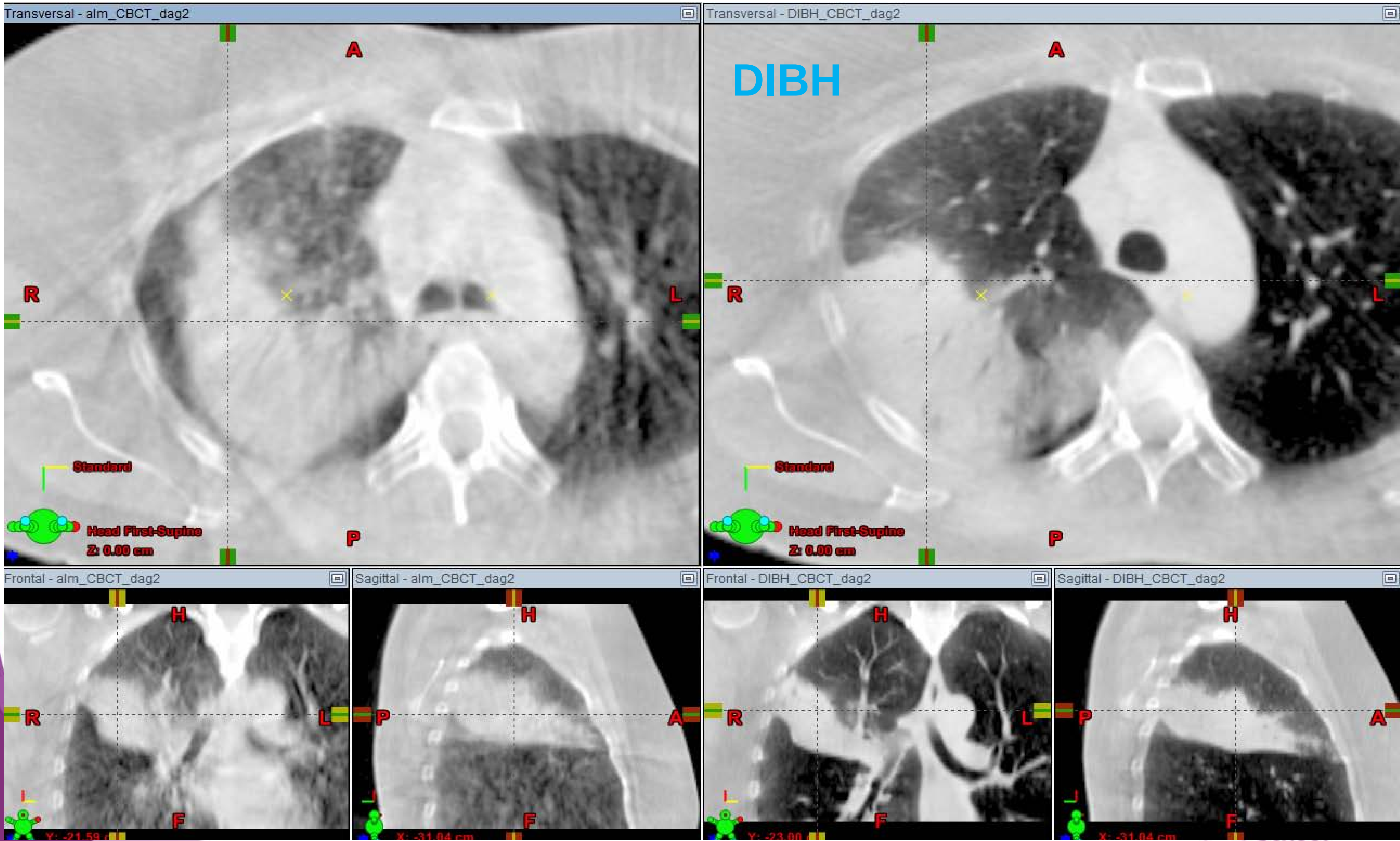
Daily treatment verification

- CBCT acquisition takes ~1 min
  - ➢ Tumour visualisation on CBCT is blurred

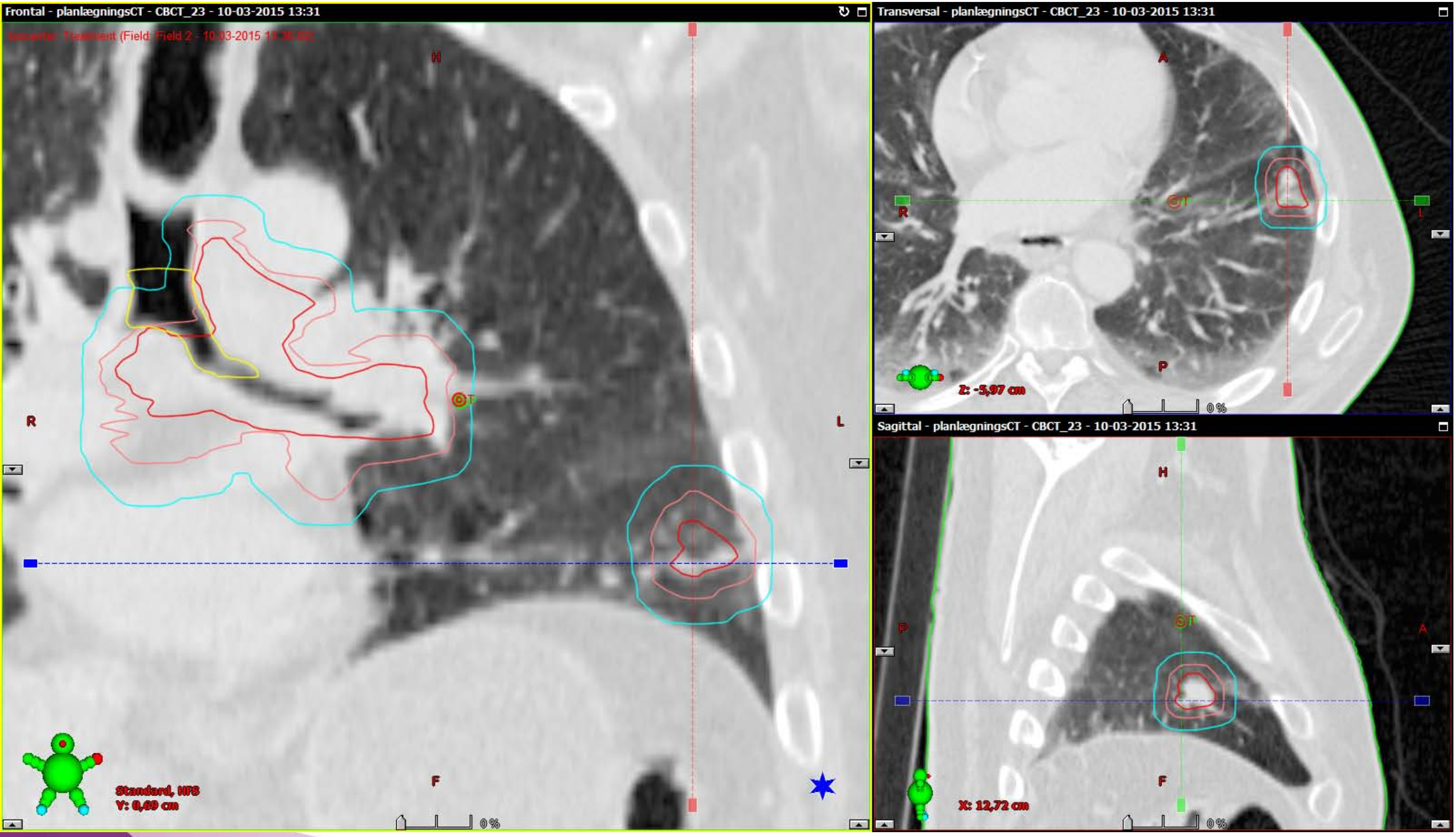


CBCT CT (MidV) match

  - ➢ ...but the image signal (of the tumour) on CBCT is strongest where the tumour is most of the time
  - ➢ Therefore it is makes good sense to match it with the midventilation bin!

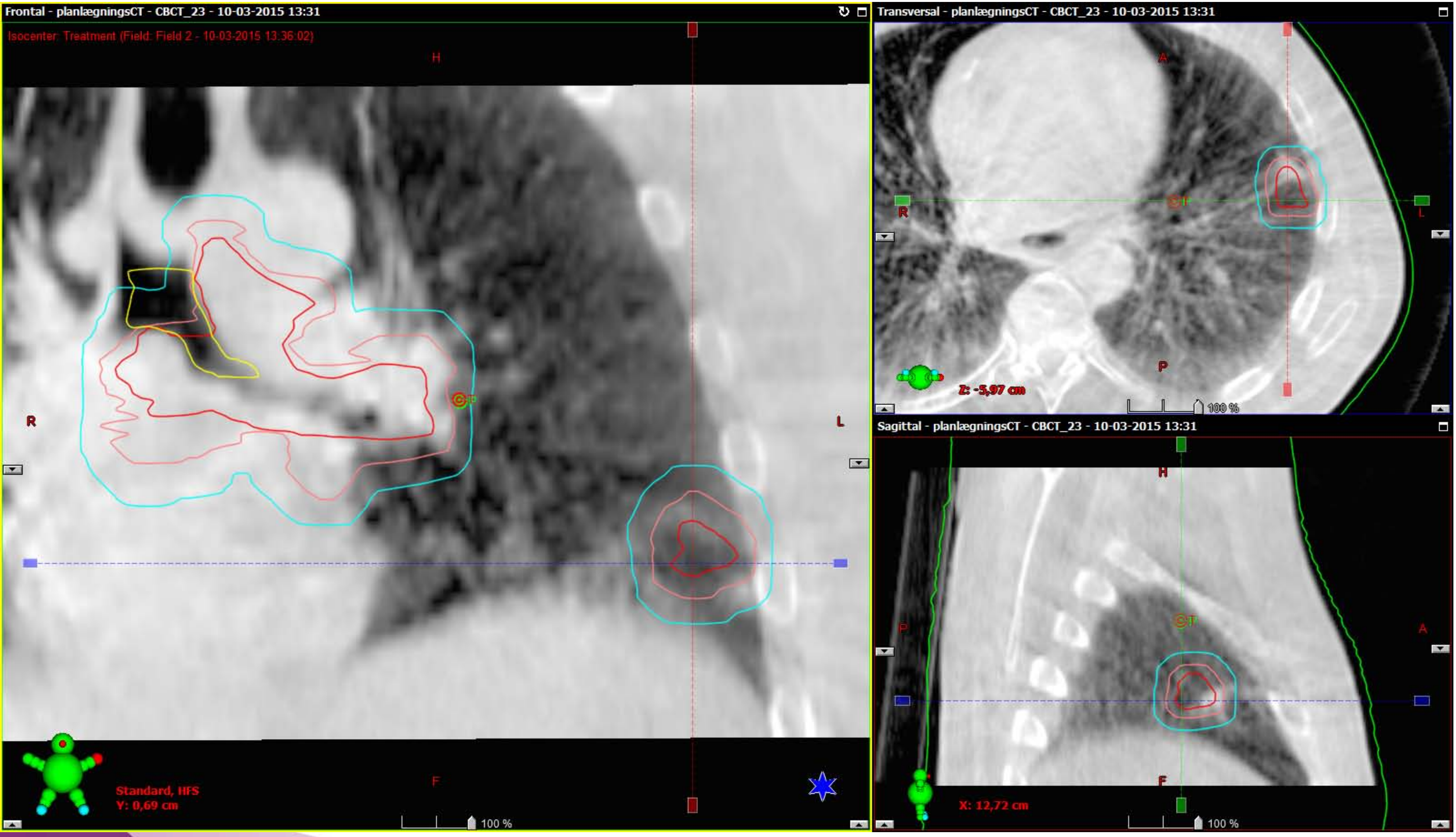

Transversal - alm_CBCT_dag2
Transversal - DIBH_CBCT_dag2
DIBH
A
R
L
P
Standard
Head First-Supine
Z: 0.00 cm
Frontal - alm_CBCT_dag2
Sagittal - alm_CBCT_dag2
Frontal - DIBH_CBCT_dag2
Sagittal - DIBH_CBCT_dag2
H
F

Case



Frontal - planlægningsCT - CBCT_23 - 10-03-2015 13:31
H
R
L
F
Standard, HFS
V: 0,69 cm
0 %
Transversal - planlægningsCT - CBCT_23 - 10-03-2015 13:31
A
R
L
P
Z: -5,97 cm
0 %
Sagittal - planlægningsCT - CBCT_23 - 10-03-2015 13:31
H
P
A
F
X: 12,72 cm
0 %

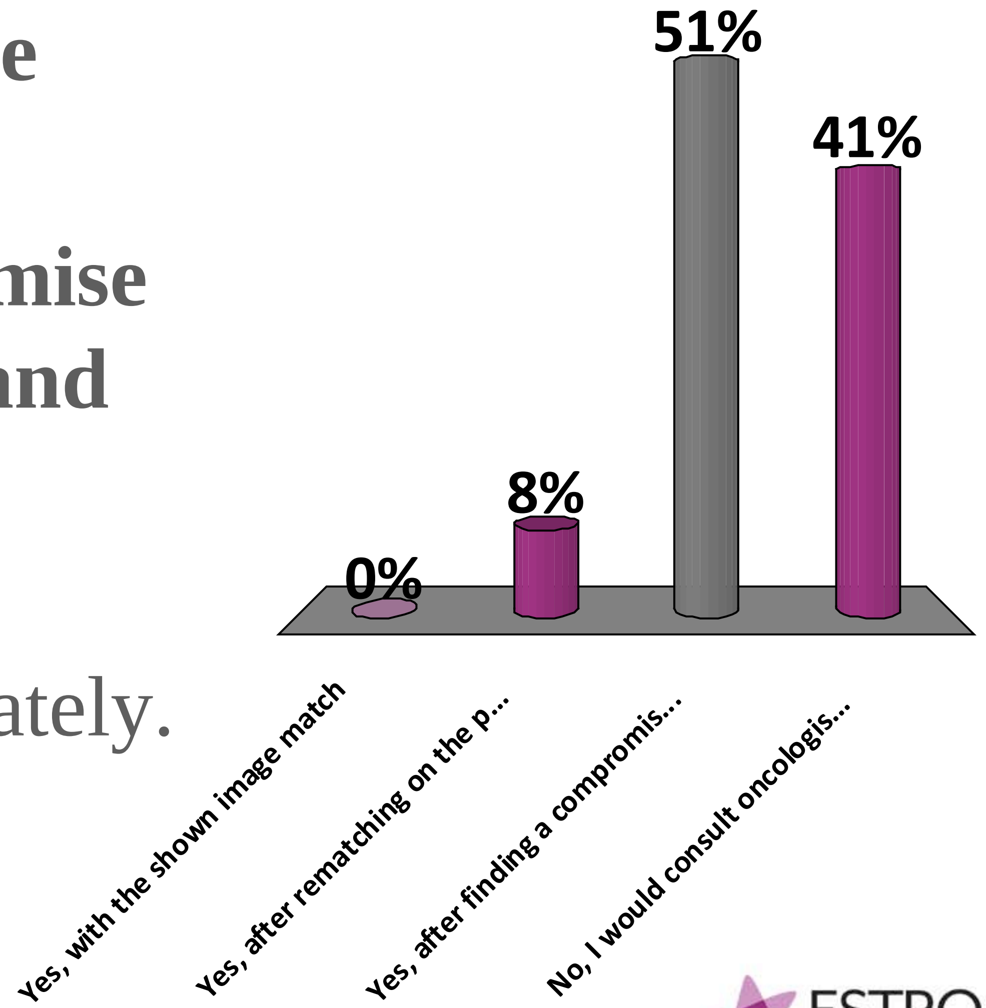
Case



Frontal - planlægningsCT - CBCT_23 - 10-03-2015 13:31
Isocenter: Treatment (Field: Field 2 - 10-03-2015 13:36:02)
H
R
L
F
Standard, HFS
Y: 0,69 cm
100 %
Transversal - planlægningsCT - CBCT_23 - 10-03-2015 13:31
A
R
L
P
Z: -5,97 cm
100 %
Sagittal - planlægningsCT - CBCT_23 - 10-03-2015 13:31
H
P
A
F
X: 12,72 cm
100 %

Would you treat this patient?

A. Yes, with the shown image match
B. Yes, after **rematching on the peripheral tumour**
C. Yes, after finding a **compromise between the mediastinum and the peripheral tumour**
D. No, I would consult oncologist/physicist immediately.



Case – differential motion

The correct answer is...

- What is your IGRT strategy?
- How are your margins designed?

- Is it the first time, (too) large differential motion was observed?

IGRT – uncertainties

- Differential motion
  - Displacement of primary tumour to/from the glands

- Tumour shrinkage during a course of 33 fractions

- Anatomical changes (atelectasis, weight loss, pleural fluid, ...)

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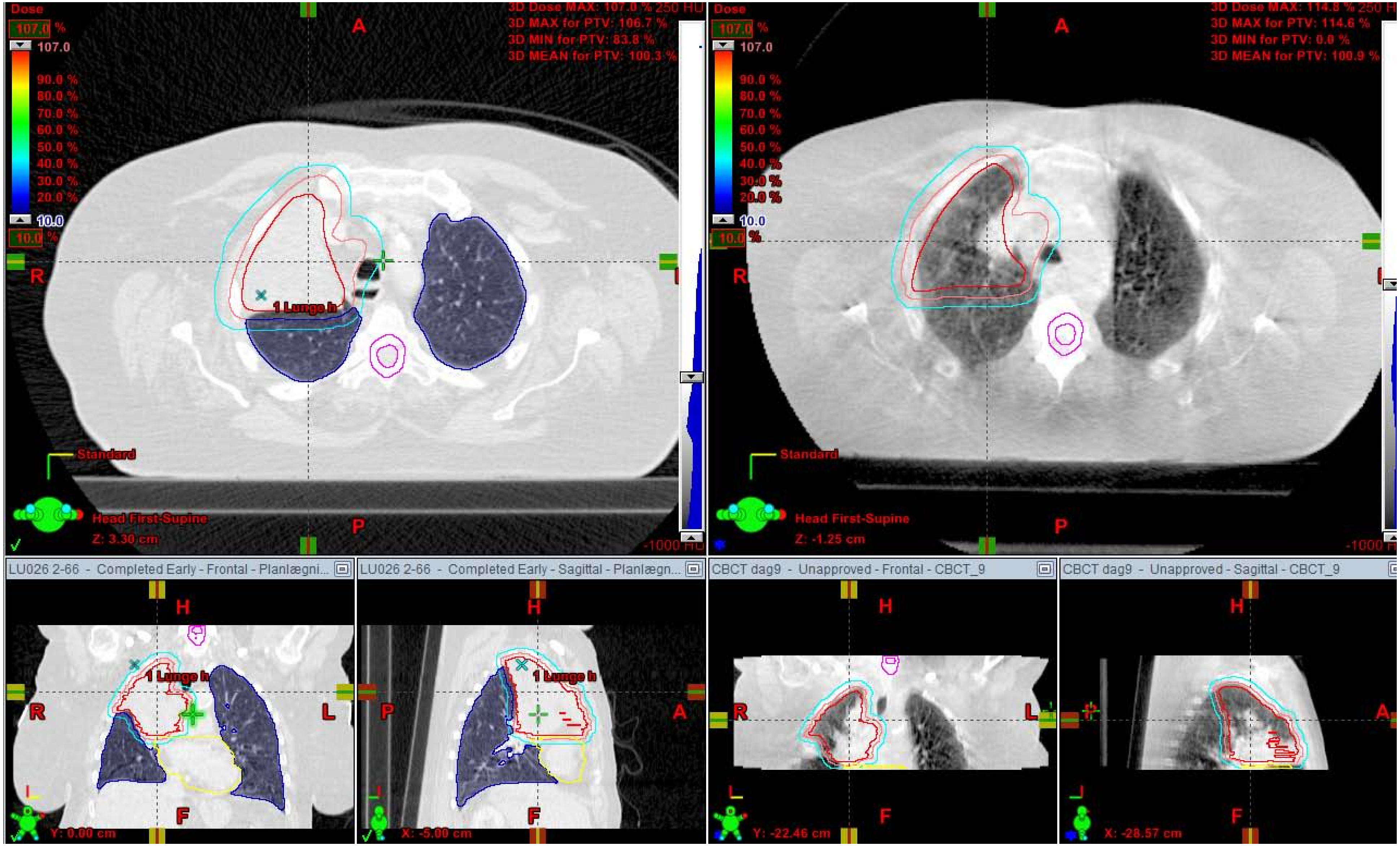
Day 1 Day 11



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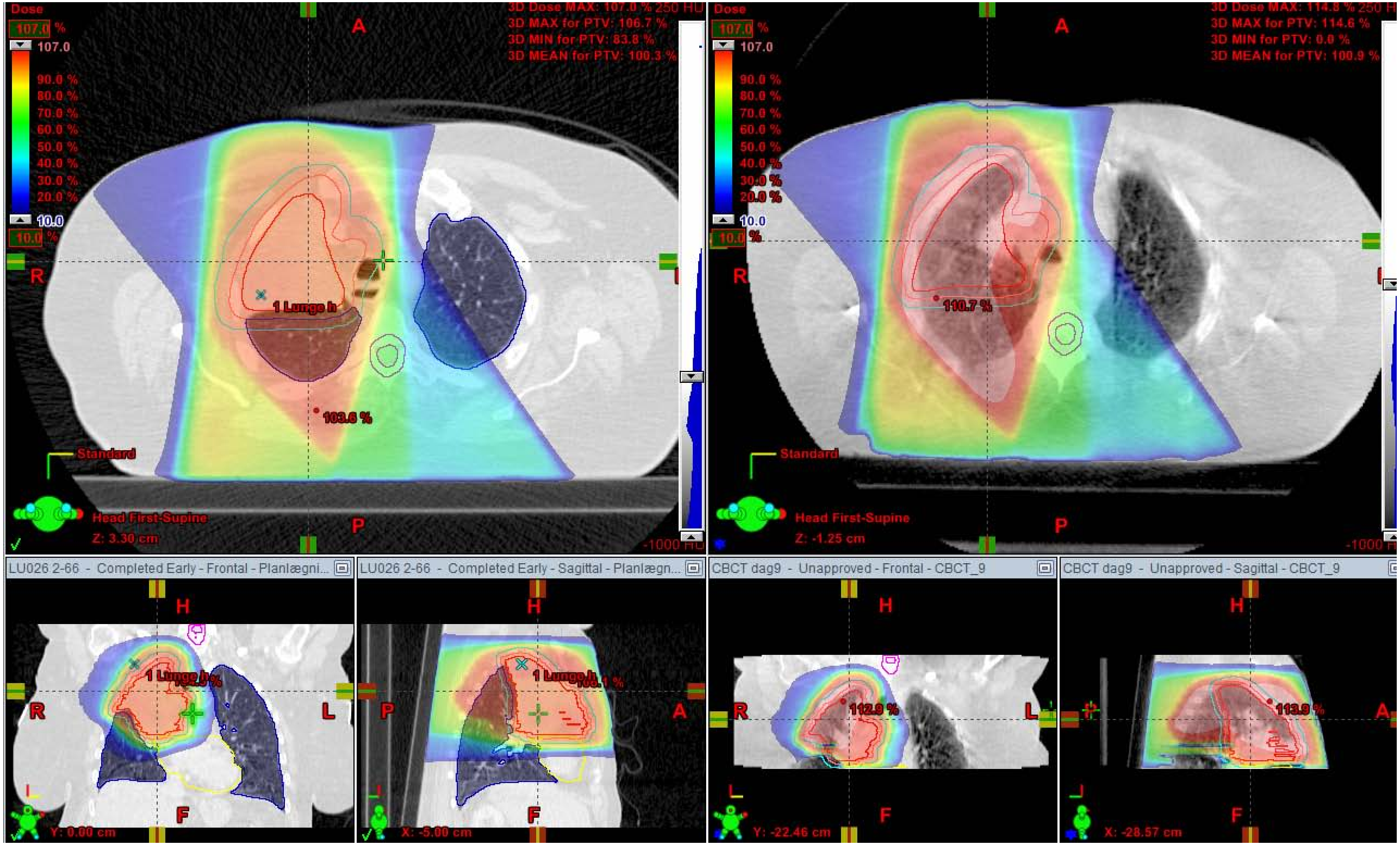
Day 1 Day 11



3DC RT

Dmax 107 →115%

Dmean 100 → 100.9 %

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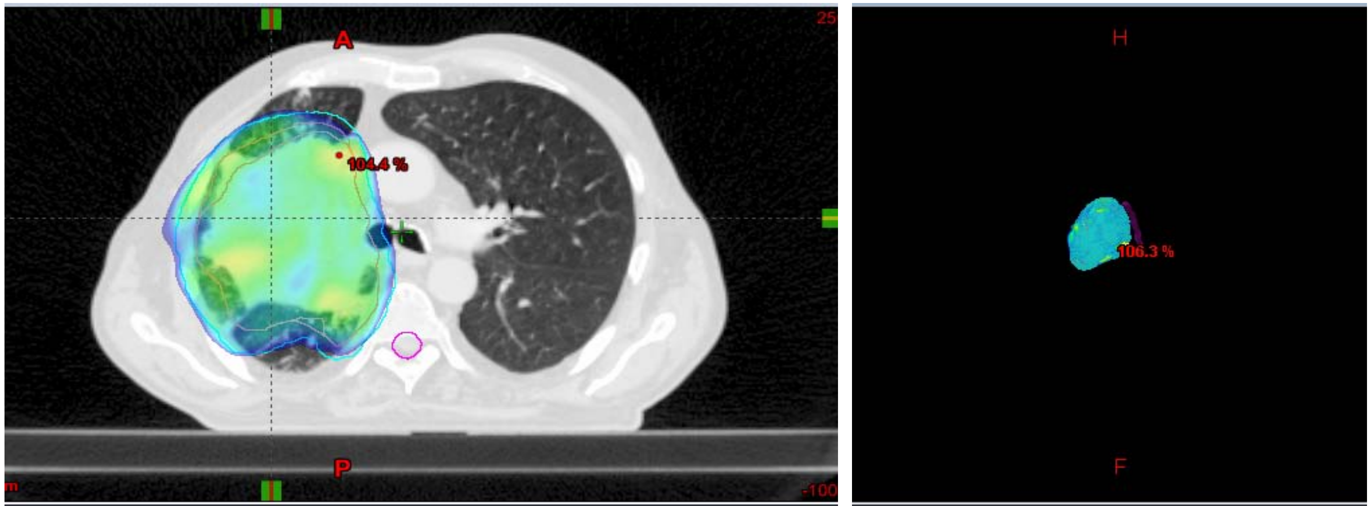
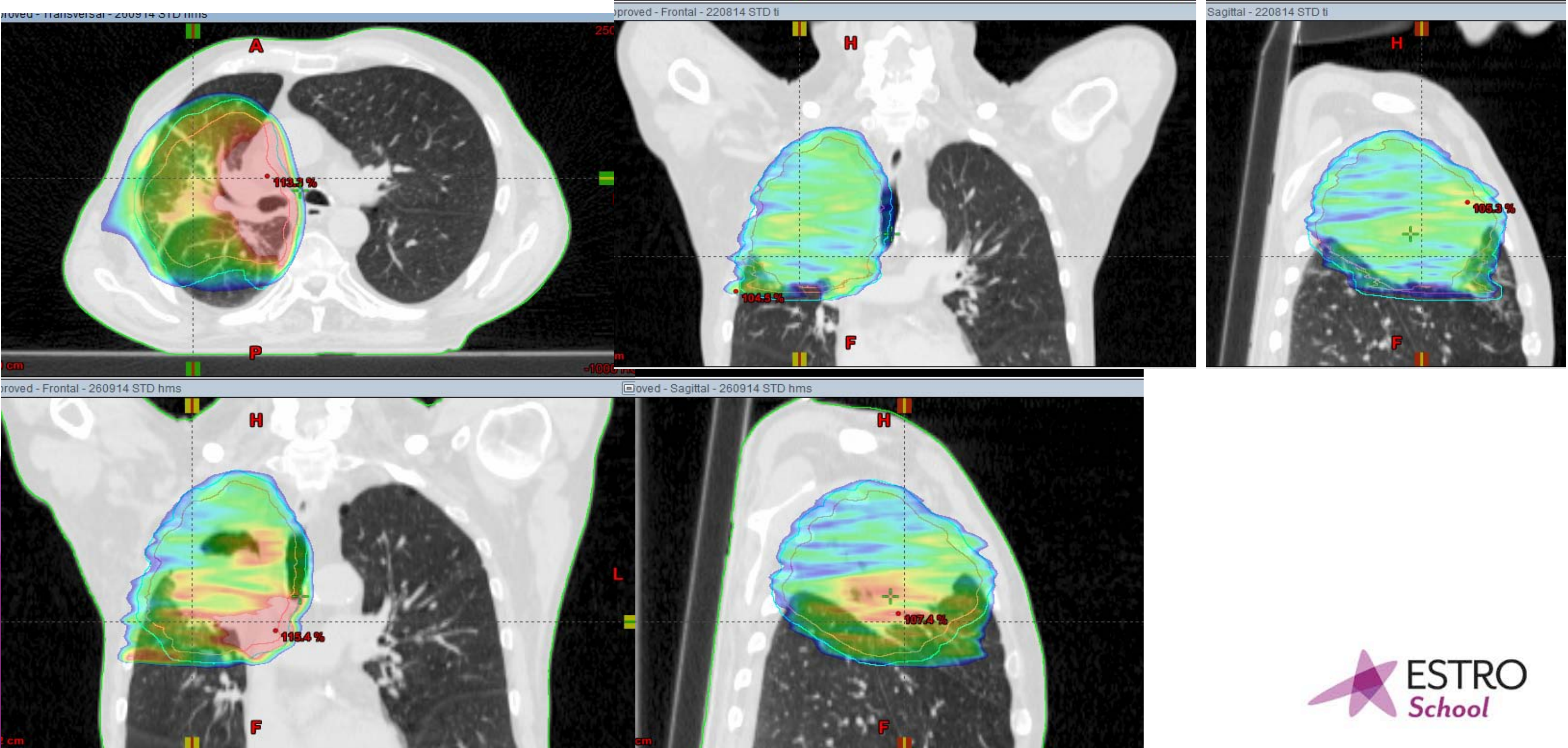
VMAT

Dmax 106 →117%
Dmean 100 → 102.4 %





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IGRT is not a solution for all challenges

- When has the anatomical change a significant impact on the treatment, i.e. when is it necessary to re-plan the patient?

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Example of adaptive strategy in lung cancer RT

Soft tissue match on GTV-T

- Evaluate every fraction
  - GTV-T
  - GTV-N ~ Surrogate
  - Medulla ~ Columna
- Notice large changes
  - Normal tissue
  - Pneumonia
  - Atelectasis
  - Pleural effusion

Deviation above tolerance

↓

Same deviation 3 consecutive fx

↓

Adaptive treatment plan
– correct systematic deviation

Large change observed

↓

Same change 3 consecutive fx

↓

Adaptive treatment plan
– correct systematic change

Courtesy of D Møller & L Hoffman, Århus, DK

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IGRT is not a solution for all challenges

- How to do the plan adaptation?
  - No published guidelines as yet.
  - Usually, conservative approach with the unchanged CTV delineation is applied

IGRT – uncertainties

- Uncertainty in image match

- To be aware of:
  - Patient may move during treatment
  - Tumour may move during treatment
    (i.e. baseline shift – Martijn's talk)

→ Resulting in intra-fractional uncertainty of tumour position relatively to the beam

Take home messages

CBCT as IGRT is the optimal solution

- 3D soft tissue visualisation

Motion management:

- 4D approach optimal

Challenge with dealing with anatomical changes during RT course

- Tumour
- Healthy tissue

Lung SBRT on the linac

Martijn Kamphuis MSc
Research Radiation Therapist IGRT

Department of Radiotherapy @
AMC
Amsterdam, the Netherlands

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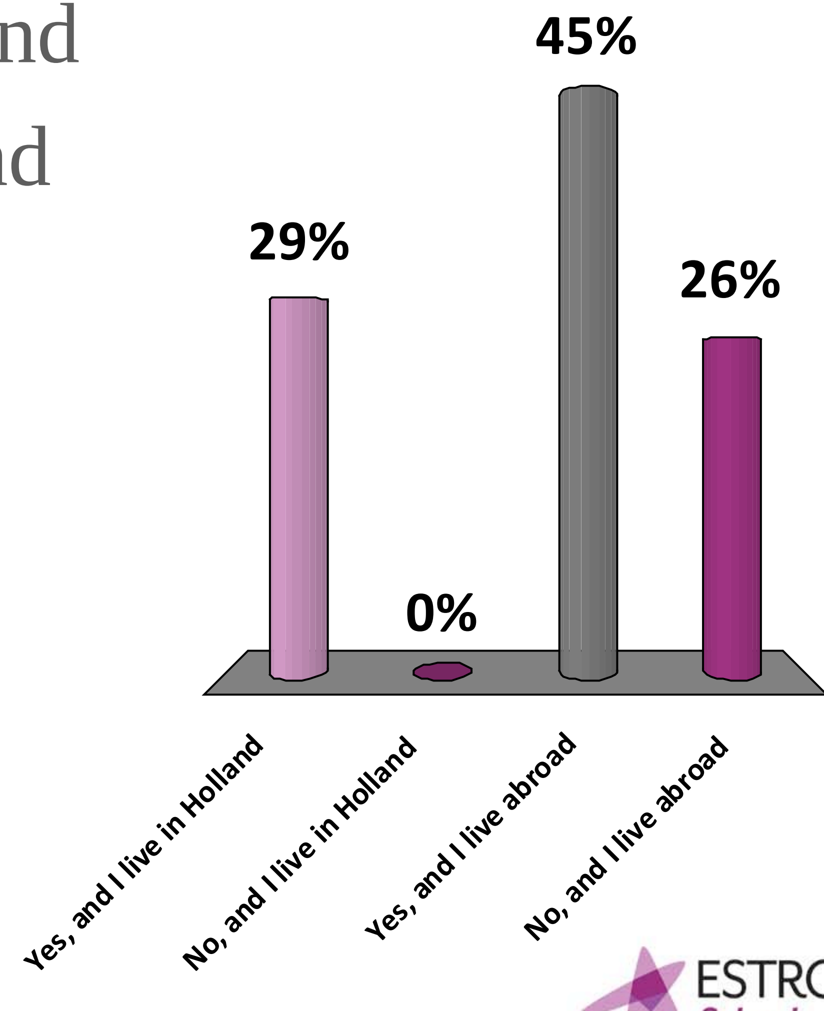
Is the institute you are working in performing SBRT for lung?

A. Yes, and I live in Holland
B. No, and I live in Holland
C. Yes, and I live abroad
D. No, and I live abroad



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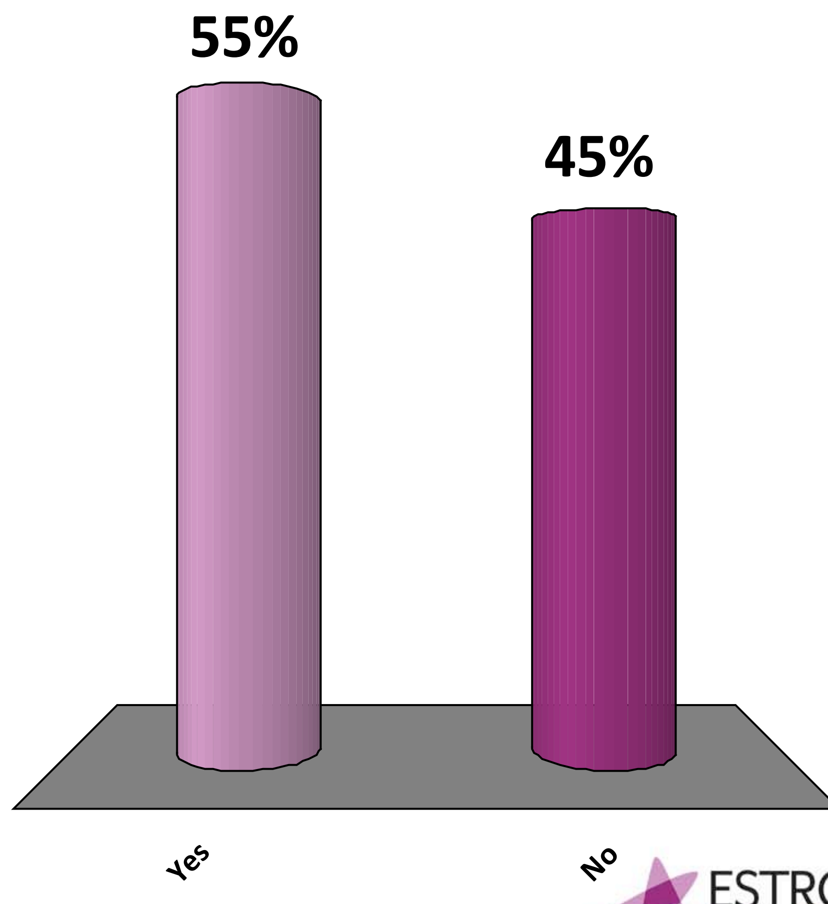
Is SBRT performed by a dedicated RTT-team?

A. Yes

B. No



Key features SBRT

- Reproducable rigid patient fixation
- Managing tumor motion:
  - During imaging
  - During planning
  - During RT
- Very steep dose gradients
- Extreme high BED (100-180 Gy)
  - 66Gy/2,75Gy→BED 85 Gy
  - 3*20Gy →BED 180 Gy (Δ 95 Gy)

What do we have to manage?

Intra fraction motion

– Breathing pattern

Inter fraction motion

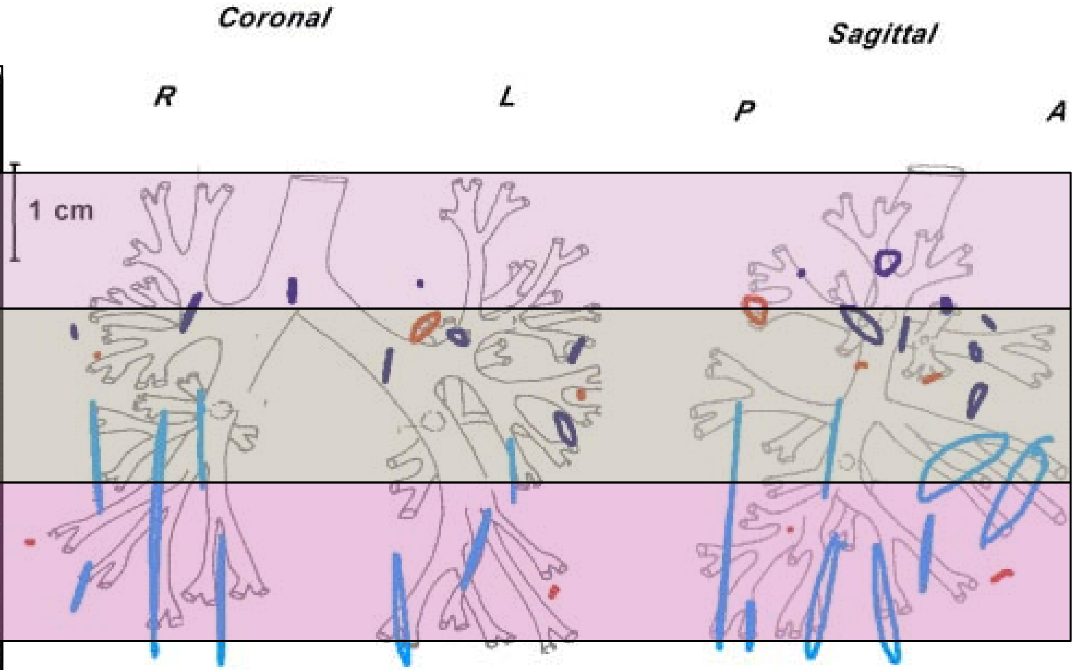
– Baseline shift

https://www.imi.uni-luebeck.de

Intra fraction motion: amplitude

CC	ML	AP
4.3 ± 2.4 (2.6 to 7.1)	3.4 ± 1.6 (1.3 to 5.3)	2.8 ± 1.3 (1.2 to 5.1)
7.2 ± 1.8 (4.3 to 10.2)	4.3 ± 2.4 (1.5 to 7.1)	4.3 ± 2.2 (1.9 to 7.5)
9.5 ± 4.9 (4.5 to 16.4)	6.0 ± 2.8 (2.9 to 9.8)	6.1 ± 3.3 (2.5 to 9.8)

Tumor mobility in quiet respiration [mm]



Seppenwolde et.al.

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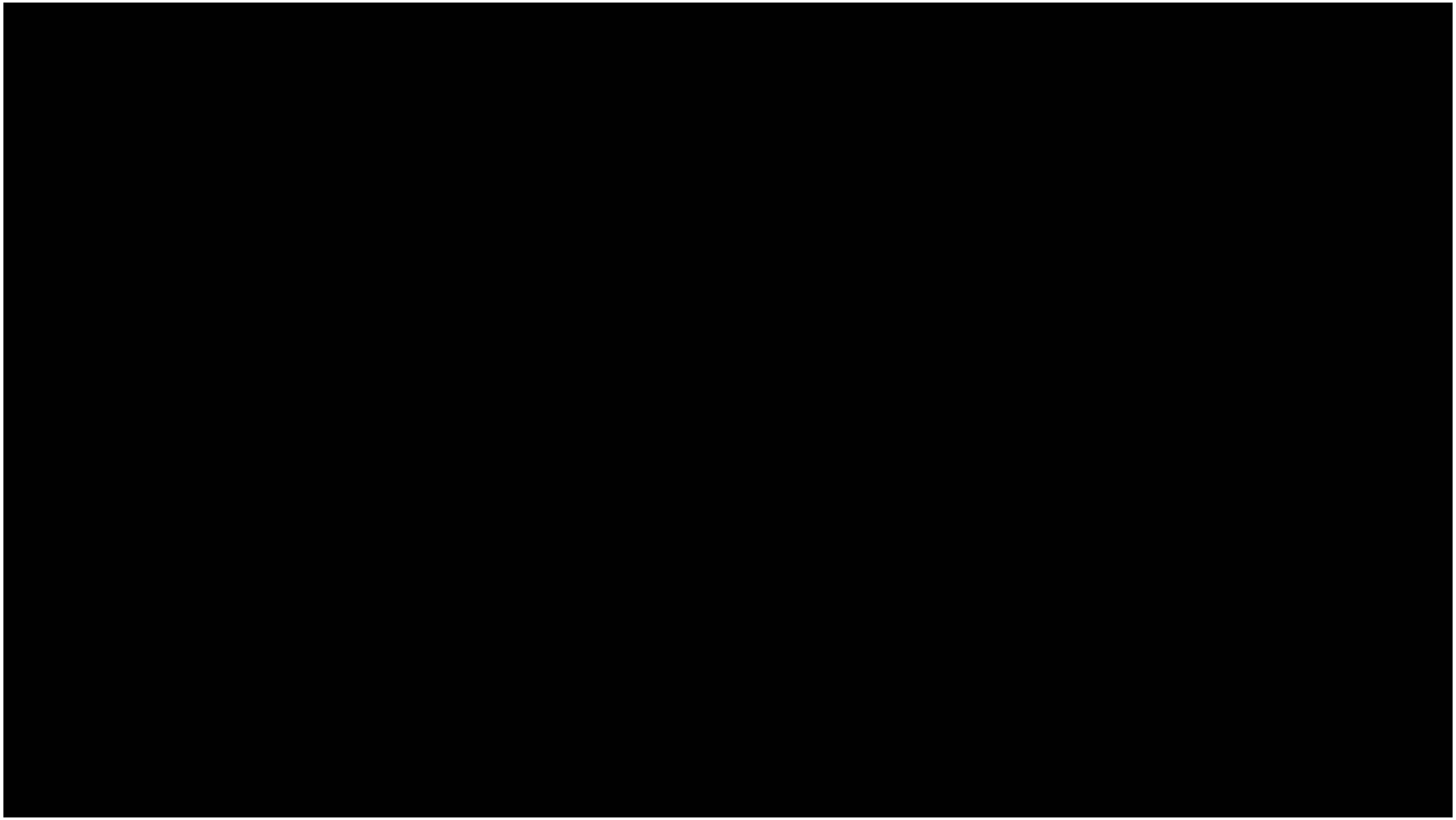
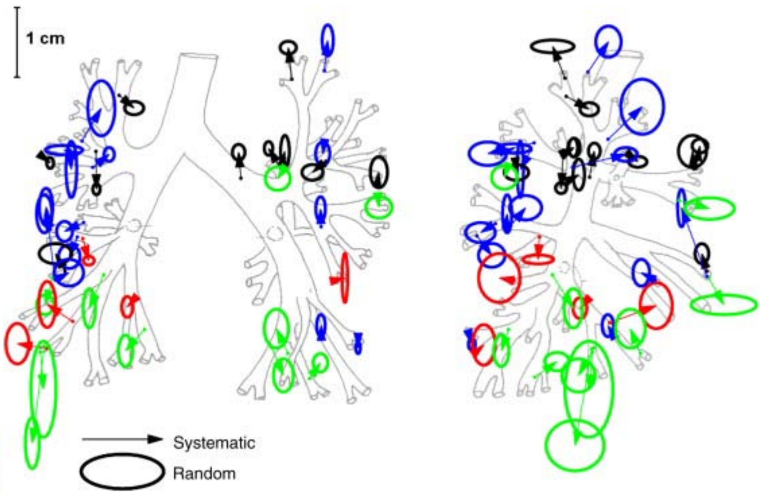
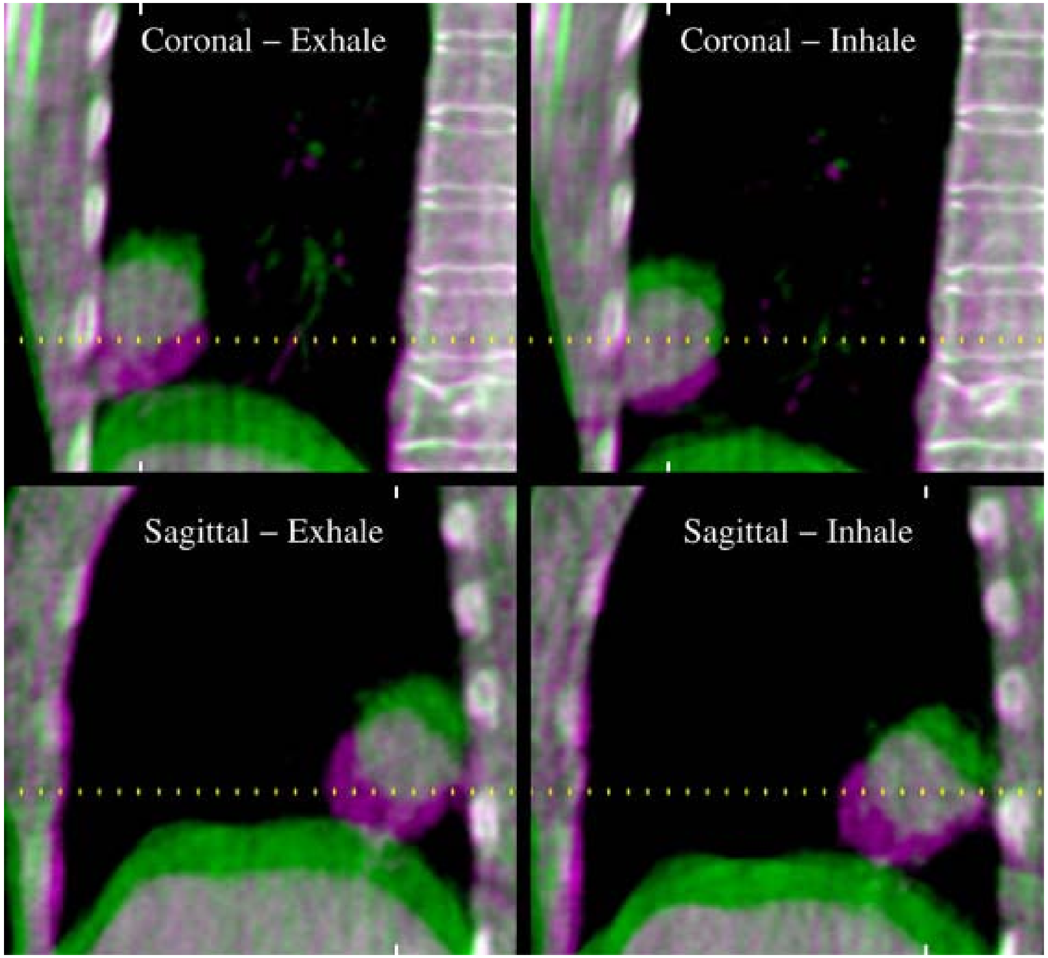
Inter fraction motion: baseline shift



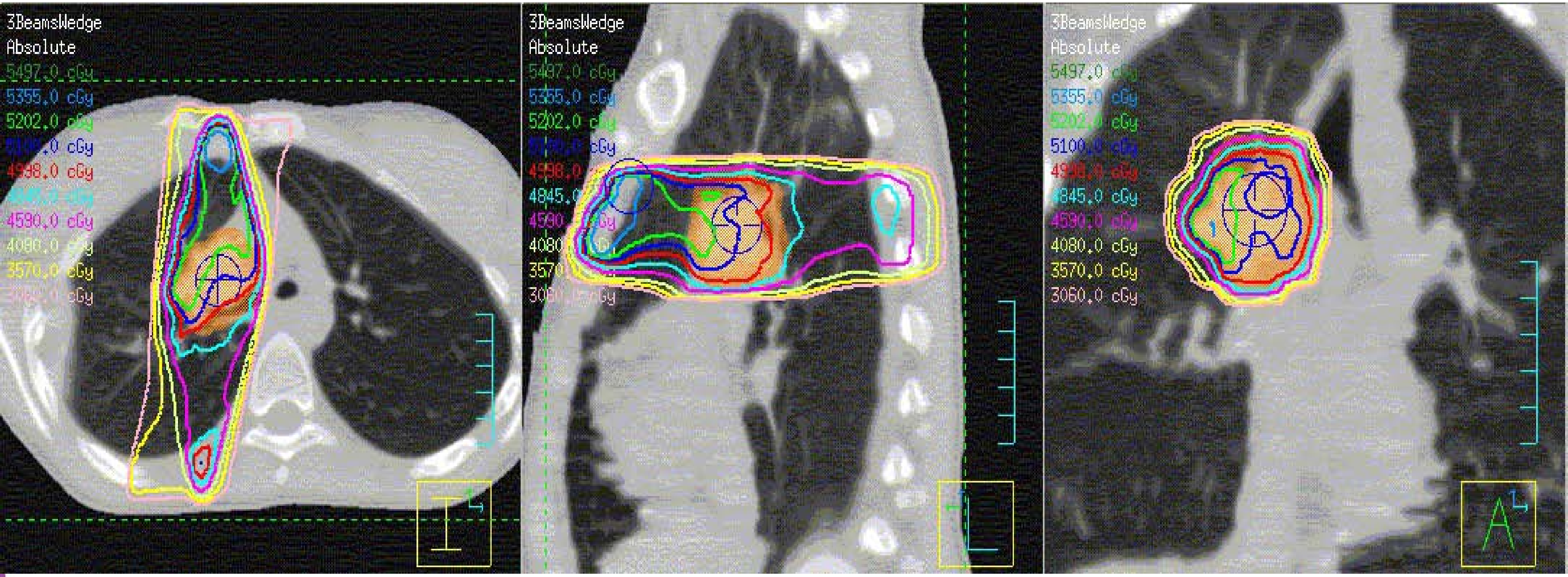
Baseline shift



J.J. Sonke *et al*, 2007

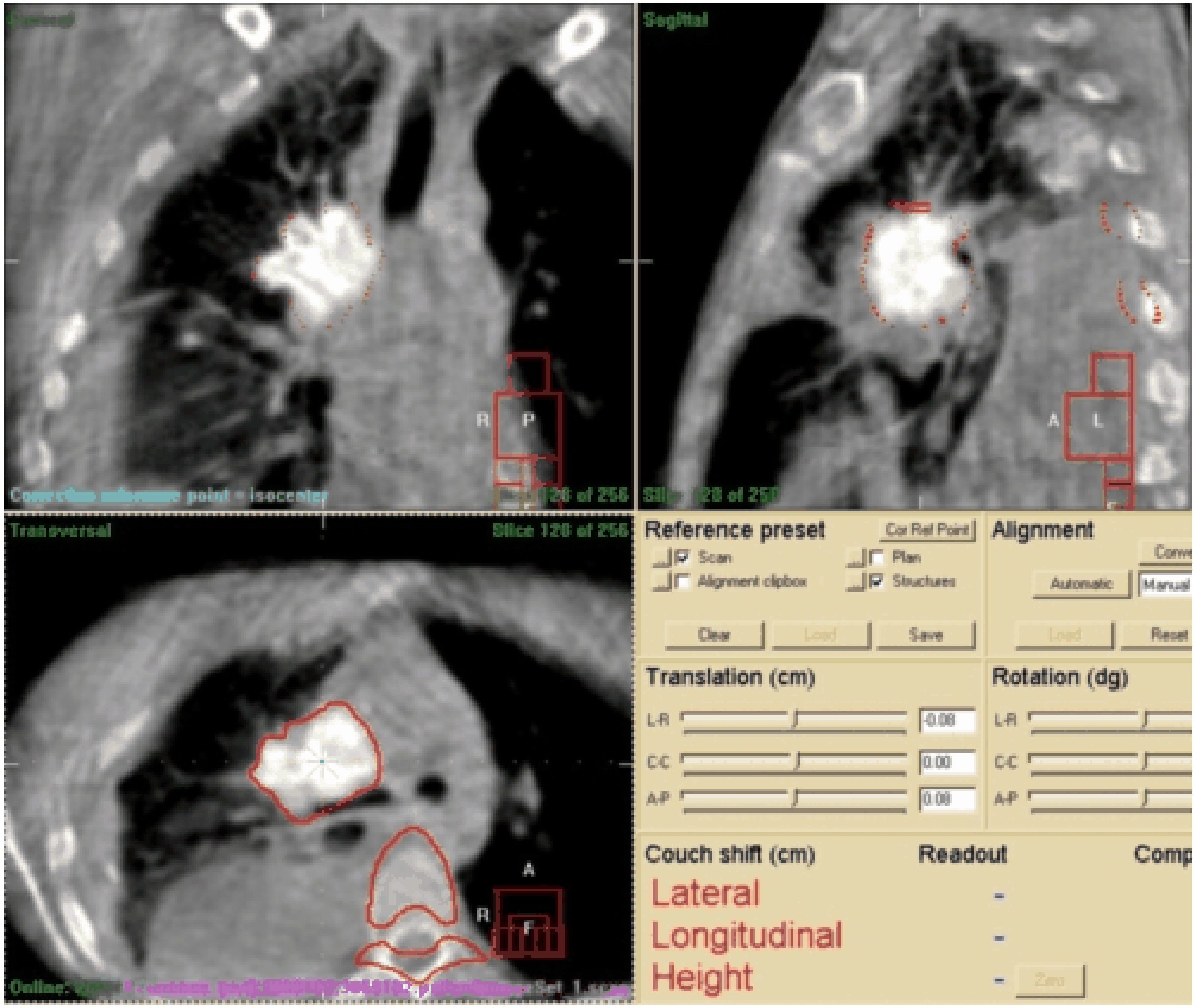


Plan: 3 wedged fields, 300 cGy/fx, 5100 cGy total



Courtesy to Alvaro Martinez

Beaumont
William Beaumont Hospital
ESTRO School



If corrected online on CBCT

Courtesy to Alvaro Martinez

Managing intra fraction motion

Passive approaches

Slow scanning

Multi CT scanning

Inhale&exhale scannin

Abdominal compr

ITV concept

Mid-v

Acti oaches

acking

oach tracking

Breathhold

Gating

Chasing/tracking

Mirjana will took care off this part ☺

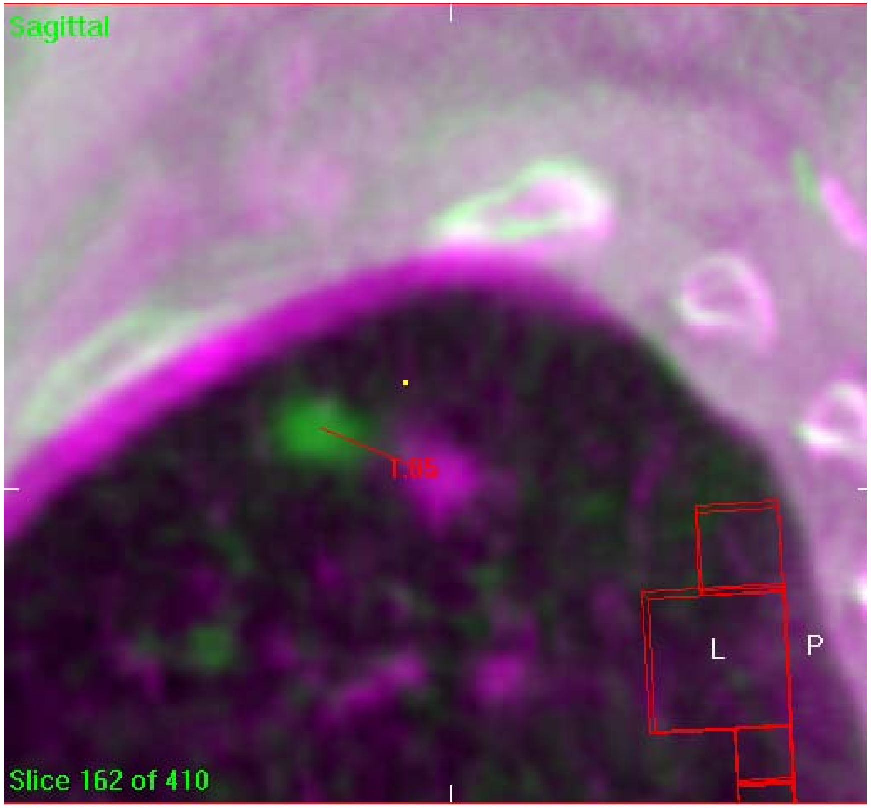
Management of baseline shifts

Introduction of the Planning Risk Volume (PRV)

- Margin around OAR

Combined with:

1. Commercial software
2. Critical isodose line
3. Homemade excel sheet



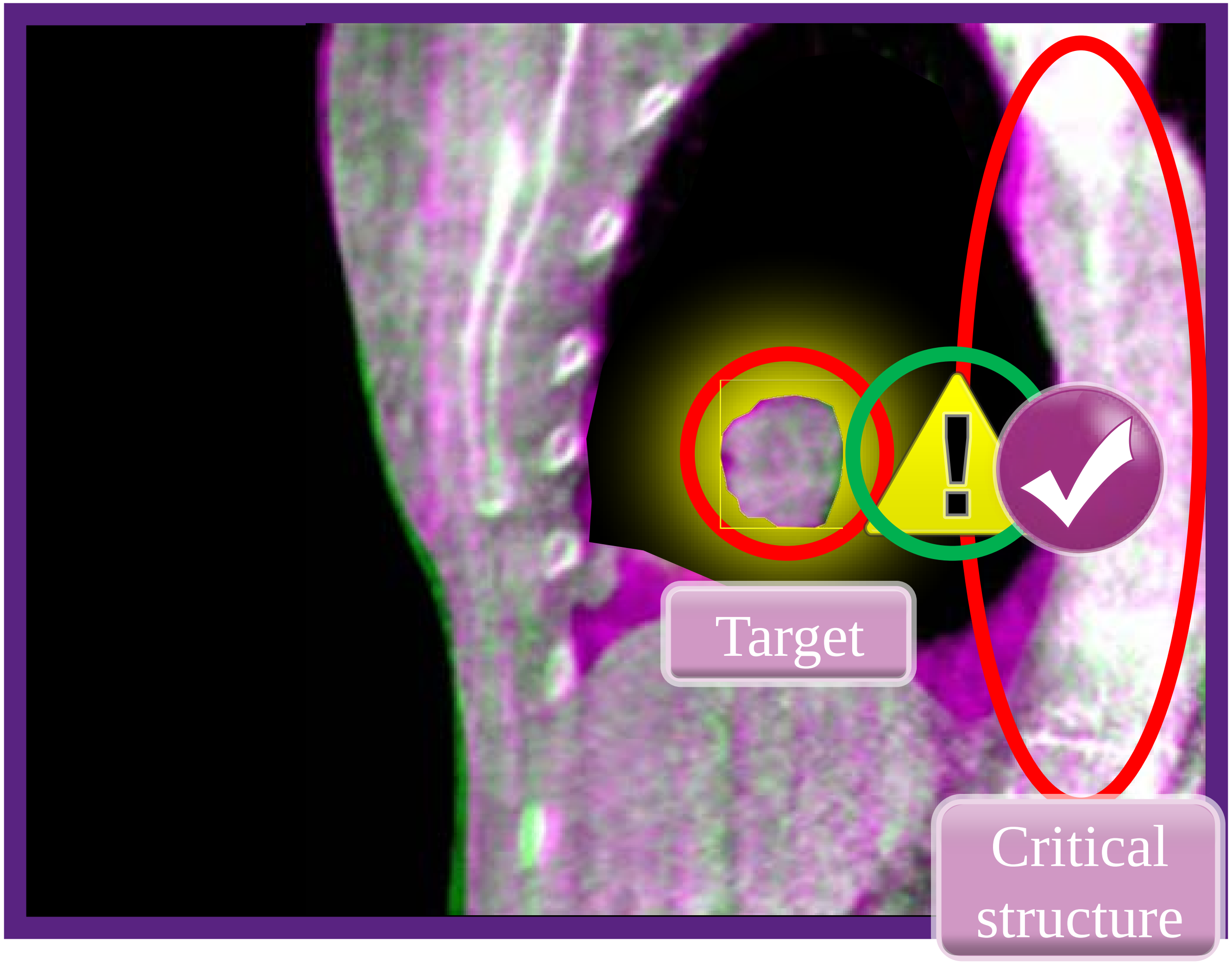
Option 1: NKI/ELEKTA solution

- Image registration on tumor & OAR (dual registration)

- Allowed deviations in distances between tumor and OAR deteremined on Treatment planning
  - Based on dose distributions

- Personal margins are put into the CB-system
  - E.g. 5mm to the Left, 15 mm to the Right

Option 1: NKI/ELEKTA solution



Critical Structure Avoidance (Dual Registration)

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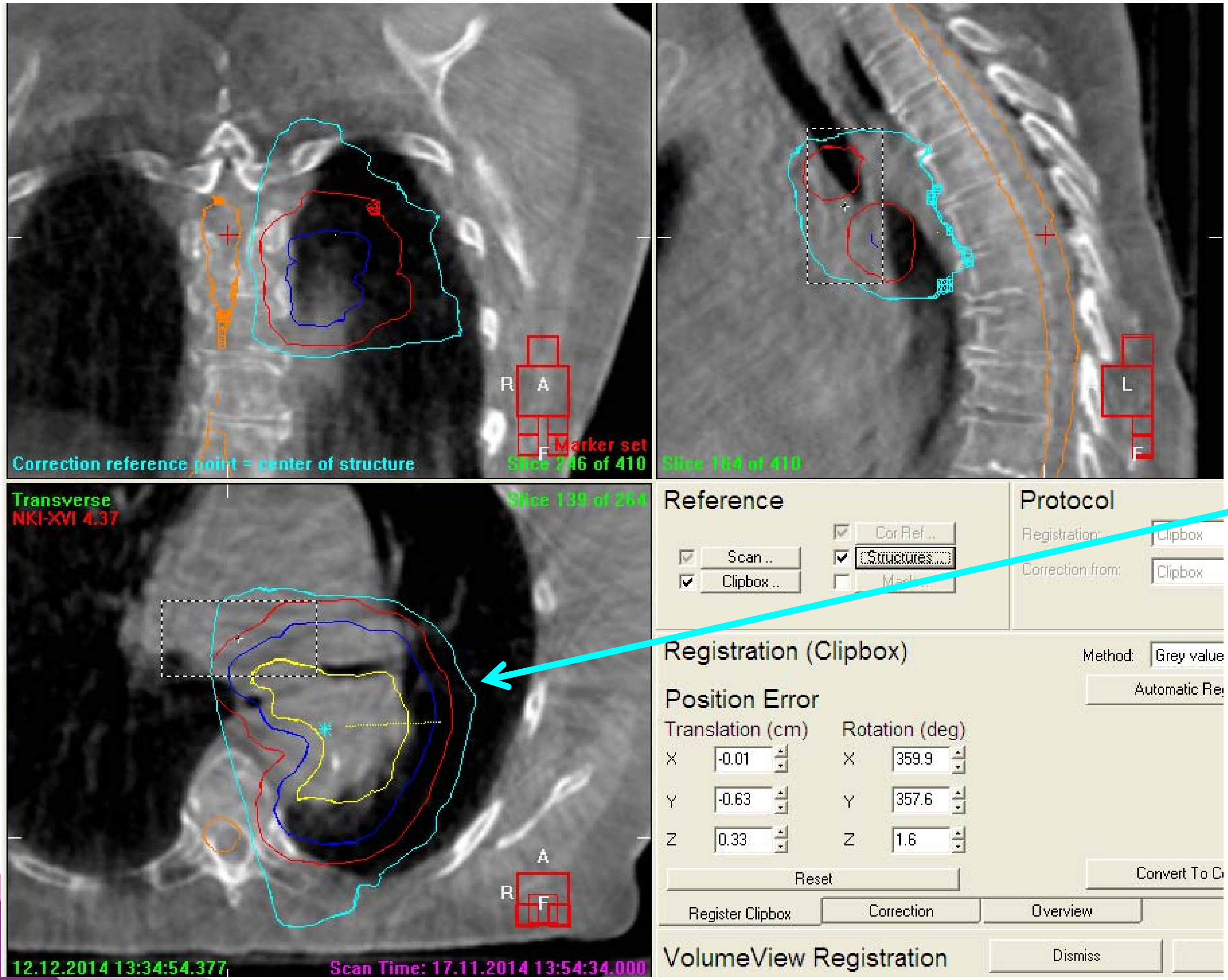
Option 2: critical isodose



51 Gy isodose

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Option 3: homemade excel sheet

- Image registration on tumor and OAR

- Allowed difference between matches is determined on TP

- Difference (baseline shift) should not exceed PRV distance
  - ➢ If so, does it harm the OAR?
  - ➢ Consession
  - ➢ Treat next day
  - ➢ Replan

- Example!

Reference CT: OAR ROI (Clipbox)

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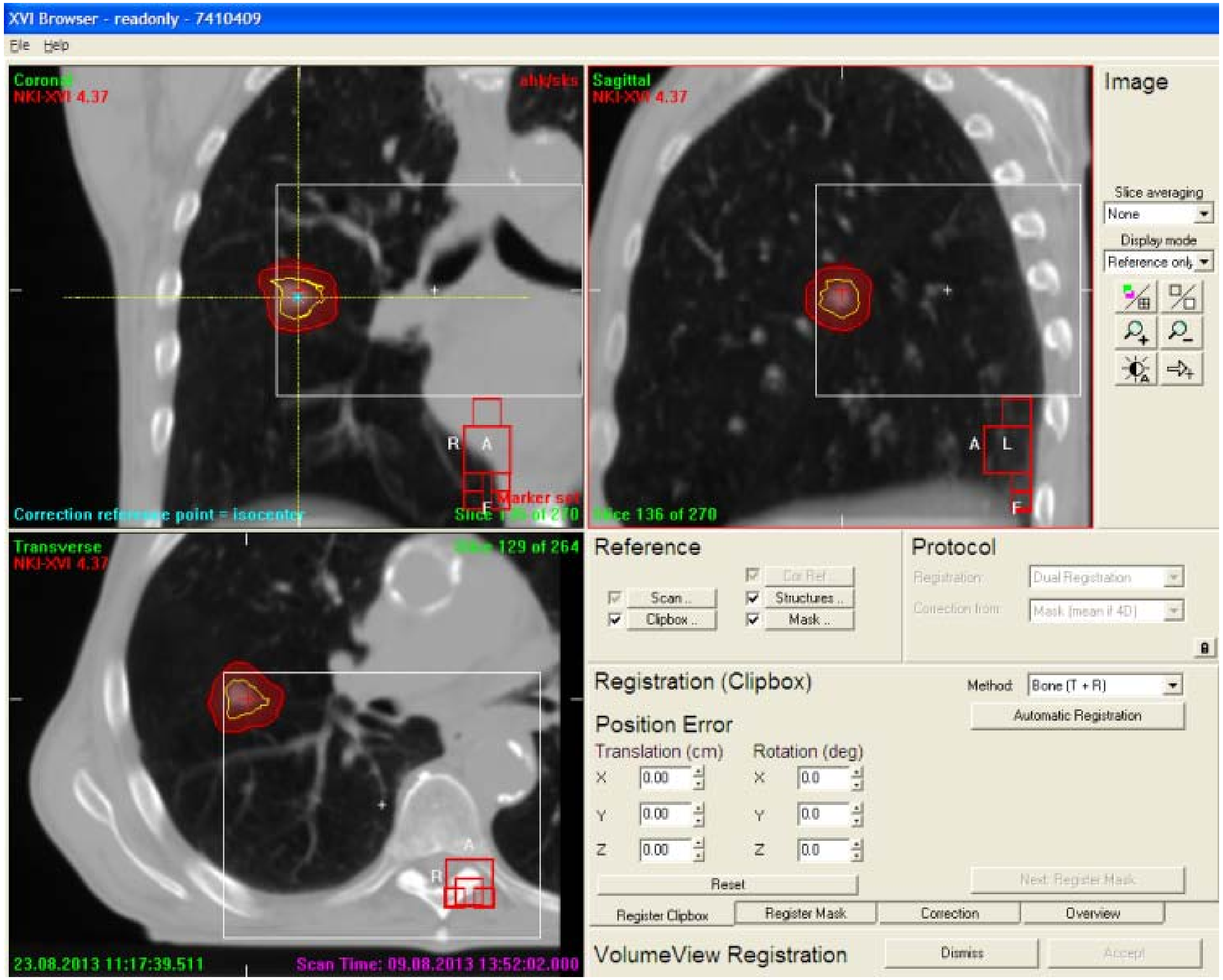
Reference CT: Tumor ROI (Mask)



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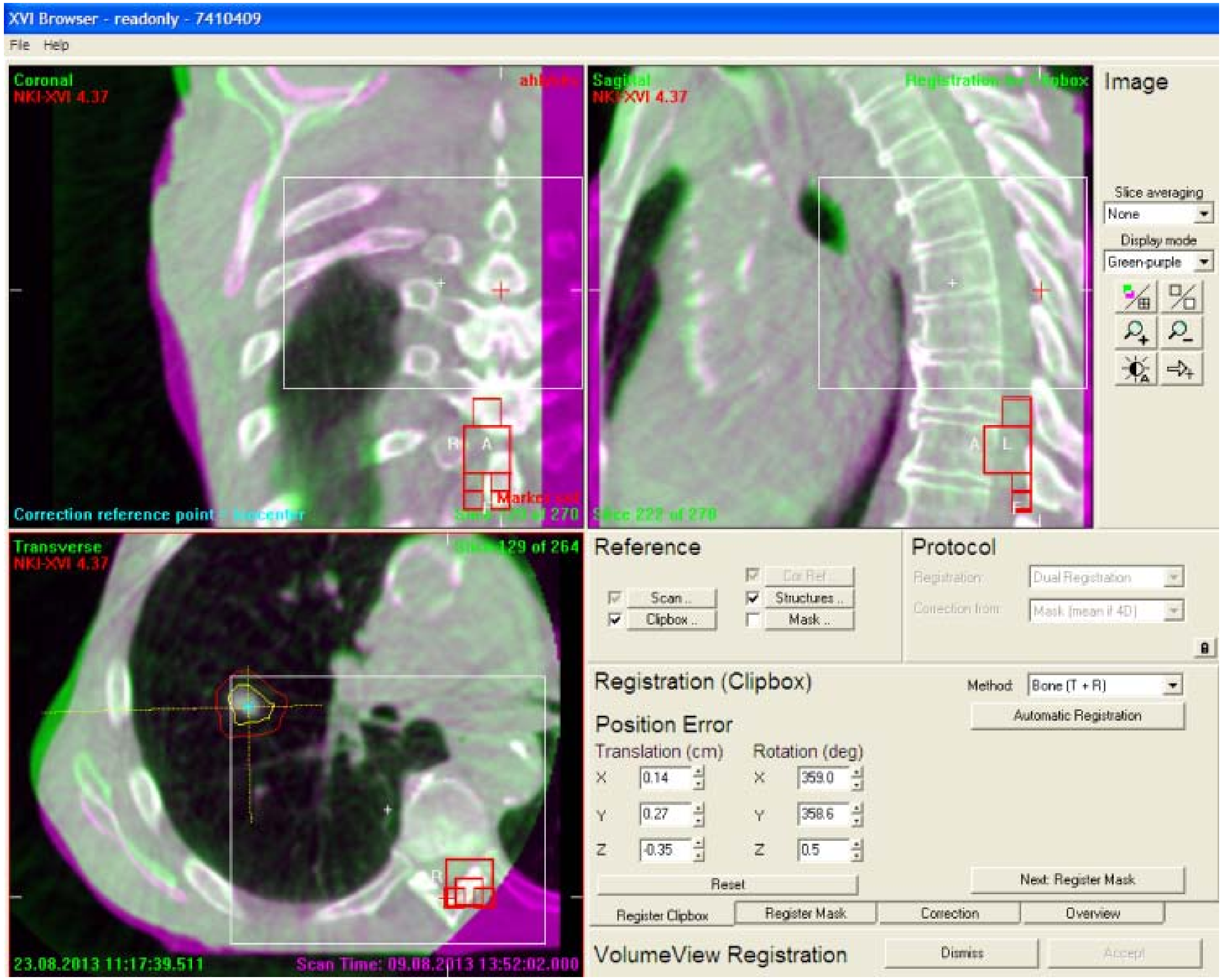
Step 1: image registration on OAR



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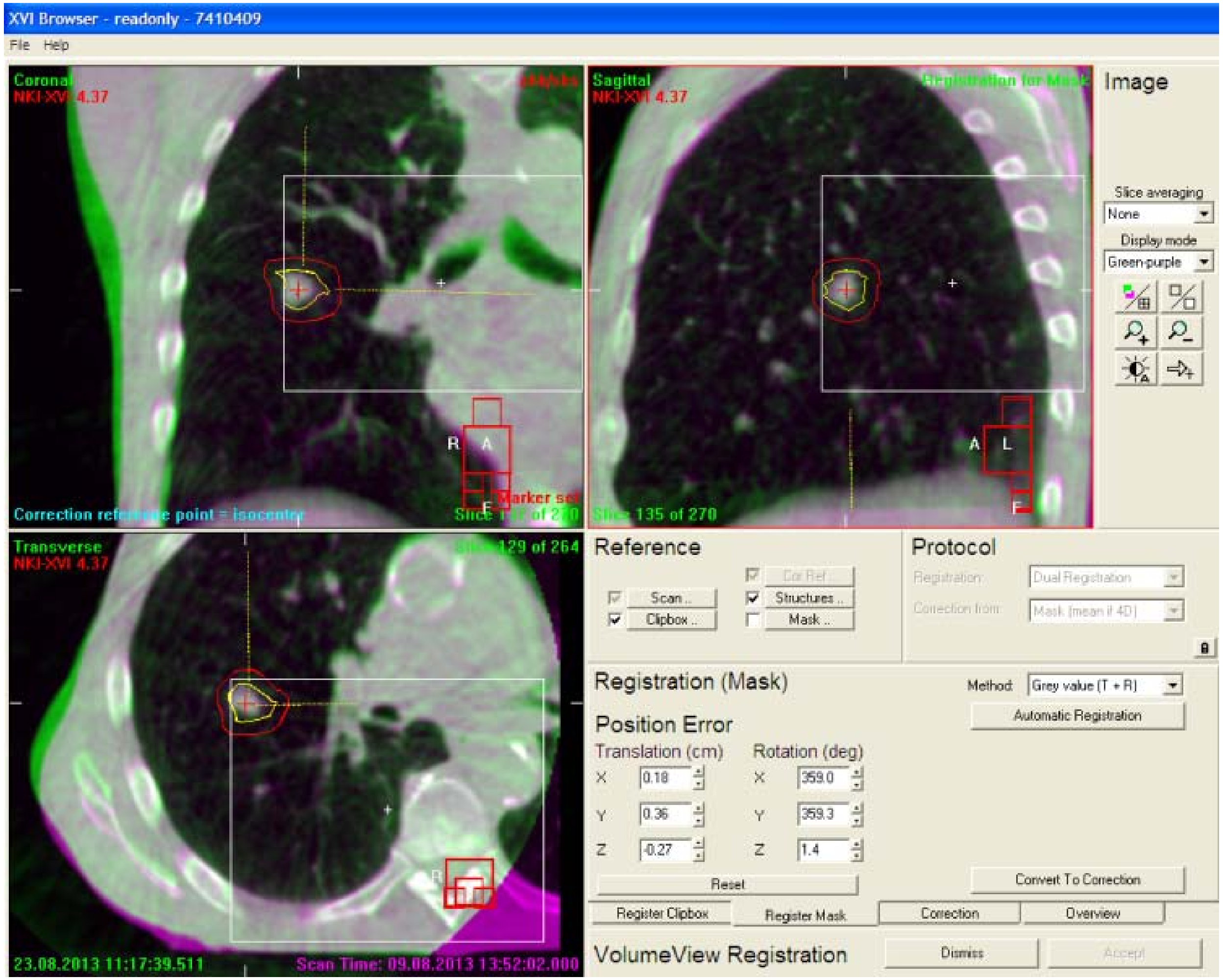
Step 2: image registration on tumor



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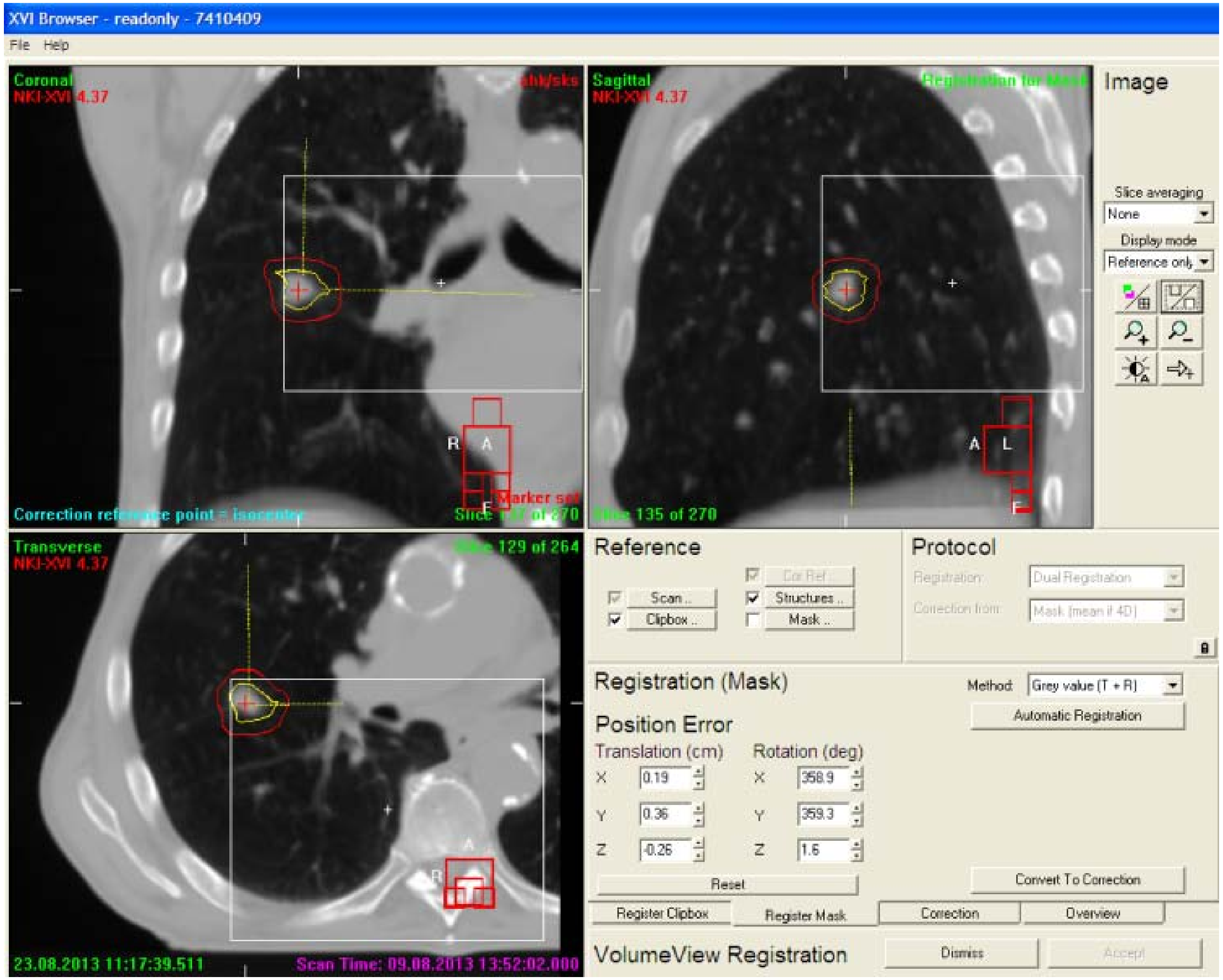
Verify the registration



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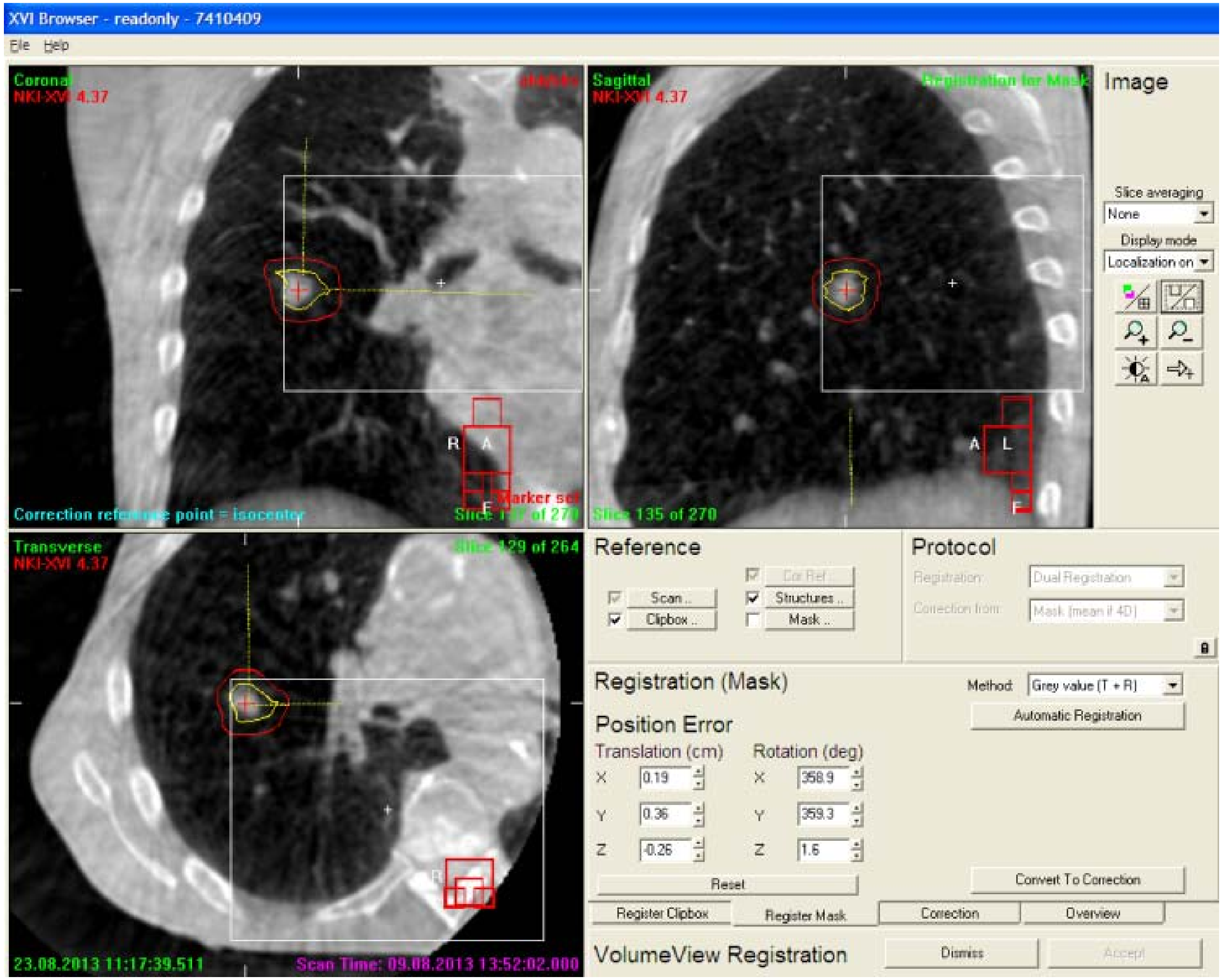

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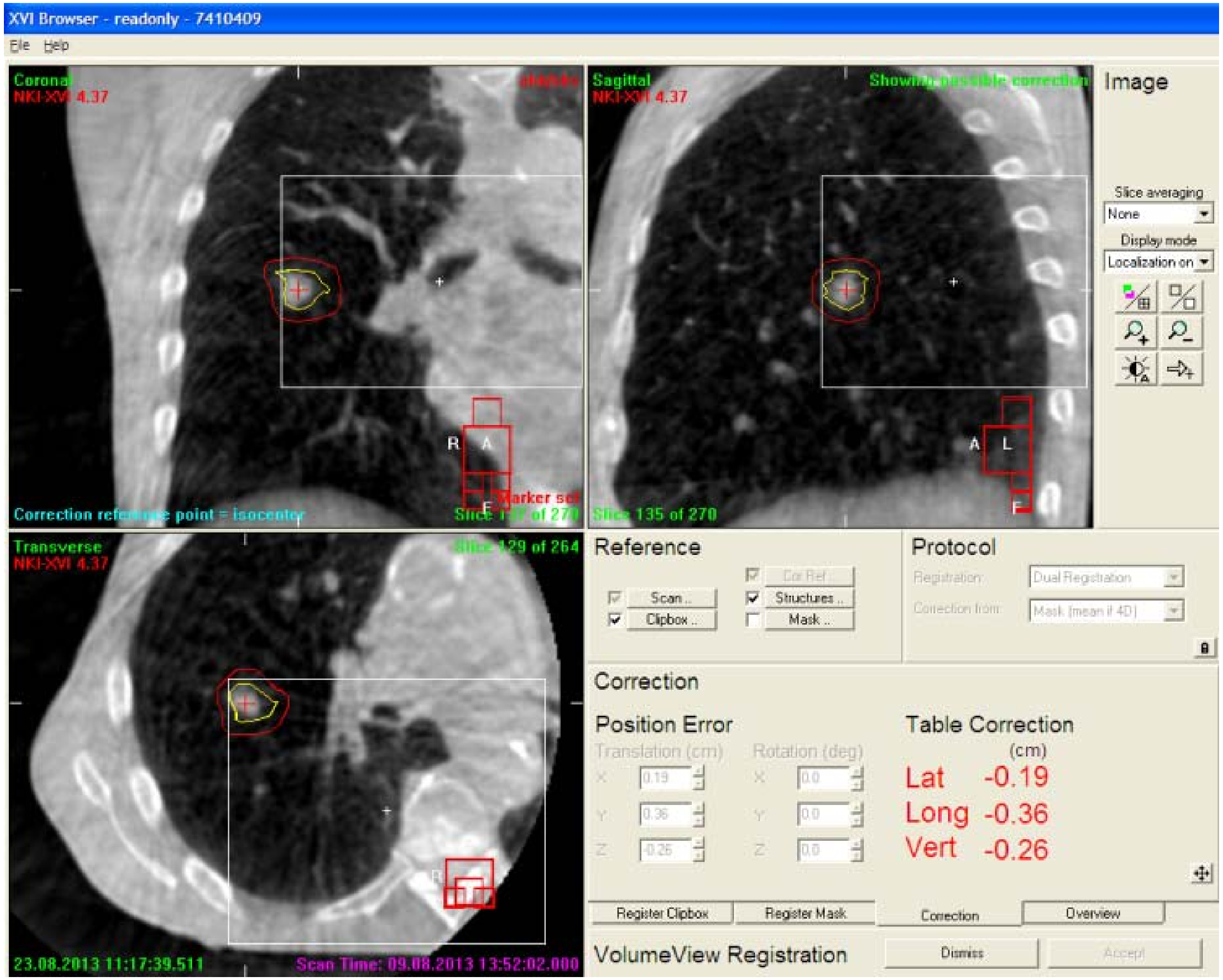
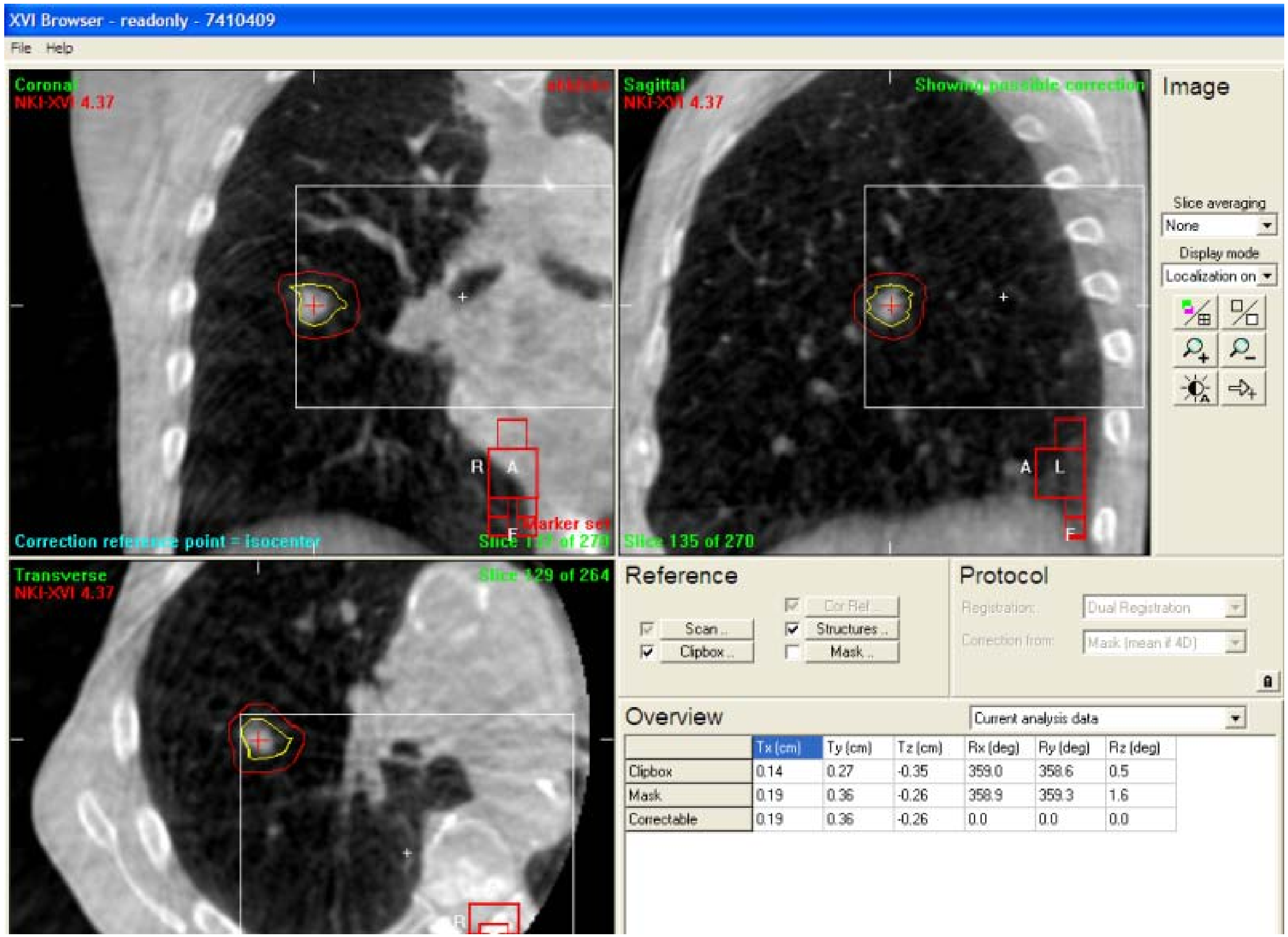
Convert to correction



Registration data in overview tab



Fill in data in excel sheet

Patiëntnummer:	ESTRO SBRT
Patiëntnaam:	ESTRO SBRT
Course:	pre course
Max. baselineshift R (cm):	1
Advies voor CB H1 bij FFF:	Geen FFF

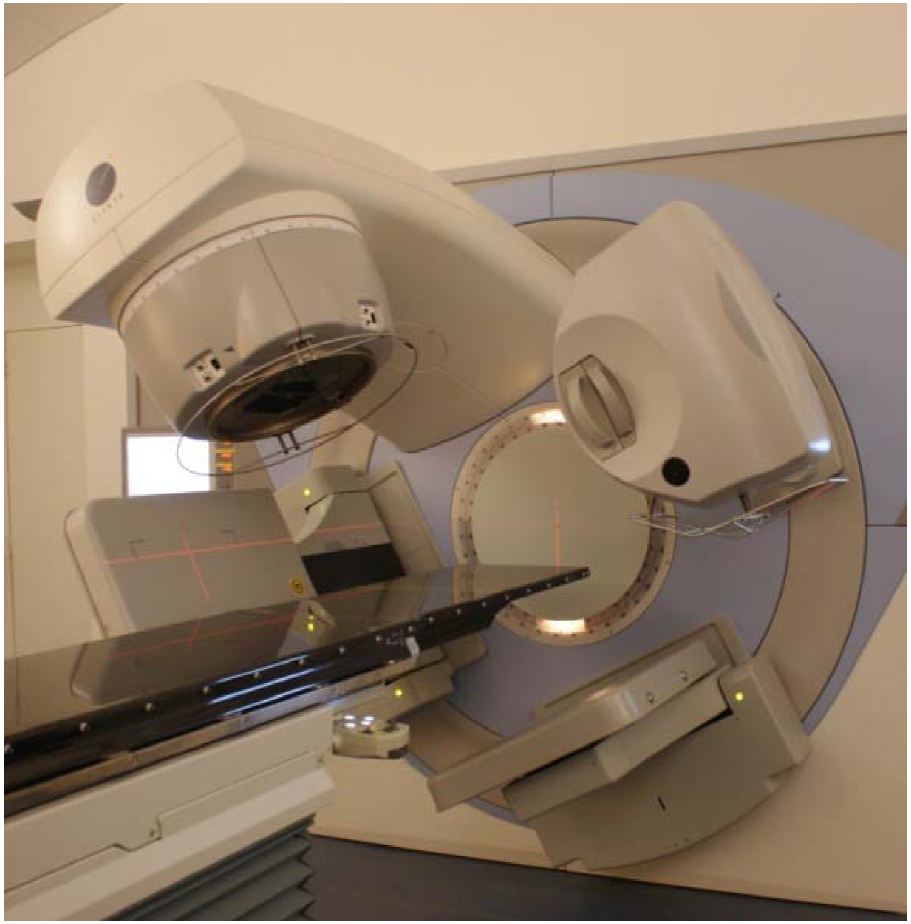
Gegevens opslaan

Initialen laboranten:	mka
Datum:	23 april 2015

NB1: BOTMATCH EN TUMORMATCH VOO
NB2: TUMOR MATCHEN ZONDER ROTATI
Indien tumorvector Tv kleiner of gelijk is aan

Moment	CBCT	Clipbox (T&R) (cm)			Mask (T) (cm)			Correctable (cm)			Baselineshift R (cm)	Tumorvector Tv (cm)
		X	Y	Z	X	Y	Z	X	Y	Z		
Vooraf	V1	0.14	0.27	-0.35	0.19	0.36	-0.26	0.19	0.36	-0.26	0.14	0.48
Vooraf	V2											
Vooraf	V3											
Vooraf	V4											
Vooraf	V5											
Halverwege	H1											
Halverwege	H2											
Halverwege	H3											
Halverwege	H4											
Halverwege	H5											
Eind	N1											

Perform table correction and 2nd CBCT



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Fill in data of 2nd CBCT in excel sheet

Patiëntnummer:	ESTRO SBRT
Patiëntnaam:	ESTRO SBRT
Course:	pre course
Max. baselineshift R (cm):	1
Advies voor CB H1 bij FFF:	Geen FFF

Gegevens opslaan

Initialen laboranten:	mka
Datum:	23 april 2015

NB1: BOTMATCH EN TUMORMATCH VOC
NB2: TUMOR MATCHEN ZONDER ROTATI
Indien tumorvector Tv kleiner of gelijk is aan

Moment	CBCT	Clipbox (T&R) (cm)			Mask (T) (cm)			Correctable (cm)			Baselineshift R (cm)	Tumorvector Tv (cm)
		X	Y	Z	X	Y	Z	X	Y	Z		
Vooraf	V1	0.14	0.27	-0.35	0.19	0.36	-0.26	0.19	0.36	-0.26	0.14	0.48
Vooraf	V2	0.01	-0.19	-0.15	0.07	-0.15	0.10	0.07	-0.15	0.10	0.26	0.19
Vooraf	V3											
Vooraf	V4											
Vooraf	V5											
Halverwege	H1											
Halverwege	H2											
Halverwege	H3											
Halverwege	H4											
Halverwege	H5											
Eind	N1											

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Starting treatment?

- Is it safe?
  - Difference (baseline shift) should not exceed PRV distance
- Is it precise enough?
  - Tumor on spot?
  - AMC: Vector <2,5mm

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Patiëntnummer:	ESTRO SBRT
Patiëntnaam:	ESTRO SBRT
Course:	pre course
Max. baselineshift R (cm):	1
Advies voor CB H1 bij FFF:	Geen FFF

Gegevens opslaan

Initialen laboranten:	mka
Datum:	23 april 2015

NB1: BOTMATCH EN TUMORMATCH VOC
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Moment	CBCT	Clipbox (T&R) (cm)			Mask (T) (cm)			Correctable (cm)			Baselineshift R (cm)	Tumorvector Tv (cm)
		X	Y	Z	X	Y	Z	X	Y	Z		
Vooraf	V1	0.14	0.27	-0.35	0.19	0.36	-0.26	0.19	0.36	-0.26	0.14	0.48
Vooraf	V2	0.01	-0.19	-0.15	0.07	-0.15	0.10	0.07	-0.15	0.10	0.26	0.19
Vooraf	V3											
Vooraf	V4											
Vooraf	V5											
Halverwege	H1											
Halverwege	H2											
Halverwege	H3											
Halverwege	H4											
Halverwege	H5											
Eind	N1	0.16	0.01	0.20	0.08	0.00	0.15	0.08	0.00	0.15	0.09	0.17

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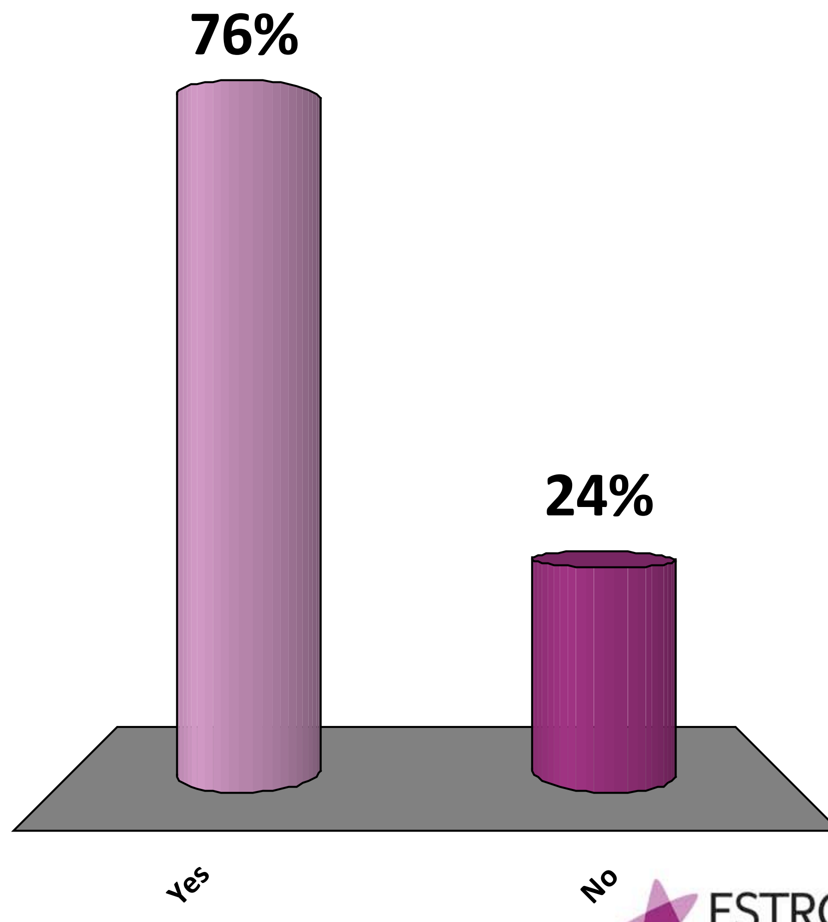
Does your clinical protocol take care baseline shifts?

A. Yes

B. No



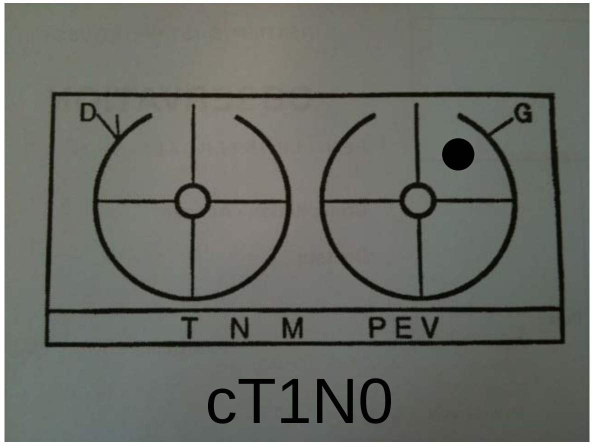
Thank you for your attention!

Case report: **Breast**

Sofia Rivera, M.D.
Radiation Oncology Department
Gustave Roussy
Villejuif, France

Advanced skills in modern radiotherapy
June 2015

Clinical case

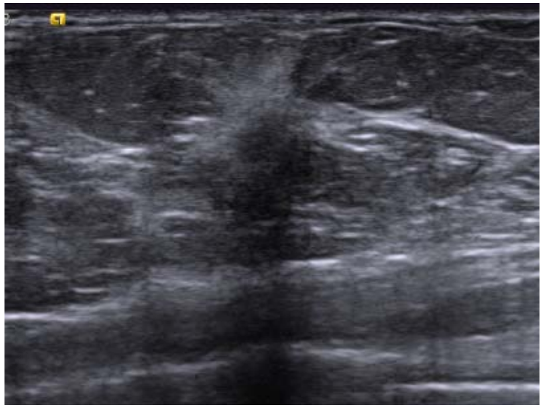


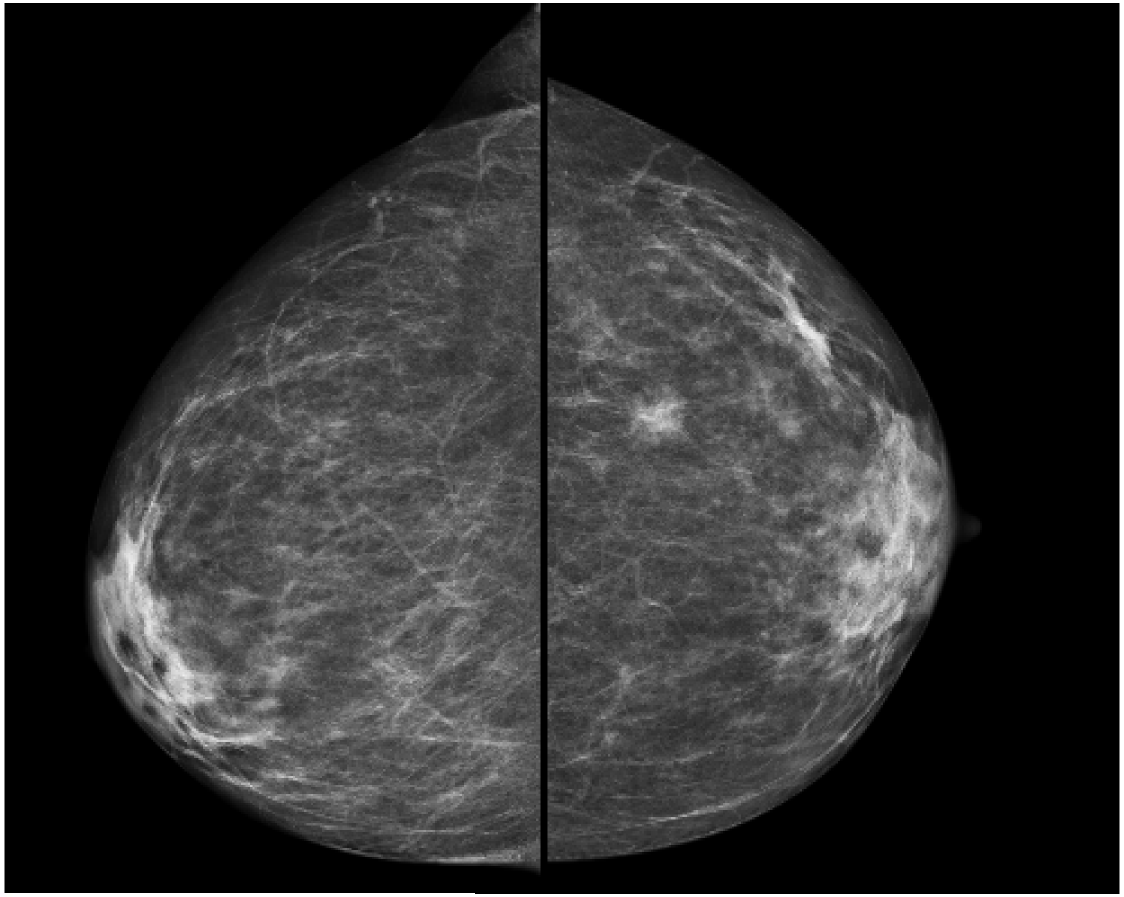
•72 years old female referred by her GP after palpation of a supra areolar hard mass of the left breast external upper quadrant measuring 1cm with no axillary or supraclavicular palpable node (breast cup: 95 D)

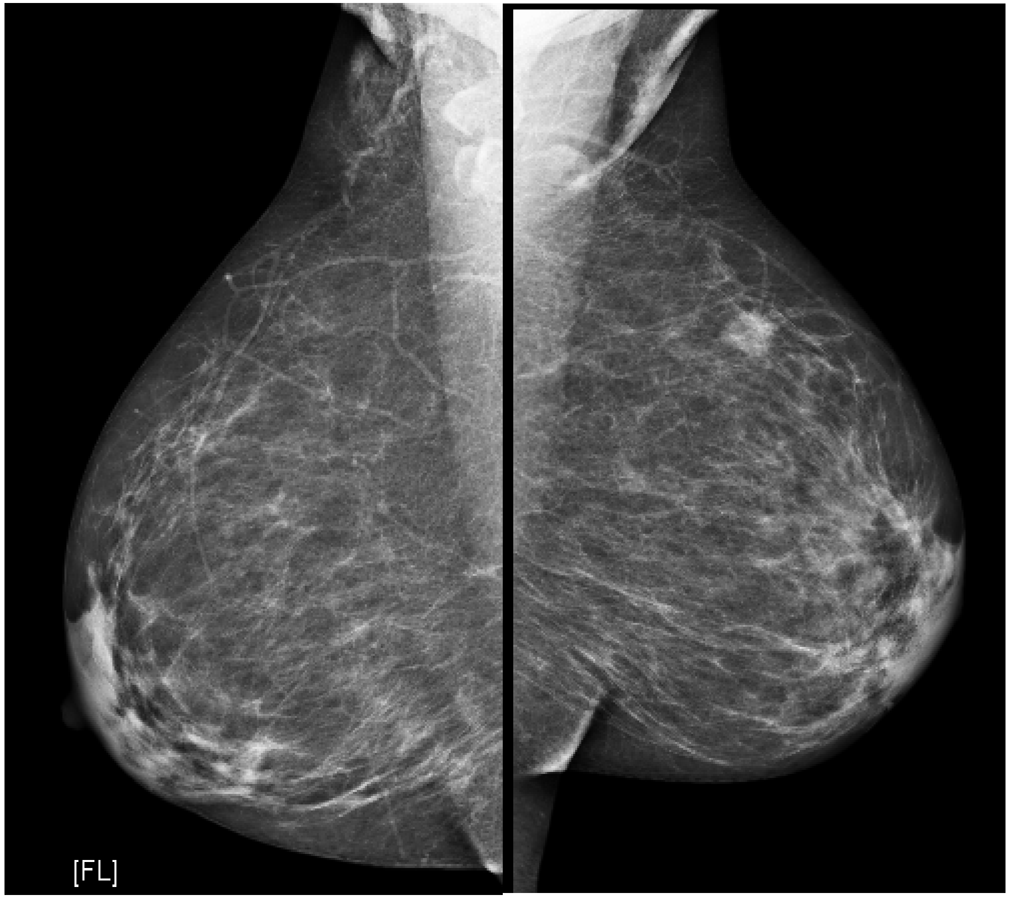
•Retired, yoga teacher, autonomous, living in an individual house with 5 cats

•Medical history of hypertension, diabetes and ischemic cardiopathy

Mammograms + US







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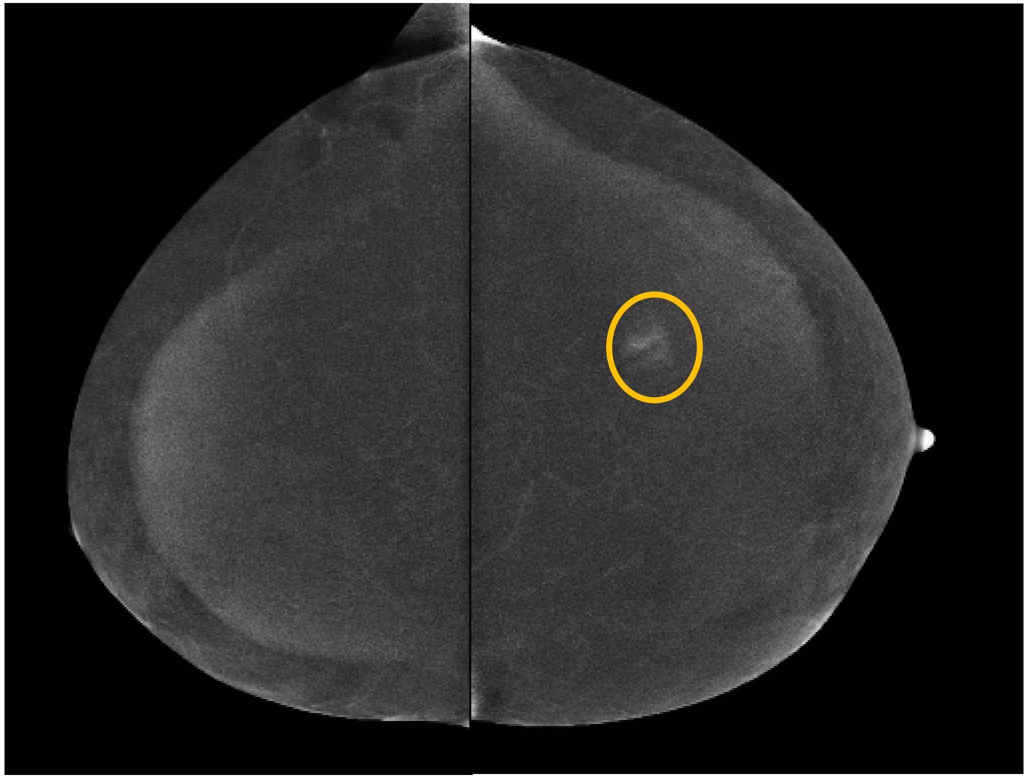
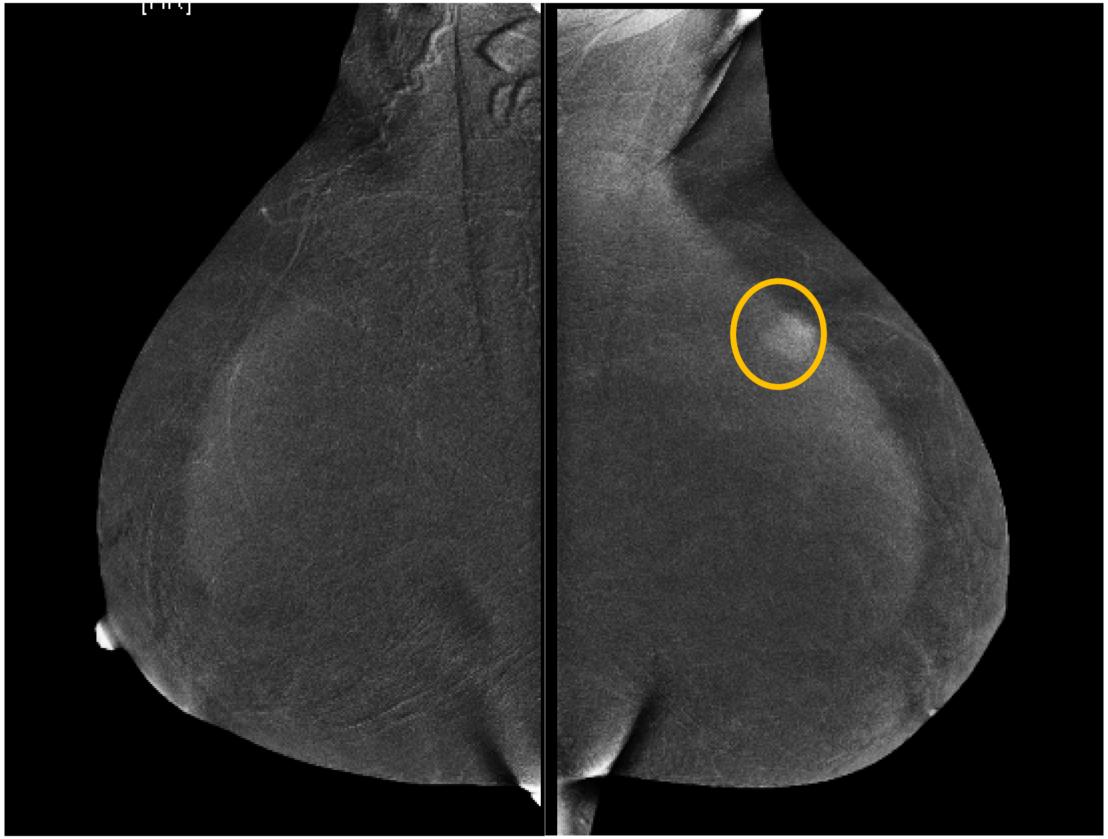
Angio mammography





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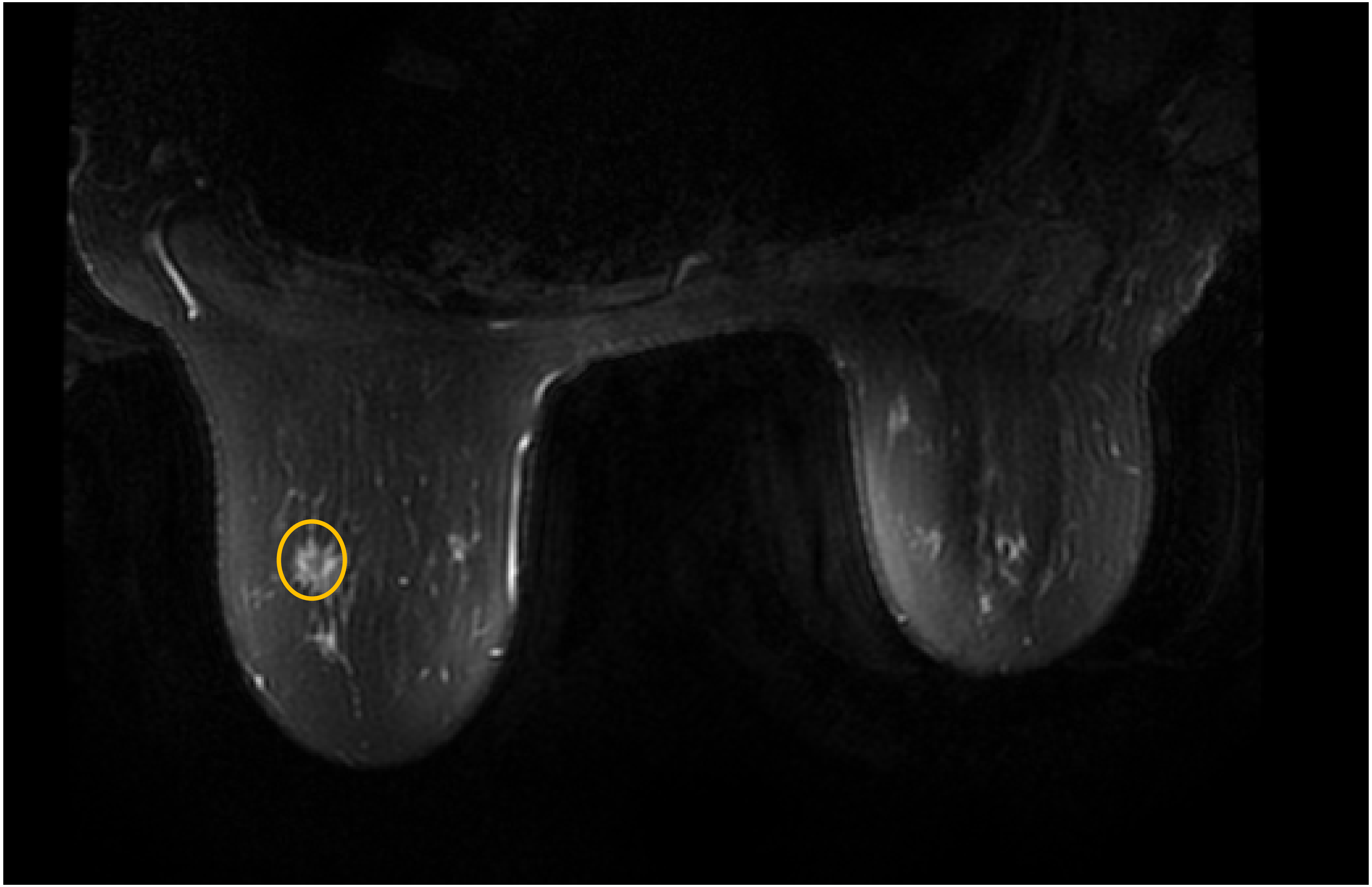
Breast MRI

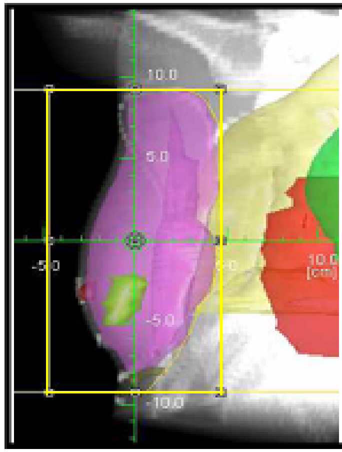


Clinical case

- Imaging: confirmation of a single lesion without any suspicious lymph node
- Biopsy: Infiltrating ductal carcinoma, ER: 90%, PR: 80%, HER2- Ki67: 2%, grade I
- Lumpectomy + sentinel lymph node procedure: pT1cN0 in complete resection
- Adjuvant radiotherapy followed by hormonotherapy for 5 years

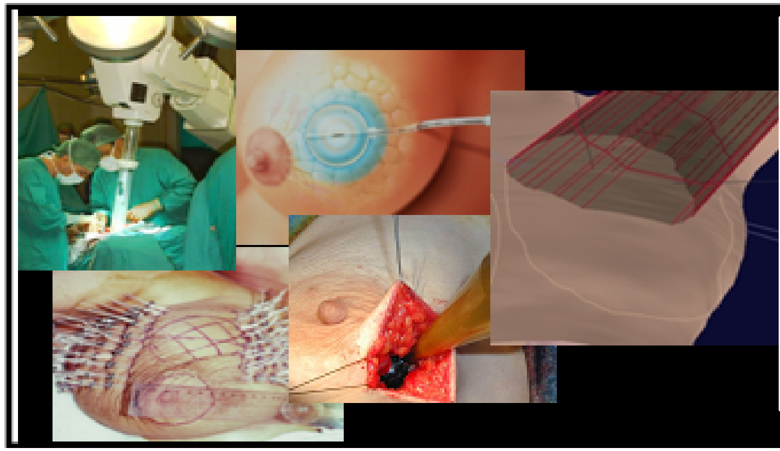
Therapeutic strategy: Which radiotherapy?

Two changing practice concepts have modified the standard whole breast irradiation 50Gy +/- boost



Hypo fractionated whole breast irradiation

Whelan NEJM 2010; START A and B Lancet Oncol 2008



Accelerated partial breast irradiation

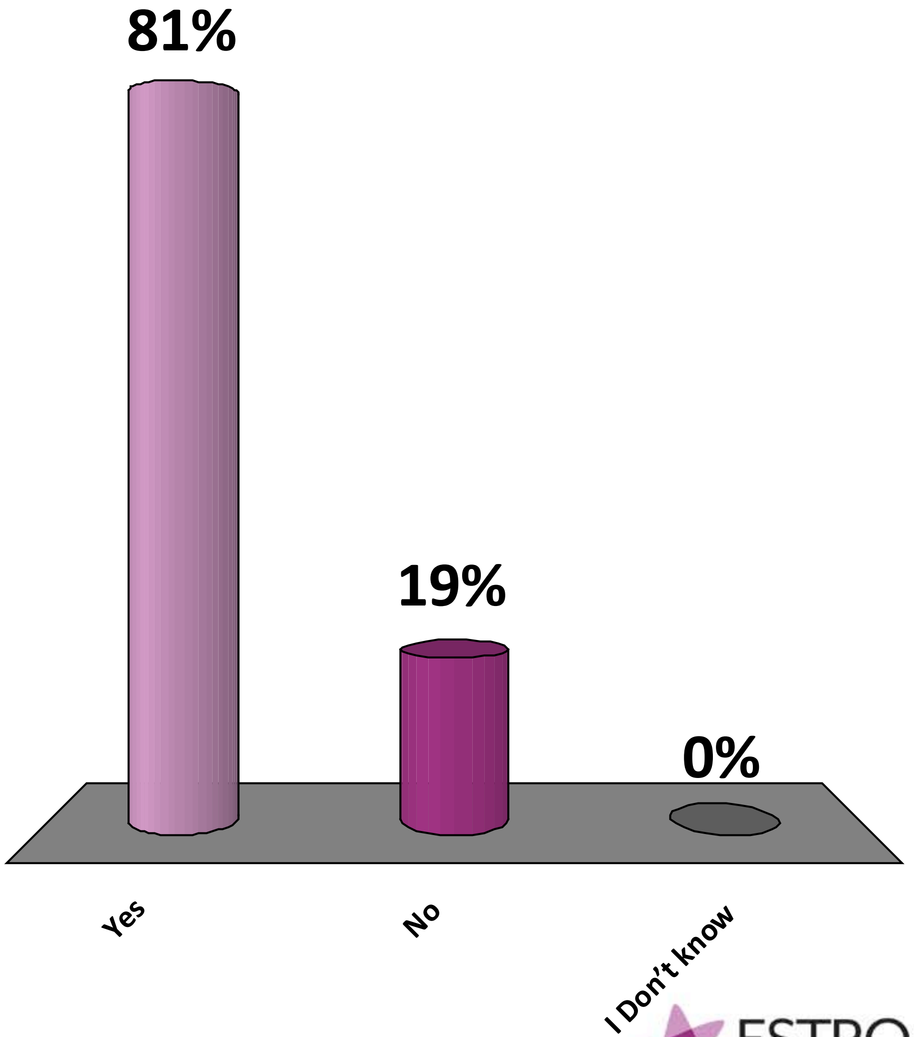
Vaidya Lancet 2010; Bourgier IJROBP 2010 ; Lemanski IJROBP 2010; Taghian IJROBP 2005; Polgar IJROBP 2004 ;Vicini IJROBP 2003; Formenti IJROBP 2003;

Do you perform hypofractionated treatments for breast cancer?

A. Yes

B. No

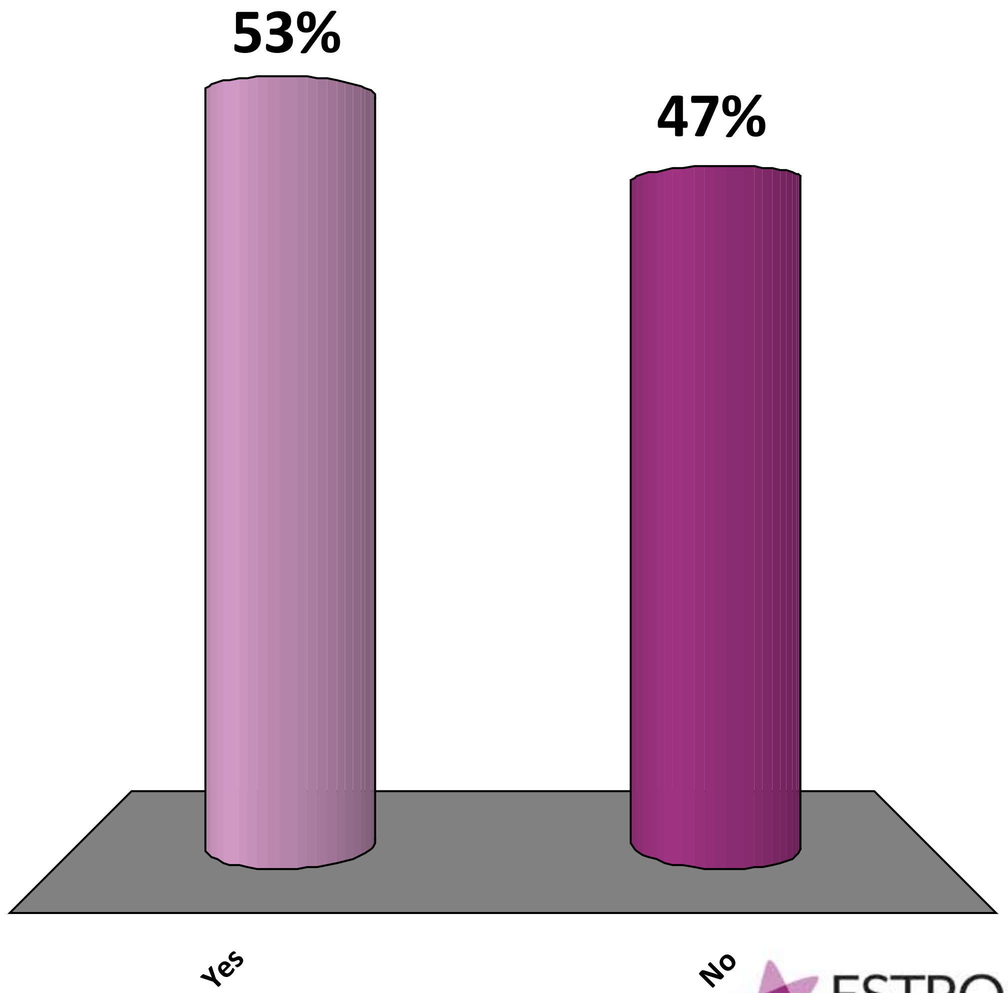
C. I Don’t know



Do you perform partial breast irradiation?

A. Yes

B. No



Whole breast irradiation

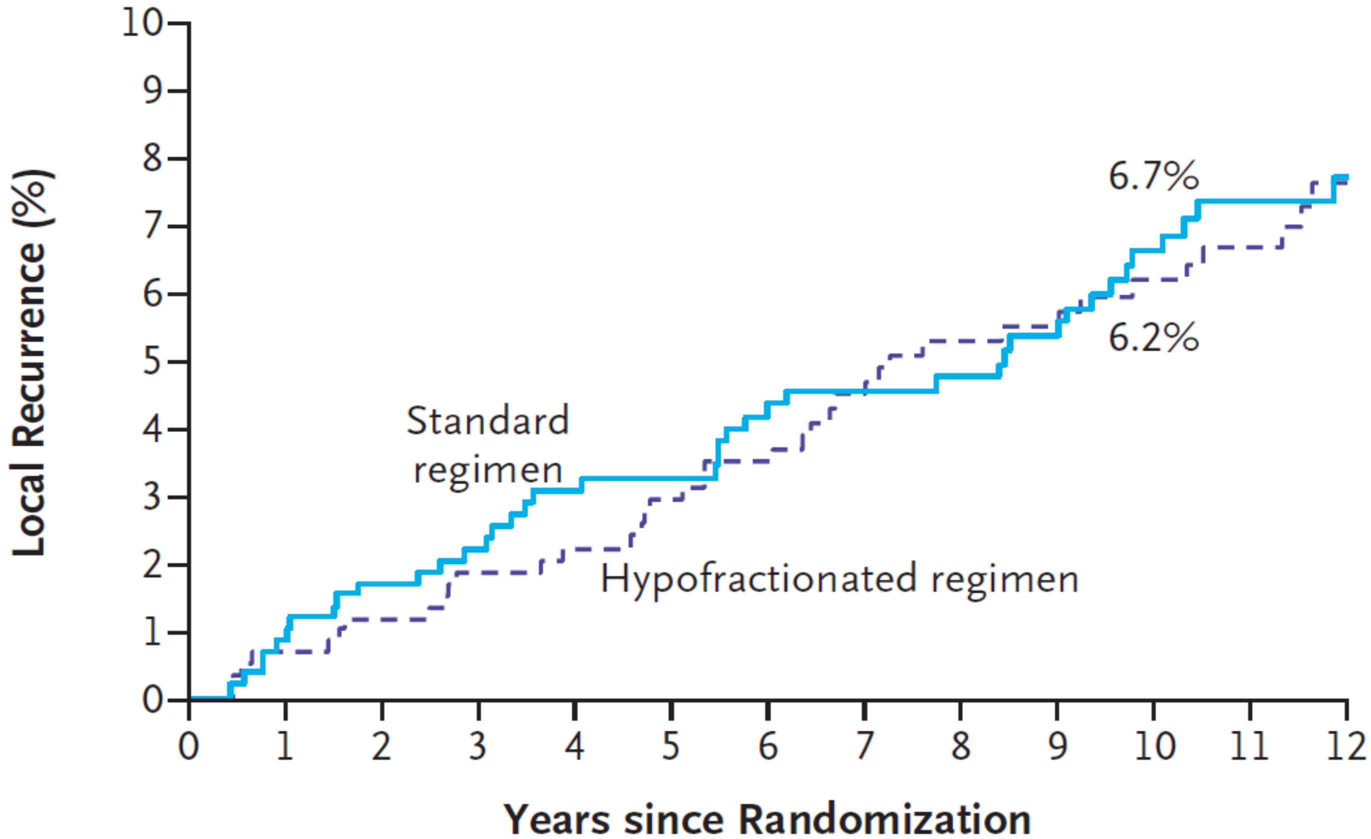
ORIGINAL ARTICLE

Long-Term Results of Hypofractionated Radiation Therapy for Breast Cancer

Timothy J. Whelan, B.M., B.Ch., Jean-Philippe Pignol, M.D., Mark N. Levine, M.D.,

N=1234

Short fractionated schedule	Long fractionated schedule
N=622	N=612
42.5Gy /16f	50Gy /25f



Whelan NEJM 2010

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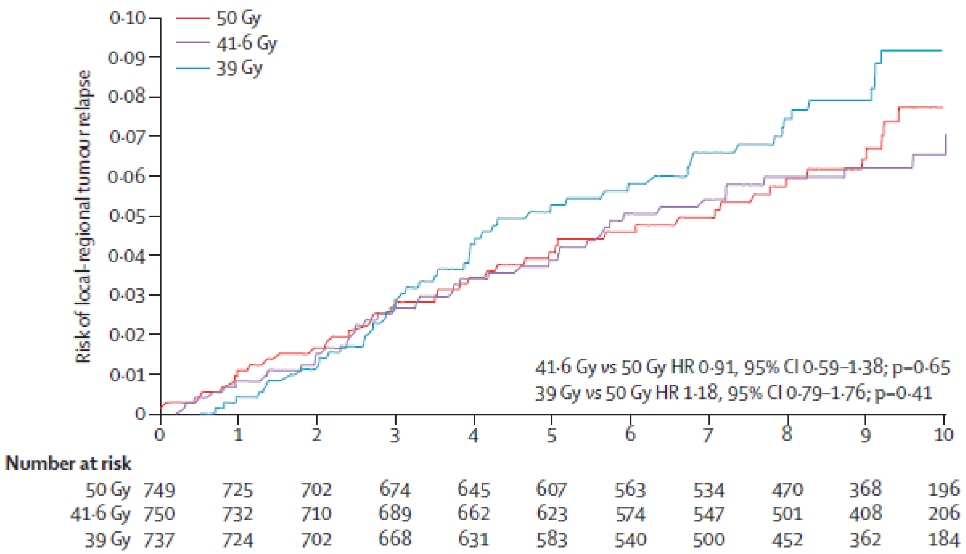
Whole breast irradiation

START A
2236 patients

50 Gy/25 fractions/ 5 weeks

41.6 Gy/13 fractions/ 5 weeks

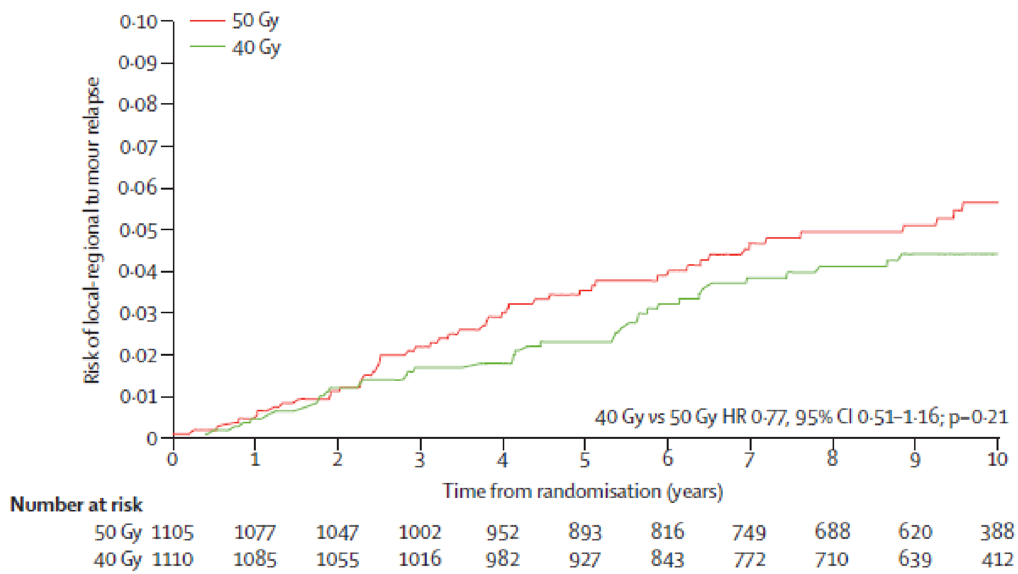
39 Gy/13 fractions/ 5 weeks



START B
2215 patients

50 Gy/25 fractions/ 5 weeks

40 Gy/15 fractions/ 3 weeks



Median follow up = 9,3 yrs
LRR-10y (50Gy) : 7,4% [5,5-10]

Median follow up = 9,9 yrs
LRR-10y (50Gy) : 5,5% [4.2-7,2]

JS Haviland; Lancet Oncol 2013

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Partial breast irradiation indication guidelines

ESTRO	ASTRO
• >50 years	• ≥60 years
• IDC, mucinous, tubular, medullary, and colloid cc.	• Invasive ductal or other favorable subtypes
• Associated LCIS allowed but not DCIS	• Pure DCIS not allowed
• Any grade, ER, PR	• ER status positive
• pT1–2 (⩽30 mm)	• pT1 : ≤2 cm
• Negative surgical margins (⩾2 mm)	• Negative surgical margins by at least 2 mm
• Unicentric, Unifocal	• Unicentric only, Clinically unifocal with total size ≤2.0 cm
• pN0 (by SLNB or ALND)	• pN0 (i^-, i^+) (by SLNB or ALND)

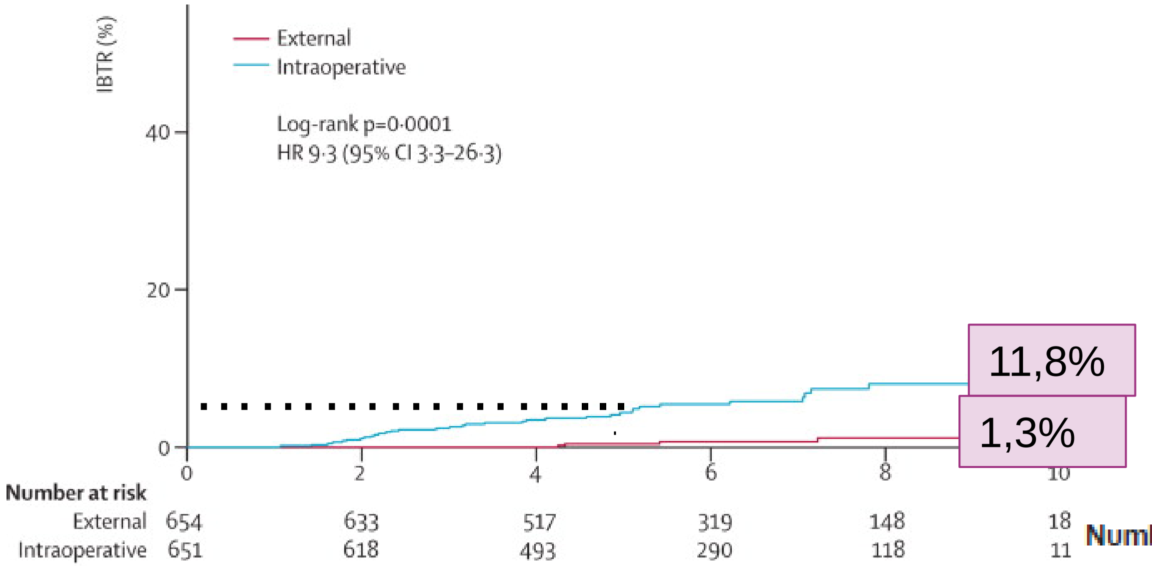
Polgar, Radiother Oncol 2010

Smith IJROBP 2009

Intraoperative Partial breast versus whole breast irradiation

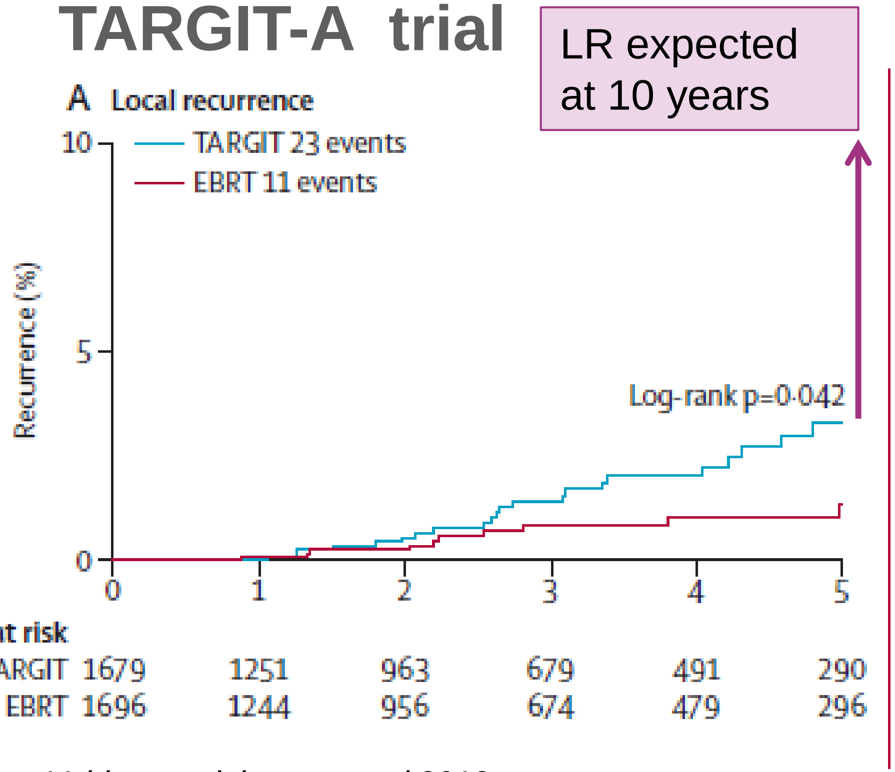
- Ipsilateral breast recurrence

ELIOT trial



Veronesi et al; lancet oncol 2013

TARGIT-A trial

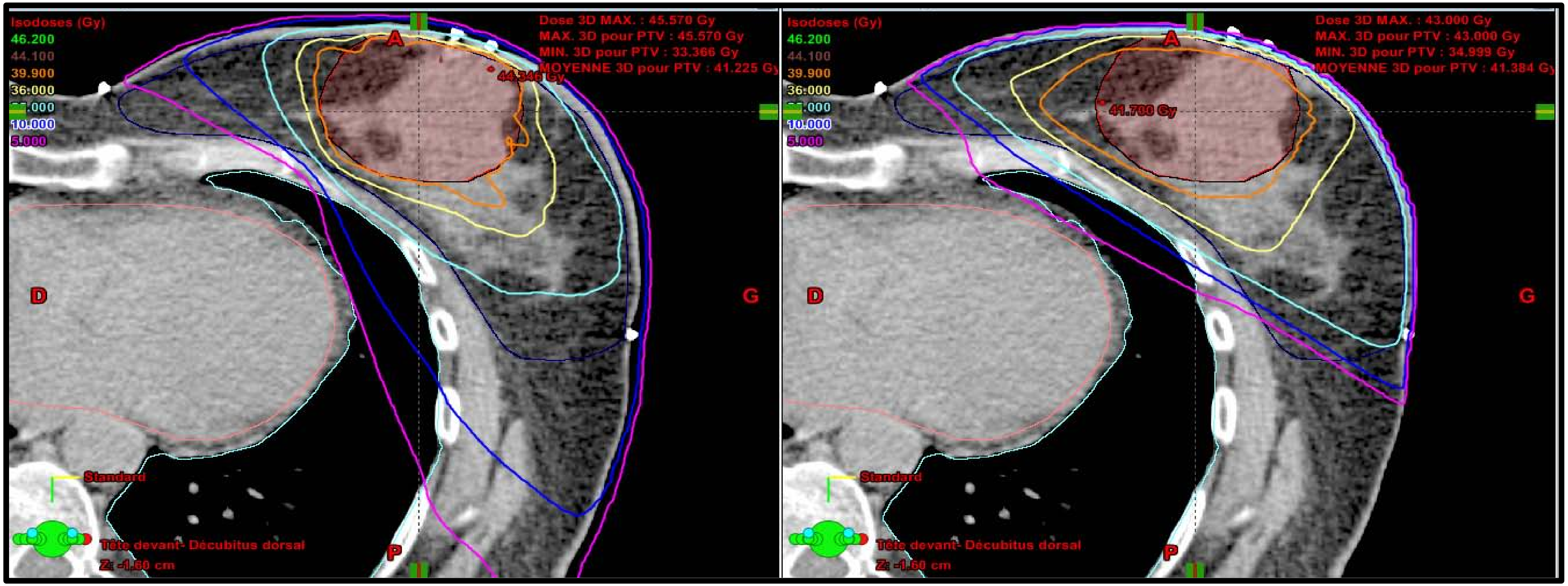


Vaidya et al; lancet oncol 2013

Dosimetric comparision between APBI

Rapidarc technique

3D conformal with photons and electrons



Advantages	Drawbacks
Lower heart dose	Higher hot spot
Lower whole breast dose	Increased low doses to lung

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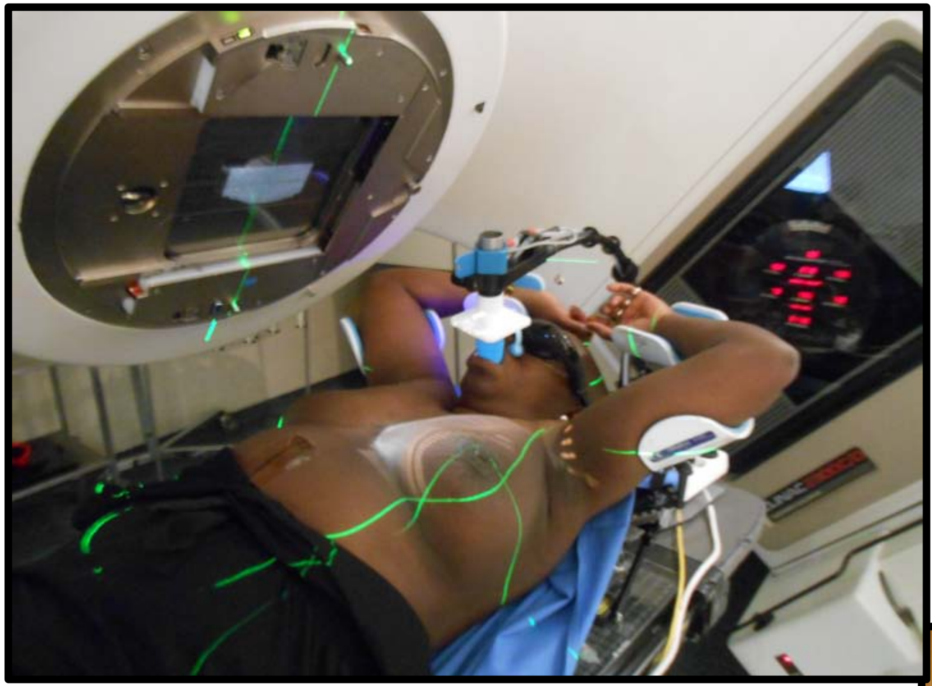
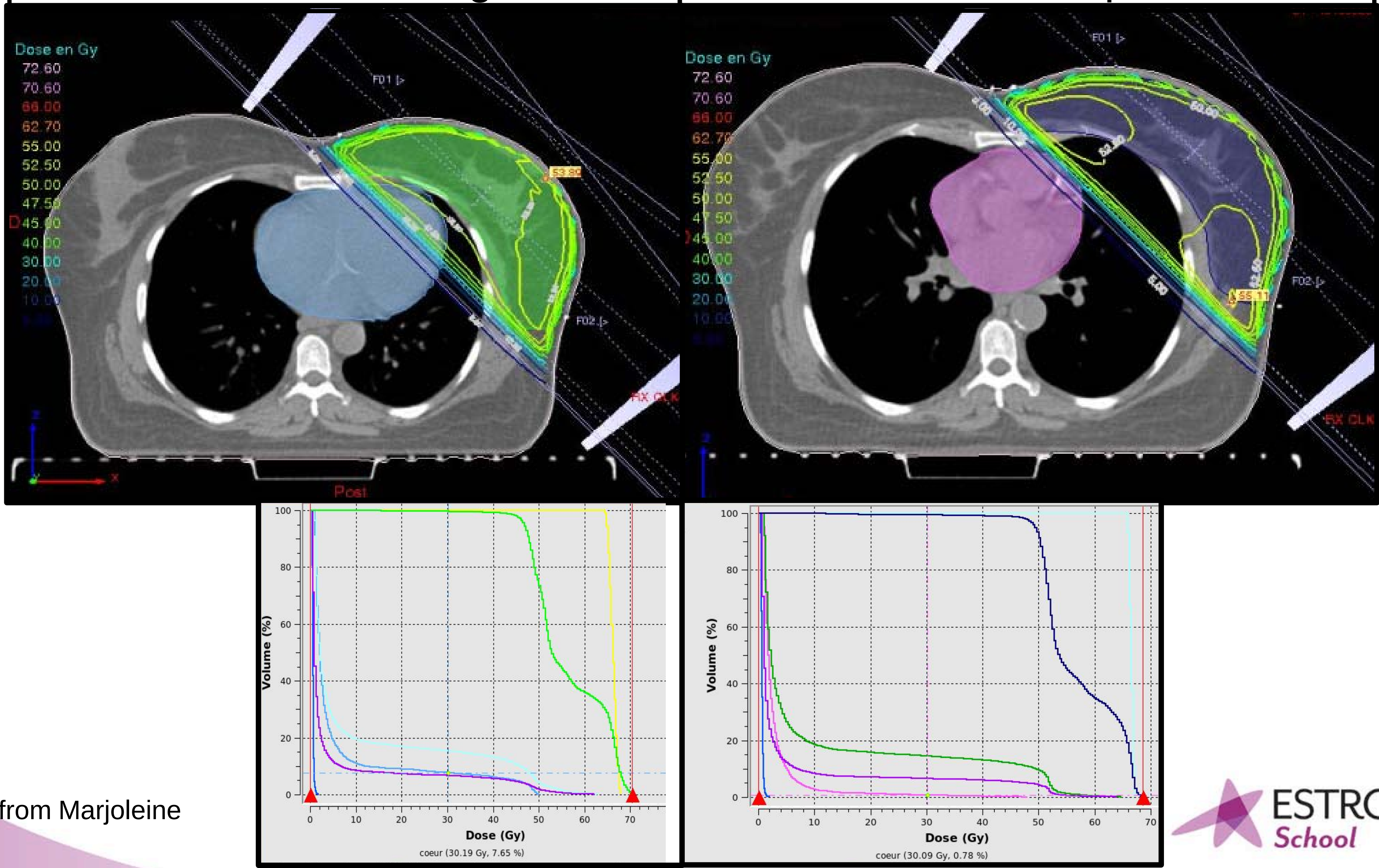
How to improve heart sparing?



- Inspiration breath hold technique

Improved heart sparing by breath hold

Free breathing	Breath hold inspiration

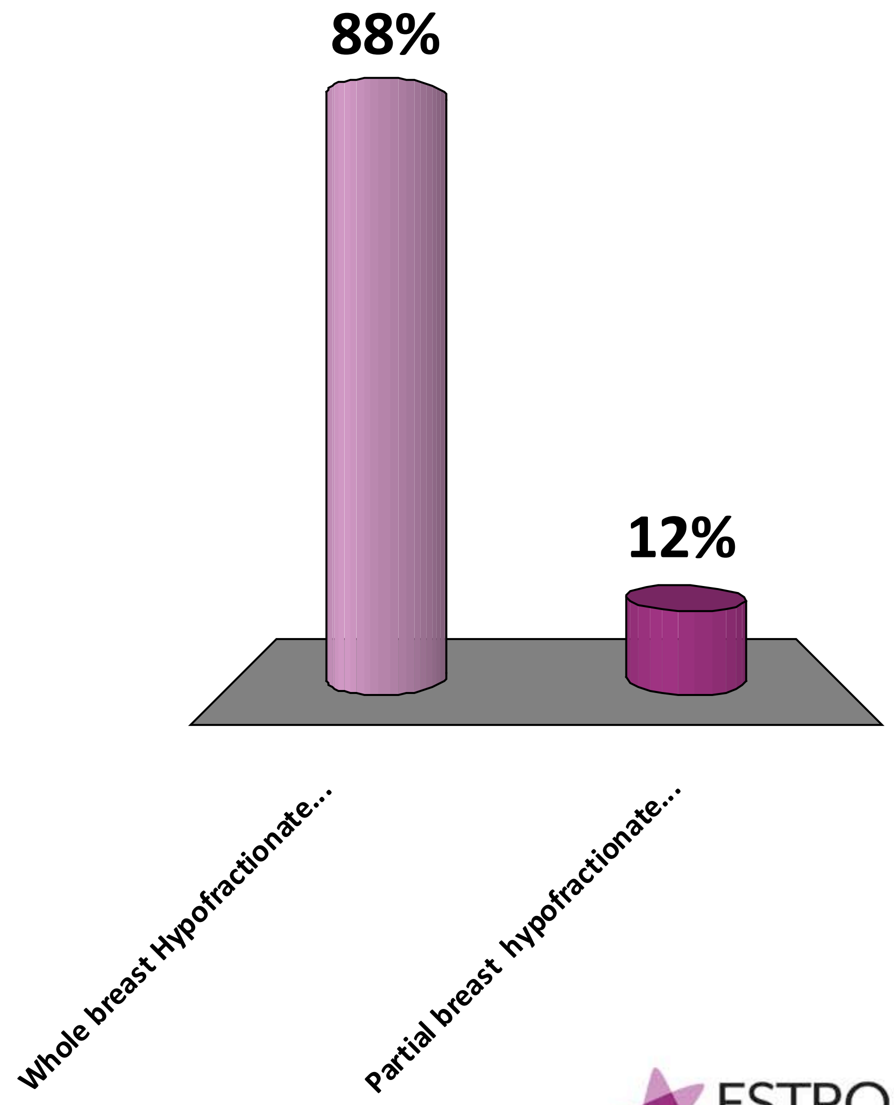


Courtesy from Marjoleine Cheve

For which of these treatments do we have the highest clinical level of proof?

A. Whole breast Hypofractionated treatment

B. Partial breast hypofractionated irradiation



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Take home messages:

- Accelerated hypofractionated whole breast and partial breast irradiation are changing our practices for early breast cancers with good prognosis factors

- Contouring and positioning remain key points for these treatment strategies

- Moving toward better sparing OAR means we need to assess low dose consequences as well

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Breast case – Physics or metaphysics?

Peter Remeijer
Department of Radiation Oncology
The Netherlands Cancer Institute

NETHERLANDS CANCER INSTITUTE
ANTONI VAN LEEUWENHOEK

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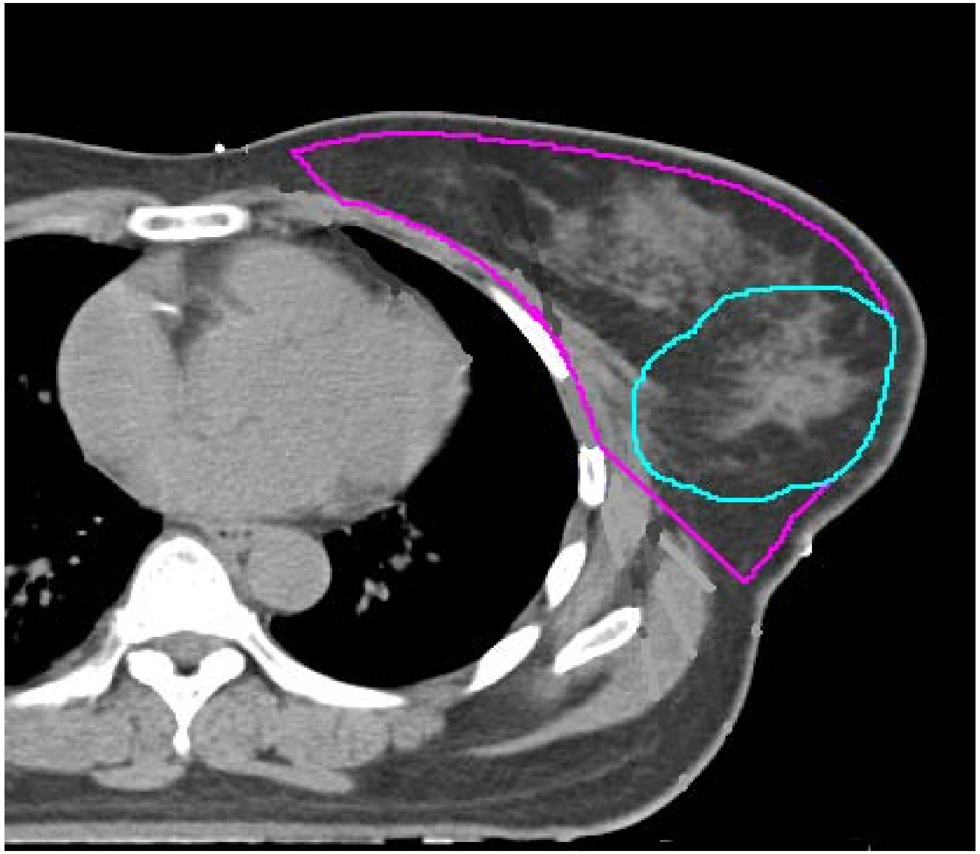
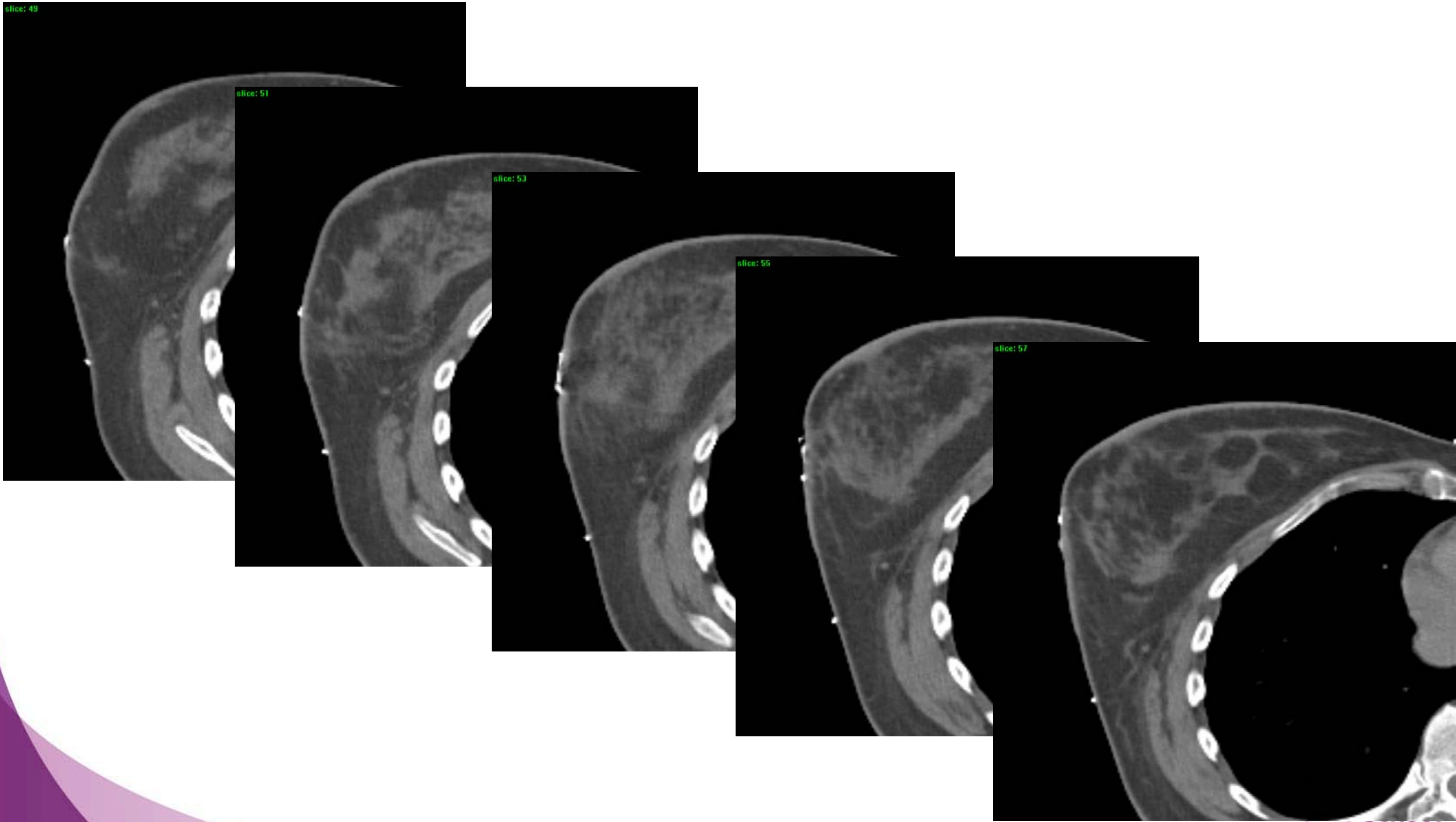
Common target volumes



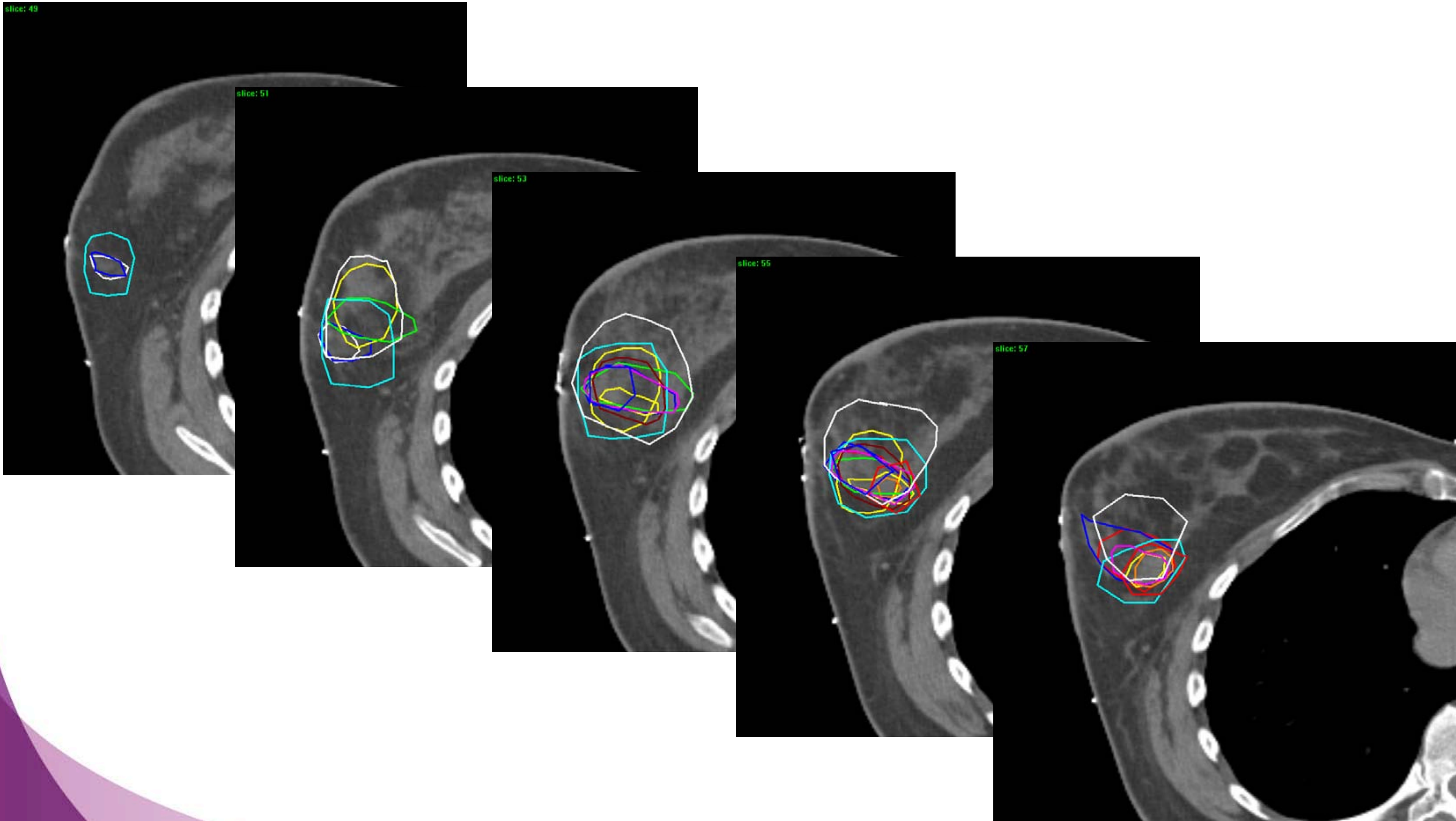
Whole breast (50 Gy)

Excision cavity (16 Gy)

Target volume delineation - variability



Target volume delineation - variability

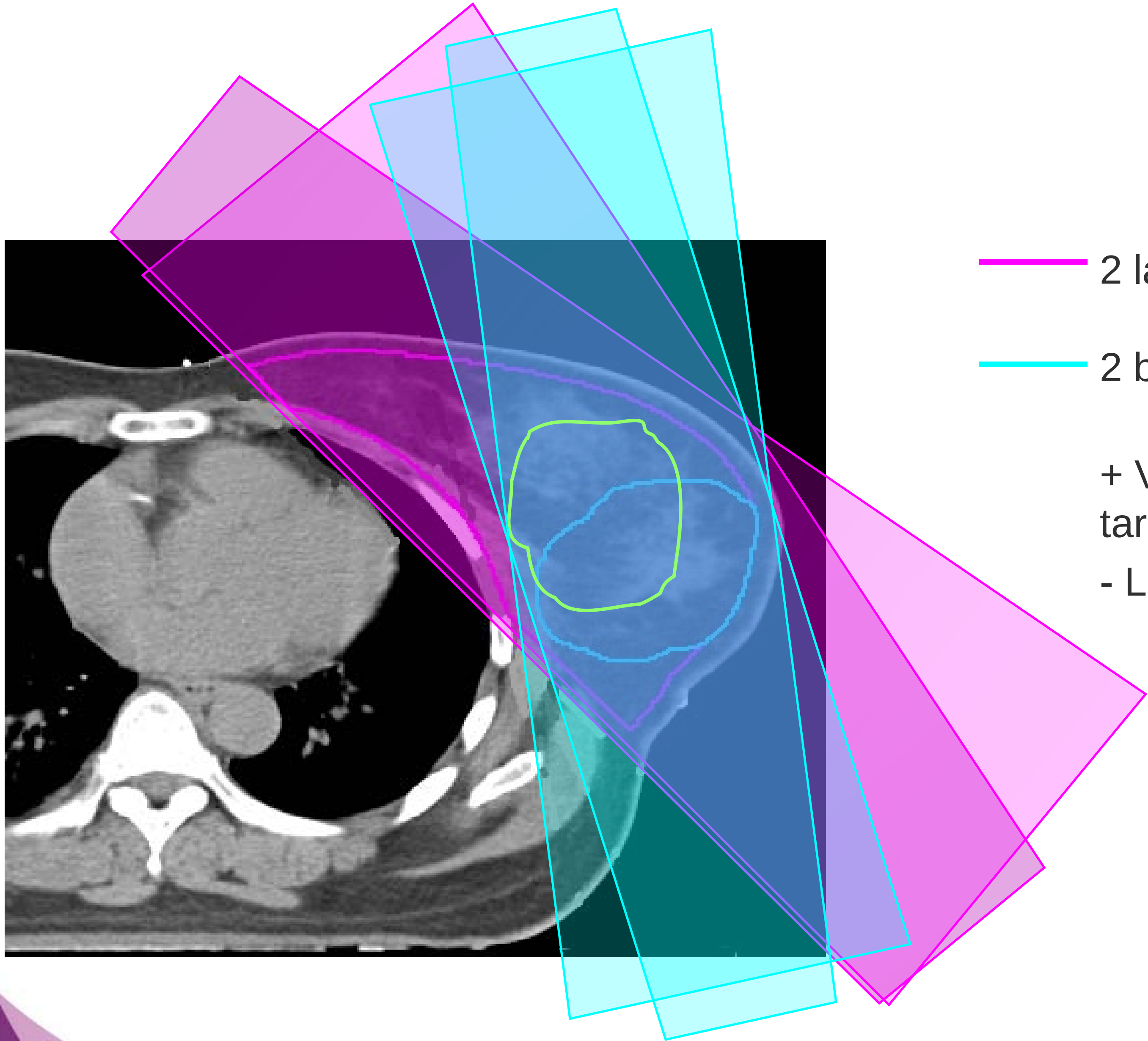


Target volume delineation - variability

- Possible causes
  - Different opinion of the clinicians
  - Image quality

- Possible solutions
  - Clear protocols, good collaboration between OR, Pathology, RT
  - Markers
  - Registration of pre-and post-op imaging (difficult!)
  - Multiple modalities

Treatment planning – Typical beam set-up



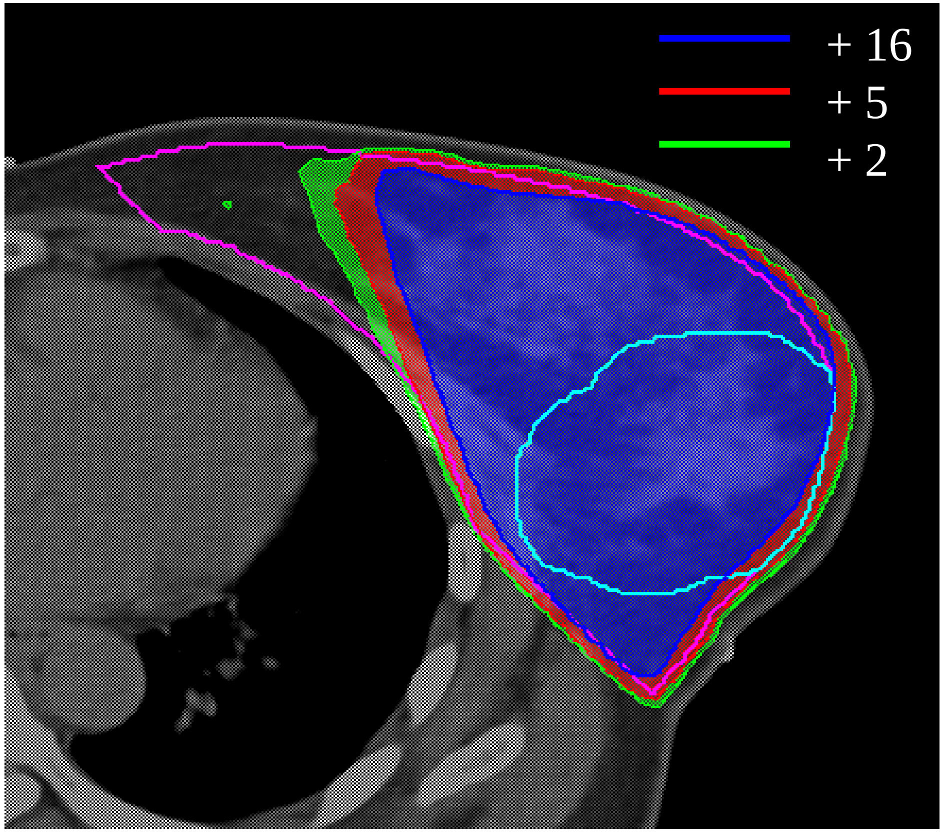
2 large fields for whole breast (50Gy)

2 boost fields for additional dose (16Gy)

+ Very insensitive to exact position of target volume

- Large volume irradiated to boost dose

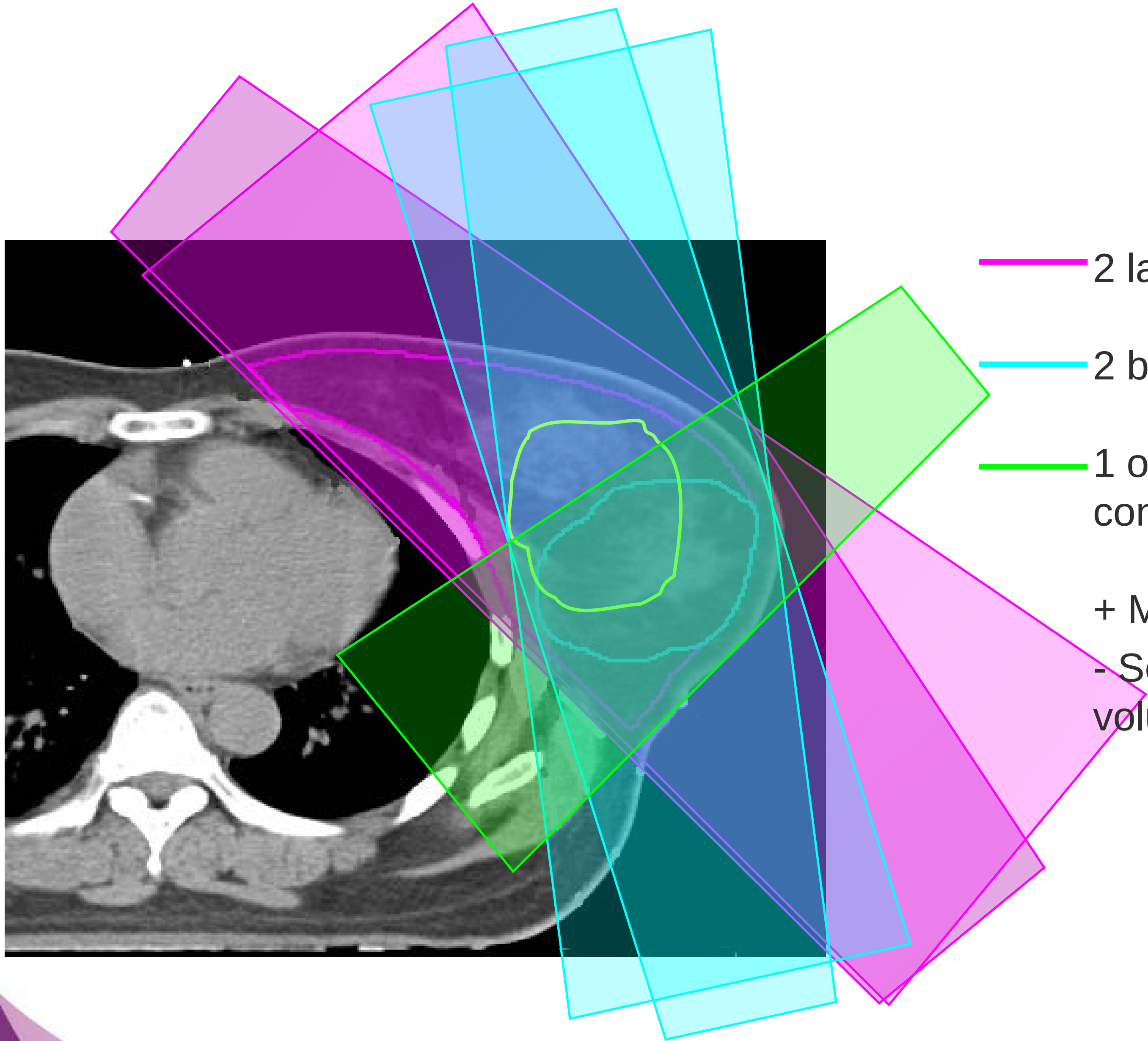
Treatment planning – Typical beam set-up



+ Very insensitive to exact position of target volume

- Large volume irradiated to boost dose

Treatment planning – Typical beam set-up



2 large fields for whole breast (50Gy)

2 boost fields for additional dose (16Gy)

1 orthogonal beam to improve conformance

+ Much smaller high dose volume

- Sensitive to exact position of target volume

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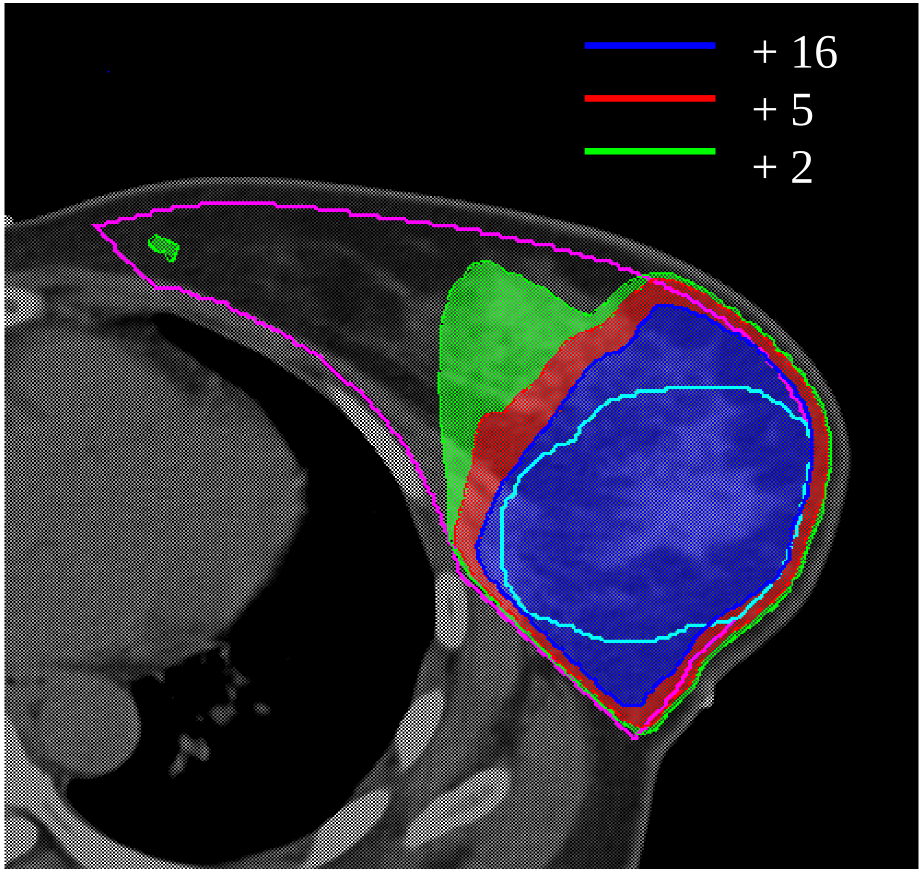
Treatment planning – Typical beam set-up



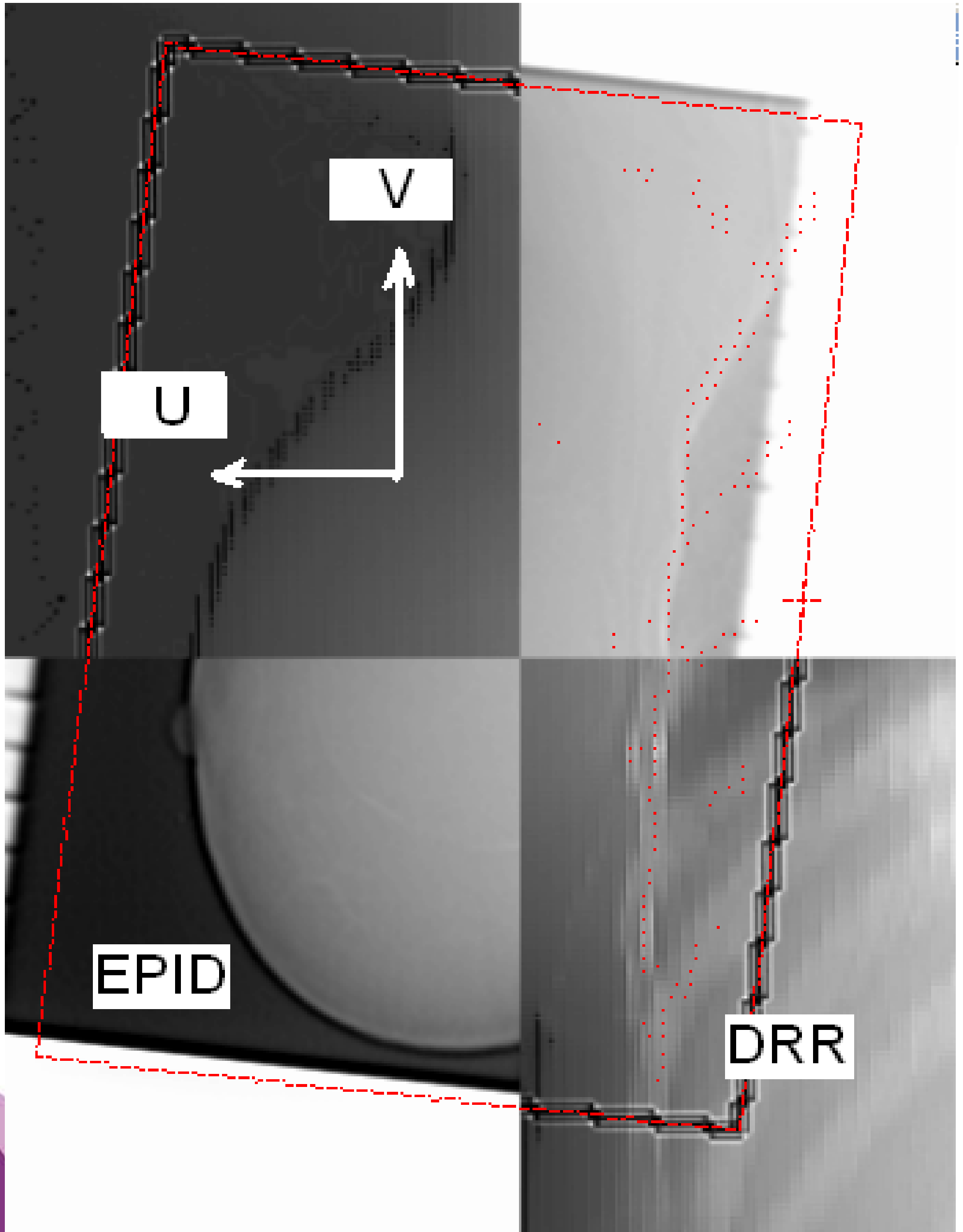
+ Much smaller high dose volume
- Sensitive to exact position of target volume

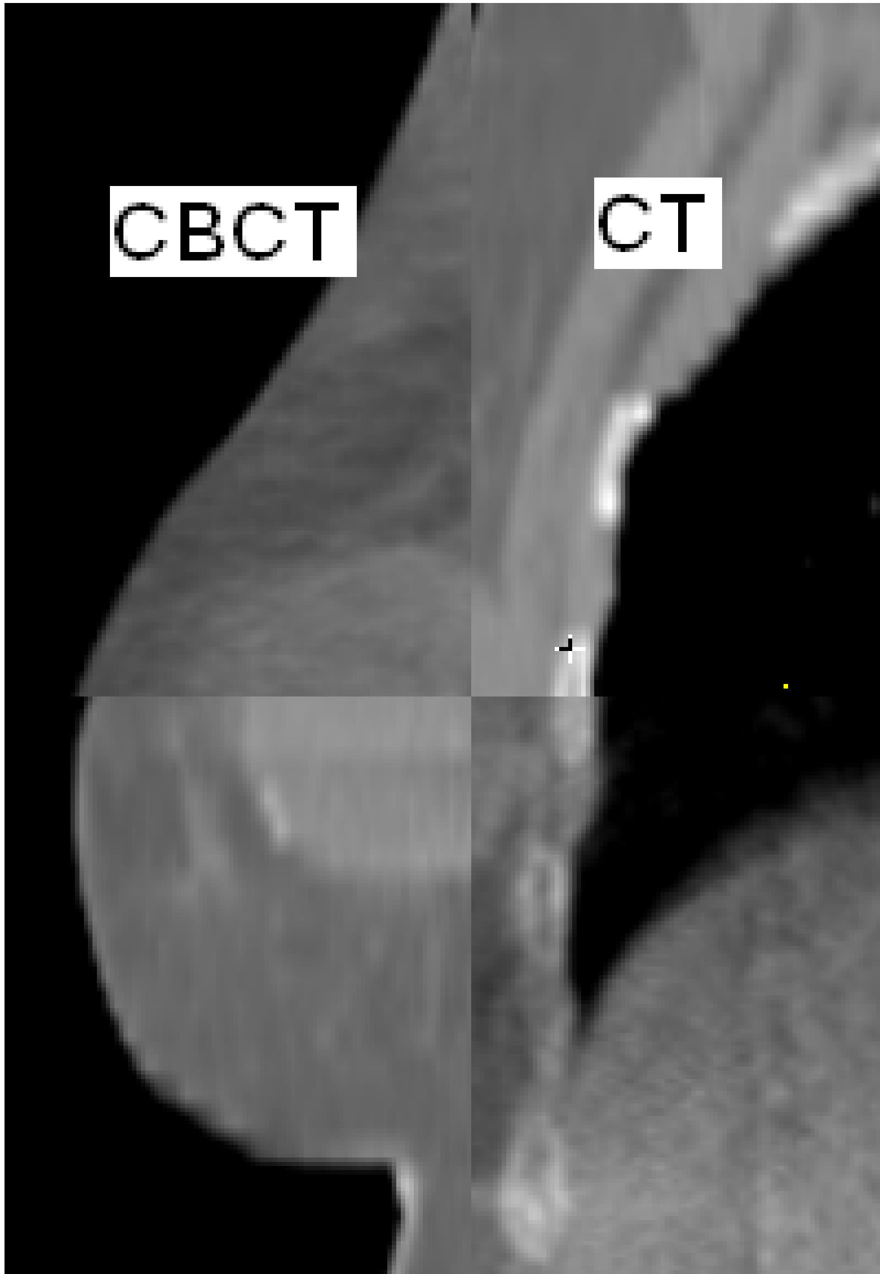
→ Image guidance / position verification

Treatment – EPID versus CBCT verification

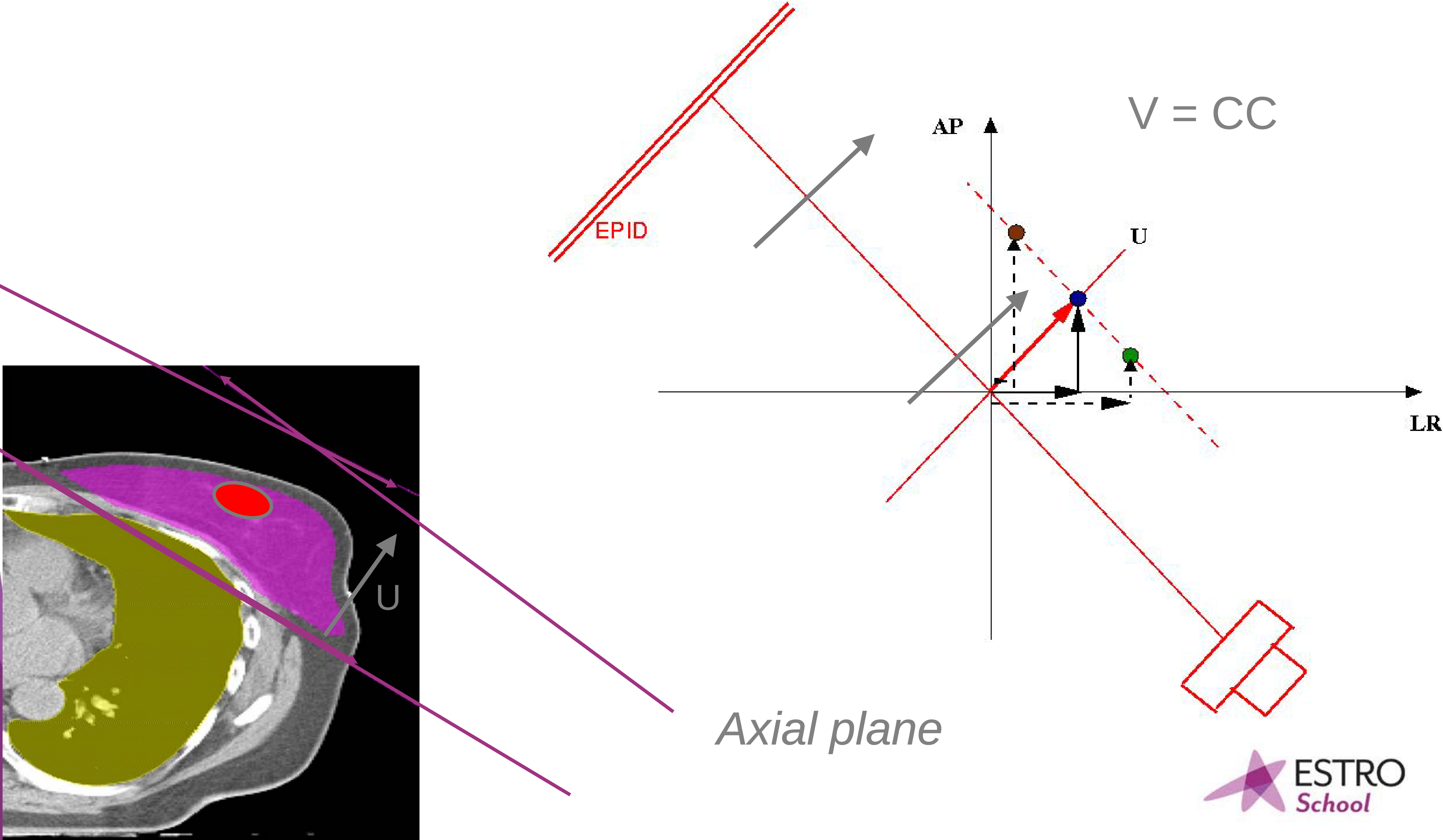
- Acquire simultaneous data
- Analyze differences
- Correction protocol
- What margin do we need

Image quality EPID & CBCT





Coordinates (LR, AP, CC versus U, V)



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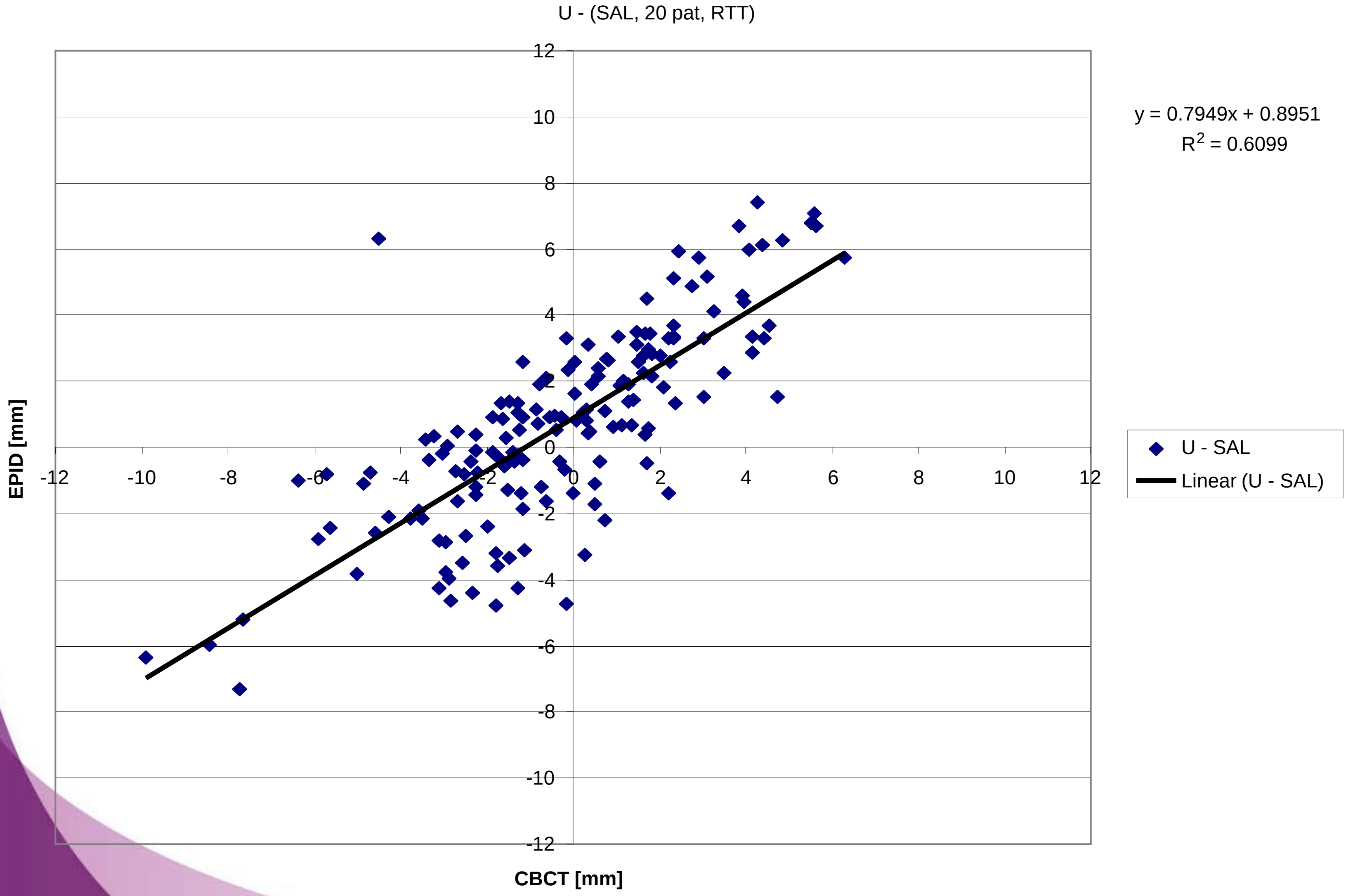
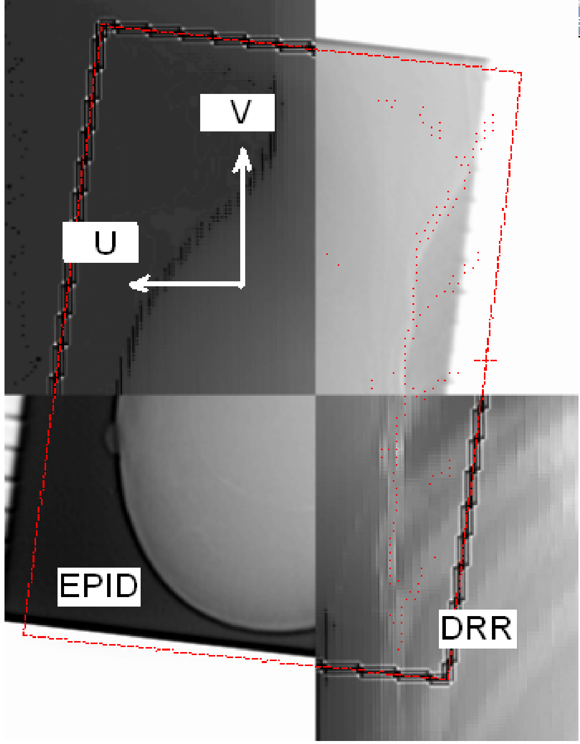
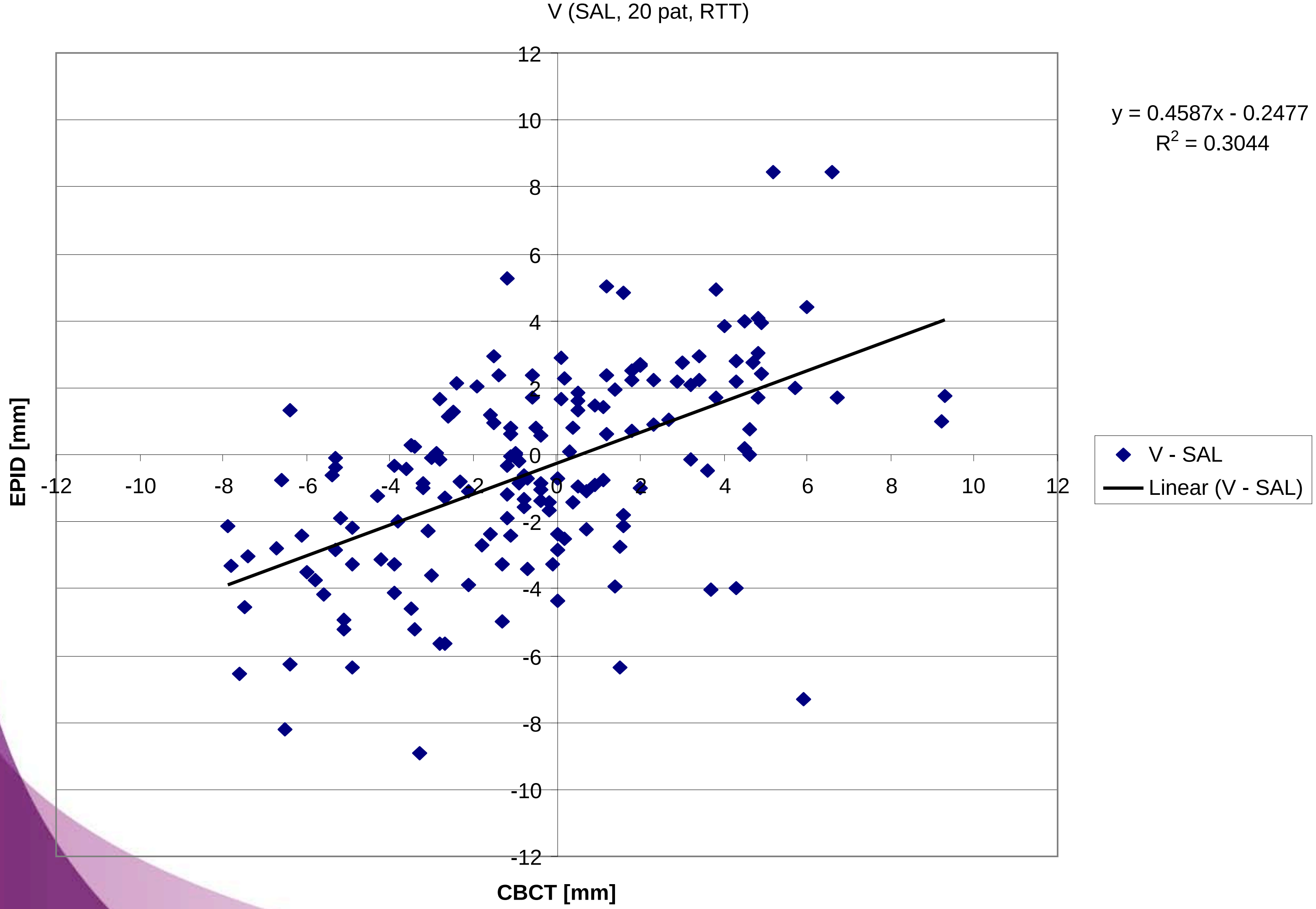
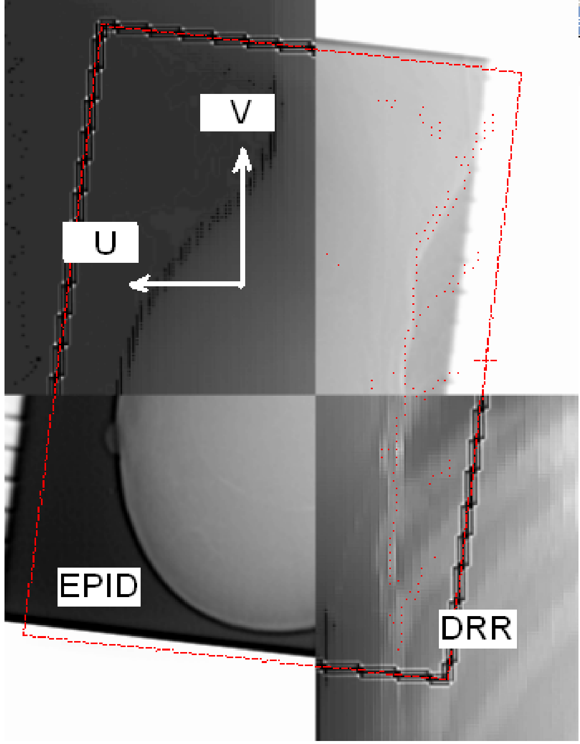
Correlation in the U – direction





Correlation in the V – direction





Results

- The slopes of linear regression:
  - U → 0.82
  - V → 0.43

- EPID underestimates setup errors in the V direction more than in the U direction.

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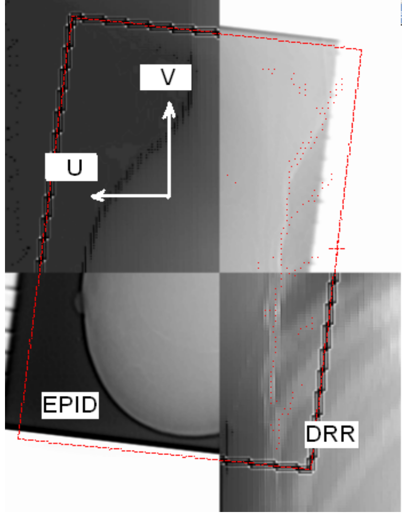
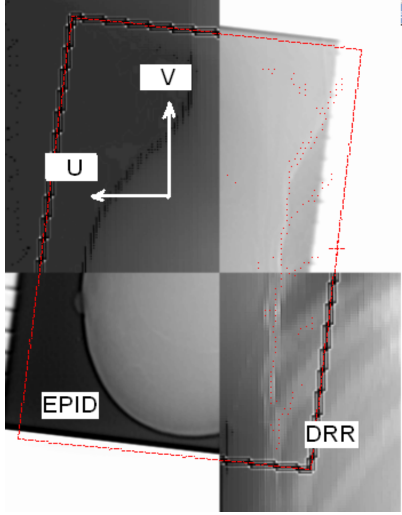
Results (CBCT)



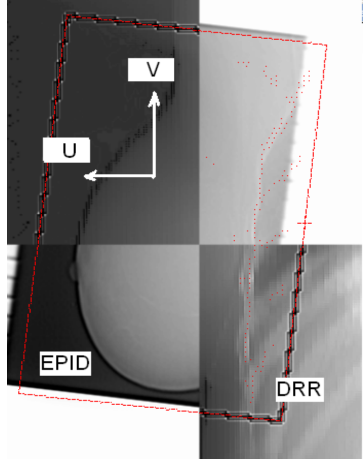
	No-correction$_{meas}$				Offline$_{meas}$			
	CBCT				CBCT			
	U	V/CC	LR	AP	U	V/CC	LR	AP
M (mm)	-0.9	-1.1	-2.1	2.0	-0.3	-0.5	-1.0	0.8
Σ (mm)	3.7	3.8	3.1	2.5	1.4	1.7	1.4	1.2
σ (mm)	2.5	2.8	2.2	2.6	2.6	3.1	2.3	3.0
$2.5\Sigma + 0.7\sigma$ (mm)	11.0	11.5	9.2	8.0	5.3	6.4	5.2	5.1

Results (CBCT versus EPID)



	$\text{No-correction}_{meas}$				Offline_{meas}			
	CBCT				CBCT			
	U	V/CC	LR	AP	U	V/CC	LR	AP
M (mm)	-0.9	-1.1	-2.1	2.0	-0.3	-0.5	-1.0	0.8
Σ (mm)	3.7	3.8	3.1	2.5	1.4	1.7	1.4	1.2
σ (mm)	2.5	2.8	2.2	2.6	2.6	3.1	2.3	3.0
$2.5\Sigma + 0.7\sigma$ (mm)	11.0	11.5	9.2	8.0	5.3	6.4	5.2	5.1

Offline_{sim}					
EPID		EPID*“real”*		CBCT	
U	V	U	V	U	V
0	-0.4	-0.9	-0.8	-0.2	-0.3
1.7	1.4	2.2	3.3	1.6	1.6
3.1	3.0	2.9	2.9	3.1	3.4
6.4	5.5	7.7	10.3	5.3	6.4



Summary

- EPID registration underestimates bony anatomy setup error in breast cancer patients.

- Using EPID instead of CBCT therefore requires larger margins

Changes during treatment

Seroma changes

- Possibly occurs after breast sparing surgery
- Fluid in excision cavity

- Boost is generally based on this seroma volume

T. Alderliesten, S. den Hollander[1], J. Yang[2], P. Elkhuizen[1], A. van Mourik[1], C. Hurkmans, C v. Vliet

Seroma changes

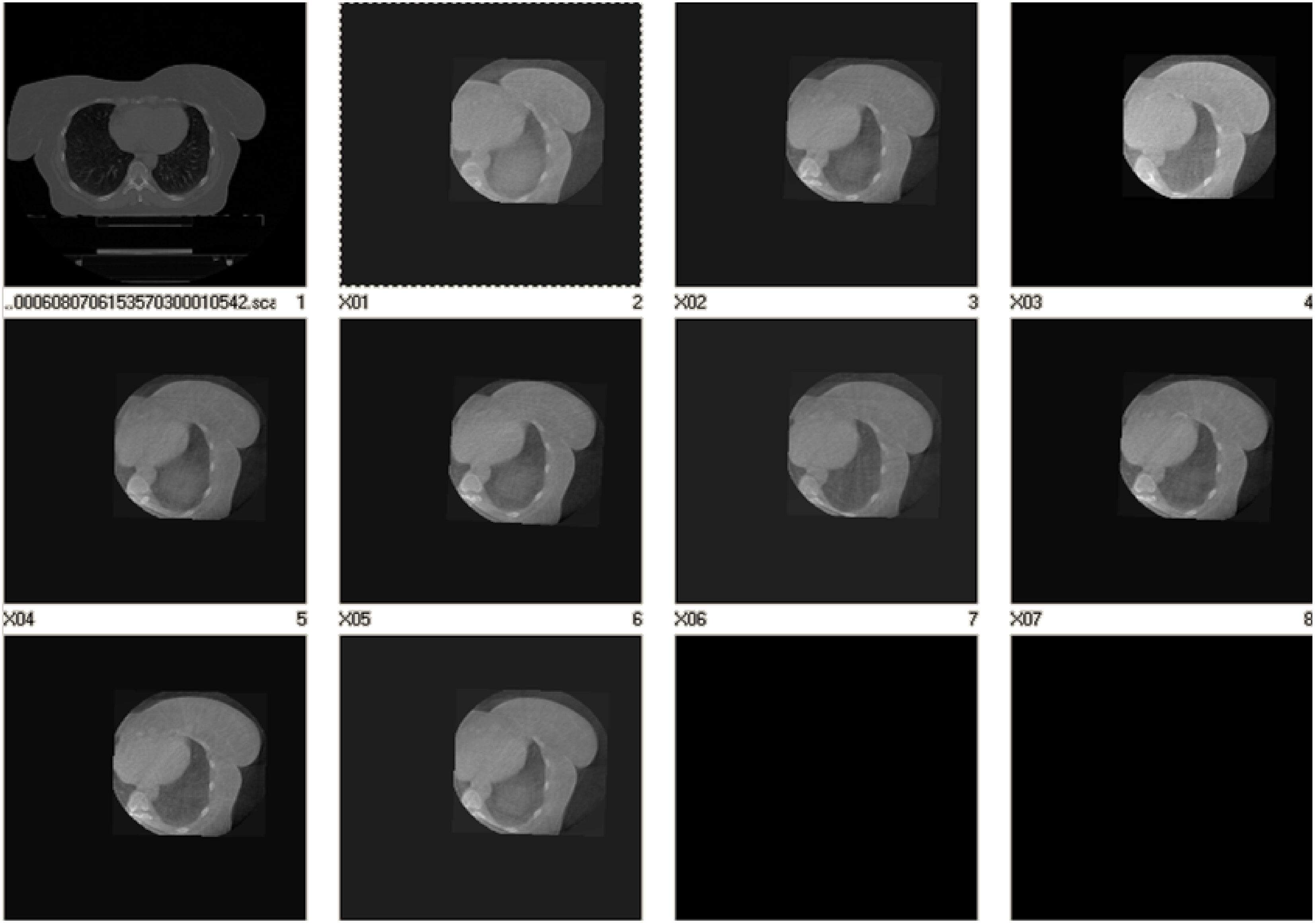
- Seroma shrinkage

Planning CT

Repeat CT (during treatment)

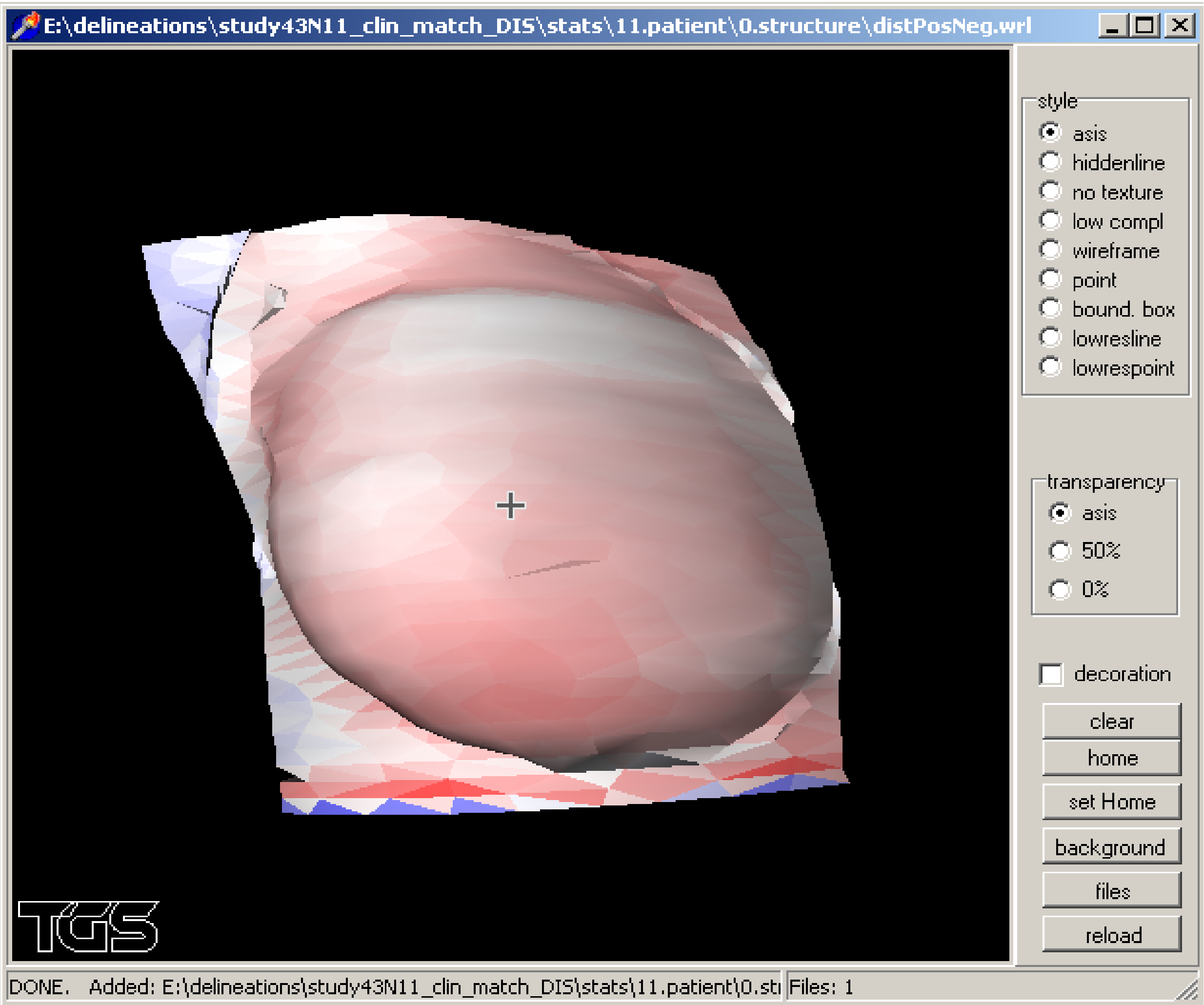
- Can be partially solved by adaptive RT

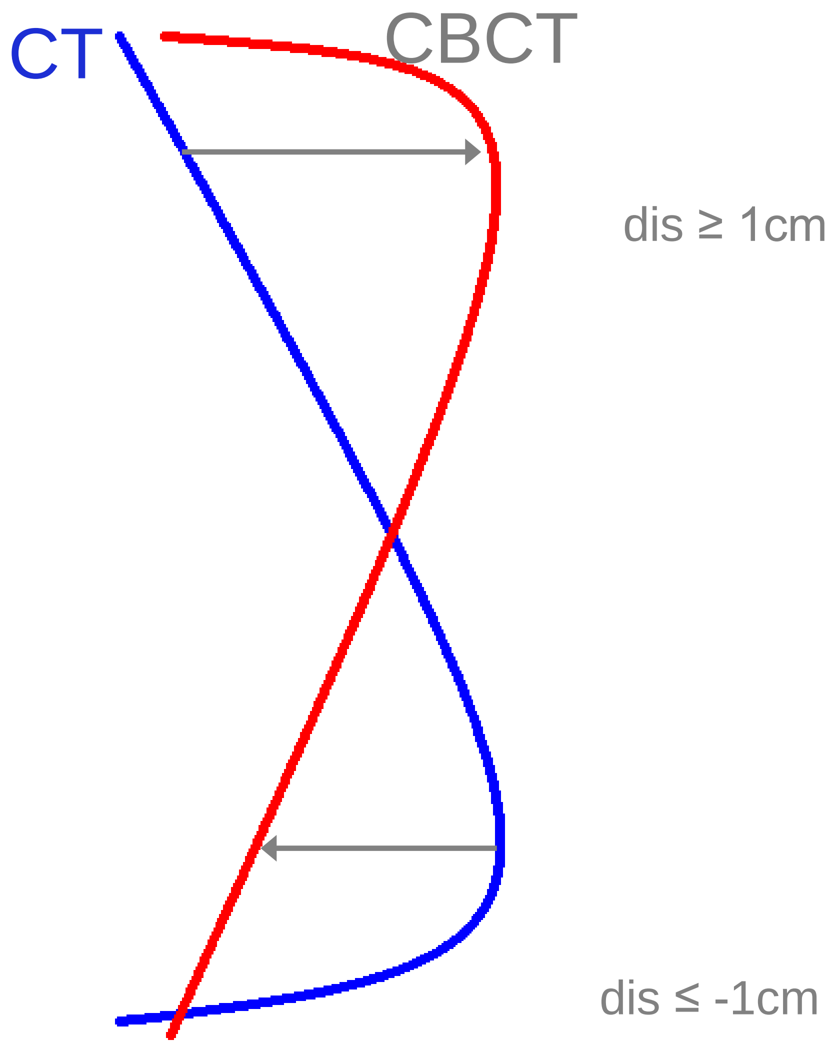
Changes in breast shape

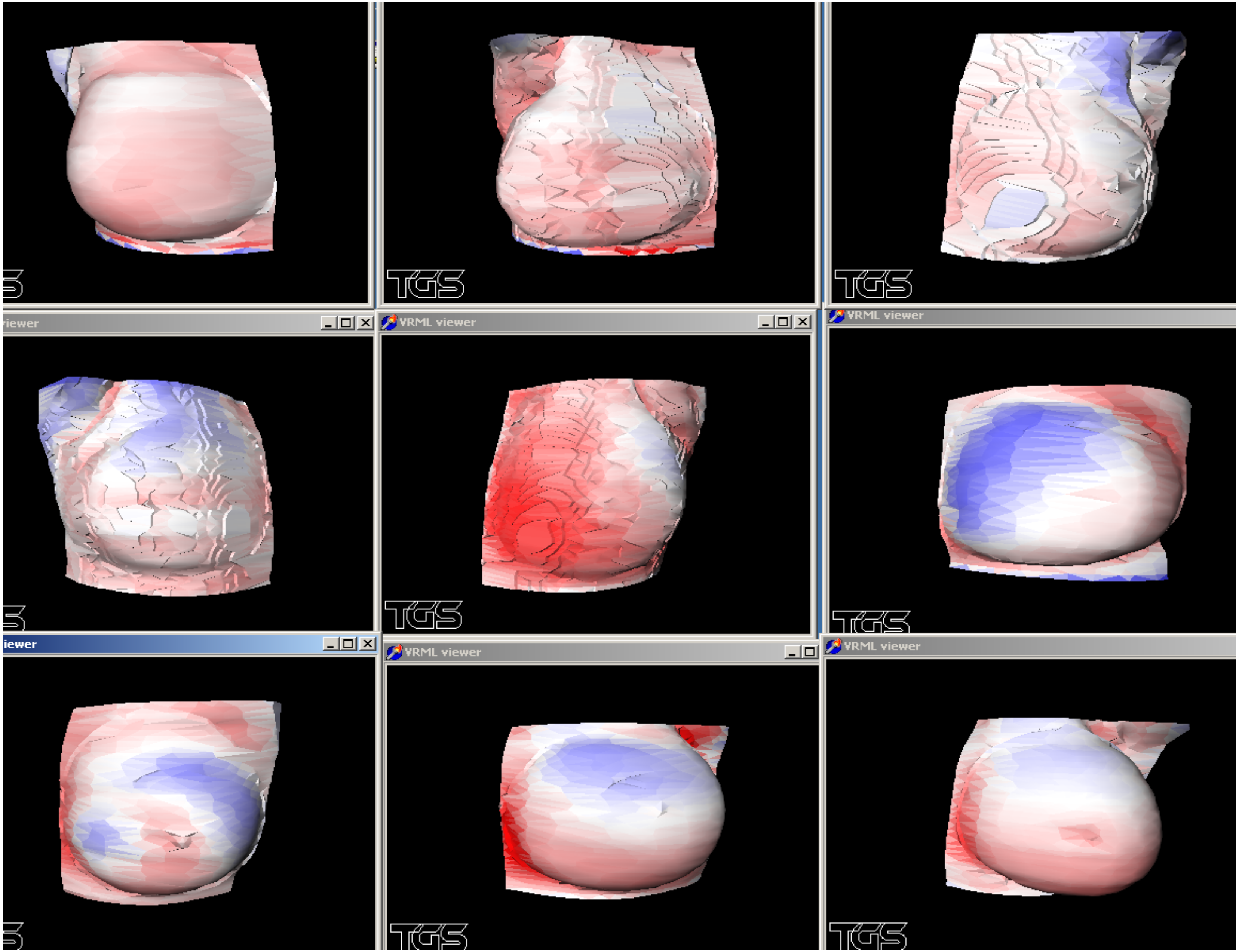


R.Topolnjak et al

Average difference (treatment → planning)

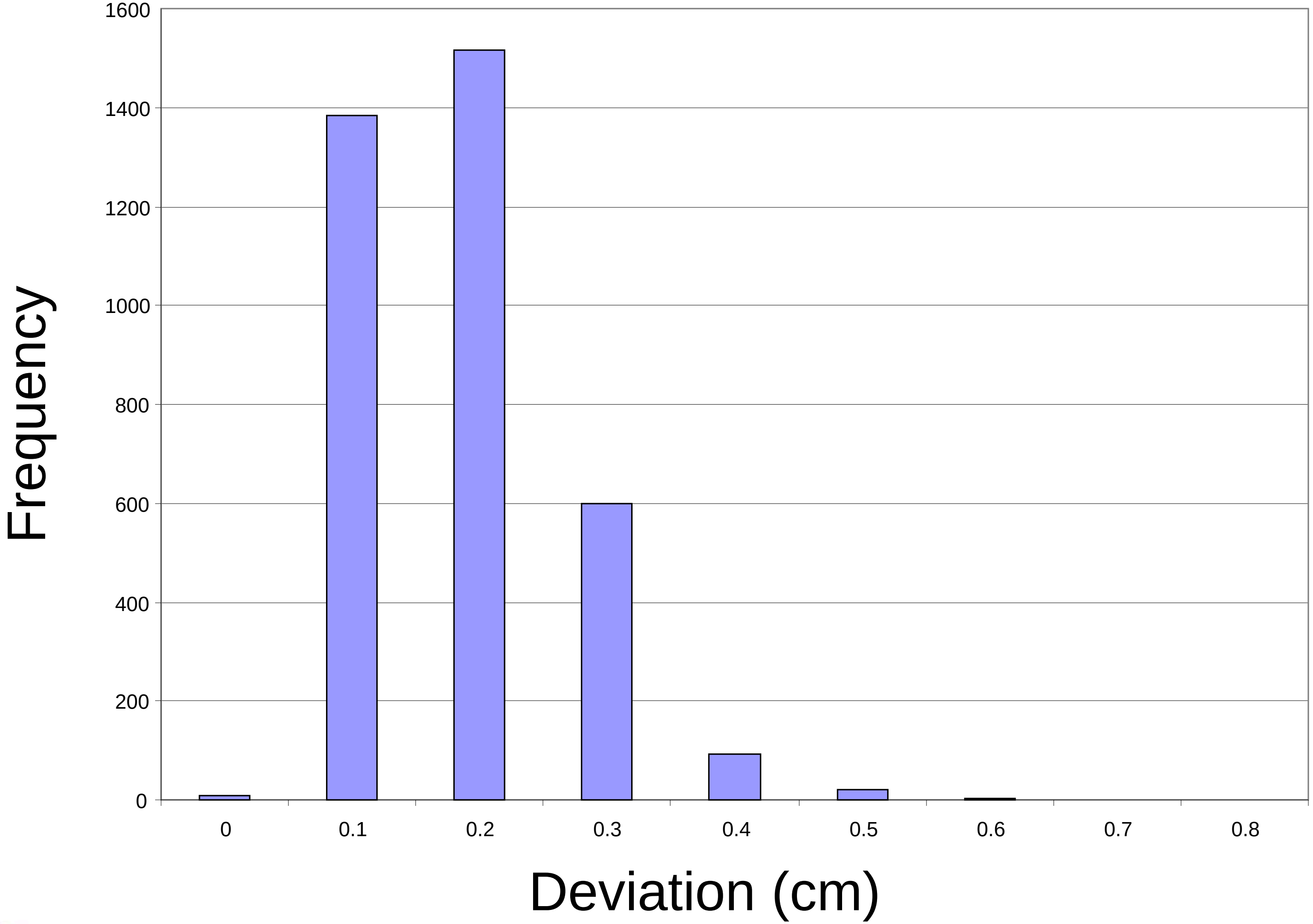






VRML viewer
VRML viewer
VRML viewer
VRML viewer
VRML viewer
TGS

Average difference (treatment → planning)



Metaphysics margins?

- Clinically used margin for breast: **0 mm!**
  - Adapted from sim-technique - it's just beam setup
  - Clearly not enough according to conventional margin ideas

- Clinically used margin for boost: 5 mm
  - Let's see if that's enough

	Systematic	Random
Delineation	2.0 mm	-
Setup	1.5 mm	2.5 mm
Shape changes	2.0 mm	2.0 mm
Total	3.2 mm	3.2 mm

  - Margin: 2.5 * 3.2 + 0.3 * 3.2 = **9 mm**

Because of
background dose

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Metaphysics margins?

- So why is this not leading to lots of local recurrences?

Metaphysics margins?

- For the whole breast

  – It’s a CTV. Small underdosage does not necessarily underdose actual tumor cells

    → Risk of tumor cell underdosage small

  – Ongoing debate whether it’s even necessary to treat the whole breast

Metaphysics margins?

- For the boost
  - It's a boost with a 50 Gy background dose, so severe underdosage will not occur
  - Conformity is not very good with current planning techniques → effectively the margin is bigger
  - This is however **not** the case for partial breast treatments
  - CTV margin is usually large → compensates for small PTV margin

Take home messages

- Conventional treatment techniques are not very critical with respect to geometrical uncertainties
- Partial breast treatments will be more critical because of lack of background dose and more advanced and conformal treatment techniques (e.g. VMAT)

Breast IGRT:
An RTT Perspective

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ARTT
Applied Radiation Therapy
Trinity Research Group

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

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Fundamental IGRT Questions

- ***When*** *should I image?*
  - *Frequency*
- ***How*** *should I image?*
  - *Technology*
  - *Projection*
- ***What*** *can I see?*
  - *What is my target*
- ***What*** *should I match to?*
  - *Surrogate for target position*

Site Specific Points to Consider

- Laterality
  - ➢ Right/Left
    - ▪ Cardiac dose

- Patient positioning
  - ➢ Supine, Prone or lateral decubitus

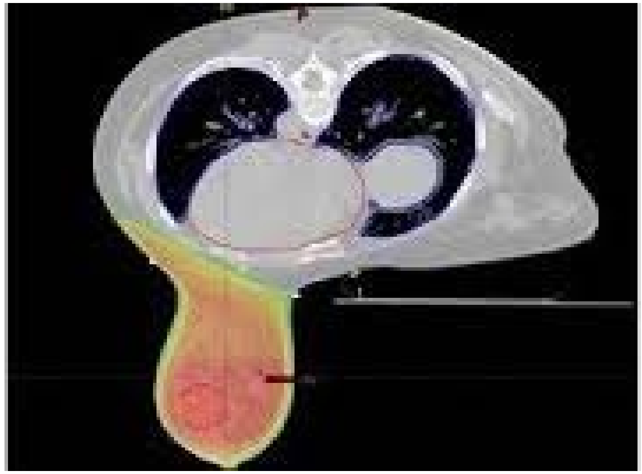
- Target volume
  - ➢ Whole or Partial Breast
  - ➢ Boost

- Breathing motion
  - ➢ DIBH
  - ➢ Free breathing

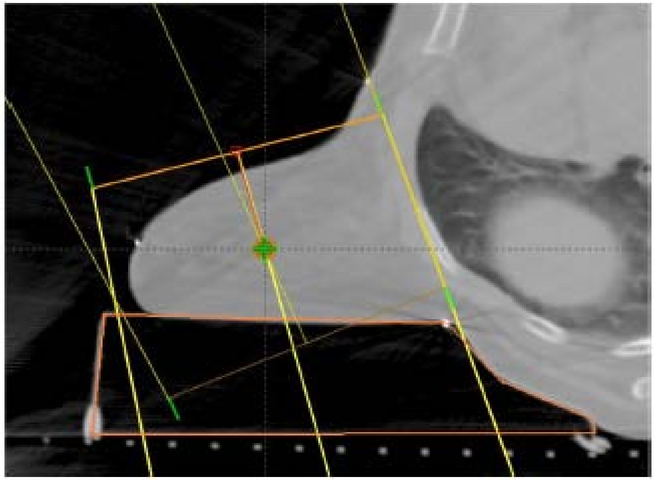
Site Specific Points to Consider

- Simulation
  - Slice thickness, scan length
  - 3D or 4D
- Planning technique
  - //op, 3DCRT, IMRT, VMAT
  - SIB
  - Multiple fields
  - Junction technique or monoiso
    - SCF, IMC

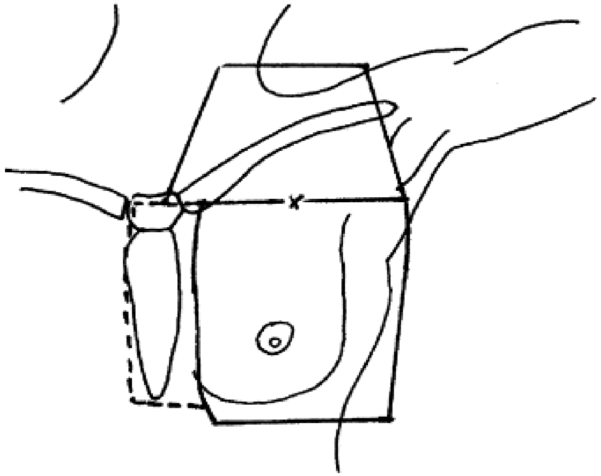
All of these factors will influence how we image this patient group



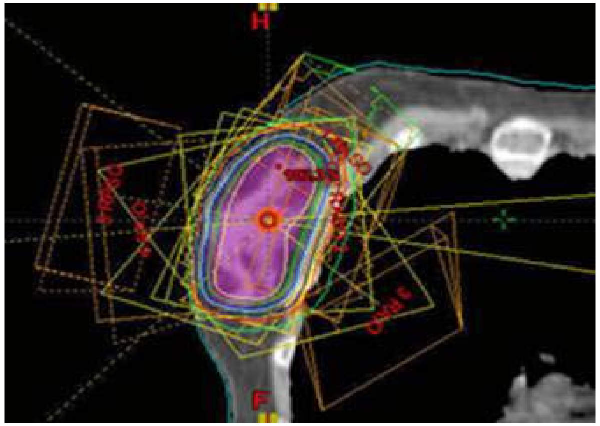
Prone



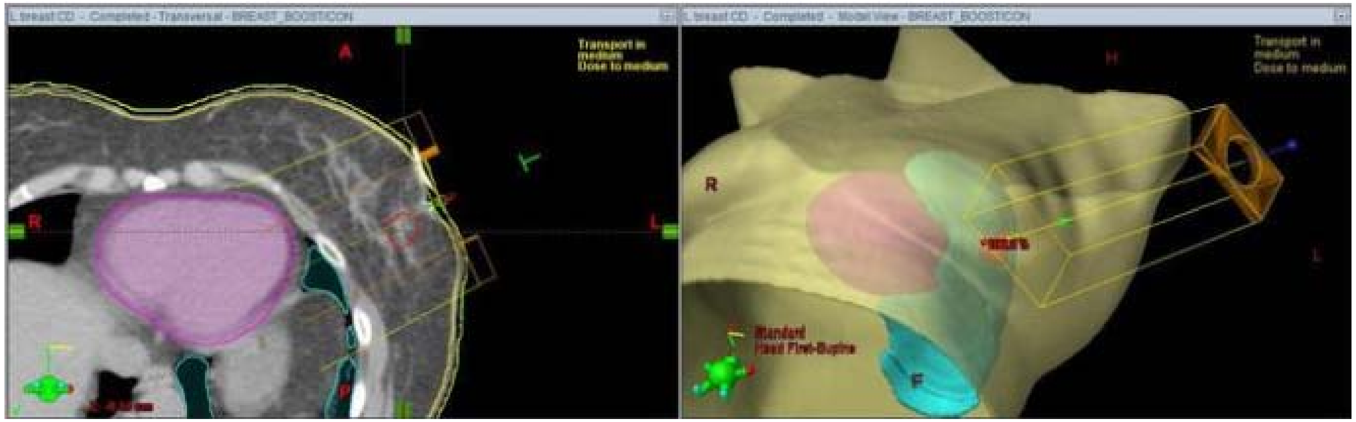
Lateral decubitus



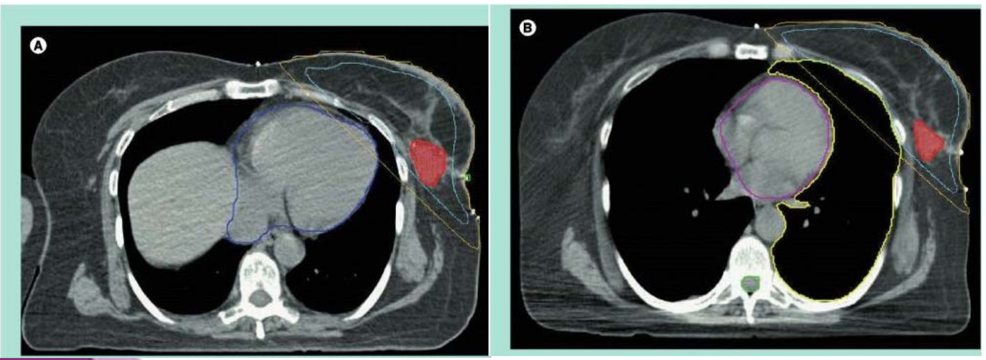
Supine: IMC (ph/e junx)



APBI



Electron boost to surgical bed



DIBH

IMRT and VMAT

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On Treatment Verification

- ***Look! There is it! I can see the target!***
  - Whole breast RT

- Confirm gross external positioning information
  - Light field
  - FSDs

- What else do we want to see?
  - Contour changes
  - Tumour bed
  - Seroma
  - Surgical clips

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Match Anatomy

- Breast contour
- Lung volume
- Ribs
- Seroma
- Surgical Clips

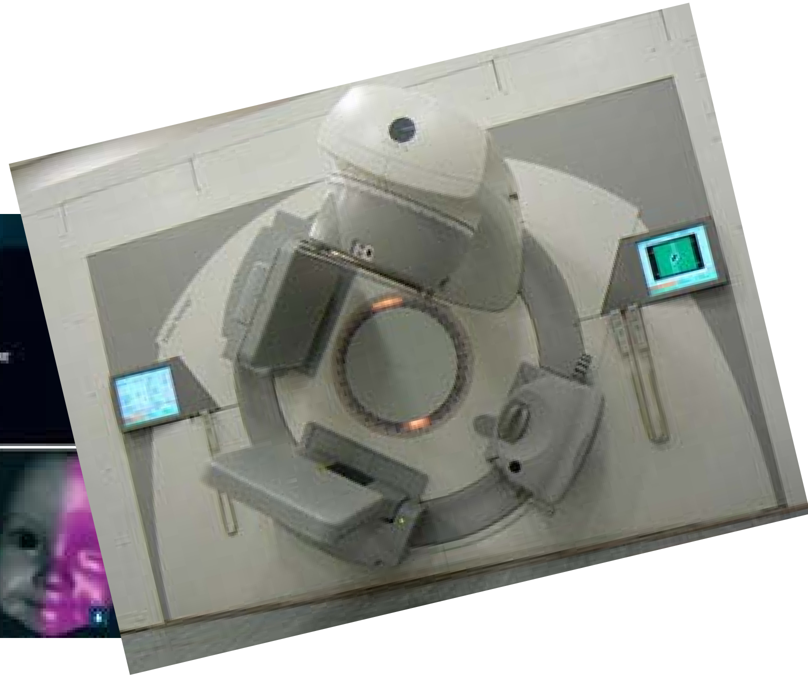
Surgical Clips

- Act as a surrogate for the tumour bed
- Improve accuracy in delineation and used for positional verification
- Clip insertion after breast conservation surgery
- Caution artefact on planning CT
    - ➢ Impact on electron beam dosimetry?

- Either use directly in match or export isodose lines from planning to ensure they fall within required dose
    - ➢ Donovan *et al.*, 2012
    - ➢ Similar to Post Prostatectomy clips

On Treatment IGRT

- Largely driven by what is available to you
- Make the most of it
- Consider the clinical impact
  - ➢ Tighter margins?
  - ➢ Reduced Toxicity?



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MV 2D

- Widely available
- Ability to acquire continuous “snapshot” during the fraction
- Will provide field border information
- Will provide assessment of lung volume, breast contour
- Adequate for whole breast RT with standard fractionation
- Typically 5mm tolerance is acceptable
- Difficult to visualise surgical clips
- Depending on lung in field, generally sufficient information from a “single” acquisition

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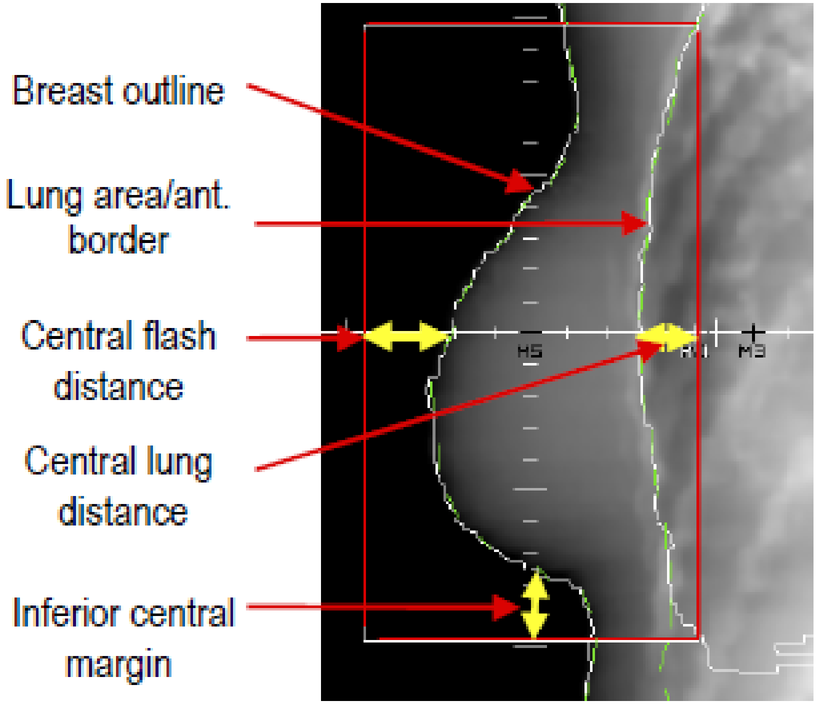
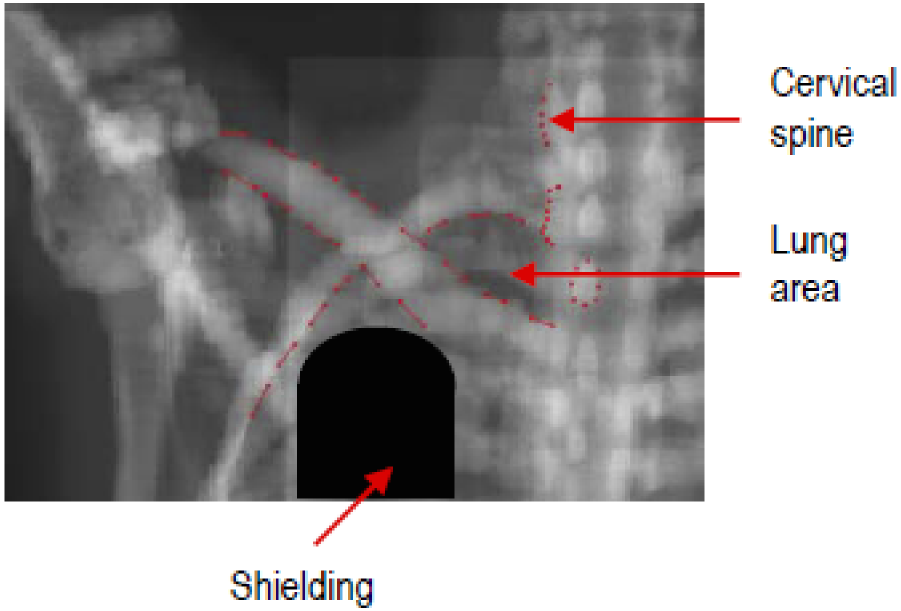
MV 2D





On Target: Ensuring geometric accuracy in radiotherapy. 2008

2D/2D (Paired orthogonal 2D)

Used for isocentre position check

Field border information is not displayed

A minimum requirement for all advanced techniques

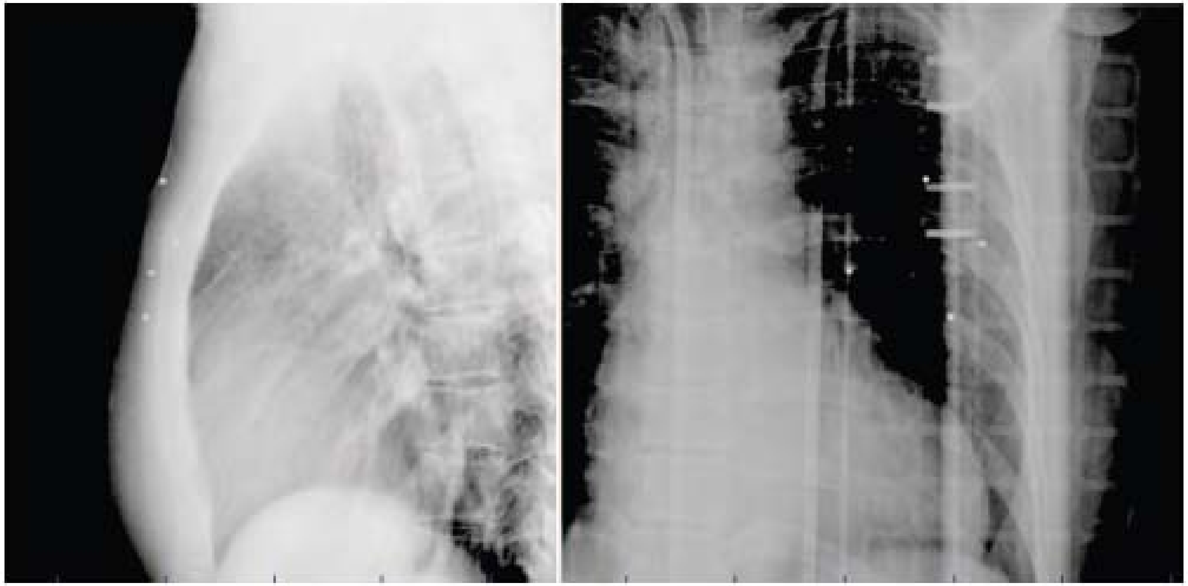


FIG. 2. Anterior–posterior and lateral paired kV images of a patient on treatment day 1. *Yue at al., 2013*

kV decreases dose burden and increases image quality

3D (CBCT)

- Provides:
  - Isocentre position verification
  - Internal soft tissue anatomy
  - Clearer image of clips
  - Information on changes in target during treatment
    - Seroma changes

- Consider:
  - Dose
  - Collision risk
  - Ease of accurate registration and match

3D (CBCT)

- Limitations
  - Collision
  - Field of view
  - Increased dose to contra lateral breast

- CBCT not acquired at the isocentre to avoid collision
- Then once matched the shift includes the offset from isocentre position
- Adds time and potential errors
- Donovan et al. (2012) stipulate limitations on iso position to account for this
- Half bowtie filter (Varian OBI) increases FOV in longitudinal direction

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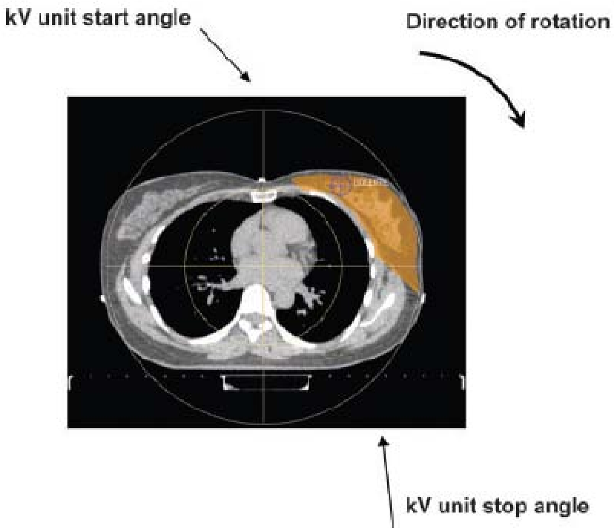
3D (CBCT): Clarity of Surgical Clips



Note: size of clip box

Isodose lines have been exported to confirm coverage

Donovan et al., 2012

3D (CBCT): Clarity of Surgical Bed

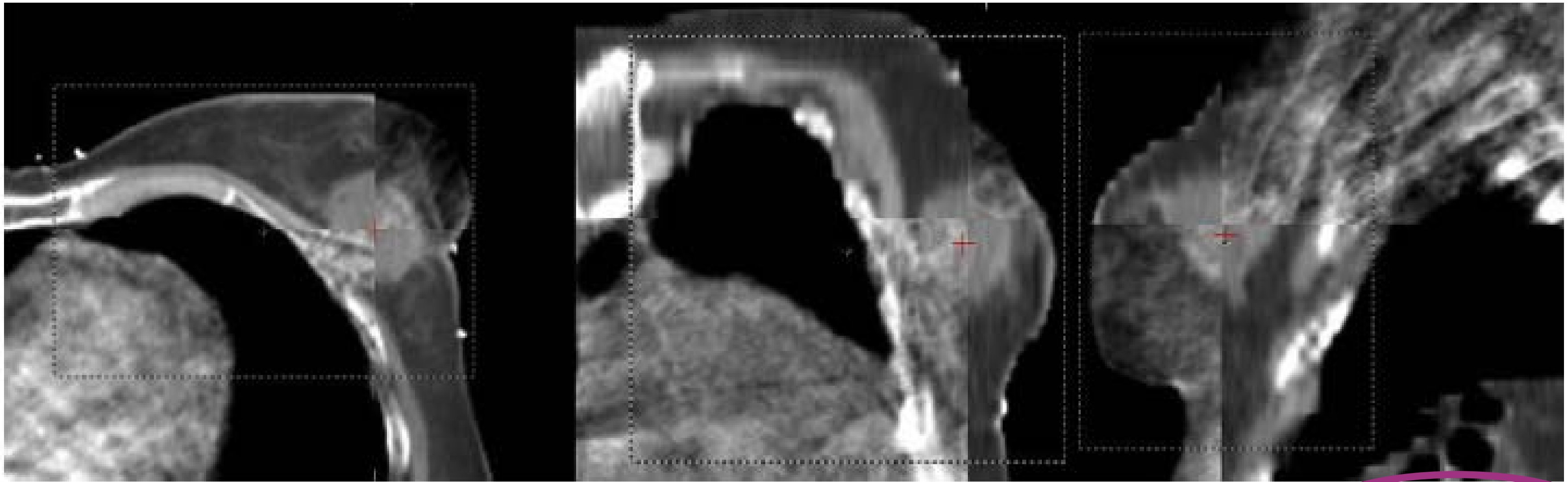


Fig. 2. Match of planning computed tomography (CT) and cone-beam CT (CBCT) images after bony (sternum and rib) anatomy registration. A bony anatomy rigid registration was performed based on image data in a user-defined, three-dimensional, box-shaped region of interest (white dashed line) using a chamfer matching algorithm.

Topolnjak et al., 2009

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Video-Based Surface Mapping

- Whole surface shape matching

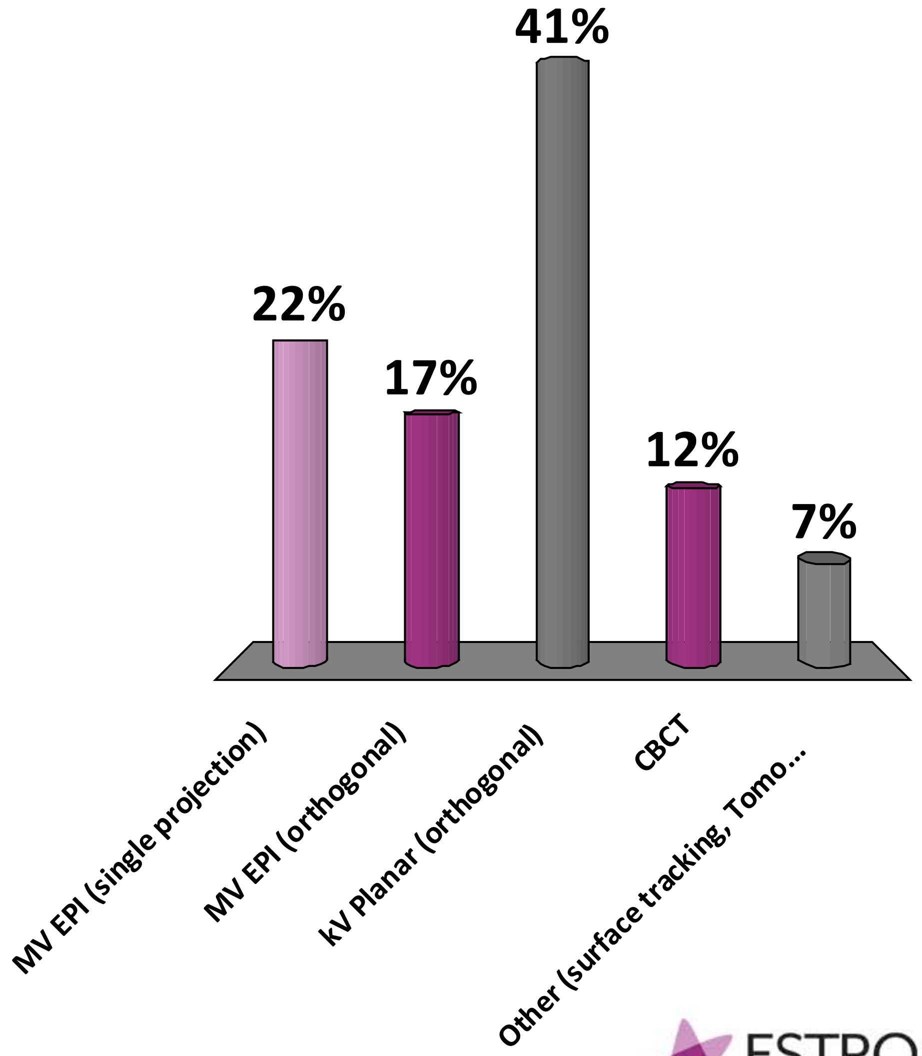
- Provides surface anatomy information and can demonstrate the impact of breathing

- Can this be correlated to provide shift/positional information?
  - ➢ Often used in conjunction with other imaging devices

- No additional radiation

In my clinical department, for standard WBRT, we image using:

A. MV EPI (single projection)
B. MV EPI (orthogonal)
C. kV Planar (orthogonal)
D. CBCT
E. Other (surface tracking, Tomotherpy)



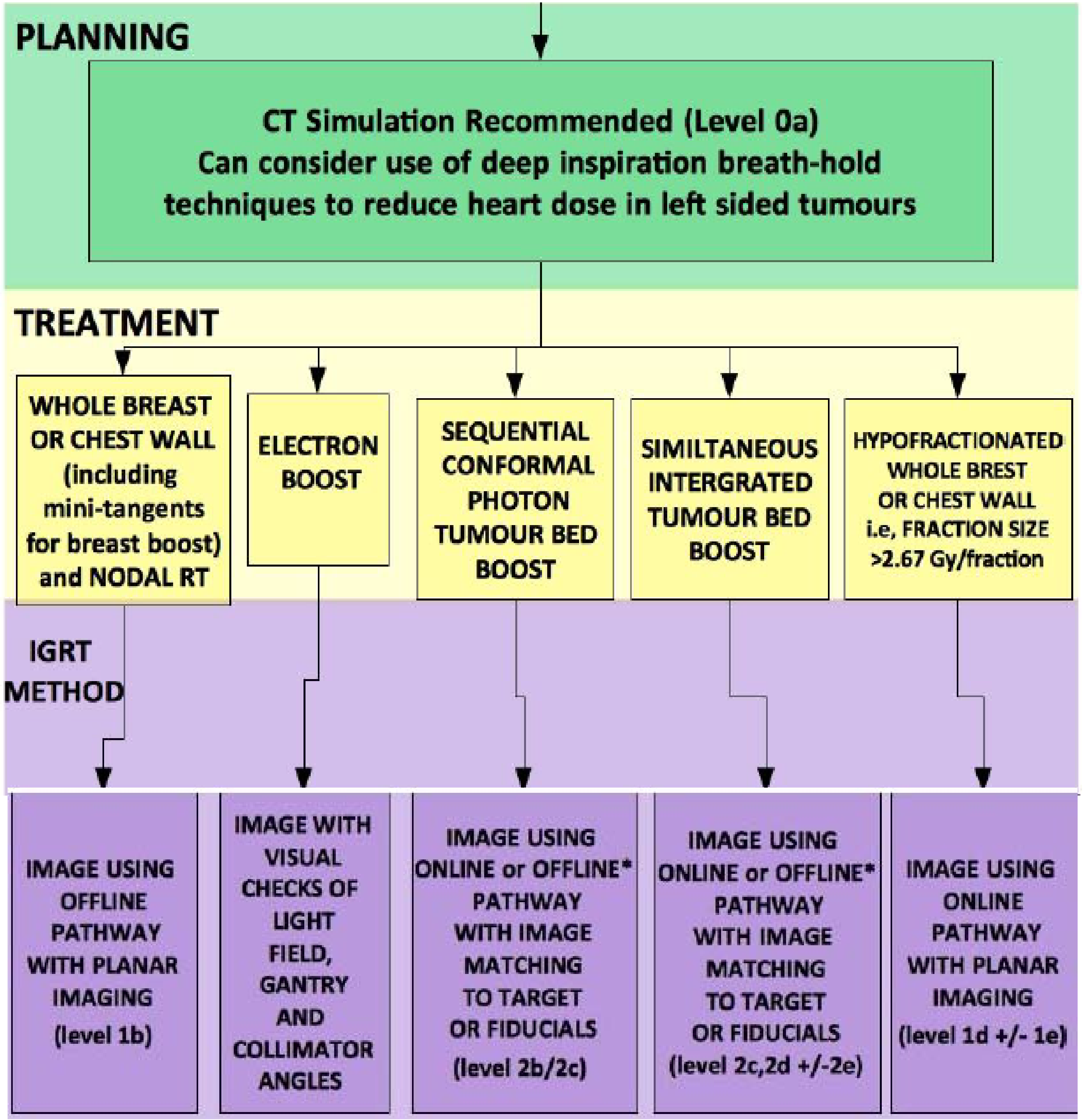
A Look at the Literature

Table 4.5 Articles that discuss doses, anatomy matching methods and seroma visualisation

KV imaging Method	Author	Matched Method	Sample Size>20	Seroma Visible	Surgical clips	Auto co-registration	Reported imaging dose to patient.	Safe to acquire at iso centre
CBCT	Jain et al.(2009)	Bones	No	No	No	Yes	Yes	No
	White et al. (2007)	Lung/external contour	Yes	Yes	No	Potential	Yes	Yes
	Kim et al. (2007)	Clips	No	Yes	Yes	Yes	Yes	No
	Topolnjak et al. (2010)	Sternum/ribs	Yes	Unknown	No	Yes	No	Unknown
	Yang et al.(2010)	Unknown	No	Yes	No	Yes	Yes	Unknown
	Donovan et al.(2012)	Clips	Yes	Yes	Yes	Yes	Yes	Yes
kV*	Yue et al. (2011)	Bony to gold fiducials	Yes	Yes	Yes	Unknown	No	Unknown
	Lawson et al. (2008)	Bony	Yes	Unknown	Yes	No	Yes	Unknown
kV* vs. CBCT	Fatunase et al. (2008)	Bones, then soft tissue	No	Yes	Yes	No	Yes	No for both.

*orthogonal kV imaging

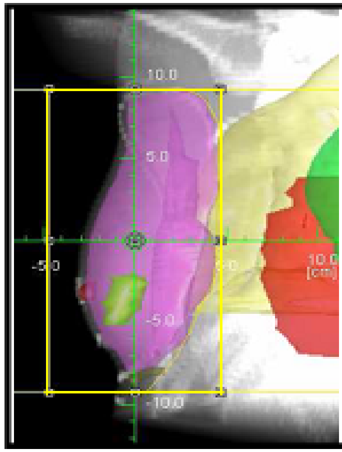
L. Lewis Improving Radiotherapy for Breast Cancer: Identification of the tumour bed and characterisation of target volume changes. 2013 MSc Thesis, available online



NHS National Radiotherapy Implementation Group Report_IGRT 2012

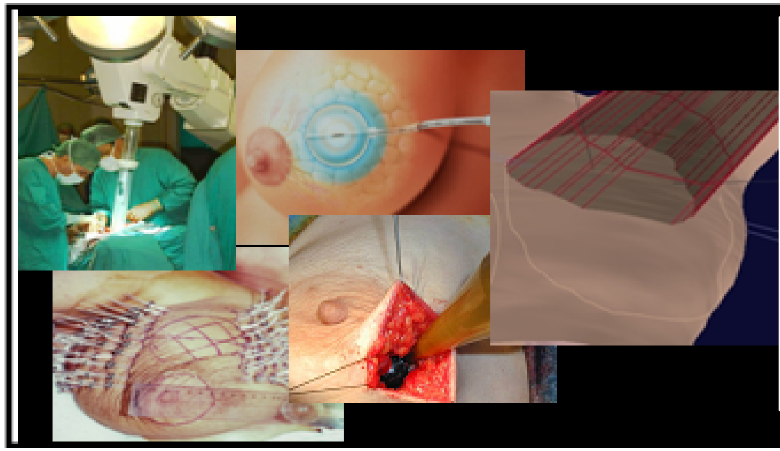
Therapeutic strategy: Which radiotherapy?

Two changing practice concepts have modified the standard whole breast irradiation 50Gy +/- boost has been replaced



Hypo fractionated whole breast irradiation

Whelan NEJM 2010; START A and B Lancet Oncol 2008



Accelerated partial breast irradiation

Vaidya Lancet 2010; Bourgier IJROBP 2010 ; Lemanski IJROBP 2010; Taghian IJROBP 2005; Polgar IJROBP 2004 ;Vicini IJROBP 2003; Formenti IJROBP 2003;

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IGRT for *(Supine)* APBI: What are people doing?

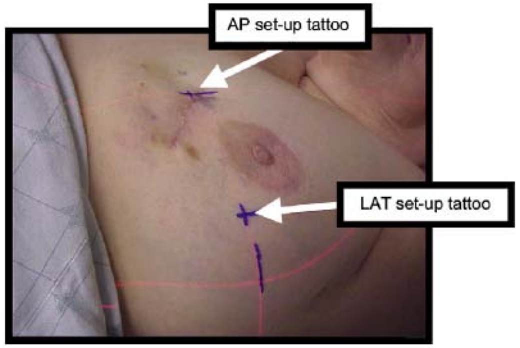

Fig. 1. Patient with skin marker crosshairs representing isocentric setup at surgical cavity.

Int. J. Radiation Oncology Biol. Phys., Vol. 76, No. 2, pp. 528–534, 2010

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0360-3016/10/$–see front matter

doi:10.1016/j.ijrobp.2009.02.001

CLINICAL INVESTIGATION — **Breast**

CLINICAL EXPERIENCE WITH IMAGE-GUIDED RADIOTHERAPY IN AN ACCELERATED PARTIAL BREAST INTENSITY-MODULATED RADIOTHERAPY PROTOCOL

Charles E. Leonard, M.D.,* Michael Tallhamer, M.S.,* Tim Johnson, Ph.D.,* Kari Hunter, C.M.D.,* Kathryn Howell, M.D.,* Jane Kercher, M.D.,† Jodi Widener, M.D.,† Terese Kaske, M.D.,‡ Devchand Paul, M.D.,§ Scot Sedlacek, M.D.,§ and Dennis L. Carter, M.D.*

*Rocky Mountain Cancer Centers, Littleton, CO; †Arapahoe Surgical Associates, Littleton, CO; ‡Sally Jobe Diagnostic Breast Center, Greenwood Village, CO; and §Rocky Mountain Cancer Centers, Rose Hospital, Denver, CO

2010
One of the first reports on IGRT APBI

Orthogonal **MV** images taken **daily**

Imaging dose included in plan

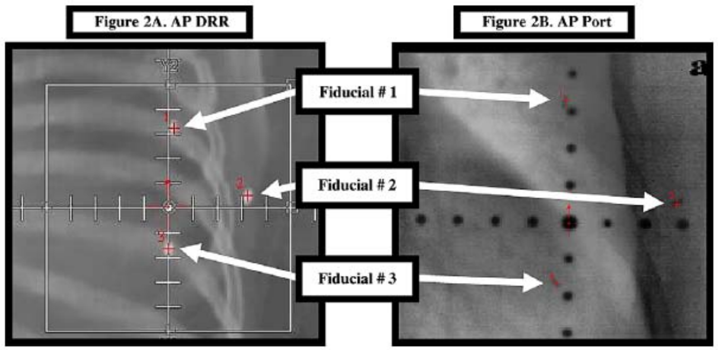

Fig. 2. Anterior/posterior digital reconstruction radiograph and corresponding port film (arrows indicate respective fiducial location).

Table 5. Individual and total dose contribution of AP and lateral port films for 5 patients over the course of accelerated partial breast radiotherapy to the isocenter and 100% of PTV using image-guided radiotherapy

	ISO dose (cGy)			
Patient	AP	Lateral	Total	100% PTV
1	30.7	25.3	56	45
2	28.1	30.7	58.8	48
3	26.4	30.1	56.5	50
4	29.7	28	57.6	49
5	30.3	29.9	60.2	54
As a percentage of prescription dose of 3,850 cGy				
1	0.8	0.7	1.5	1.2
2	0.7	0.8	1.5	1.3
3	0.7	0.8	1.6	1.3
4	0.8	0.7	1.5	1.3
5	0.8	0.8	1.6	1.4

IGRT for *(Supine)* APBI: What are people doing?

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CLINICAL INVESTIGATION **Breast**

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*Rocky Mountain Cancer Centers, Littleton, CO; †Arapahoe Surgical Associates, Littleton, CO; ‡Sally Jobe Diagnostic Breast Center, Greenwood Village, CO; and §Rocky Mountain Cancer Centers, Rose Hospital, Denver, CO

Because of the reliability of these fiducial markers, we have reduced the size of port films for IGRT. Before the use of fiducials, reviewing physicians required visualization of the surrounding anatomy, specifically the ribs, clavicle, and sternum. This required the more traditional double-exposure port with the second larger field exposure. When it is not necessary to view surrounding anatomical landmarks because of fiducial placement in proximity to the target cavity, it is possible to reduce port field sizes.

cerning their use in partial breast treatment. This could suggest that margins might be reduced for a smaller PTV volume than is used currently. Up to this time, an additional margin of 1 cm from the CTV had been used. However, owing to the use of these fiducial markers, this additional margin may be reduced by 5 mm. This would be well within two standard deviations of the average mean error of our IGRT experience.

IGRT for *(Supine)* APBI: What are people doing?

Distinction b/w surgical clips and fiducials

Textured gold fiducials for stability and visualisation

Daily orthogonal MV EPI

Published 2012

Clinical Investigation: Breast Cancer

Validating Fiducial Markers for Image-Guided Radiation Therapy for Accelerated Partial Breast Irradiation in Early-Stage Breast Cancer

Catherine K. Park, M.D., M.P.H.,* Jakub Pritz, M.S.,† Geoffrey G. Zhang, Ph.D.,* Kenneth M. Forster, Ph.D.,* and Eleanor E.R. Harris, M.D.*

*From the *Department of Radiation Oncology, H. Lee Moffitt Cancer Center & Research Institute, Tampa, FL; and †Department of Physics, University of South Florida, Tampa, FL*

Received Jan 12, 2011, and in revised form Jun 22, 2011. Accepted for publication Jul 18, 2011

Visualisation of fiducials on 100% MV images
Centre of fiducials correlated to centre of seroma

When matching to fiducials margins can be reduced to 6mm compared to bone (10mm)

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Assessment of changes in the seroma cavity over time based on fiducial displacement

IGRT for *(Supine)* APBI: What are people doing?

Tracking the dynamic seroma cavity using fiducial markers in patients treated with accelerated partial breast irradiation using 3D conformal radiotherapy

Ning J. Yue and Bruce G. Haffty
Department of Radiation Oncology, The Cancer Institute of New Jersey, UMDNJ/Robert Wood Johnson Medical School, New Brunswick, New Jersey 08903

Thomas Kearney and Laurie Kirstein
Division of Surgical Oncology, The Cancer Institute of New Jersey, UMDNJ/Robert Wood Johnson Medical School, New Brunswick, New Jersey 08903

Sining Chen
Department of Biostatistics, The Cancer Institute of New Jersey, UMDNJ/School of Public Health, New Brunswick, NJ 08901

Sharad Goyal[a)]
Department of Radiation Oncology, The Cancer Institute of New Jersey, UMDNJ/Robert Wood Johnson Medical School, New Brunswick, New Jersey 08903

(Received 24 January 2012; revised 26 December 2012; accepted for publication 27 December 2012; published 28 January 2013)

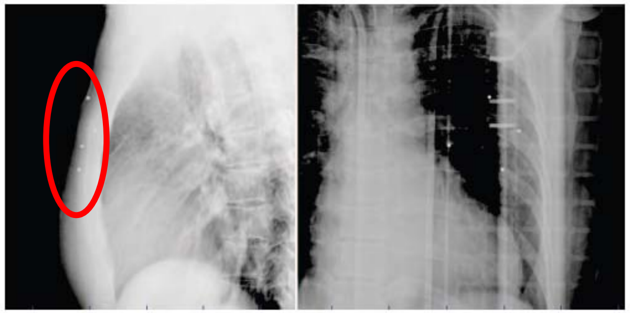

FIG. 2. Anterior–posterior and lateral paired kV images of a patient on treatment day 1.

Daily paired kV images

Radiation appears to have minimal impact of seroma size (physiological instead)

Recommend RT to start 45-60 days post surgery

IGRT for *(Supine)* APBI: What are people doing?

Aim: to assess the residual and intrafraction errors

PTV = CTV+10mm
5 fld non coplanar
95%/95%

Cai *et al. Radiation Oncology* 2010, 5:96
http://www.ro-journal.com/content/5/1/96

RADIATION ONCOLOGY

RESEARCH Open Access

Impact of residual and intrafractional errors on strategy of correction for image-guided accelerated partial breast irradiation

Gang Cai[1†], Wei-Gang Hu[1*†], Jia-Yi Chen[1*], Xiao-Li Yu[1], Zi-Qiang Pan[1], Zhao-Zhi Yang[1], Xiao-Mao Guo[1], Zhi-Min Shao[2], Guo-Liang Jiang[1]

Pre and post fx XVI
Grey value match
Manual adjustment
2-3 mins
Matched by RO

CBCT does not guarantee absolute accuracy
13mm margin required to account for initial setup and intrafraction errors

Take Home Message

- There is an abundance of imaging technologies and strategies available for this site

- IGRT for breast is largely dependant not only what is available to you, but the planning technique that is used

- Advanced treatment techniques require more sophisticated imaging techniques
  - APBI, IMRT, VMAT

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Image Registration and Evaluation: Part 2 CBCT (Varian)

Liz Forde, MSc (RTT)
Assistant Professor
The Discipline of Radiation Therapy
School of Medicine
Trinity College Dublin

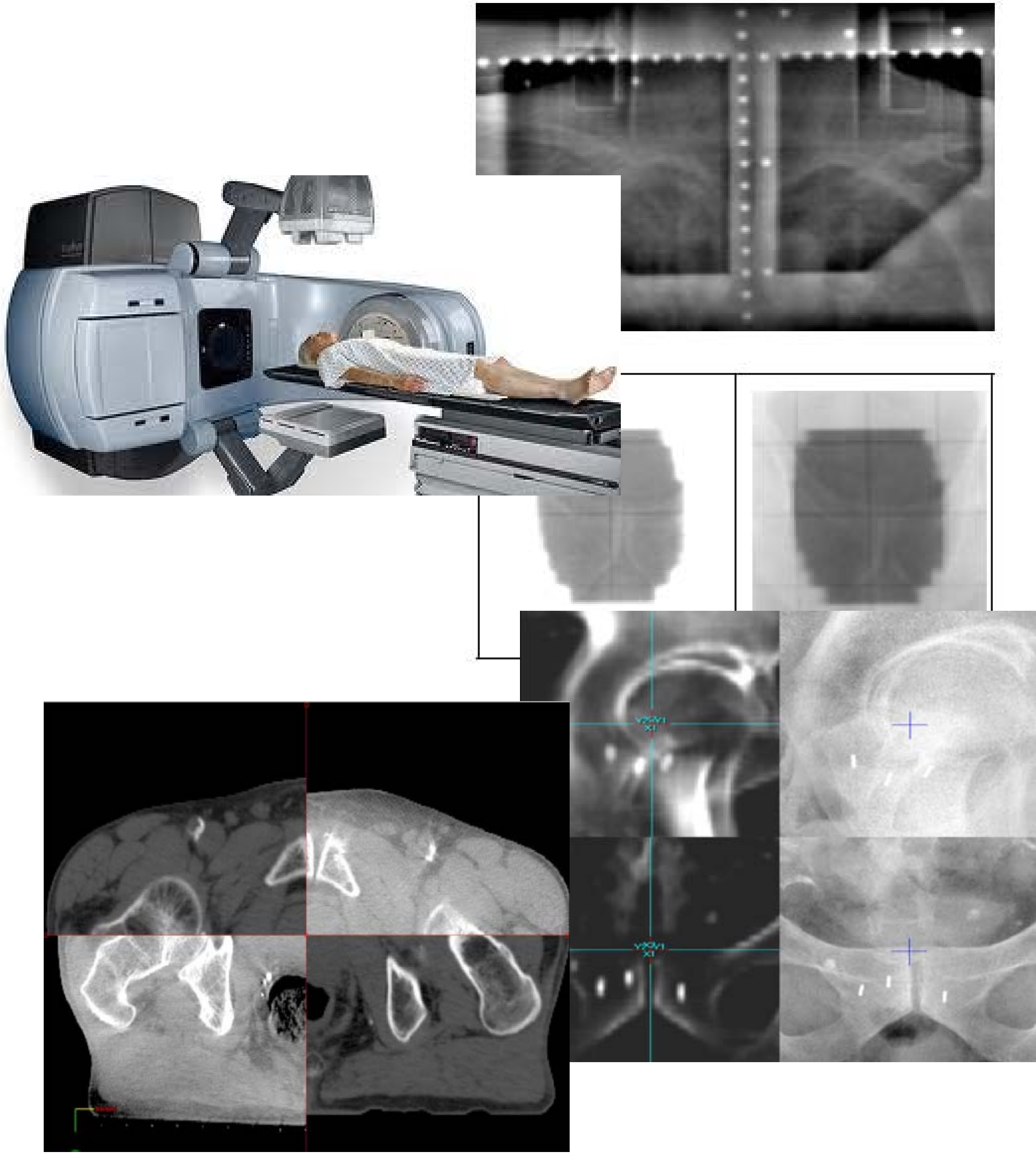
Learning Outcomes

- Identify the key features of the Varian OBI system
    - 2D and 3D image acquisition, registration and verification
- Outline the CBCT acquisition, registration and evaluation process
- Discuss what influences CBCT image quality
- Identify appropriate match structures for the main tumour sites
    - kV 2D/2D and CBCT
- Discuss possible clinical scenarios that require troubleshooting

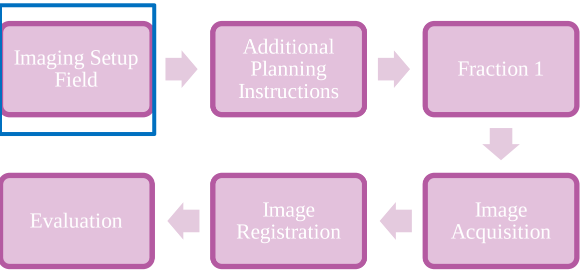
Key Features of Varian OBI

- 2D
  - MV and kV
- 2D/2D
  - MV and kV
- 3D
  - kV
- Fluoroscopy (2D + time)

- Remote couch shift

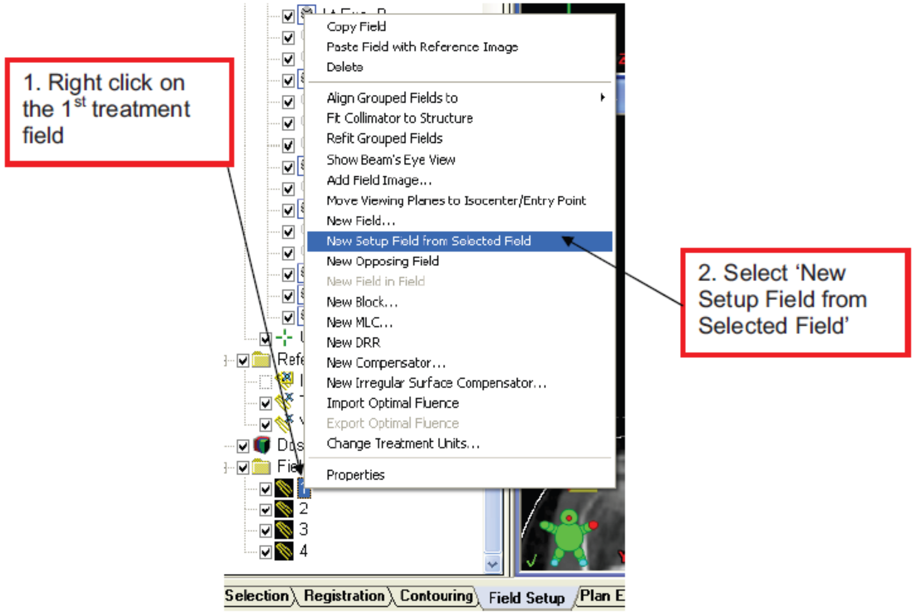


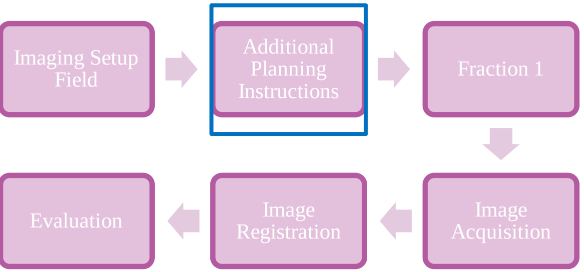
The IGRT Process



IGRT Setup in Planning

- Create setup fields in planning
- For CBCT no DRR needs to be created
  - For 2D ensure DRR quality is adequate and displays realistic structures
- Consider the position of the isocentre
  - CBCT may need to shift laterally for clearance
  - You will be prompted on the linac





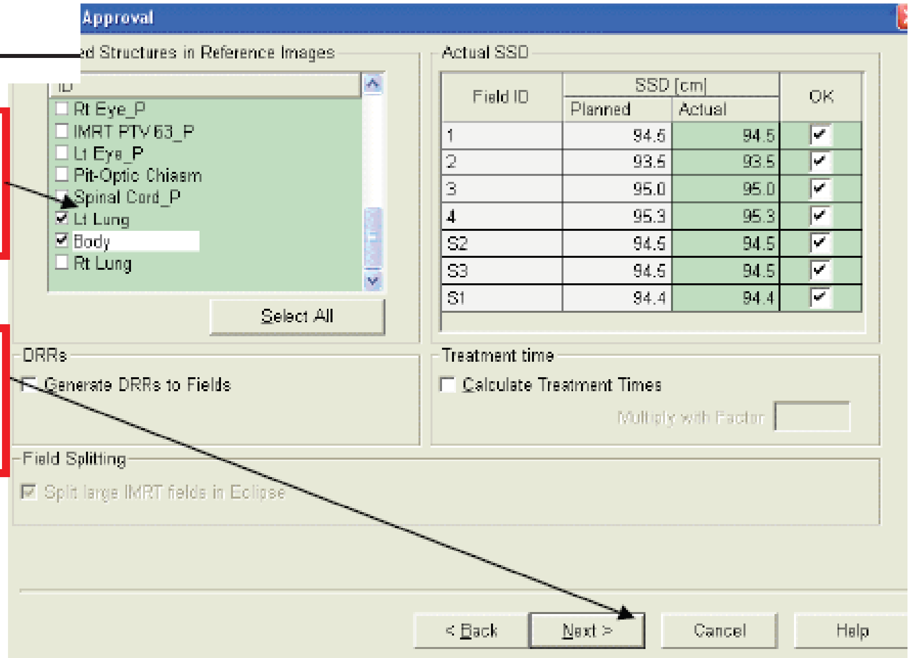
IGRT Setup in Planning

- Additional contours to be outlined and/or “sent across” for image verification

Treatment Area	Imaging Type	Extra Contouring
All treatment areas	CBCT, kV or MV	PTV
All treatment areas	CBCT	FSD tolerance rings (see site specific planning protocols for instructions and size of the rings)
Chest	kV or MV or CBCT	Carina
Abdomen	kV or MV or CBCT	Carina
Breast/Chest Wall	MV	Lung (treatment side) and Body
Prostate	CBCT	Convert dose to structure (see prostate protocol for instructions)
Post-Prostatectomy	CBCT	Convert dose to structure (see prostate protocol for instructions)

1. Select the structures to be projected

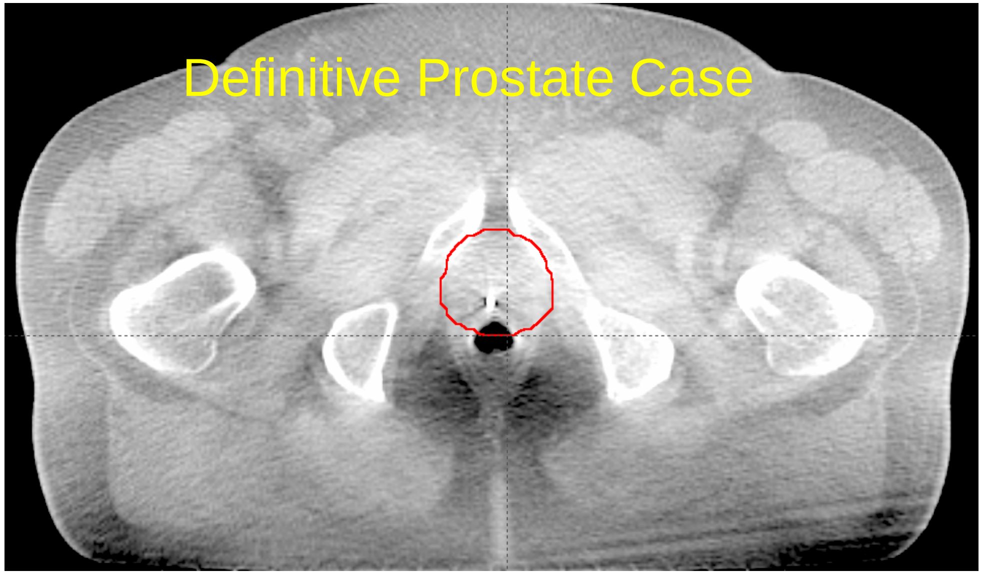
2. Select ‘Next’



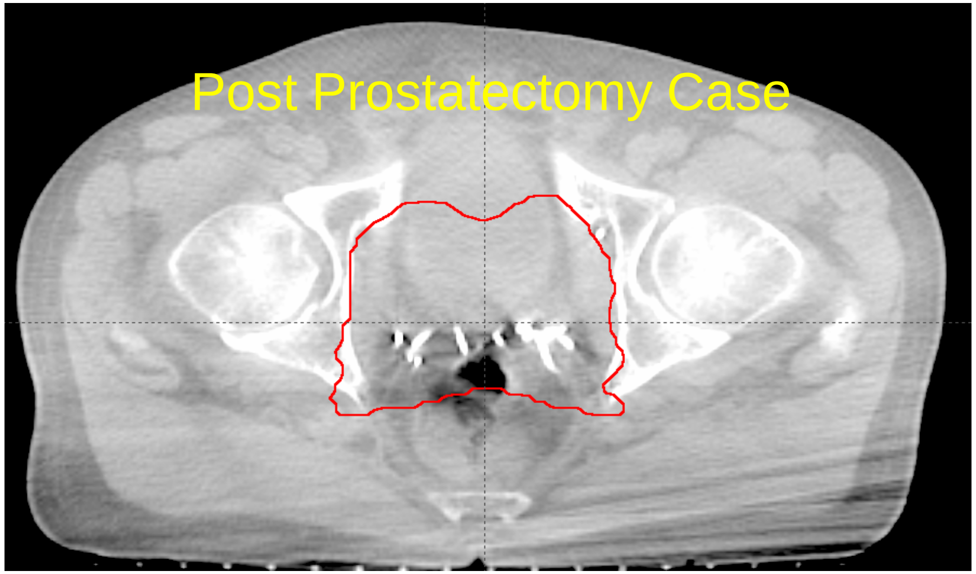
IGRT Setup in Planning

- Additional contours to be outlined and/or “sent across” for image verification
  - ➢ In Field Setup (Eclipse TPS) “Convert isodose line to structure”

80Gy isodose line

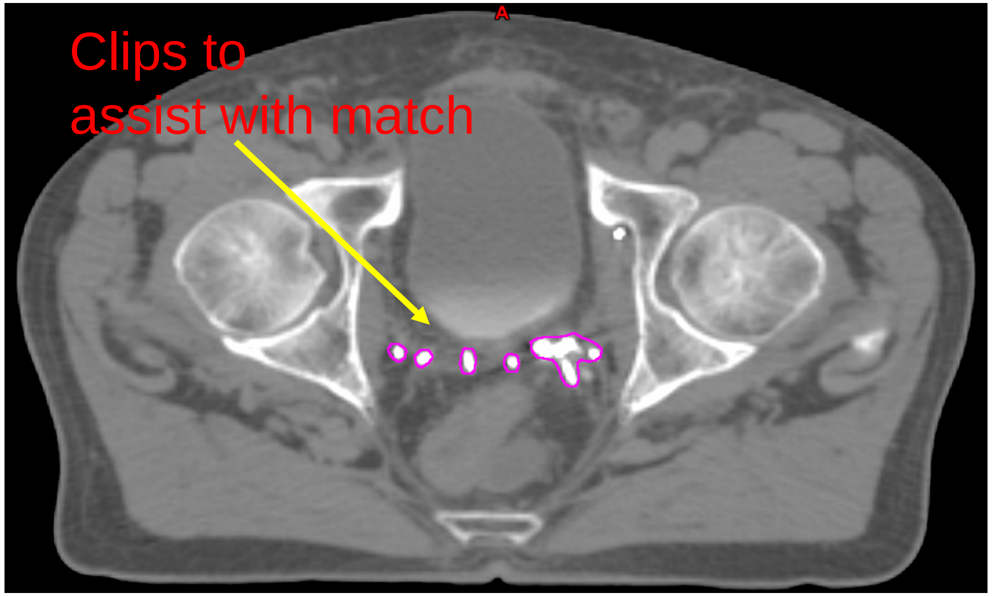


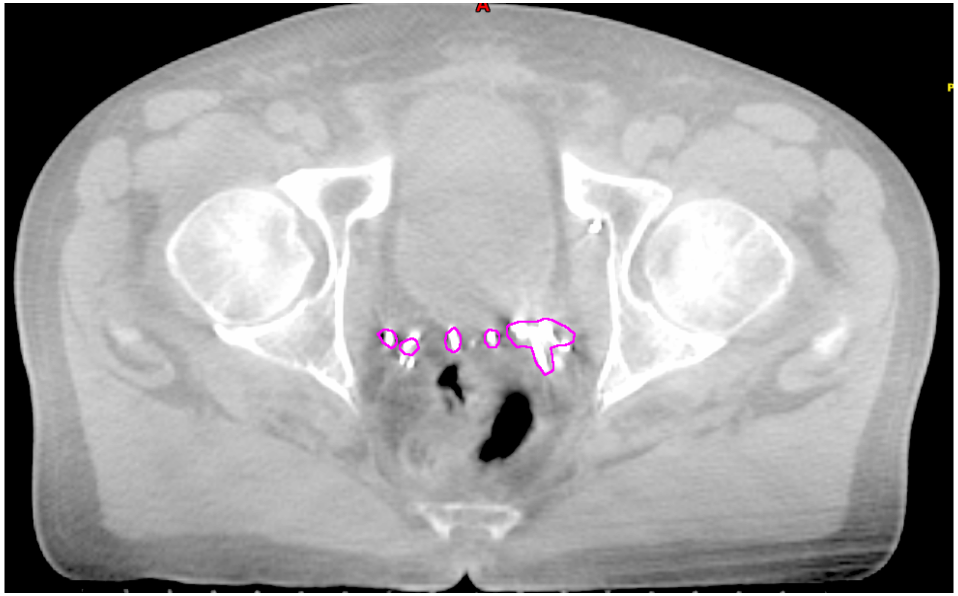
68Gy isodose line



IGRT Setup in Planning

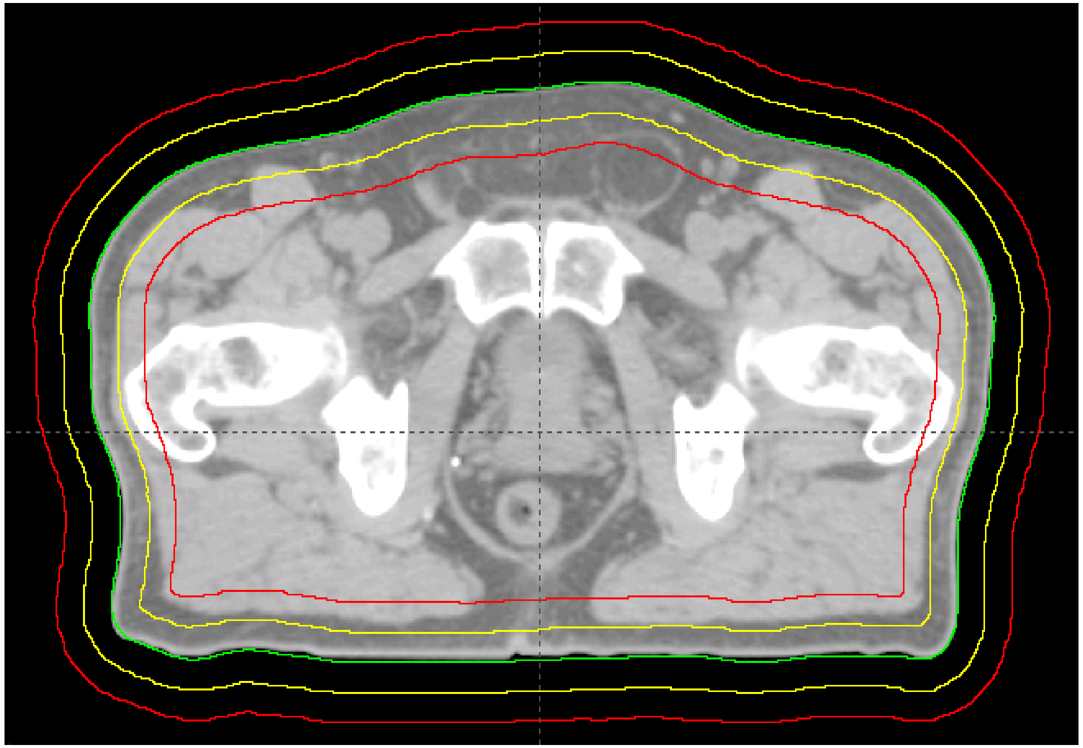
- Additional contours to be outlined and/or "sent across" for image verification
  - ➢ In Contouring Workspace in Eclipse TPS

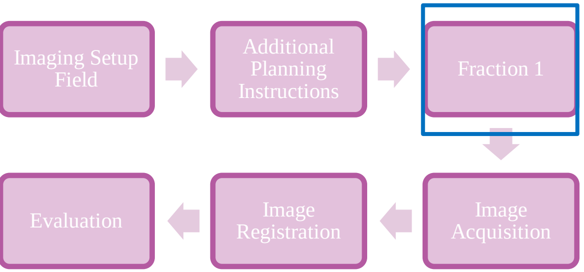




IGRT Setup in Planning

- Additional contours to be outlined and/or “sent across” for image verification
  - ➢ In Contouring Workspace in Eclipse TPS “Wall Extraction” tool from Body contour





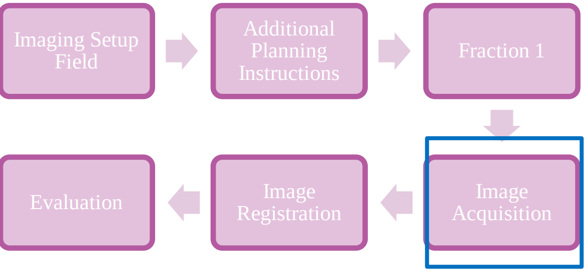
Fraction 1 Considerations

- Clearance

- Education
  - Who should be present for first day scan?
  - RO, MP, RTT responsible for plan, Senior RTT

- Documentation!
  - Anything weird and wonderful
  - Structures to include/avoid

- Set VOI box



The Image Acquisition Process - CBCT

1. Select correct bow tie filter for treatment site

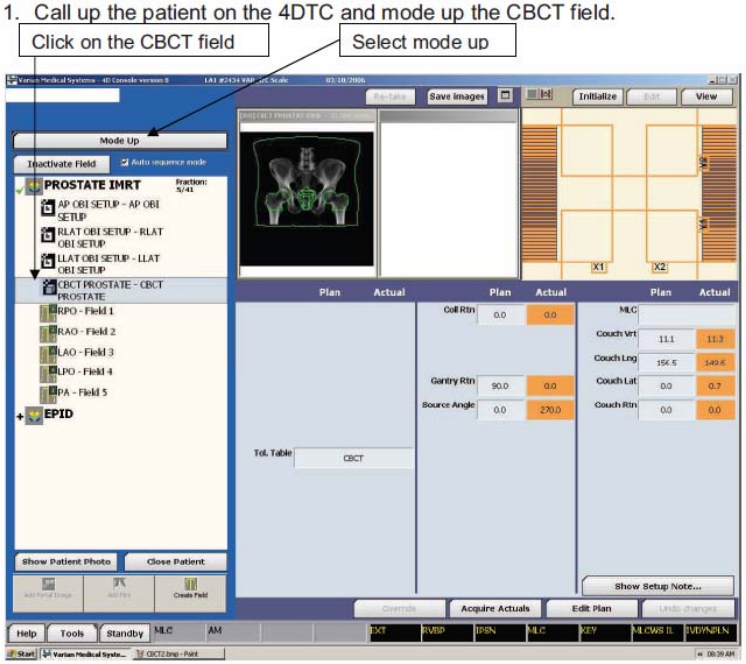
2. On fraction 1 consider checking rotation/clearance whilst in room

3. Mode up CBCT setup imaging field
    1. Note this is incorporated in the individual patient's plan

Scan Name	Gantry Rotation Required	Bow-tie Filter Required	Treatment sites to be used on	Field of View
Standard-dose head	200	Full	-	24cm
Low-dose head	200	Full	-	24cm
High-quality head	200	Full	Head & Neck Brain	24cm
Pelvis	360	Half	Pelvis (includes: Prostate Rectum Bladder Gynecological)	45cm
Pelvis spotlight	200	Full	-	24cm
Low-dose thorax	360	Half	Chest Abdomen	45cm

NB: See pictures below to distinguish between the bow-tie filters

1. Call up the patient on the 4DTC and mode up the CBCT field.



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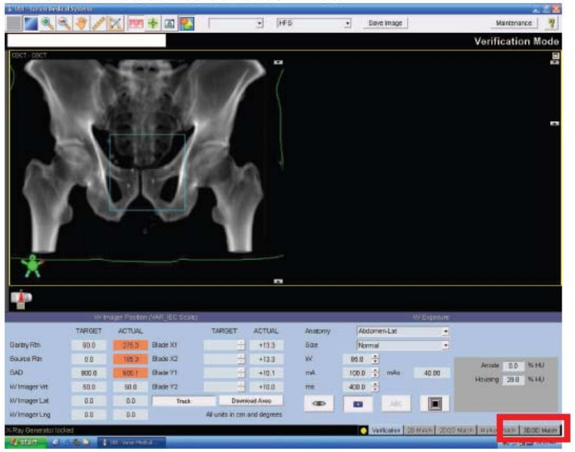
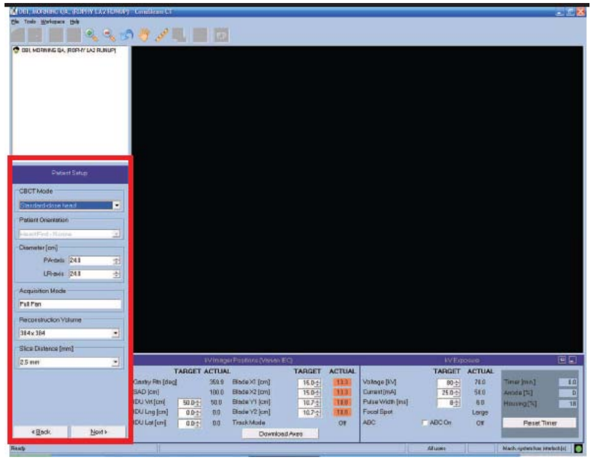
The Image Acquisition Process - CBCT

4. Select 3D/3D match



5. Acquire new scan
6. Complete details
   1. Slice thickness
   2. Orientation
   3. Full fan or half fan



7. Start scan
8. Accept and export

CBCT Image Quality

- What impacts on image quality?
  - CBCTs use a large flat panel detector – increases scatter
  - Permanent anti scatter filter built into detector panel

Scatter decreases image contrast, increases noise, possible registration errors and also patient dose

↓

CT Numbers (HU) affected

CBCT Image Quality

- Machine characteristics
  - MV or kV
  - Acquisition time
  - Scan length
  - Filters used
    - Bow Tie filter added to source panel

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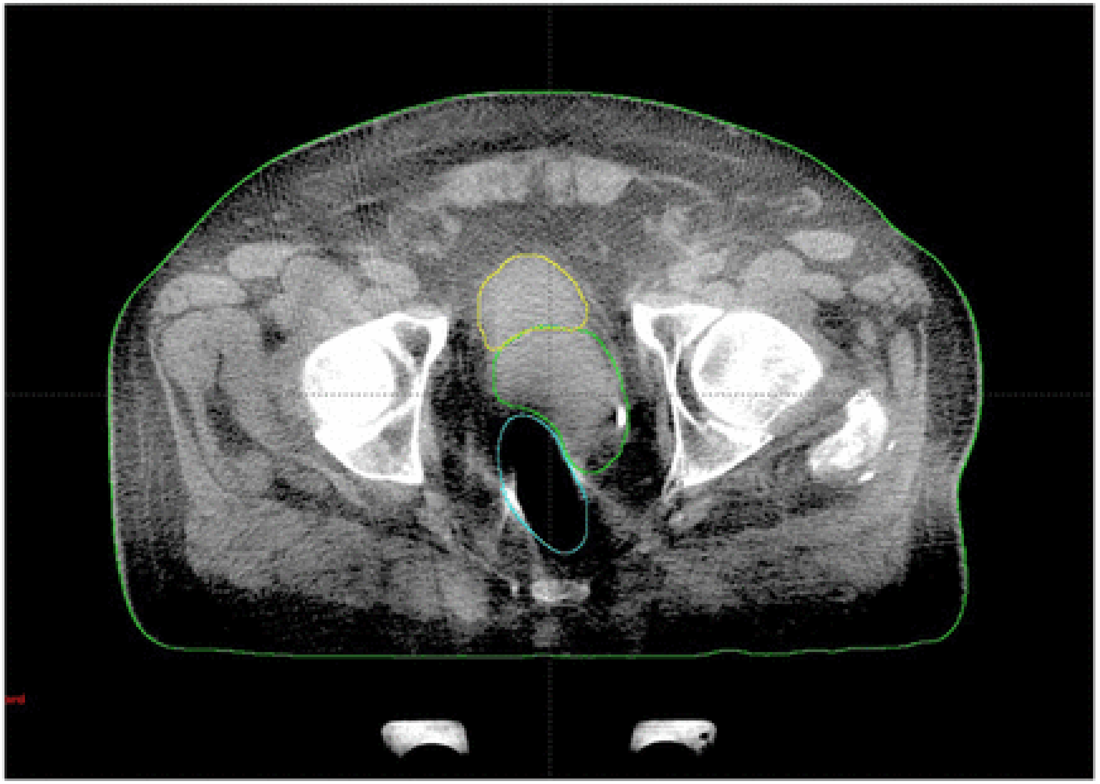
Bow Tie Filters

- Decrease patient dose
- Two types used in different modes: Full fan or half fan mode
- Full fan mode: image is acquired at the central axis on the detector panel and images acquired from 200^0 rotation
- Half fan mode: the detector is offset laterally acquiring only half of the projection of the patient
  - ➢ Detector panel is offset laterally, rotates a full 360^o captures only half a projection and reconstructs the image from that
  - ➢ Recommended for larger FOV (pelvis)
  - ➢ Half fan filters result in the greatest HU discrepancy b/w CT and CBCT (Ding *et al.*, Yoo and Fang-Fang, Seet *et al.*)

CBCT Image Quality

- Patient characteristics
  - Size
    - Poor image quality as the patient contour approached the limits of the FOV
  - Tissue heterogeneity
  - High dense structures
    - Hip prosthesis
  - Motion
    - Increased risk of motion with slow scan time
    - E.g. peristalsis, breathing and gas

CBCT Image Quality

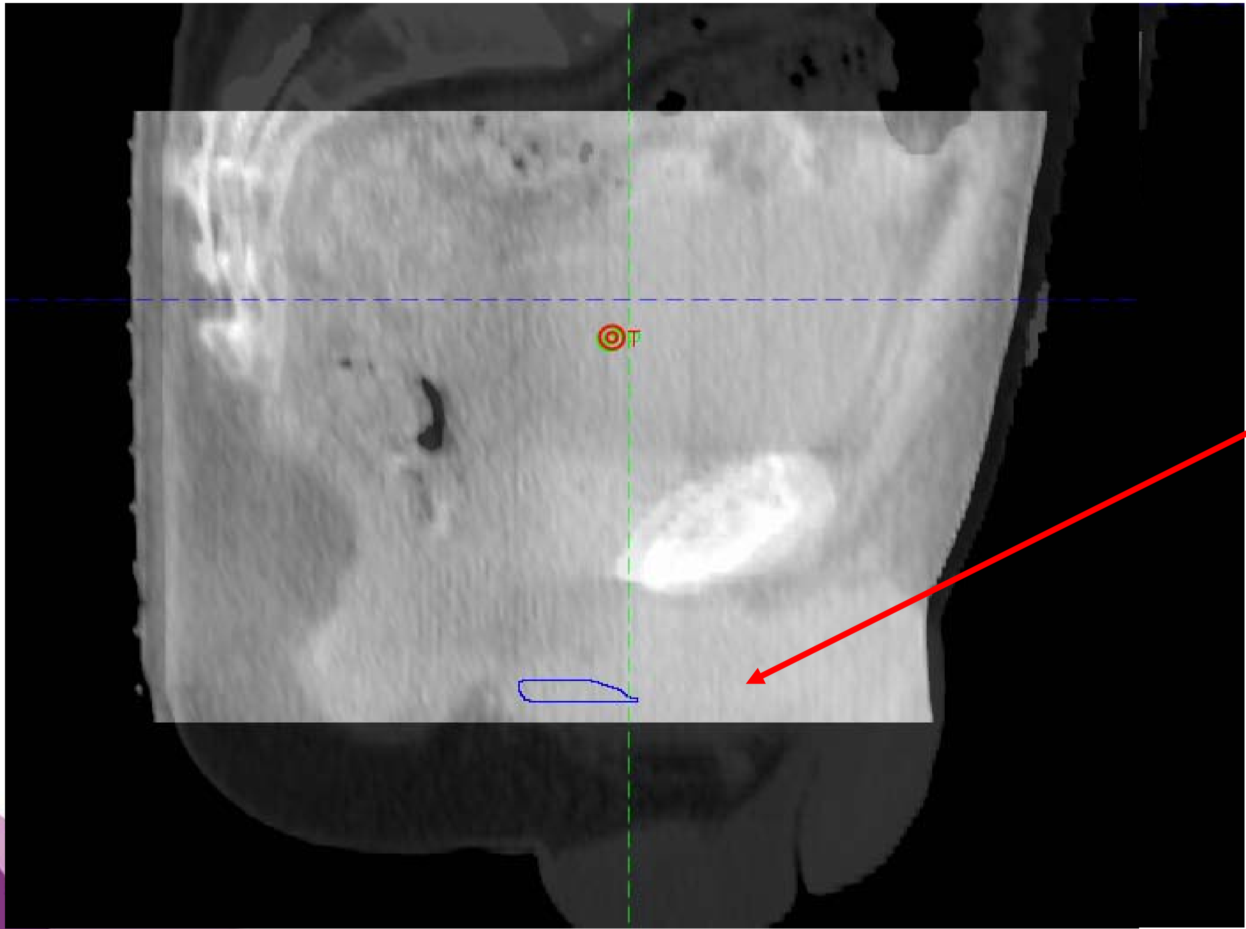


Reggiori et al., 2010

Degradation of image quality due to patient size and gas passing through rectum at time of scan

The Image Acquisition Process

- Make sure you image what you need to match and review to
- Option to offset the couch to ensure appropriate anatomy is visualized



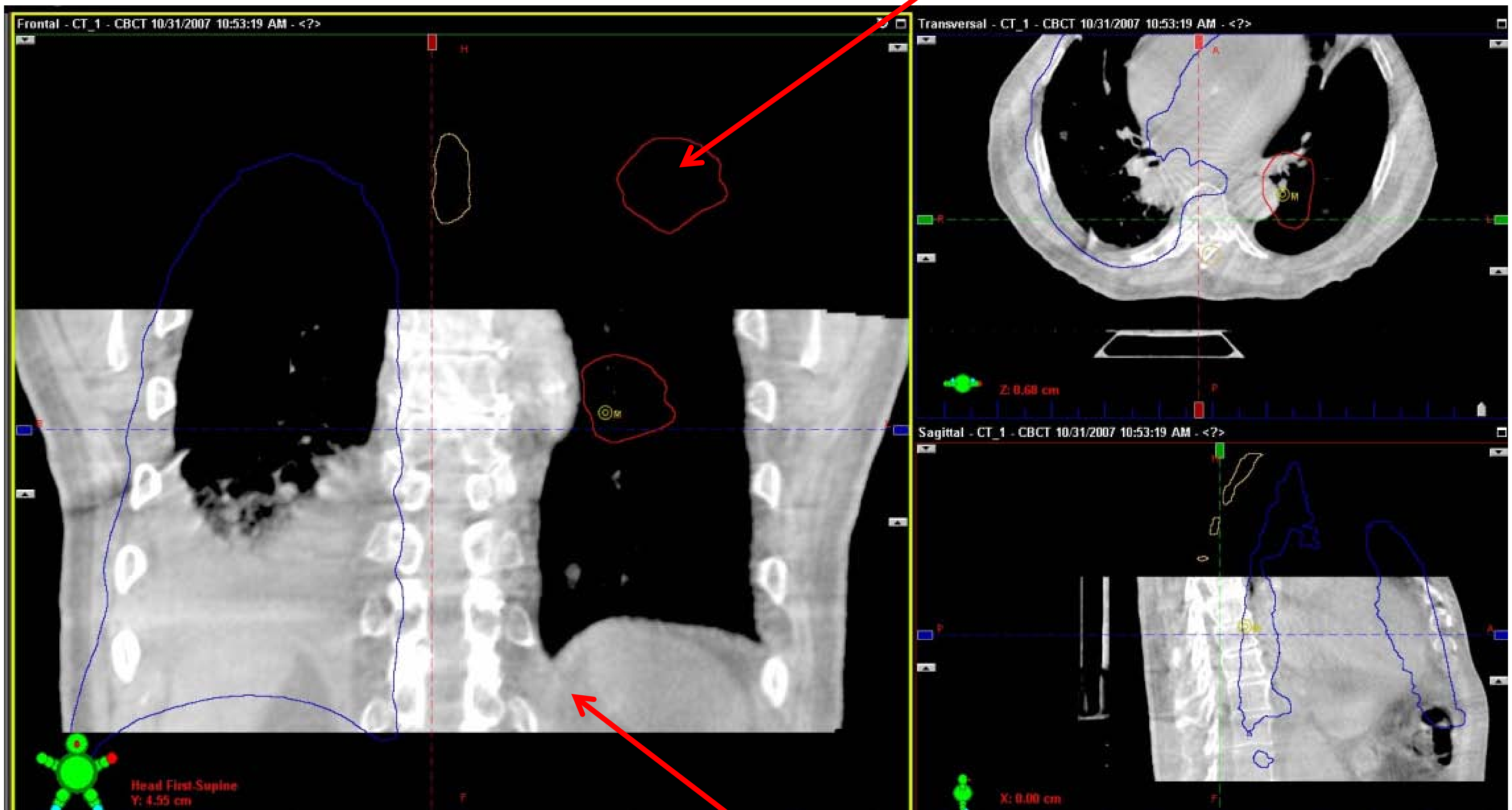
Definitive Prostate Case

Couch now offset to include Penile Bulb in image

The Image Acquisition Process

- Option to offset the couch to ensure appropriate anatomy is visualized

Missing Superior PTV



Excessive inferior

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Radiotherapy and Oncology 94 (2010) 129–144

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Review

The European Society of Therapeutic Radiology and Oncology–European Institute of Radiotherapy (ESTRO–EIR) report on 3D CT-based in-room image guidance systems: A practical and technical review and guide

Stine Korreman[a], Coen Rasch[b], Helen McNair[c], Dirk Verellen[d], Uwe Oelfke[e], Philippe Maingon[f], Ben Mijnheer[b], Vincent Khoo[c,g,*]

[a]Department of Radiation Oncology, The Finsen Centre, Rigshospitalet, Copenhagen, Denmark; [b]Department of Radiation Oncology, The Netherlands Cancer Institute/Antoni van Leeuwenhoek Hospital, Amsterdam, The Netherlands; [c]Department of Clinical Oncology, Royal Marsden NHS Foundation Trust, Chelsea and Sutton, London, UK; [d]UZ Brussel, Oncologisch Centrum, Radiotherapie, Brussels, Belgium; [e]Department of Medical Physics in Radiation Oncology, Deutsches Krebsforschungzentrum, Heidelberg, Germany; [f]Département de Radiothérapie, Centre Georges-François-Leclerc, Dijon, France; [g]Institute of Cancer Research, Chelsea, London, UK

Table 1
Factors for consideration in image acquisition and their relevance.

What field of view (FOV) length is available in the cranio-caudal direction?
Determines the length of scan available and possible solutions if longer scan lengths are required
What size is the reconstruction circle?
Determines the lateral FOV
Are filters required? – Which filters are available?
Involves time to select and insert, and affects image quality
Are filters interlocked?
If not, then risk of poor quality or unusable scans from incorrect filters selection
Can panel be positioned remotely? If so, does this the system come with an anti-collision system?
Will involve time to position if not remotely accessed
What are the available rotation speeds?
Determines the acquisition time
What are the possible angles of rotation?
Affects the flexibility of scanning; e.g. the possibility of performing half-scans for small regions, rotations through 180 degrees (underneath the patient) and using preset or flexible start and stop angles
How ergonomic is the operation?
One- or two-button operation, foot- or hand-control, several screens affects the ease of operation and the risk of aborted scans
Can the scan be stopped and restarted?
Will result in extra dose if the scan is interrupted inadvertently, and has to be started from the beginning
Also allows the scan to be acquired with the patient in several breath holds.

The Image Registration Process

Automatic Match

- Uses matching algorithm based on "Mutual Information" within the defined field of view

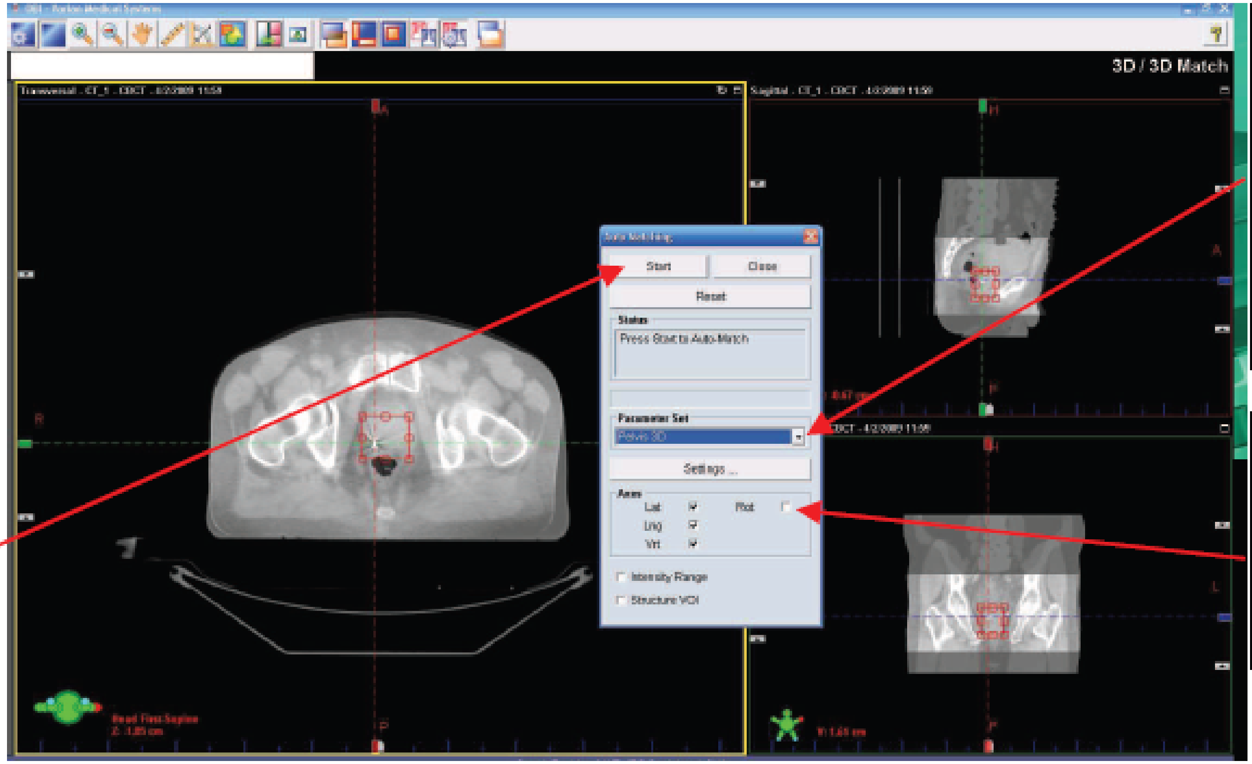
Manual Match

- Allows adjustments to be made using either mouse or keyboard
- User dependant
  - Respect the learning curve

Thank you Mirjana ☺

The Image Registration Process

- ?***Rotation*** correction to be included



1. Select the treatment site from the parameter set drop down menu.

2. Ensure Rot is deselected in the axes box

3. Select Start

The Image Registration Process

- Correctional shifts are displayed to the nearest 1mm

- Any automatic match ***must*** be reviewed by both the RTTs prior to treatment

- No machine can replace clinical judgement

- Know your volumes
  - Be aware of possibility of additional “planning volumes”

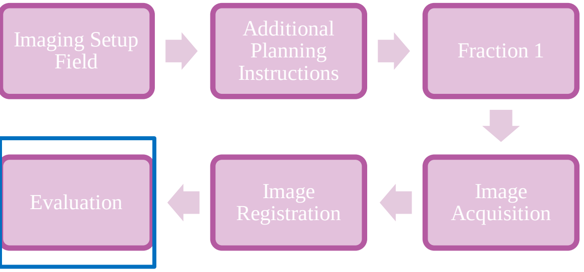
The Image Registration Process

- How can we decrease inter observer variability?

  - Education of staff (encourage CPD, training packages, competency based assessment)

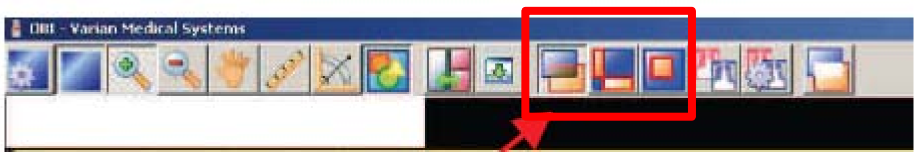
  - Protocolised imaging methods

  - Protocolized matching methods
    - Sequence of matching process
      - Automatic Match ***must be followed by manual review*** and adjustment
    - VOI set for each site and "locked" on Fx 1
      - Anatomy to include in VOI box



The Image Evaluation Process

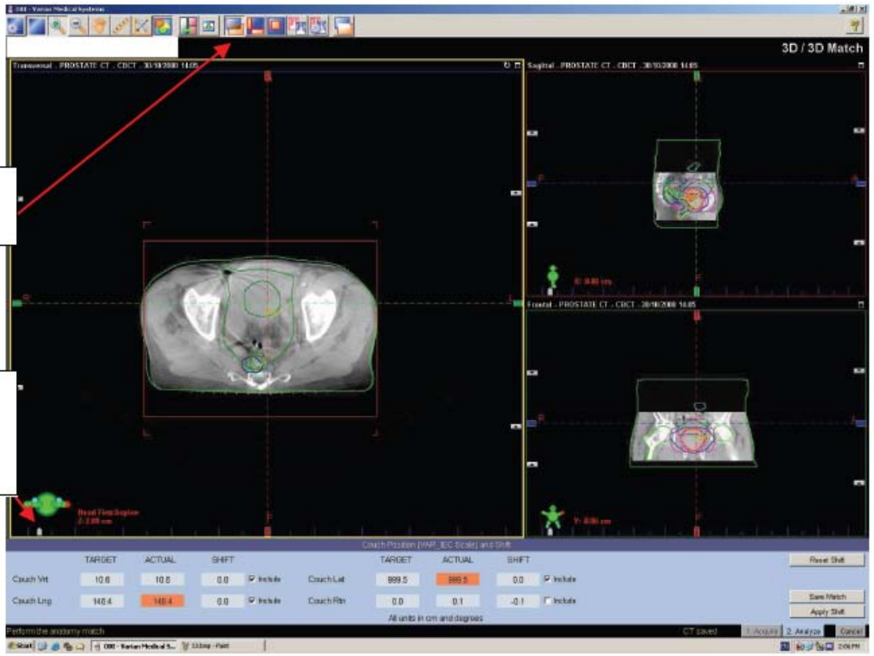
- Processes available to assist in image evaluation



- Blending
  - ➢ Blending of the planned and acquired image
  - ➢ Colour or greyscale

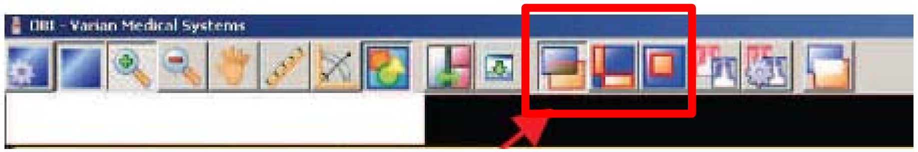
Select the blend tool.

Drag the blend arrow to the LEFT to see the CBCT

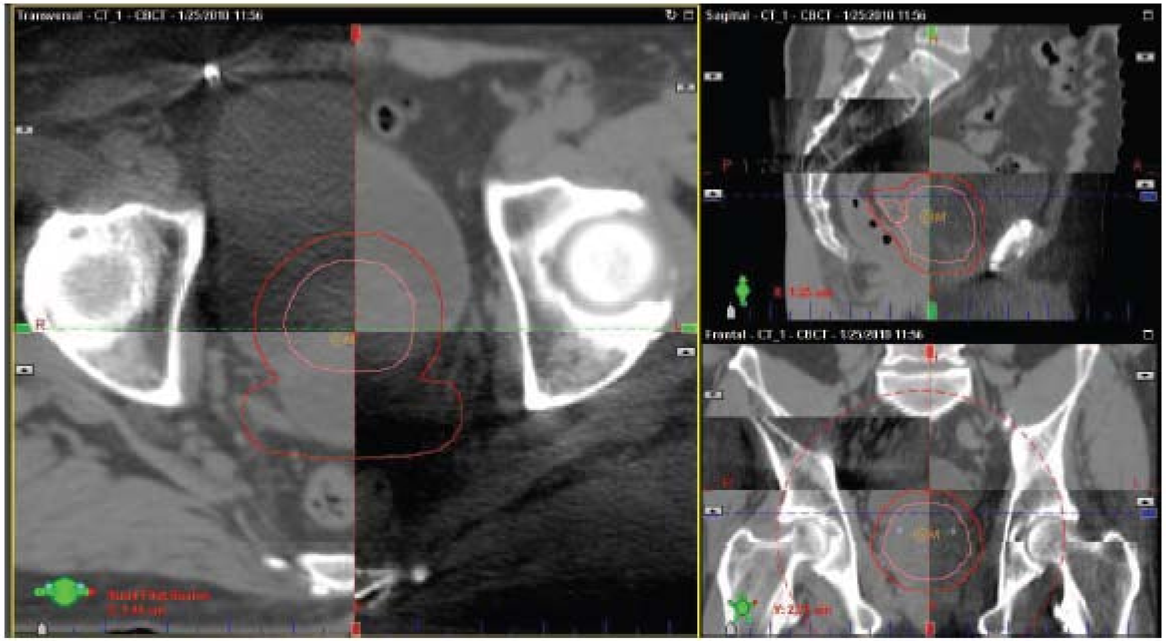


The Image Evaluation Process

- Processes available to assist in image evaluation

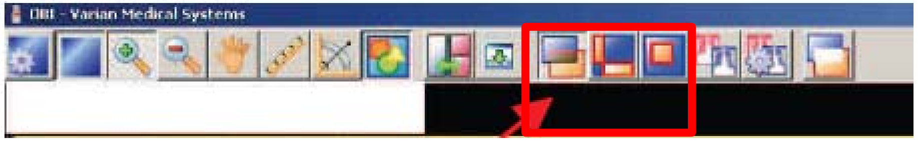


- Split screen

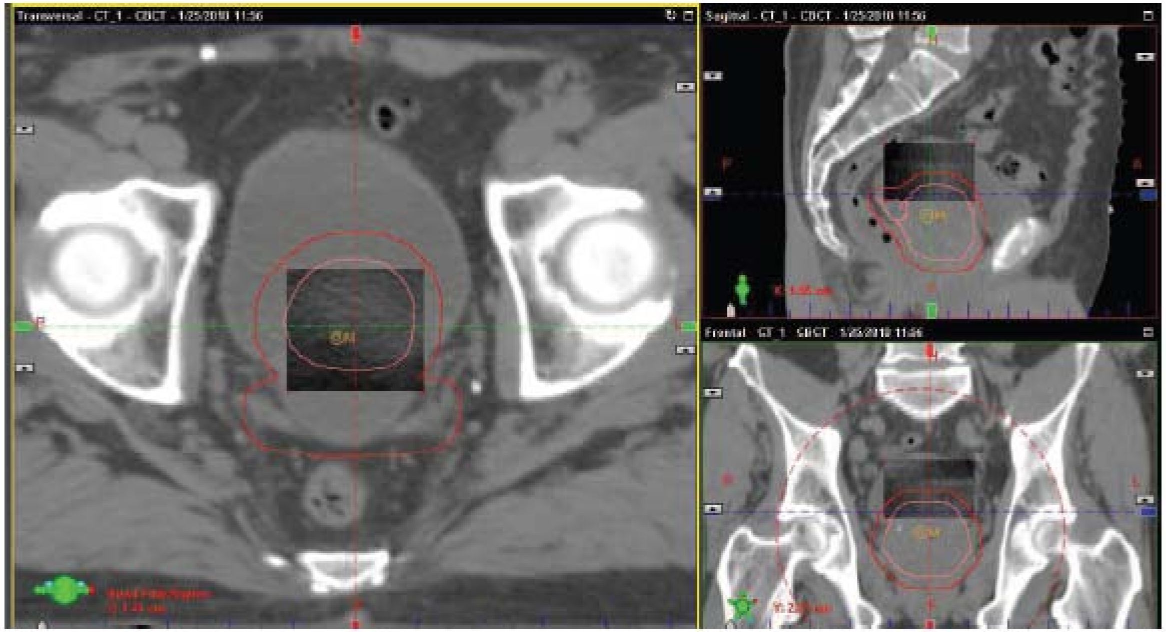


The Image Evaluation Process

- Processes available to assist in image evaluation



- Moving window tool



Always scroll through the entire length of the PTV and view in all 3 planes

Don't forget to adjust the window level and move your views around

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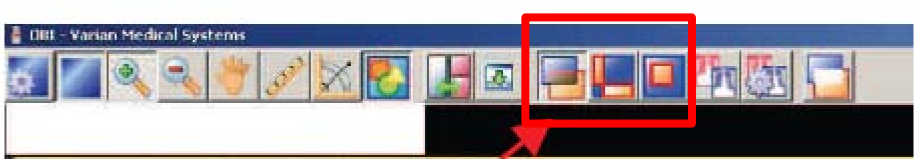
The Image Evaluation Process

- Processes available to assist in image evaluation



- Overlay Structure
  - ➢ Volumes that were contoured at the planning stage

The Image Evaluation Process

- The evaluation process must not be rushed
  - ➢ Check that the shifts are *sensible*

- Both RTTs must confirm the match

- *"If that were my mum…"*

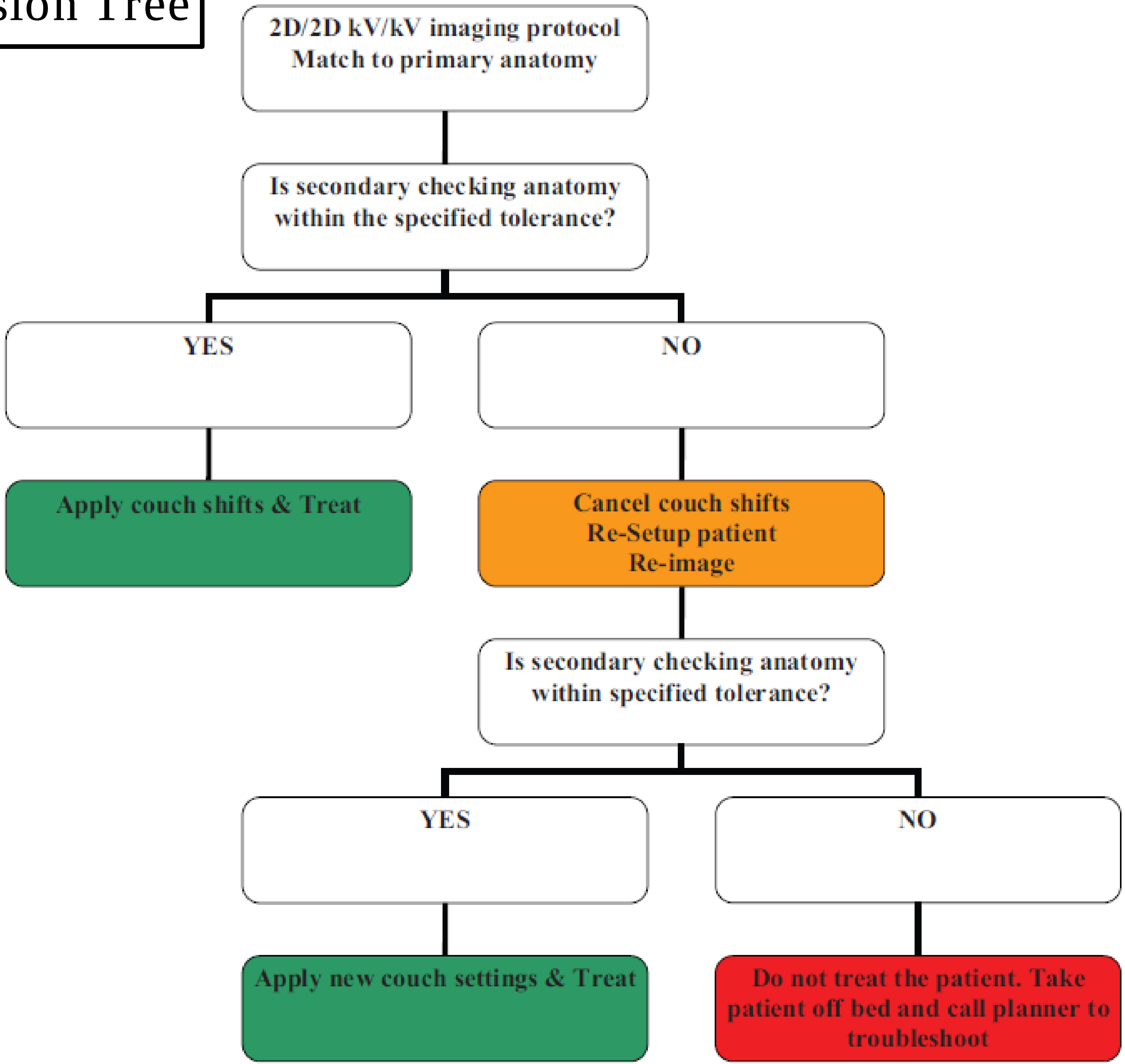
- It is better be check than treat the patient incorrectly

- IGRT is a team approach and if unsure there are always people to help

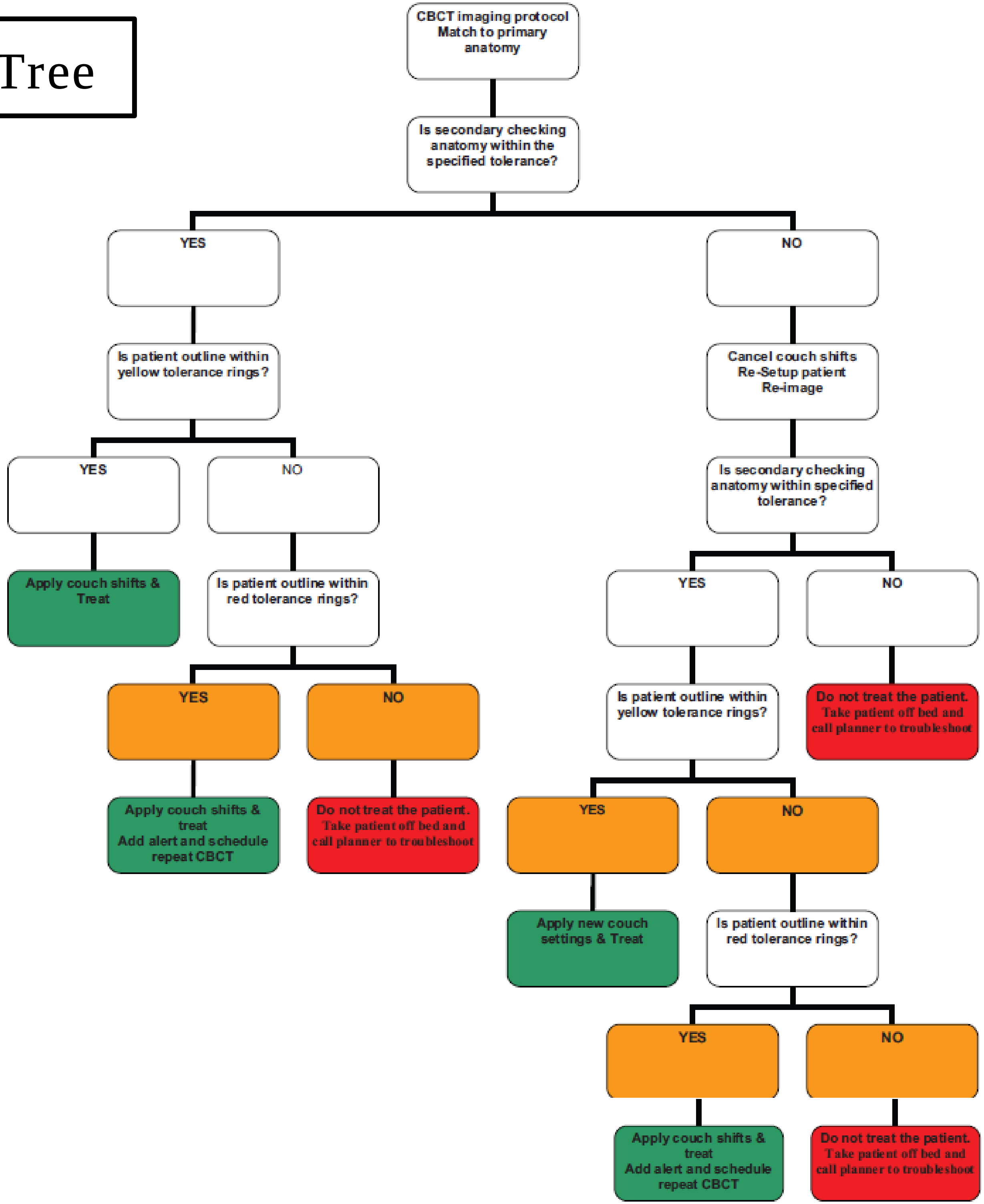
- Communicate!
  - ➢ Journal, Alerts, annotation on the image

"the importance of this visual inspection cannot be over-emphasized and the user is encouraged to assess the accuracy of these automated registration tools" (Korreman et al., 2010)

2D/2D Decision Tree



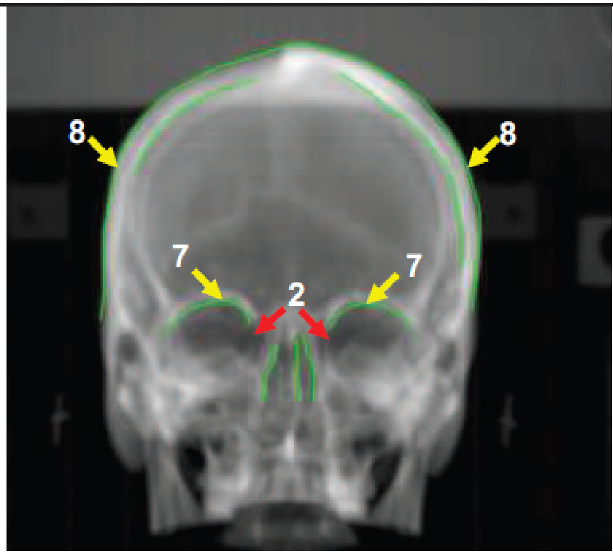
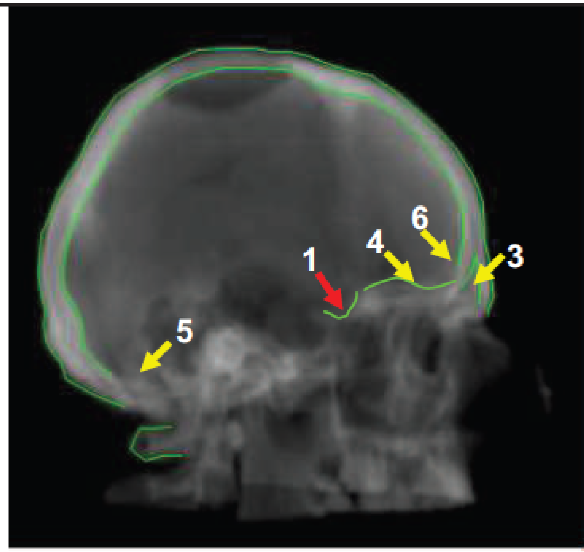
CBCT Decision Tree



Site Specific Application

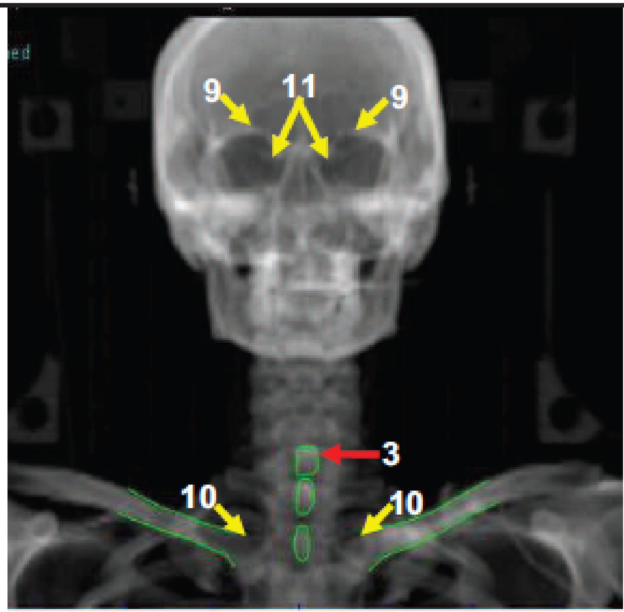
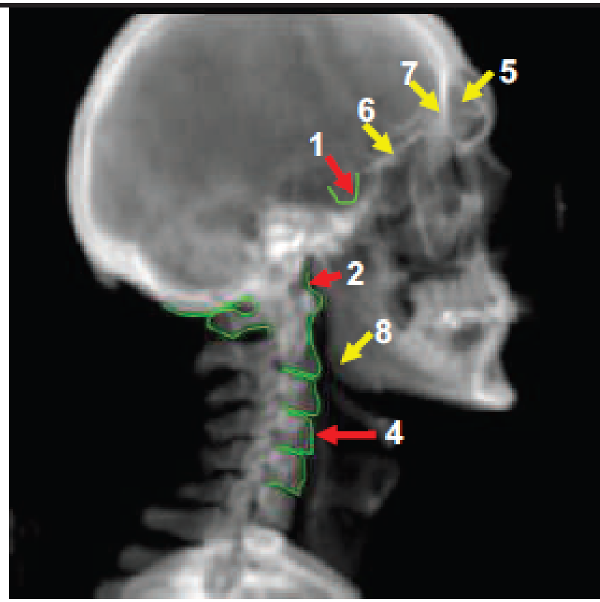
Radical CNS

- Examples of structures to outline on DRR for 2D/2D match

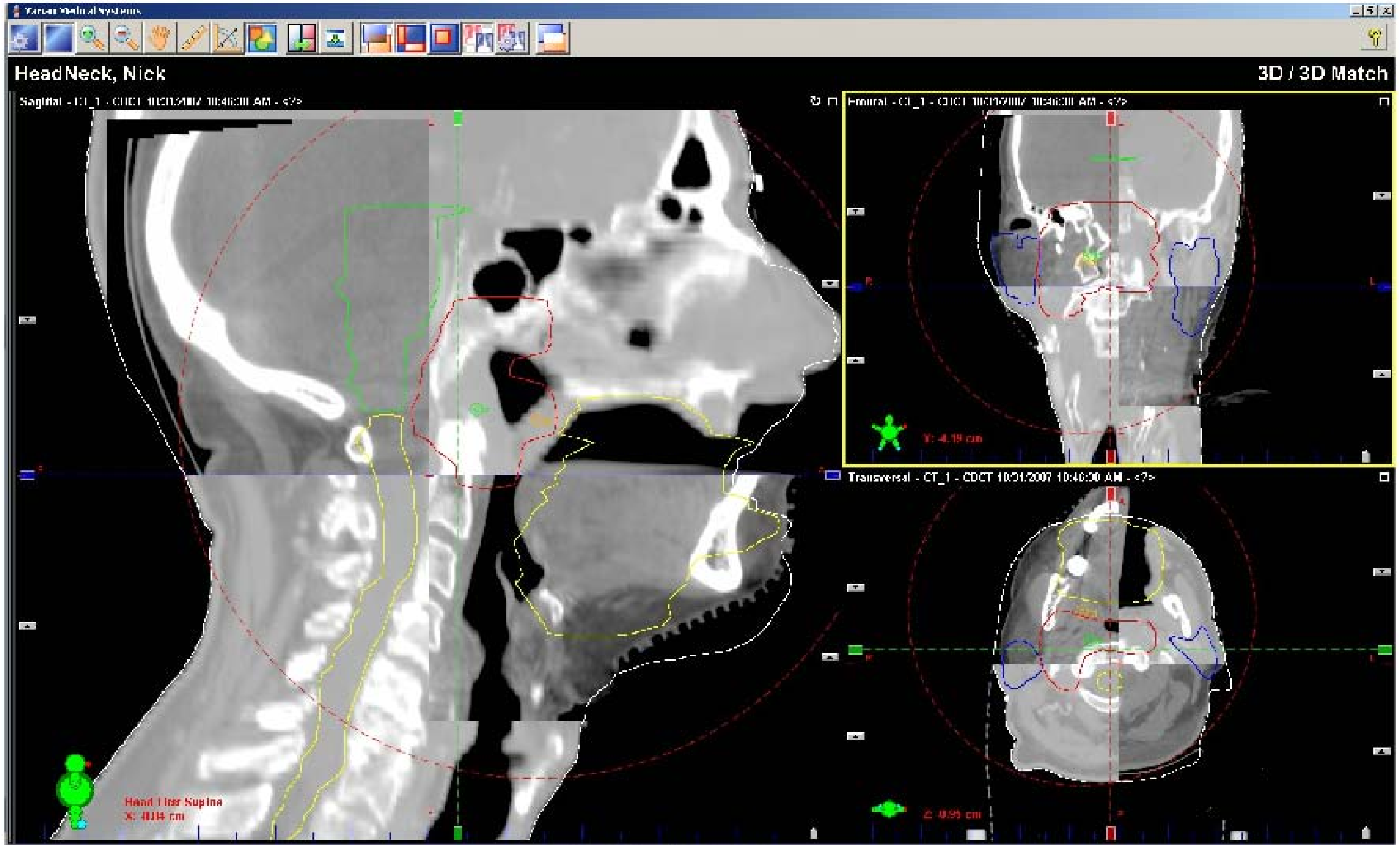
Site	Image type	Primary (red) and Confirming (yellow) matching anatomy	
Brain	KV & CBCT	 2. Medial orbital rims 7. Superior orbital rims 8. Lateral skull wall (parietal region)	 1. Pituitary fossa (volumend and transferred to reference image) 3. Frontal sinus 4. Base of skull in pituitary fossa region 5. Base of skull in Occipital bone region 6. Anterior cranial fossa

Head and Neck

- Examples of structures to outline on DRR for 2D/2D match

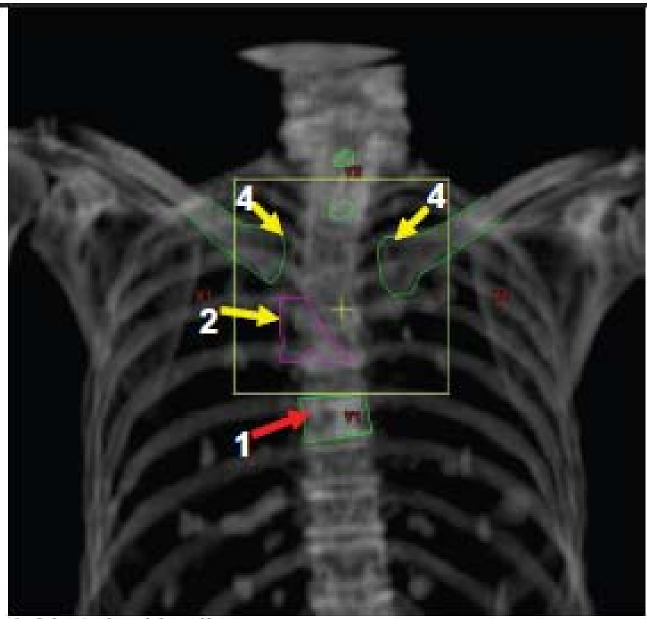
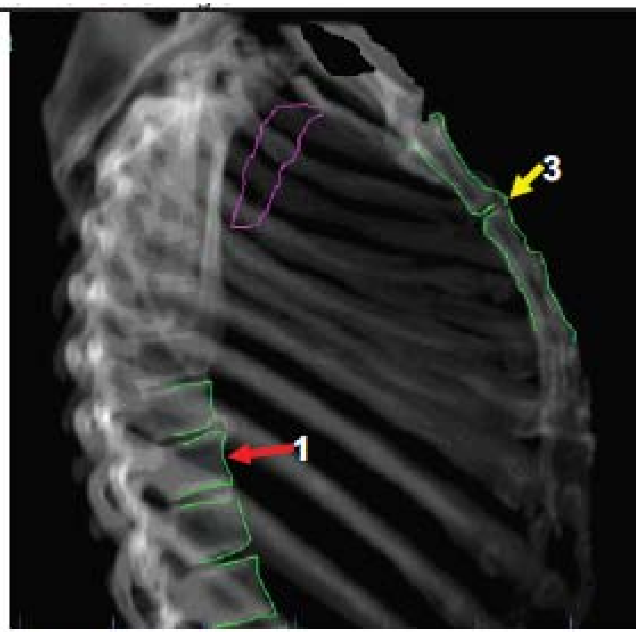
Naso-Pharynx	kV & CBCT	 3. Spinuous processes 9. Superior orbital rim 10. Head of Clavicles 11. Medial orbital rims	 1. Pituitary fossa (volumed and transferred to reference image) 2. Intersection of anterior vertebral column and base of skull 4. Vertebral bodies 5. Frontal sinus 6. Base of skull in pituitary fossa region 7. Anterior cranial fossa 8. Mandible angle

Head and Neck



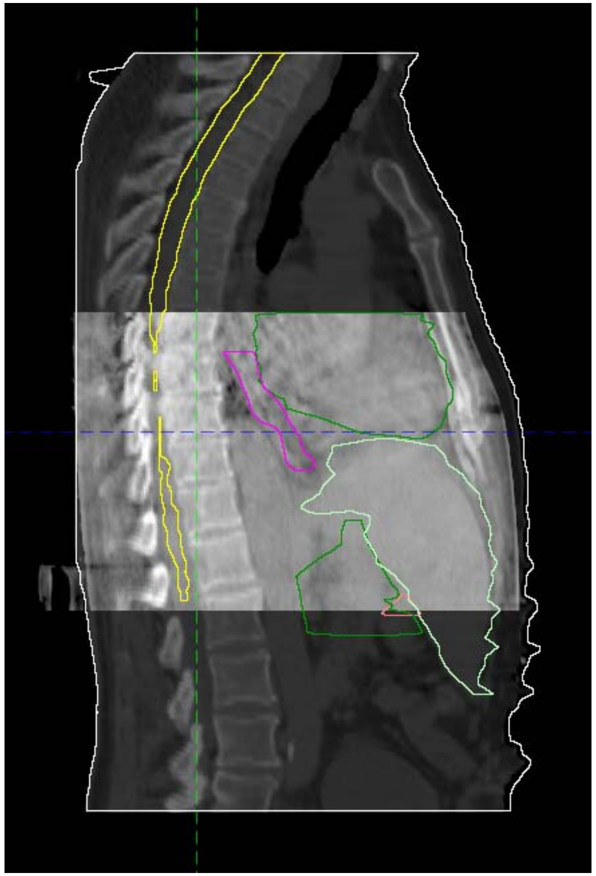
Thorax and Upper Abdomen

- Examples of structures to outline on DRR for 2D/2D match

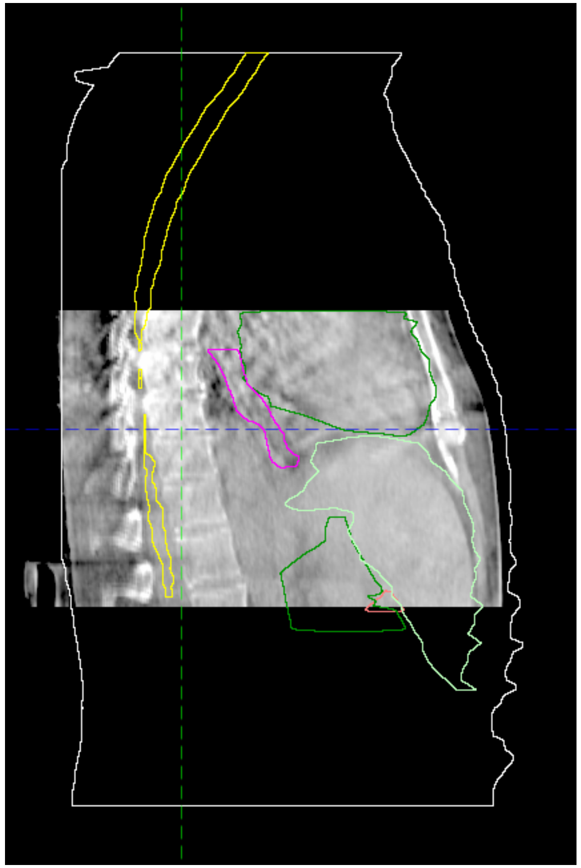
Chest	kV & CBCT	 1. Vertebral bodies 2. Contoured Carina 4. Head of Clavicles	 1. Vertebral bodies 3. Manubrial-sterno joint

Thorax and Upper Abdomen

Blended View

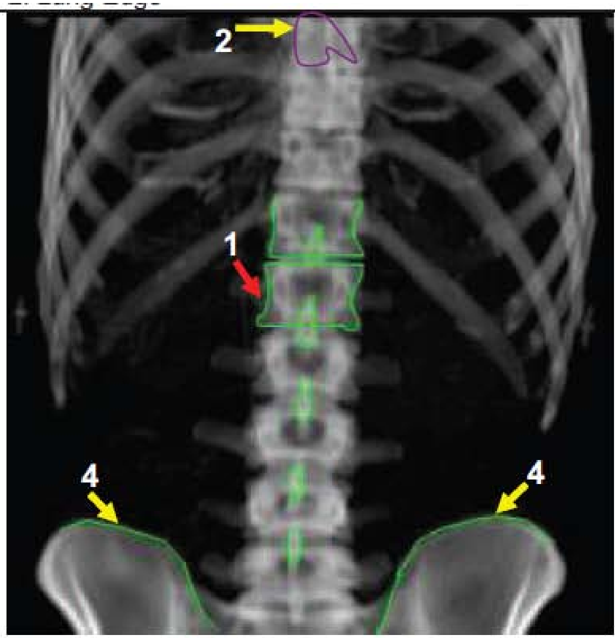
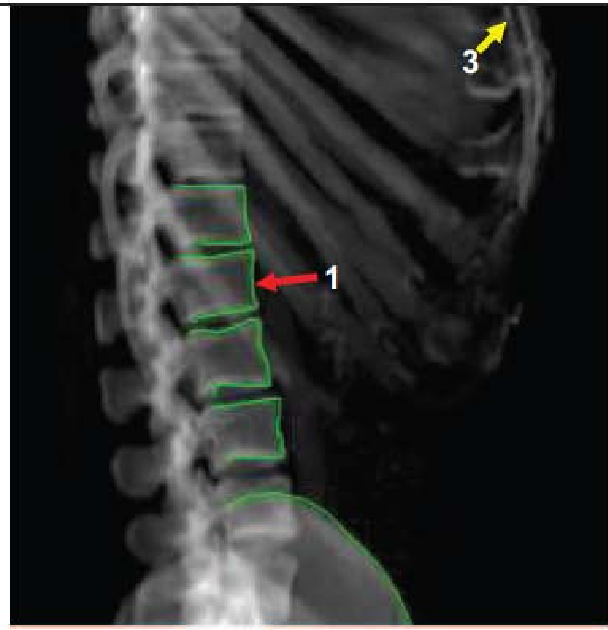


Contour Overlay



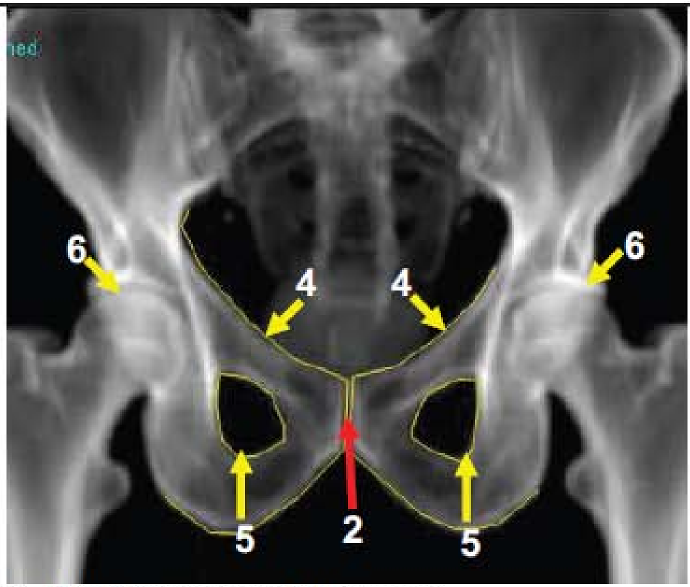
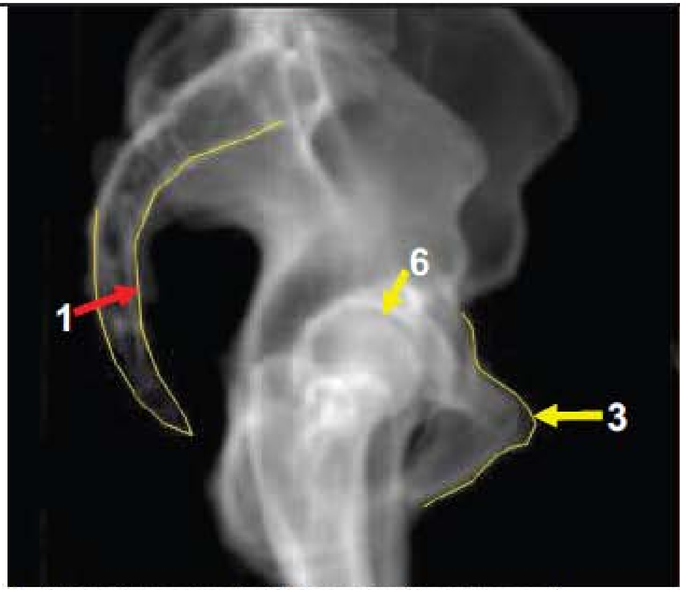
Abdomen

- Examples of structures to outline on DRR for 2D/2D match

Abdomen Pancreas Adrenal Gastric	kV & CBCT	 1. Vertebral bodies 2. Contoured Carina (if on image) 4. Iliac crest	 1. Vertebral bodies 2. Contoured Carina (if on image) 3. Manubrial-sterno joint

Rectum

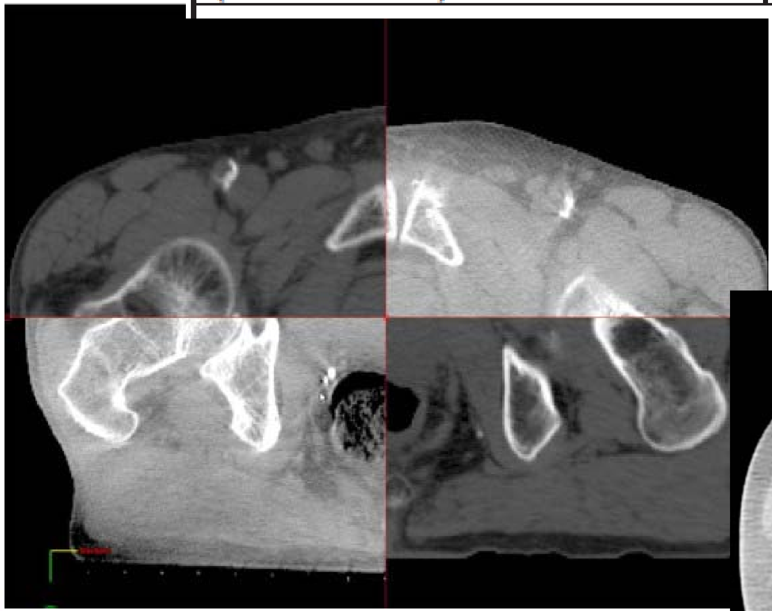
- Examples of structures to outline on DRR for 2D/2D match

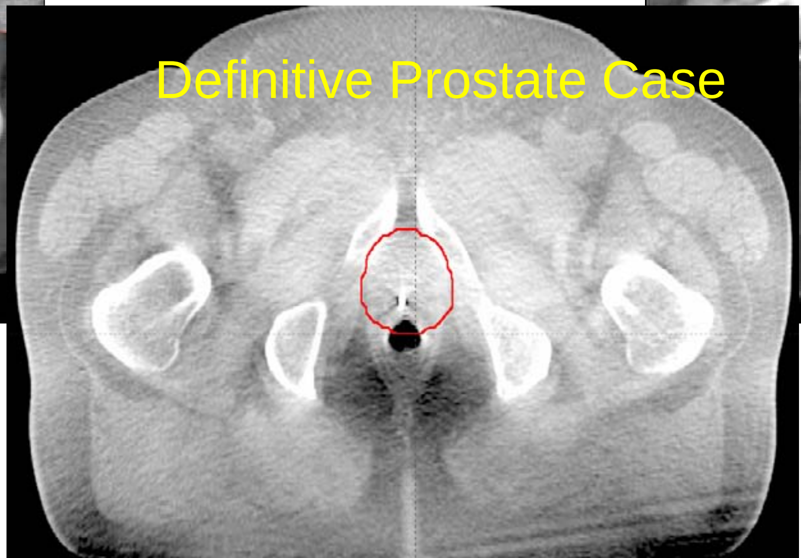
Rectum/ Anus	kV & CBCT	 2. Pubic Symphasis (AP image) 4. Pelvic Rim 5. Obturator Foramen 6. Head of Femur	 1. Anterior aspect of Sacrum (Lat image) 3. Pubic Symphasis 6. Head of Femur

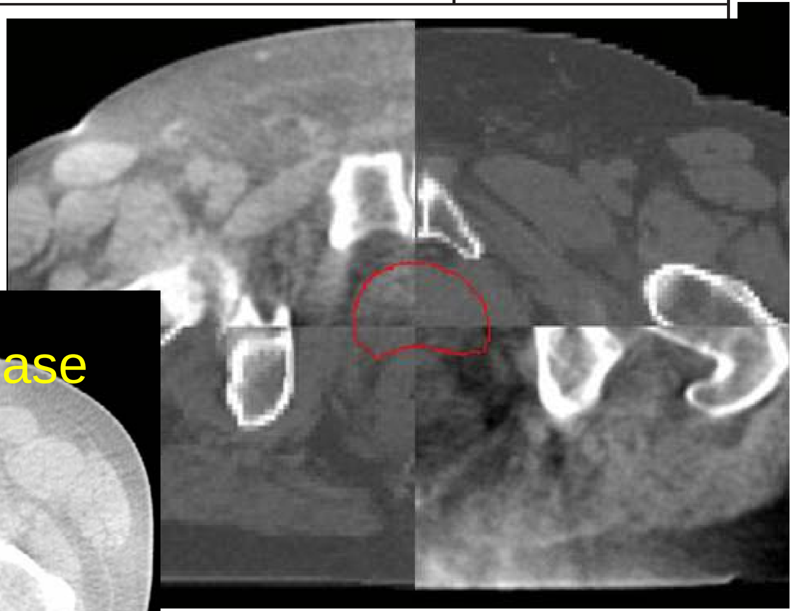
Prostate

- Do ***not*** match to bones for definitive cases (unless you have large margins to account for this practice)

Definitive Prostate (seeds)	kV	All fractions except CBCT	Daily moves
	CBCT	1,2,3,5,10,15,20,25,30,35,40	
Definitive Prostate (soft tissue)	CBCT	All fractions	Daily moves







Prostate – Soft tissue

- Process for CBCT soft tissue match
  - Manual confirmation of match

1. Change window level to visualise rectum & superior prostate
2. Position superior CTV prostate contour to superior aspect of prostate at junction with bladder
3. Position posterior edge of CTV prostate structure (at mid prostate) to the anterior rectal wall
4. Check inferior CTV prostate structure to inferior edge of prostate, using penile bulb to assist
5. Position lateral edges of CTV prostate to pelvis muscles

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Prostate Bed

- Have an ***anatomical understanding*** of exactly what the target is post surgery

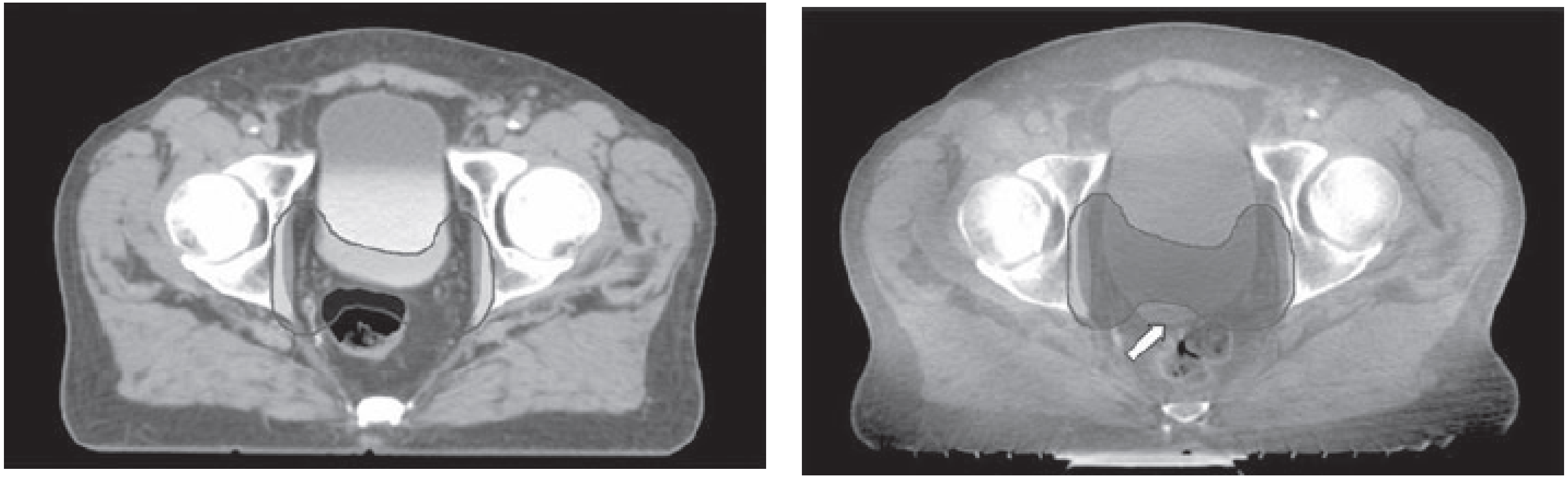

Fig. 4. CBCT of a patient undergoing radiotherapy following radical prostatectomy. Panel (a) shows the initial planning scan with the PTV displayed. Panel (b) shows a change in rectal volume resulting in the treated volume shifting outside the planning PTV (white arrow). CBCT, cone beam computed tomography; PVT, planning target volume.

Prostate Bed

Radiation Oncology—Original Article

Prostate bed motion may cause geographic miss in post-prostatectomy image-guided intensity-modulated radiotherapy

Linda J Bell[1,2,*], Jennifer Cox[1,2], Thomas Eade[1], Marianne Rinks[1,†], Andrew Kneebone[1]

Article first published online: 9 JUL 2013

DOI: 10.1111/1754-9485.12089

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Issue

Journal of Medical Imaging and Radiation Oncology

Volume 57, Issue 6, pages 725–732, December 2013

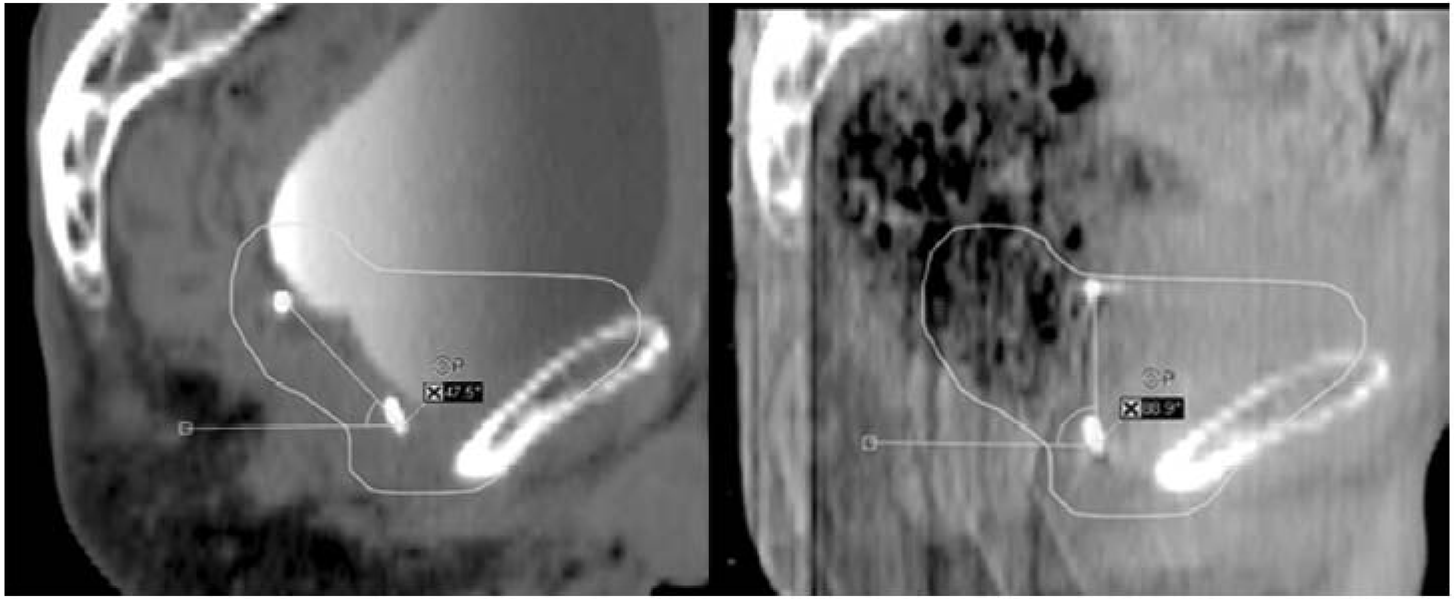

Fig. 1. Method used to measure prostate bed tilt. The angle between the superior and inferior clip relative to a horizontal line at the inferior clip was measured on the planning CT scan (left) and the cone beam CT scans (right). The angle-measuring tool in the Varian Offline Review® software was used to calculate this on the sagittal slice closest to midline of each scan where the clips could be visualised. The difference between the planning CT and cone beam CT angles was calculated. In this extreme case the angle on the planning CT (left) is 47.5° and that on the cone beam CT scan (right) is 88.9°. This is a difference of 41.4°. The FROGG-acceptable planning target volume expansion is delineated on these scans.

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Troubleshooting

- These are all well suited and ideal cases

- What about when things aren't so clear?! *Troubleshoot*

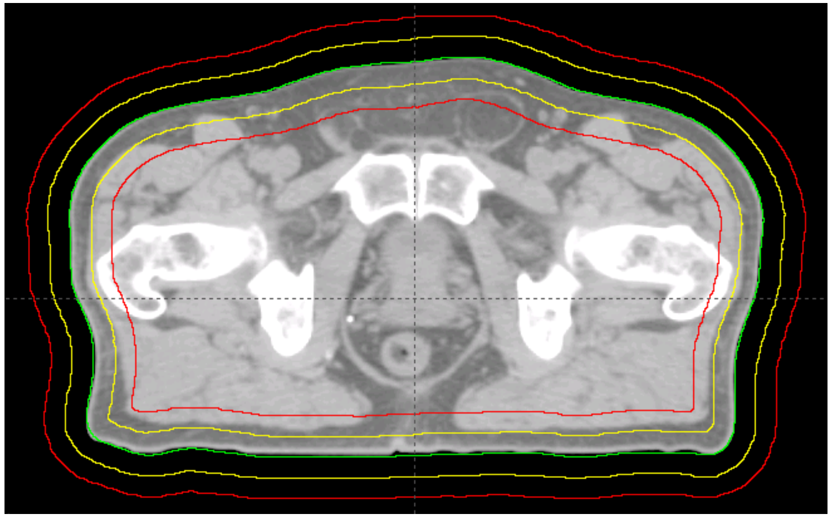
Troubleshooting

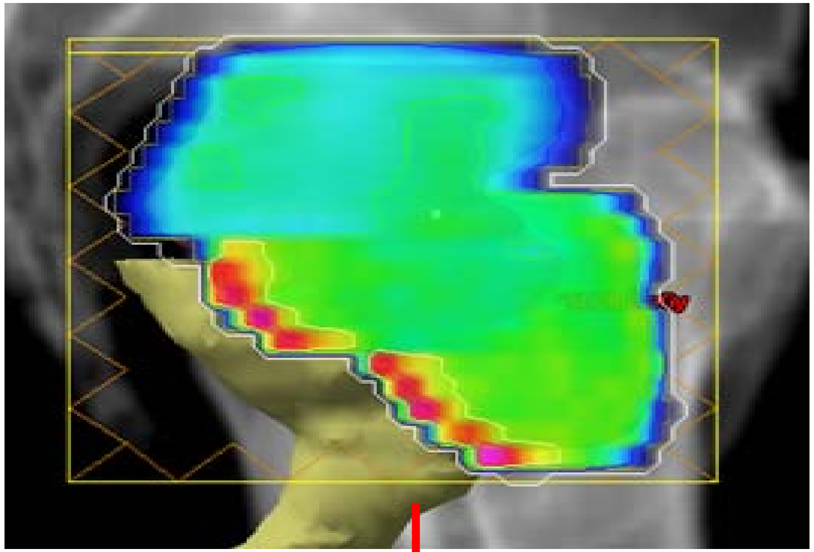
- Look beyond the target!

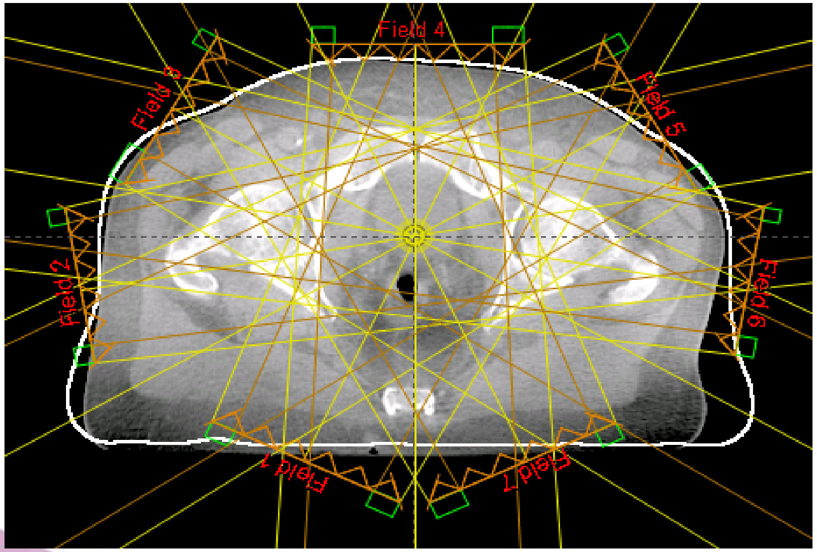
- Impact not on target ***position***, but on target ***dosimetry***

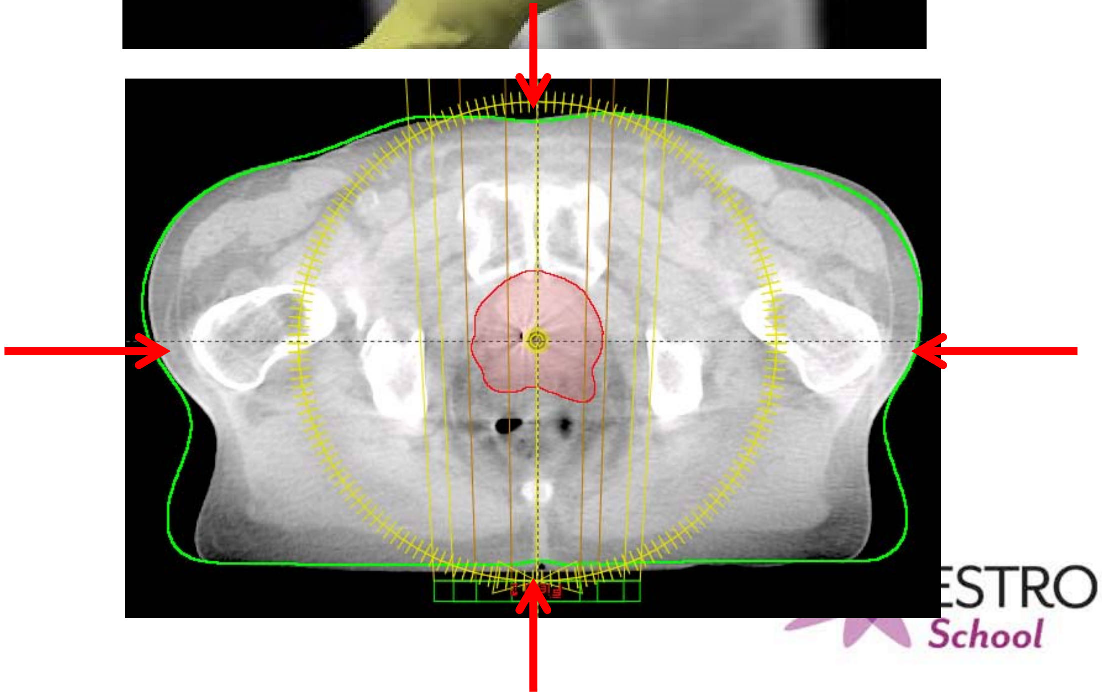
Troubleshooting

Integrate your planning knowledge –
Clinical Intelligence!









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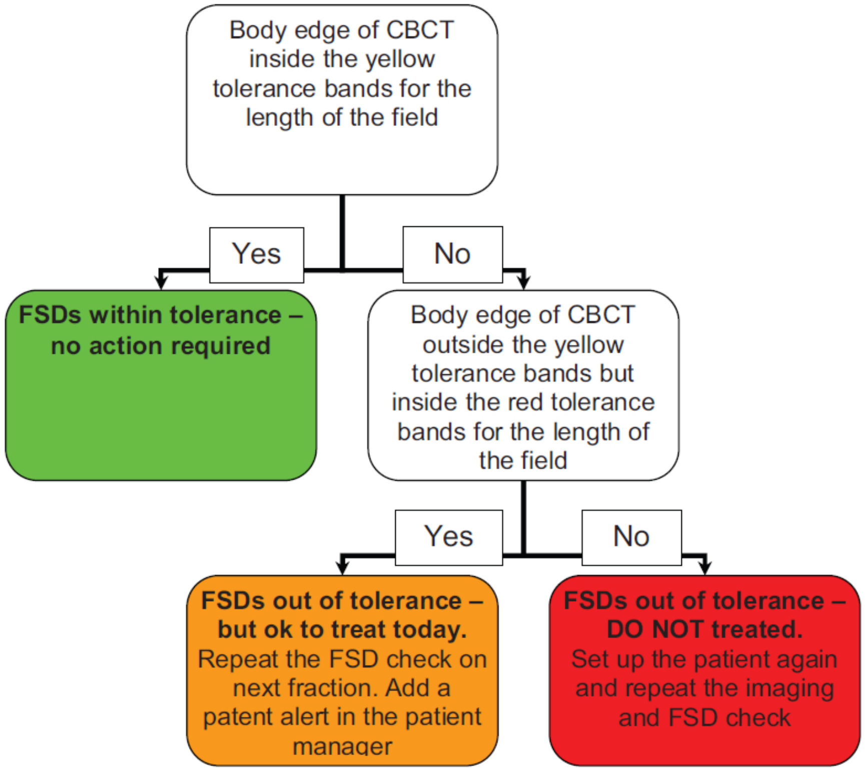
Troubleshooting

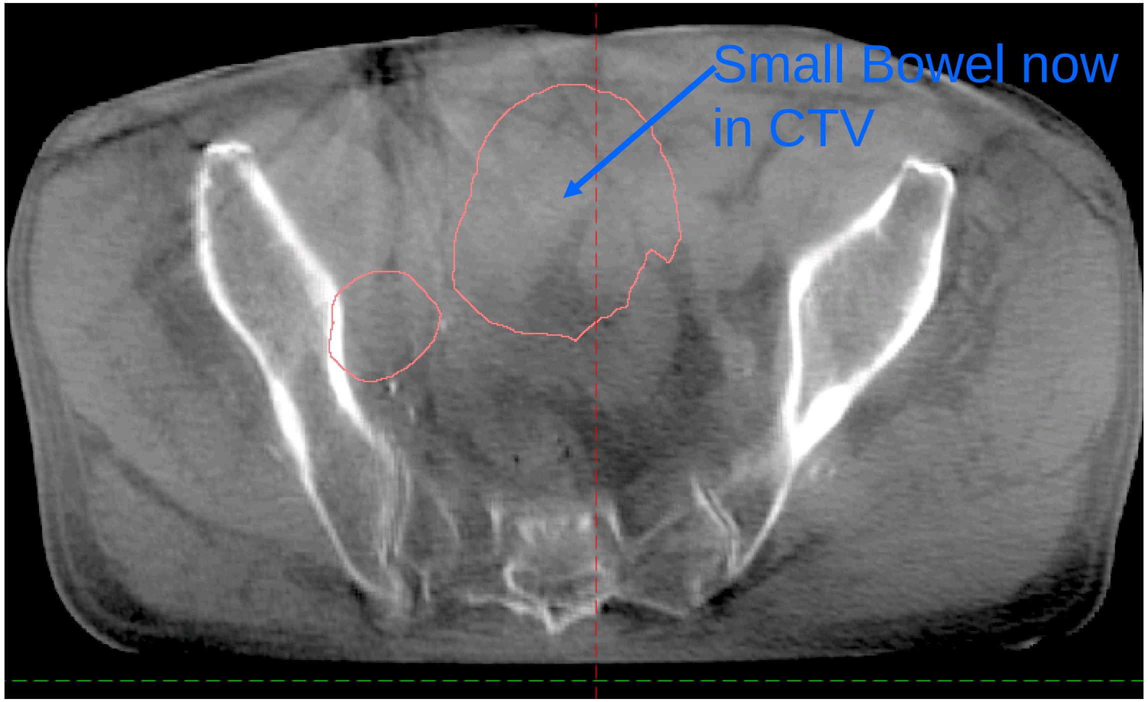
- What about when things aren't so clear?! *Troubleshoot*
  - ➢ Contour Variation
    - ▪ Weight Loss/Gain
    - ▪ Shoulder position
      - o Neubauer et al 2012



Troubleshooting

- What about when things aren't so clear?! *Troubleshoot*
  - ➢ Changes in bowel and bladder filling
    - Impact on target position and possibly dose
    - Impact on OAR dose

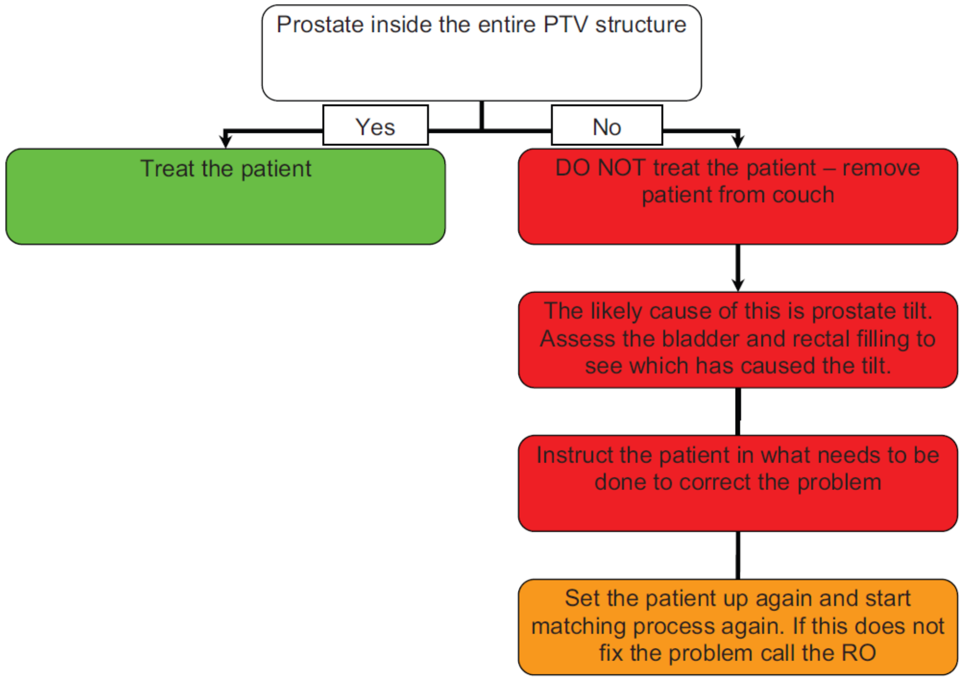
This is a bladder case, but also applicable to other sites (prostate bed)



Troubleshooting

- What about when things aren’t so clear?! *Troubleshoot*

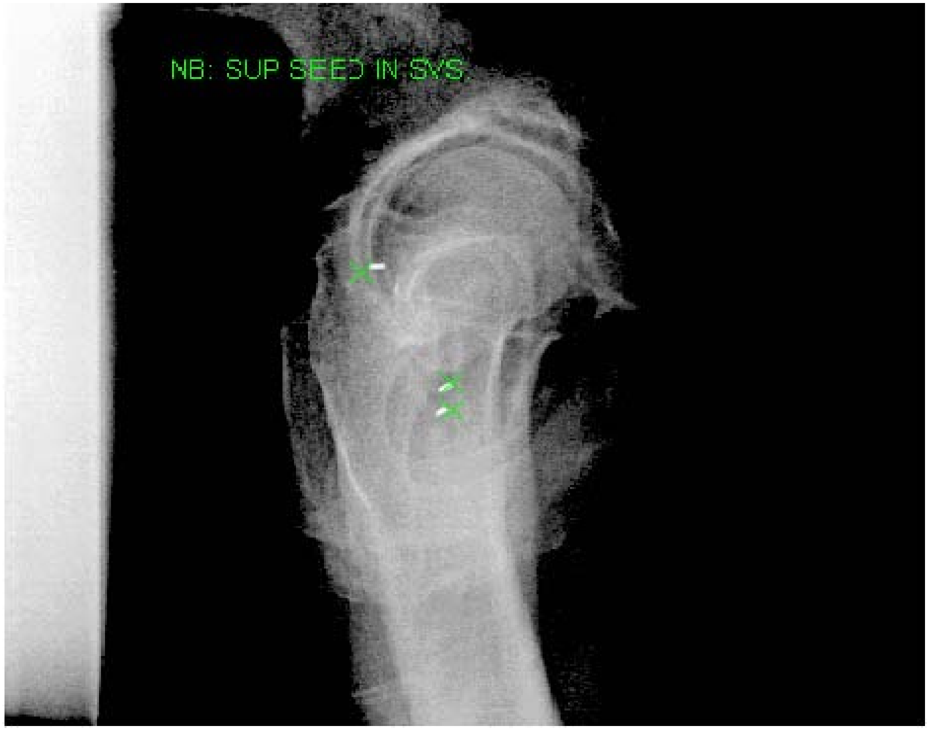
  - ➢ Displacement of CTV/PTV
    - Likely cause rotation or tilt
    - Motion of adjacent structures
    - Anatomical changes of target



Troubleshooting

- What about when things aren't so clear?! *Troubleshoot*

  - ➢ Seed Migration
  - ➢ Poorly placed fiducials (SVs, Rectal wall etc)

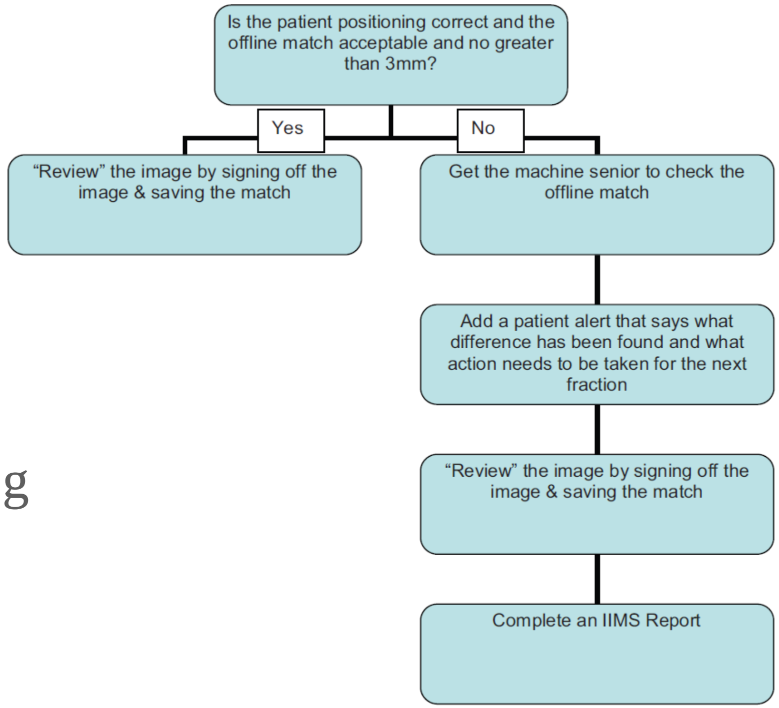


Troubleshooting

- Online IGRT protocols should still include an offline review by an independent party

- This eliminates the time pressures of the machine

  - RTT on machine
  - RTT in planning
  - RO
    - Can also then feedback to patient
    - Patient education
  - Discuss at weekly MDT Audit Meeting



“The therapists are the front-runners for execution of the developed IGRT programs, and the quality of their performance will have a substantial impact on the success of IGRT” *(AAPM Report 104)*

Take Home Message!

- Use your "clinical intelligence"
  - Don't just automatch and hit apply to whatever the result is.
  - ***Think!*** Does the match result make sense?

- Dosimetric Impact – Thinking beyond the treatment unit

- Good idea to overlay the planned D95 or D100 isodose line on the CTV position

- Consider what is your target and what is the best surrogate for that

- Include the whole MDT

Acknowledgements

- **Linda Bell**, RTT and IGRT Specialist at Northern Sydney Cancer Centre

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Case report: **Head and Neck**

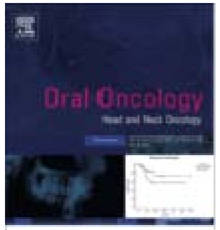
Jesper Eriksen, Odense University hospital, Denmark
Sofia Rivera, Gustave Roussy, Villejuif, France

Advanced skills in modern radiotherapy
June 2015

WWW.ESTRO.ORG/SCHOOL

Changing traditional scenario in H&N cancer

- Increasing incidence of HPV positive tumors (+++ Oral Cavity)
- Improved outcome compared with HPV-negative tumors
- younger patients with limited comorbidity and good performance status, less likely to abuse tobacco and alcohol



Epidemiology of oral human papillomavirus infection

Christine H. Chung [a,b], Ashley Bagheri [a], Gypsyamber D'Souza [c,*]

[a] Department of Oncology, Johns Hopkins Medical Institute, Baltimore, MD, United States
[b] Department of Otolaryngology, Head and Neck Surgery, Sidney Kimmel Comprehensive Cancer Center, Johns Hopkins Medical Institute, Baltimore, MD, United States
[c] Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, United States

S U M M A R Y

Objective: To describe what is known about the epidemiology of oral human papillomavirus (HPV) infection.
Methods: In this article we review current data on HPV prevalence, natural history, mode of acquisition, and risk factors for oral HPV infection.
Results & Conclusion: Over the past several years new studies have informed our understanding of oral HPV infection. These data suggest oral HPV prevalence is higher in men than women and support the sexual transmission of HPV to the mouth by oral sex. Data is emerging suggesting that most oral HPV infections usually clear within a year on and describing risk factors for prevalent and persistent infection. Recent data support likely efficacy of the HPV vaccine for oral HPV, suggesting vaccination may reduce risk of HPV-related oropharyngeal cancer.

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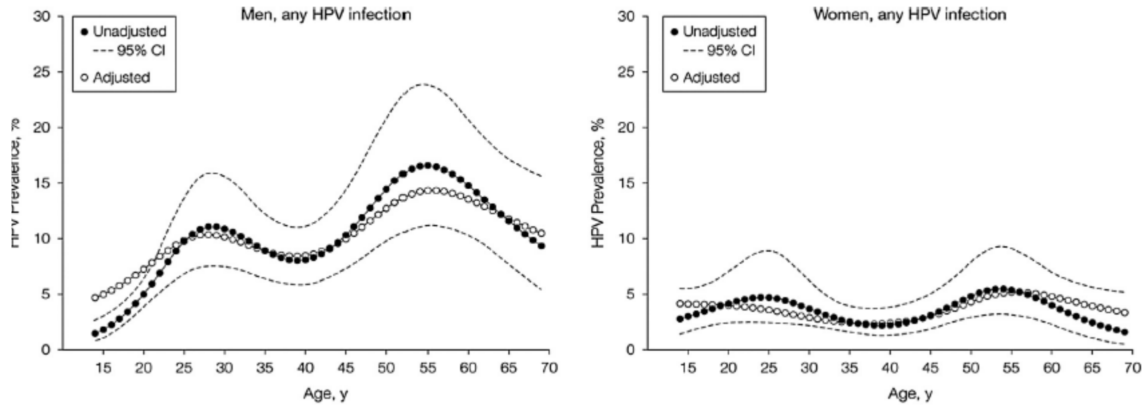

Lassen et al ;Radiother oncol 2013
Chung et al; oral oncol 2013

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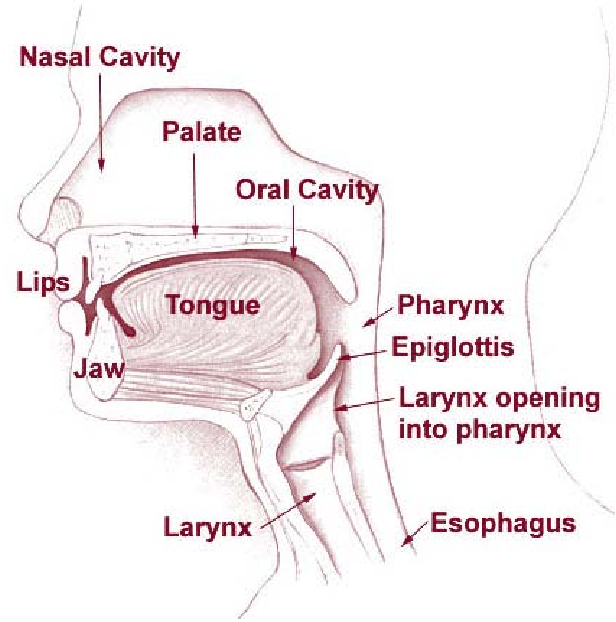
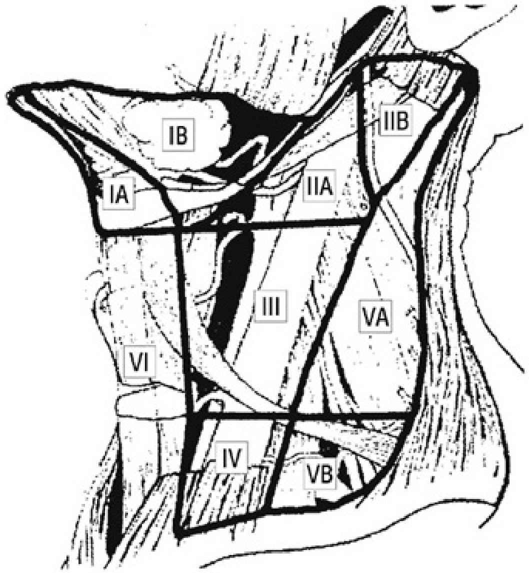
Patient history



- 60-year old man.
- 3 week history of nodal swelling , left side of the neck.
- No pain or dysphagia. No weight loss.
- No co-morbidity except from back pain.
- Ceased smoking in 1990, 10 pack-years.
- No daily use of alcohol.

Clinical examination



•Good performance (WHO PS 0)

• Base of tongue/vallecula area a 3x2x2cm large tumour is seen.

•Proximal border of the tumour seems to be close to the lower pole of the left tonsil

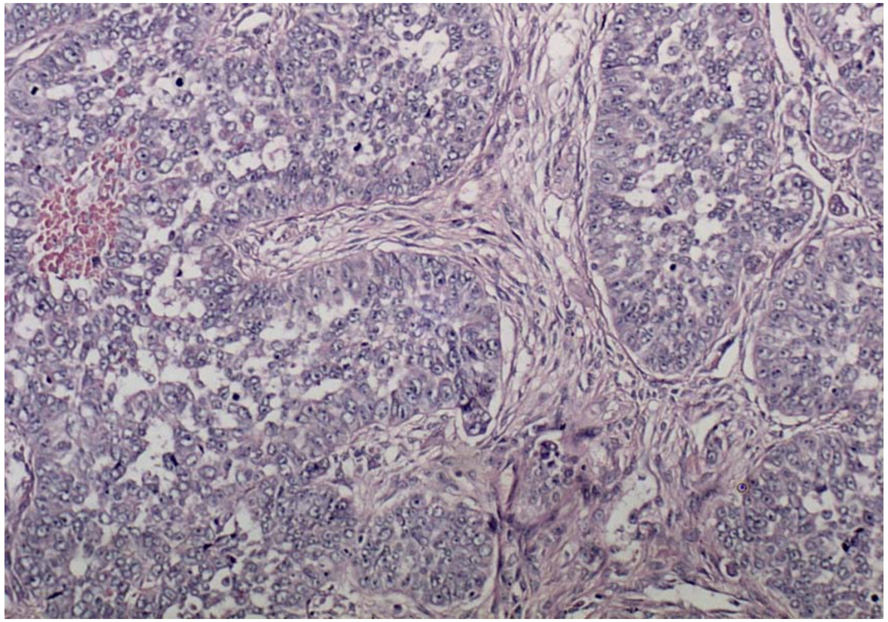
• Otherwise normal fiber optic examination.

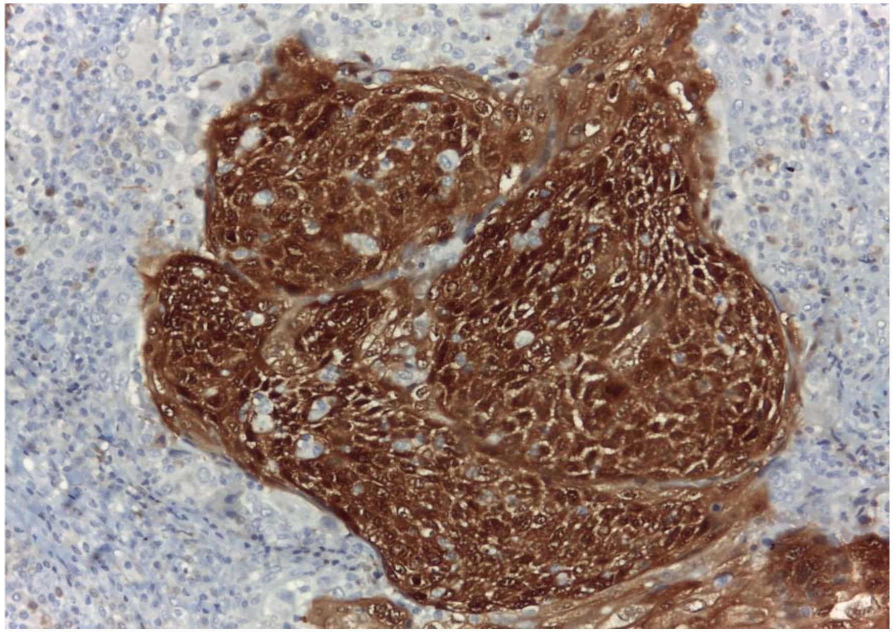
• Palpable node in region II, left side.

• Contralateral side normal.

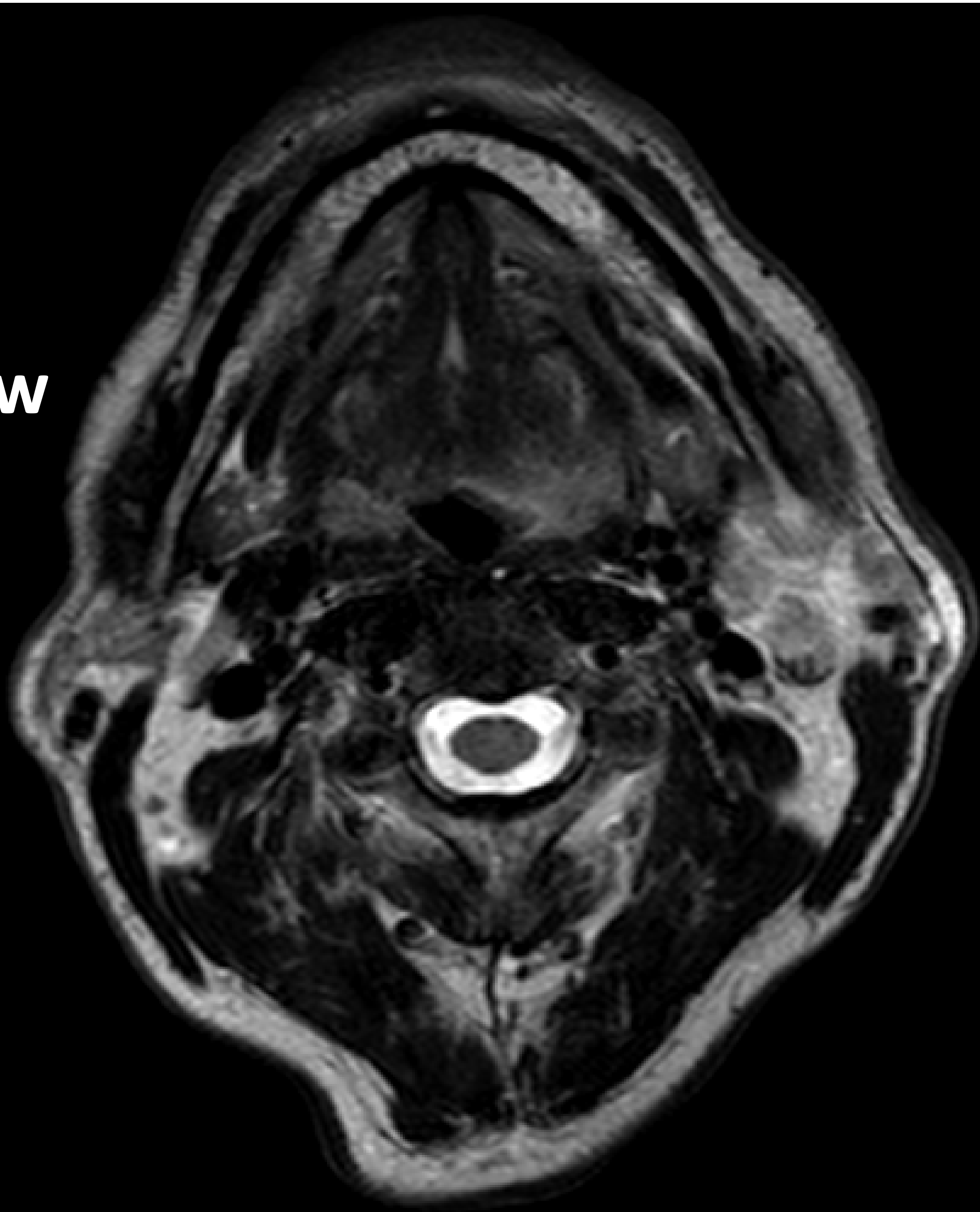
Pathology

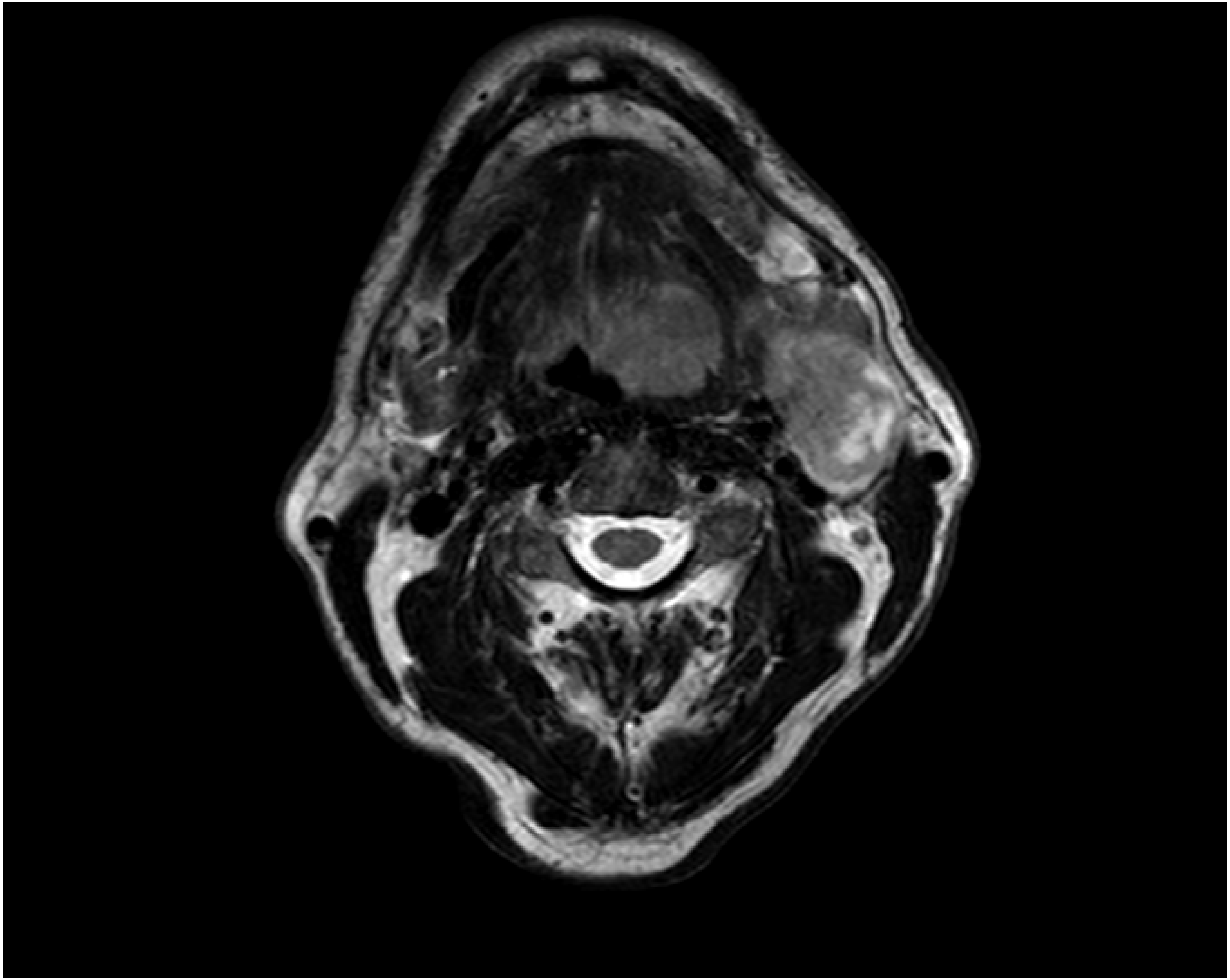
- Moderate differentiated squamous cell carcinoma (G2).
- p16 positive (HPV marker)

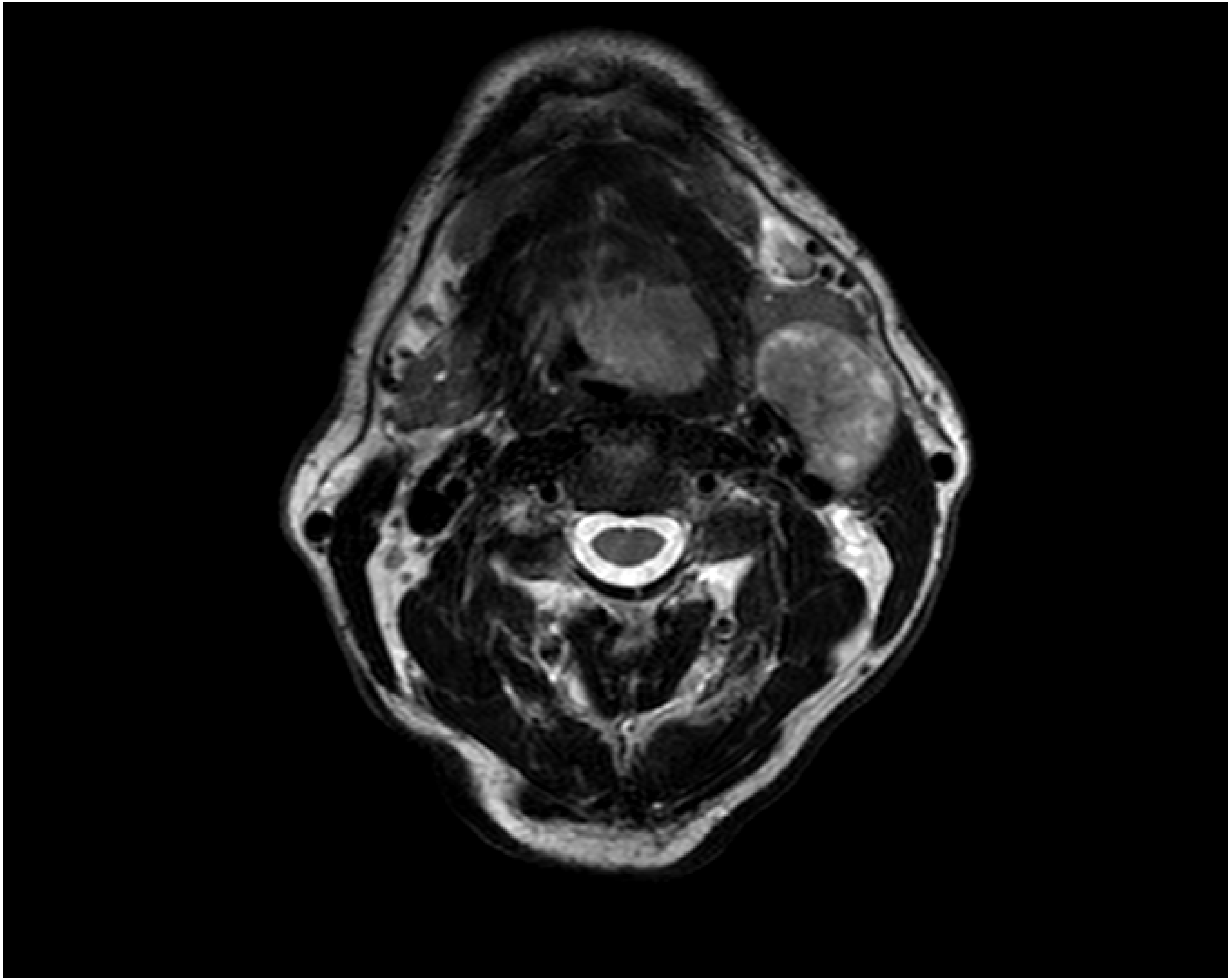


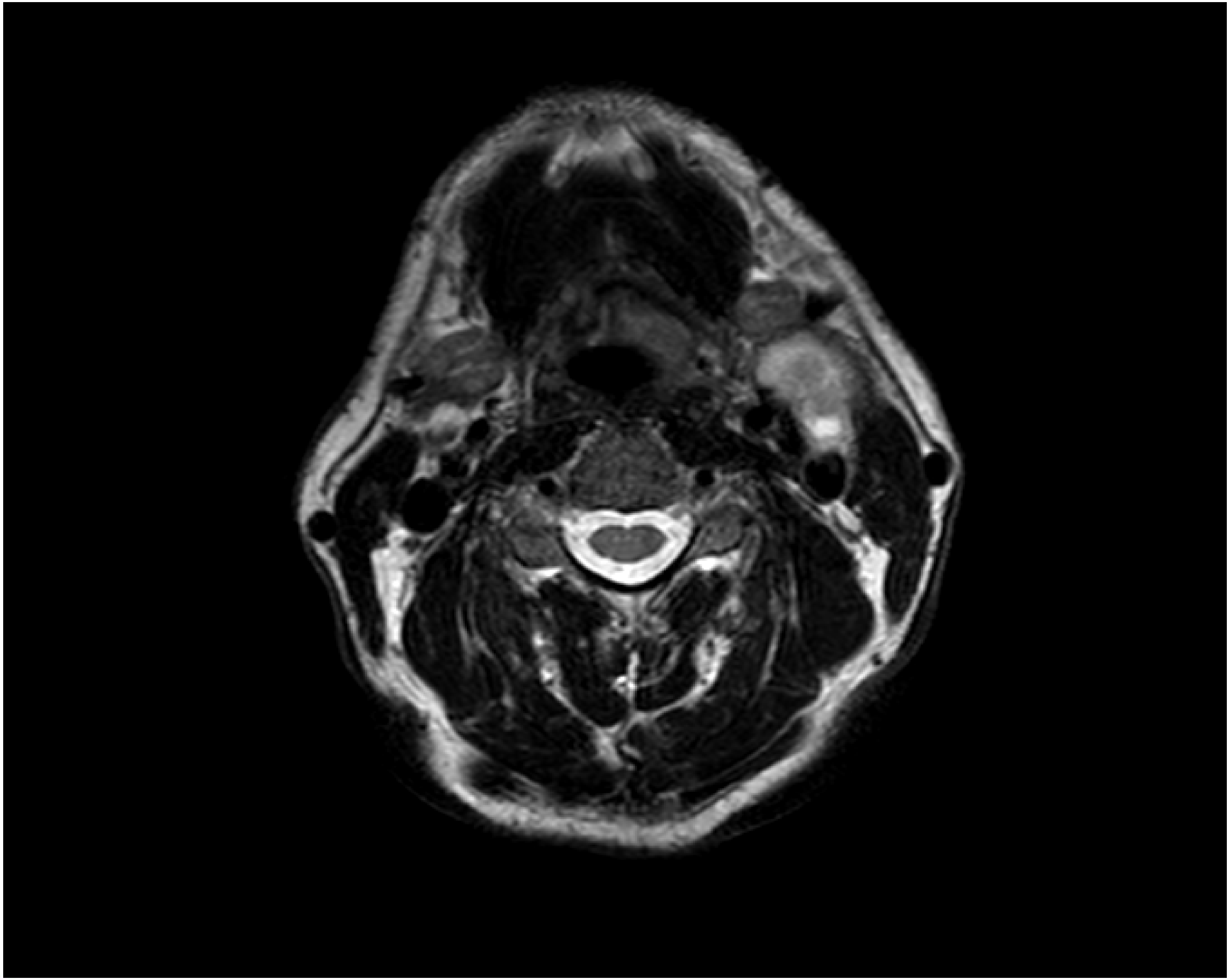


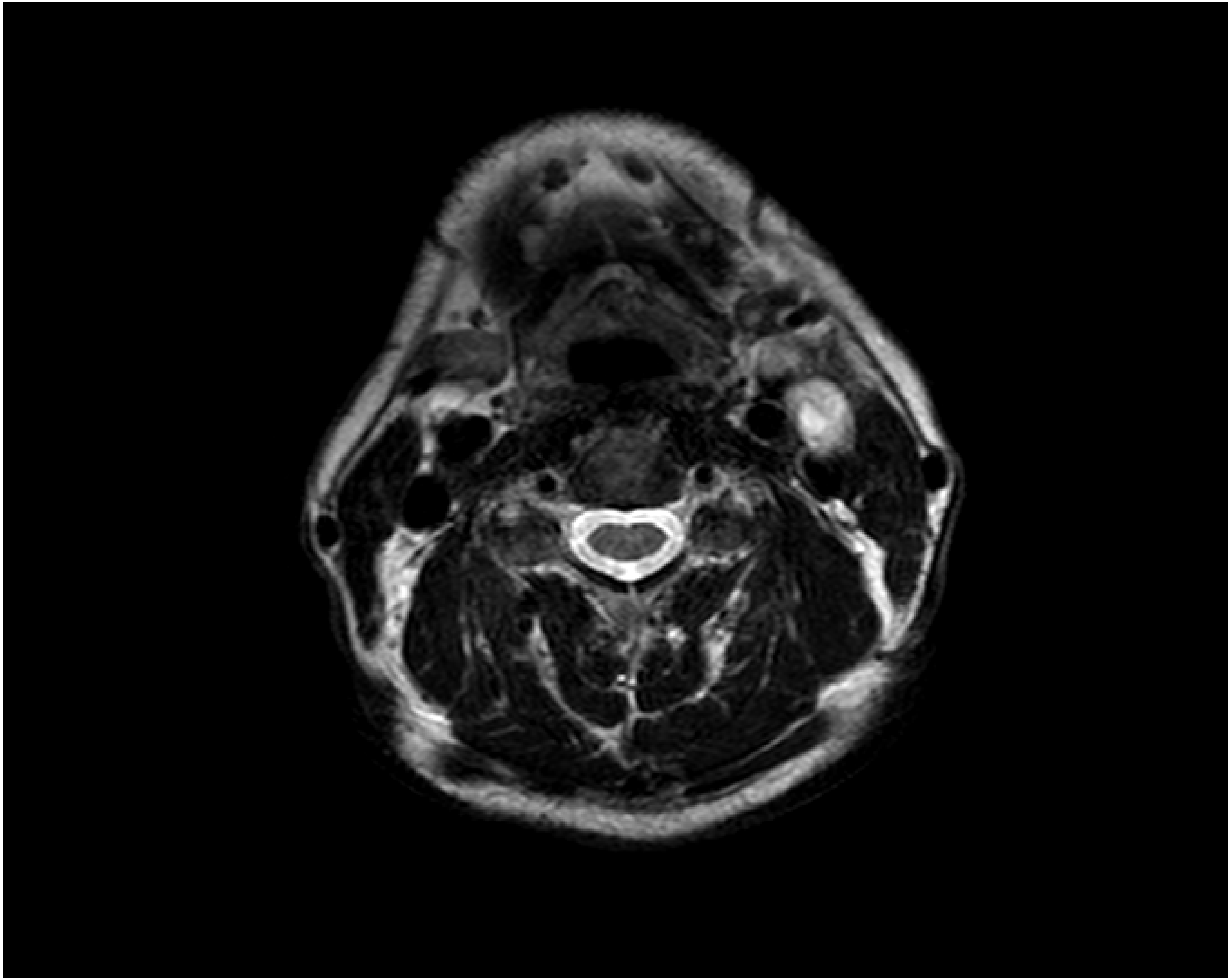
MR
Axial view

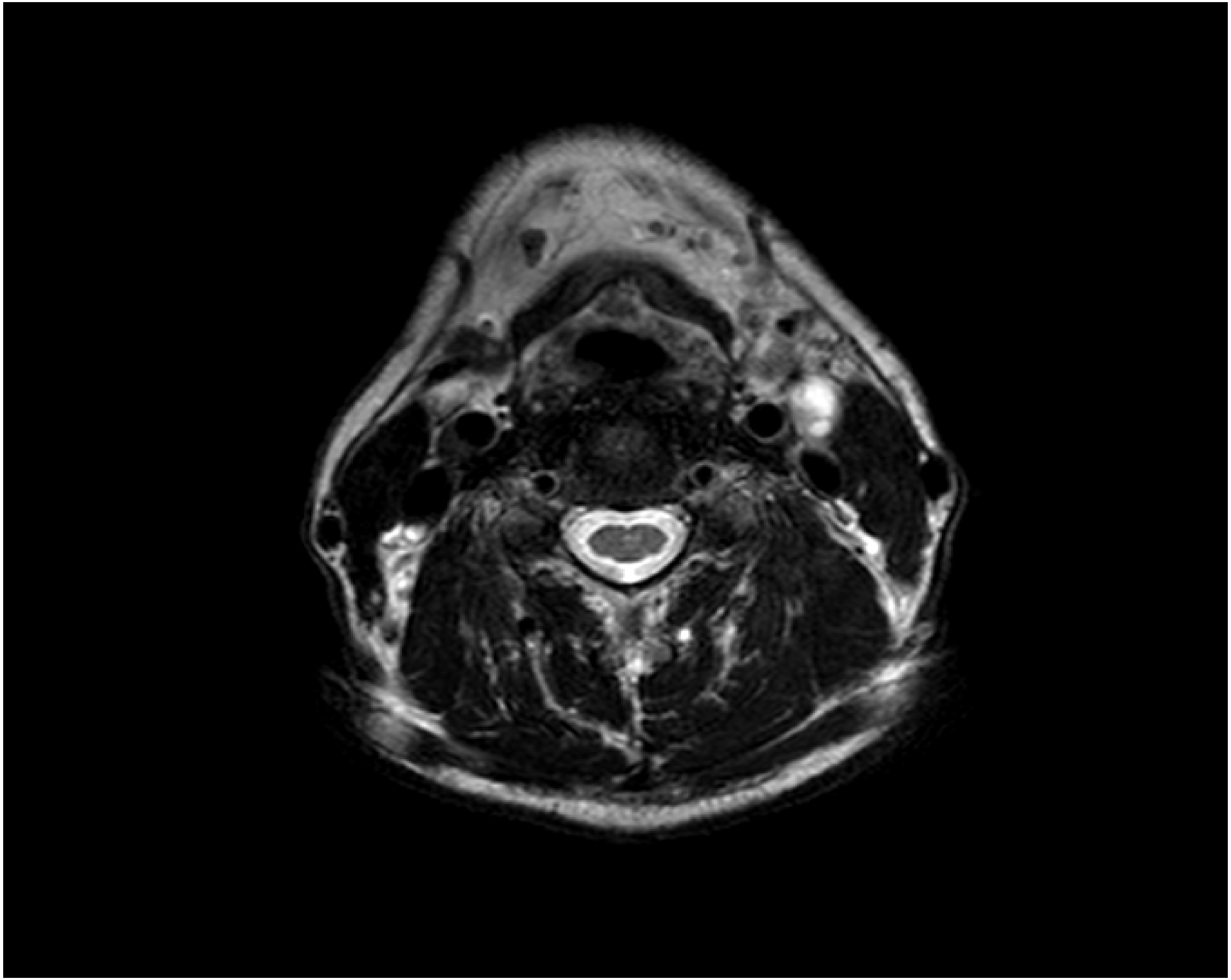


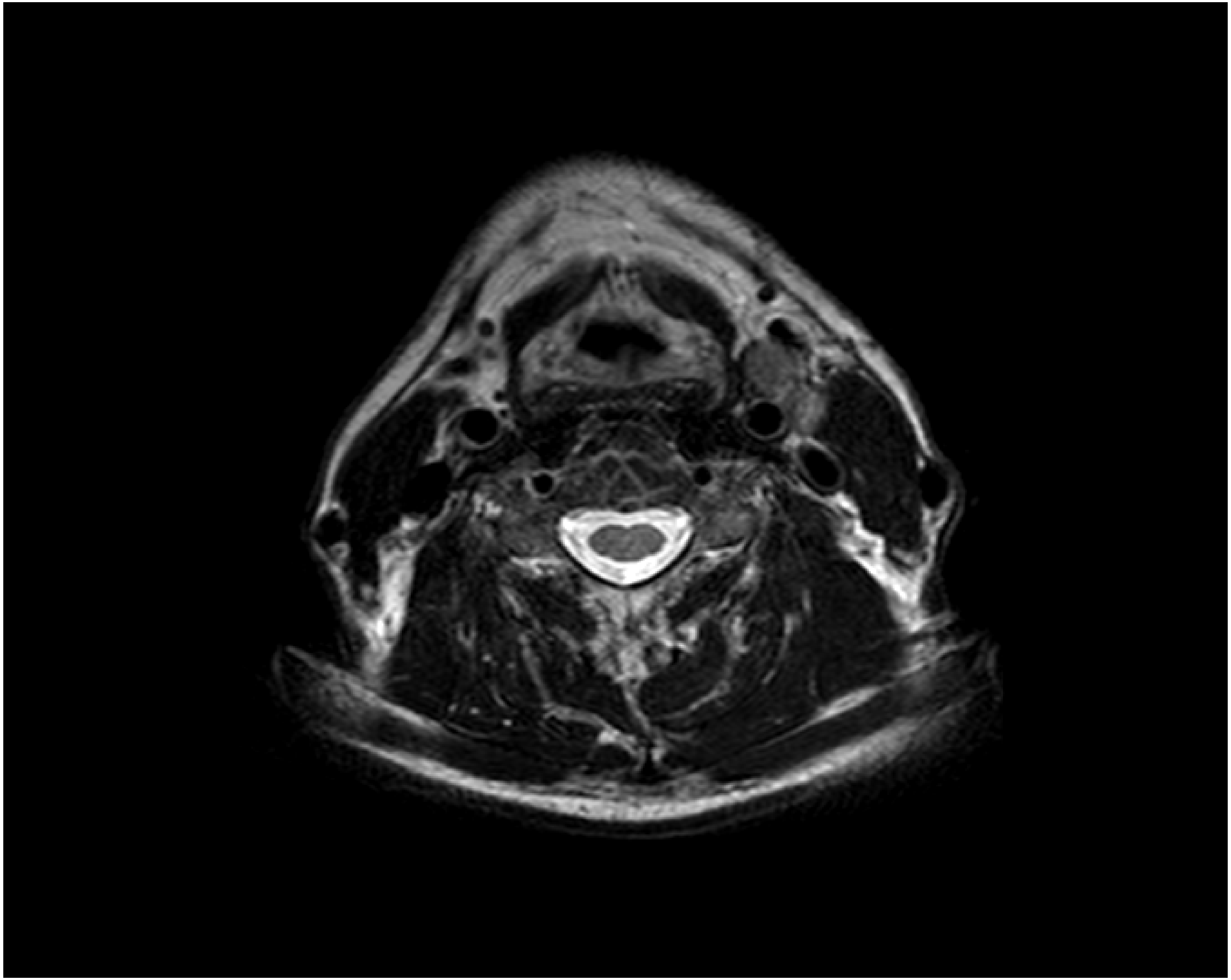




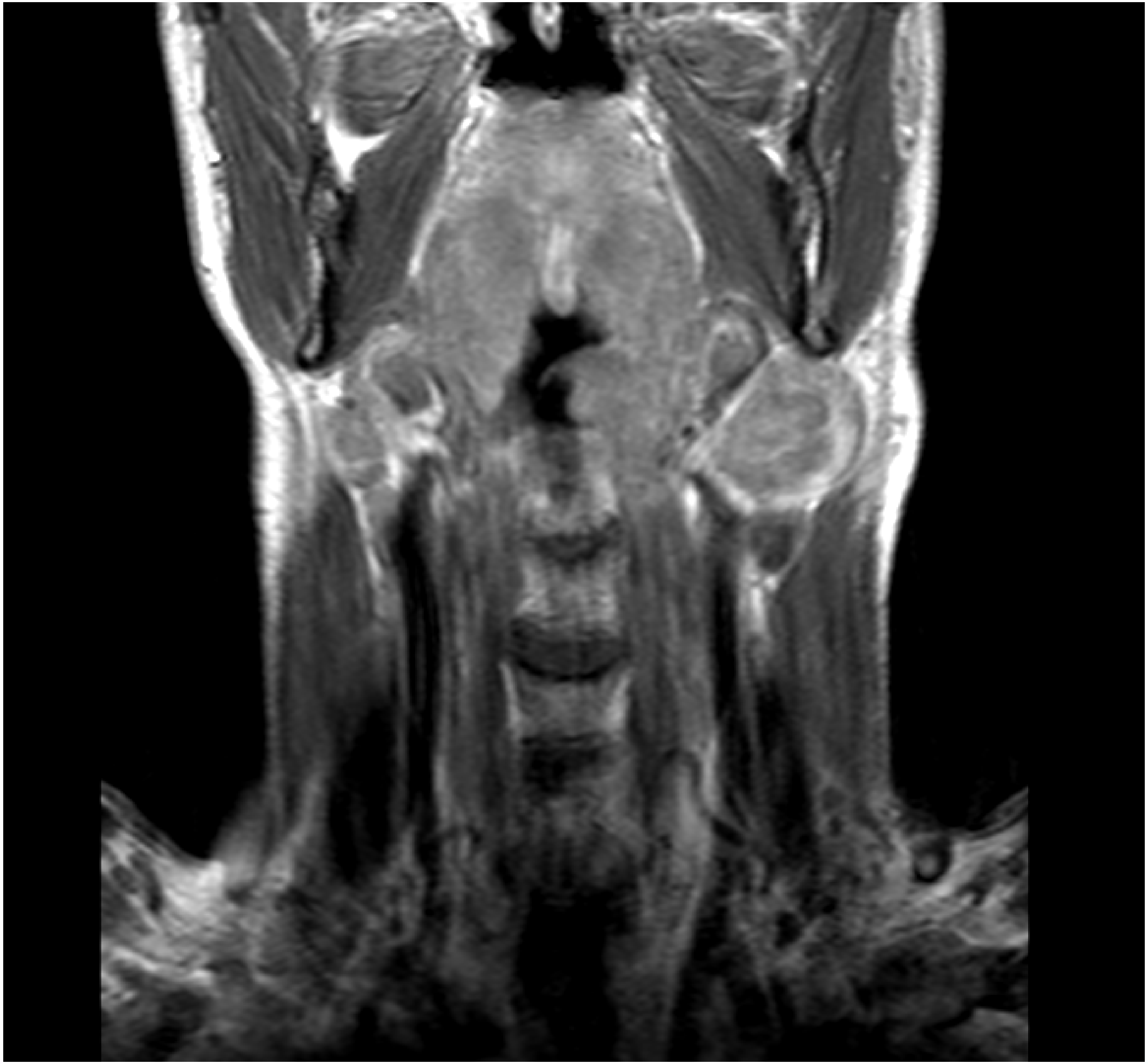


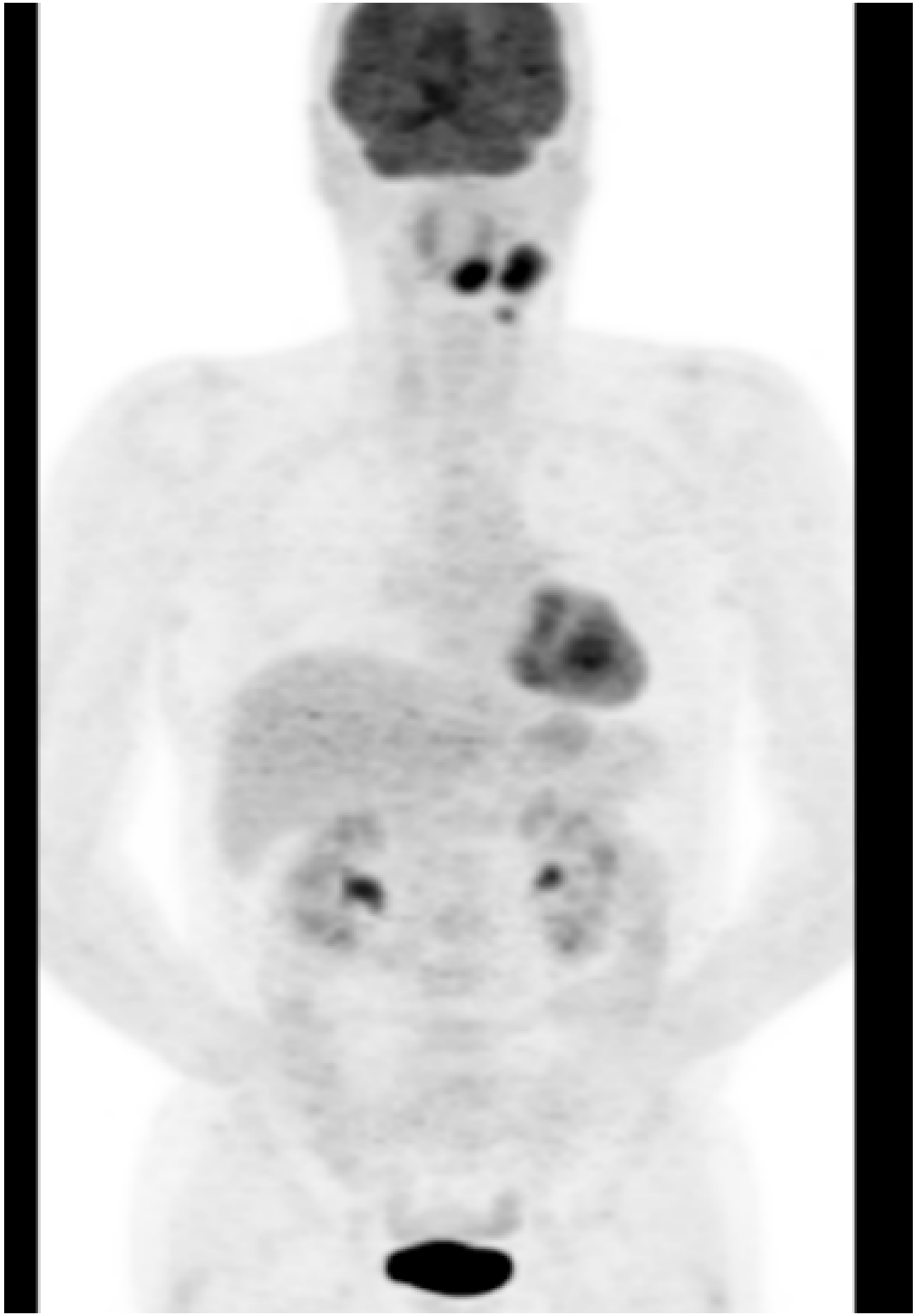


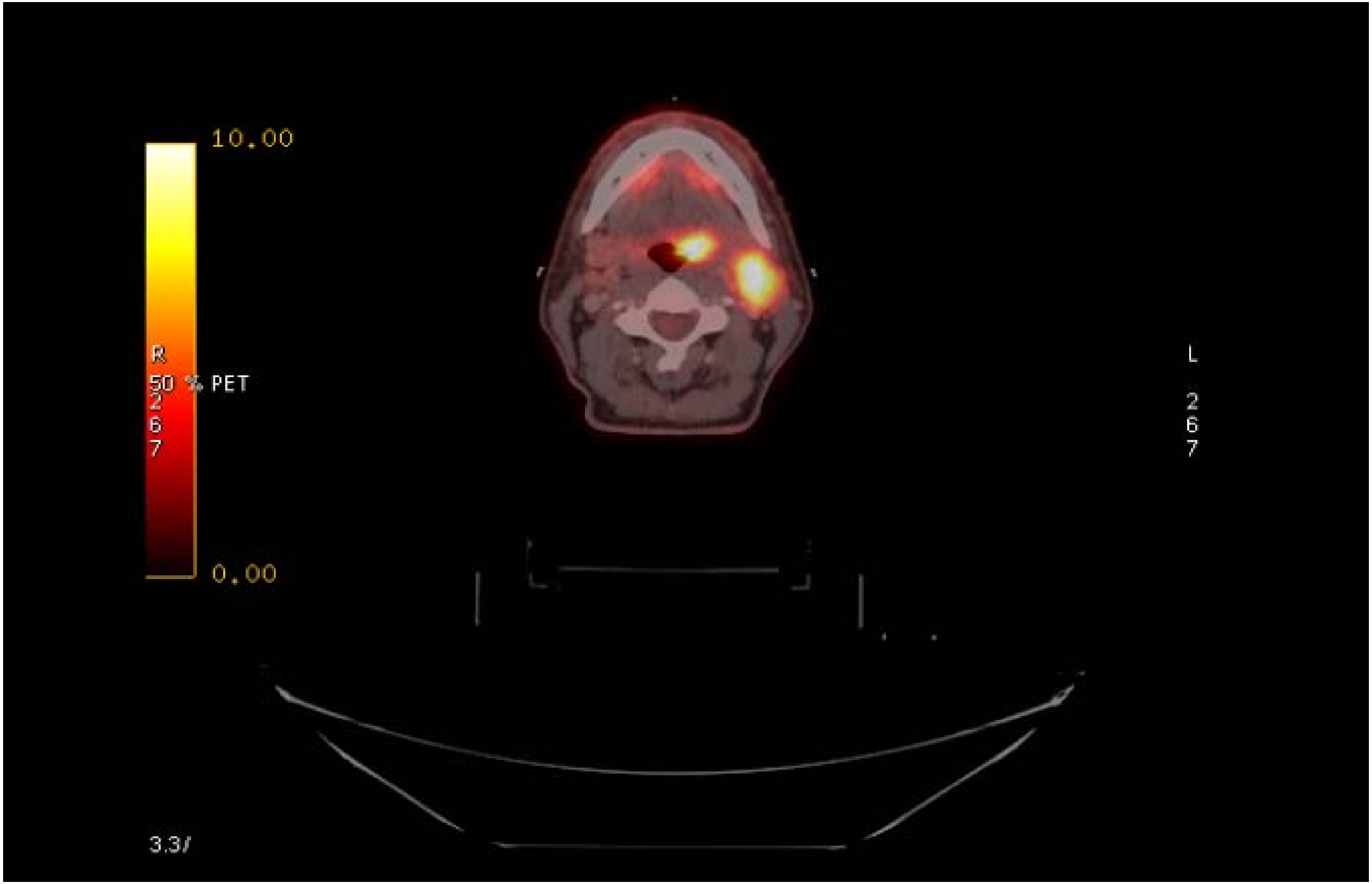




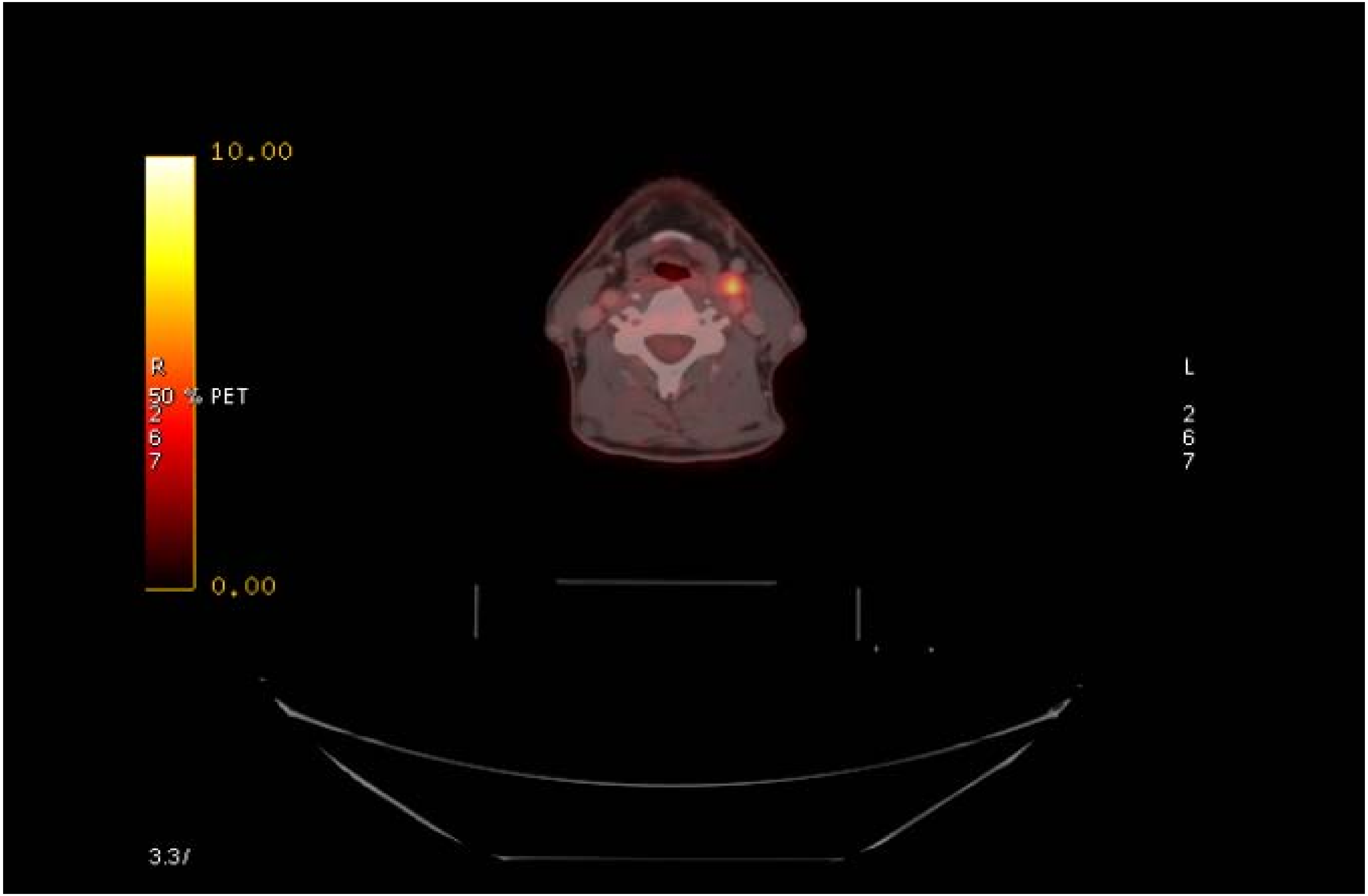

MR
Coronal view







10.00
R
50 % PET
2
6
7
0.00
L
2
6
7
3.3/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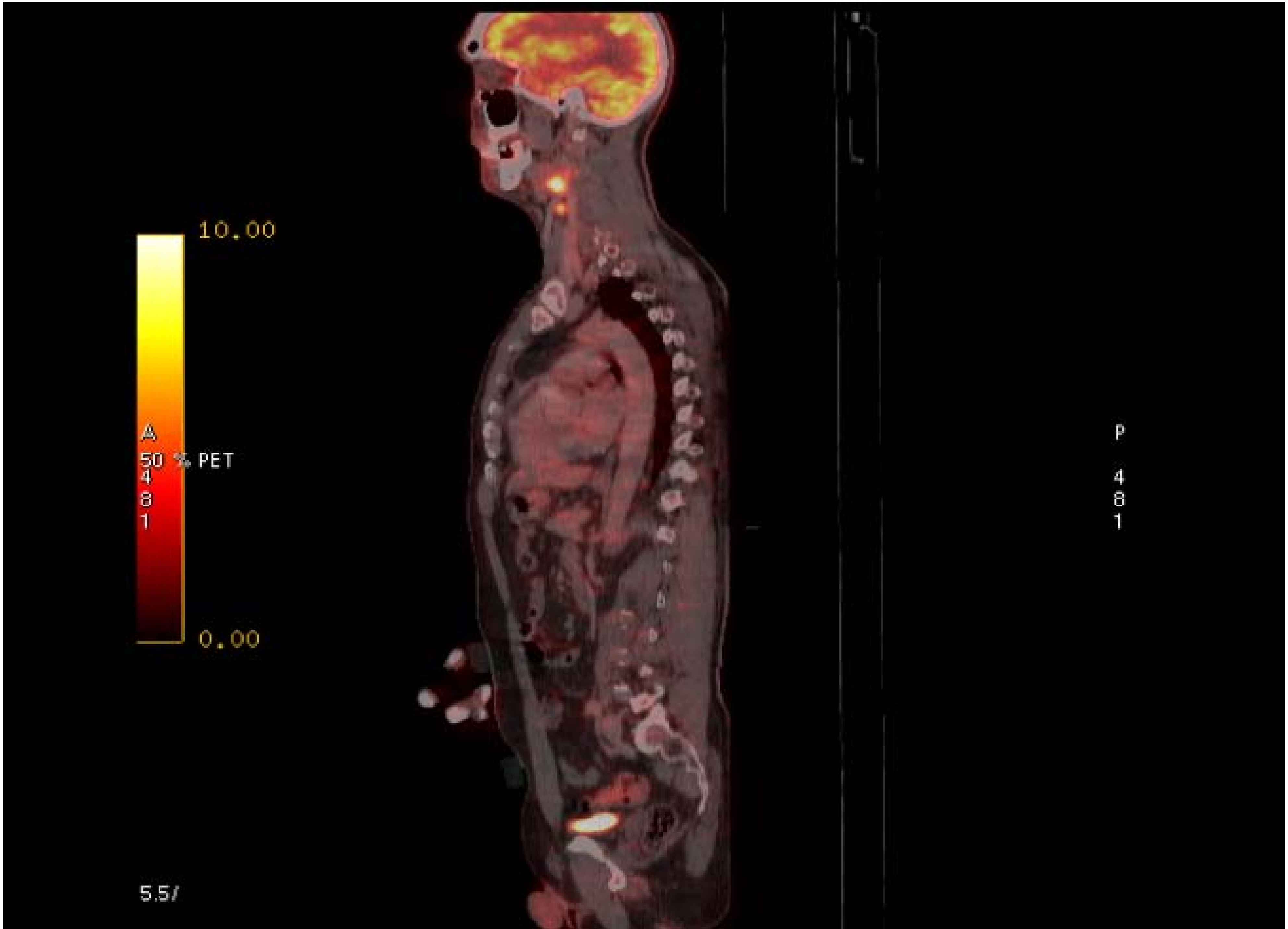
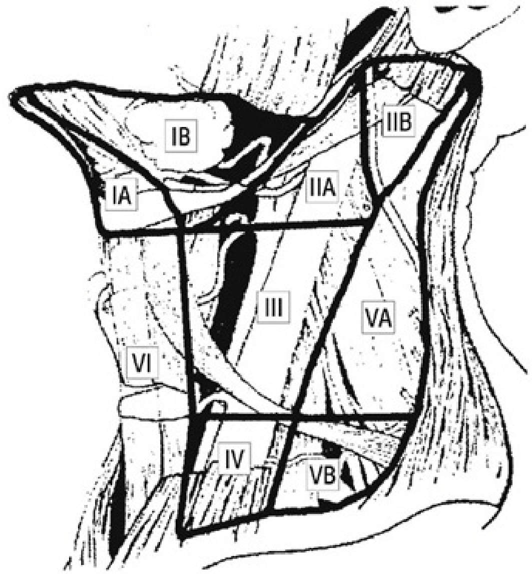

10.00
A
50 % PET
4
8
1
0.00
P
4
8
1
5.5/

Ultrasound of neck

- One necrotic node in the upper part of left region II close to the submandibular gland; 3.5x2x2 cm.
- One node in left region III, 1.5x1x1 cm without preserved hilar region.
- Right side of the neck is normal.



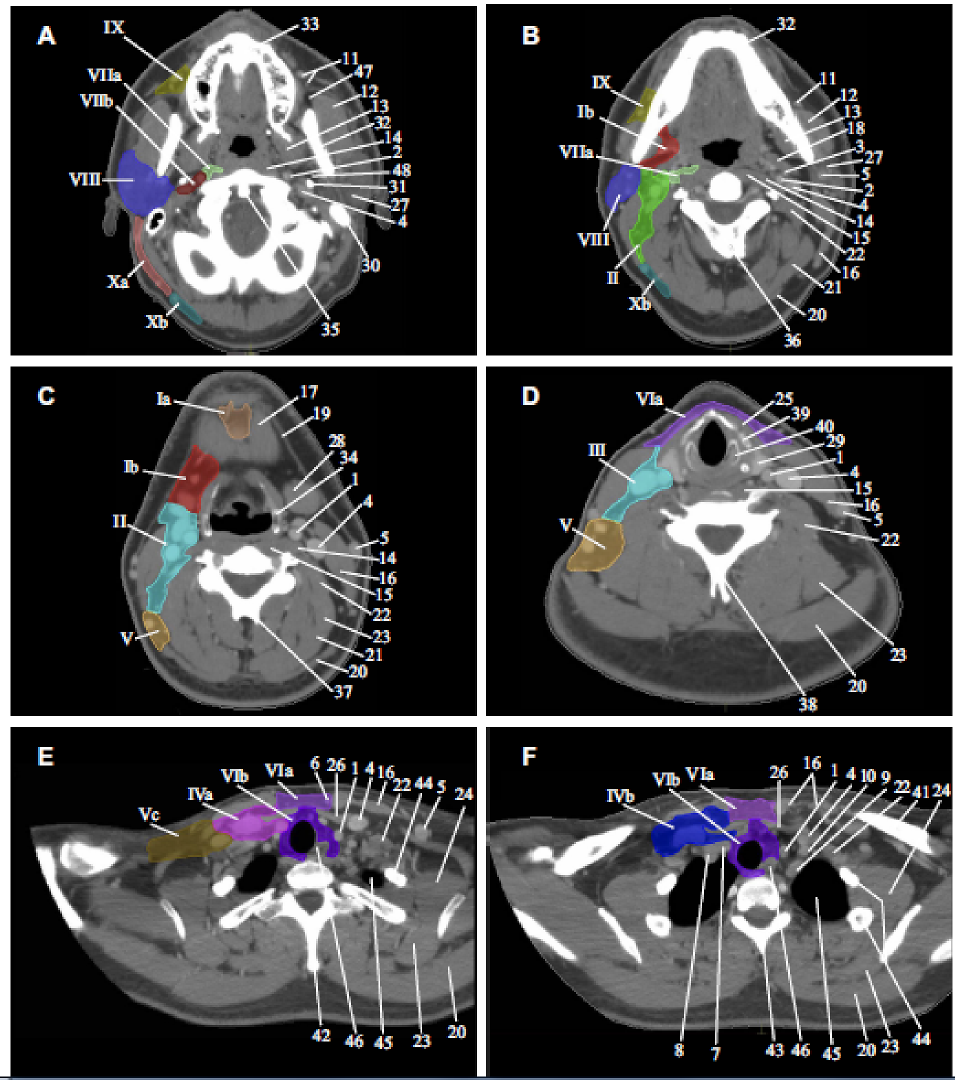
Conclusions after diagnostic workup

- T2N2bM0 (stage IVa) SCC oropharyngeal tumour.
- Patient in a good performance with no relevant co-morbidity.

Treatment done

- 66 Gy/33 Fx; 2 Gy/Fx; 6 Fx/week.
- Concomitant weekly low-dose cisplatinum 40 mg/m² (maximum 70 mg/m²).
- Concomitant hypoxic radiosensitization with nimorazole according to DAHANCA guidelines

Contouring guidelines



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Radiotherapy and Oncology xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

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Original article

Delineation of the neck node levels for head and neck tumors: A 2013 update. DAHANCA, EORTC, HKNPCSG, NCIC CTG, NCRI, RTOG, TROG consensus guidelines ☆

Vincent Grégoire [a,*], Kian Ang [b], Wilfried Budach [c], Cai Grau [d], Marc Hamoir [e], Johannes A. Langendijk [f], Anne Lee [g], Quynh-Thu Le [h,i], Philippe Maingon [j], Chris Nutting [k], Brian O'Sullivan [l], Sandro V. Porceddu [m], Benoit Lengele [n]

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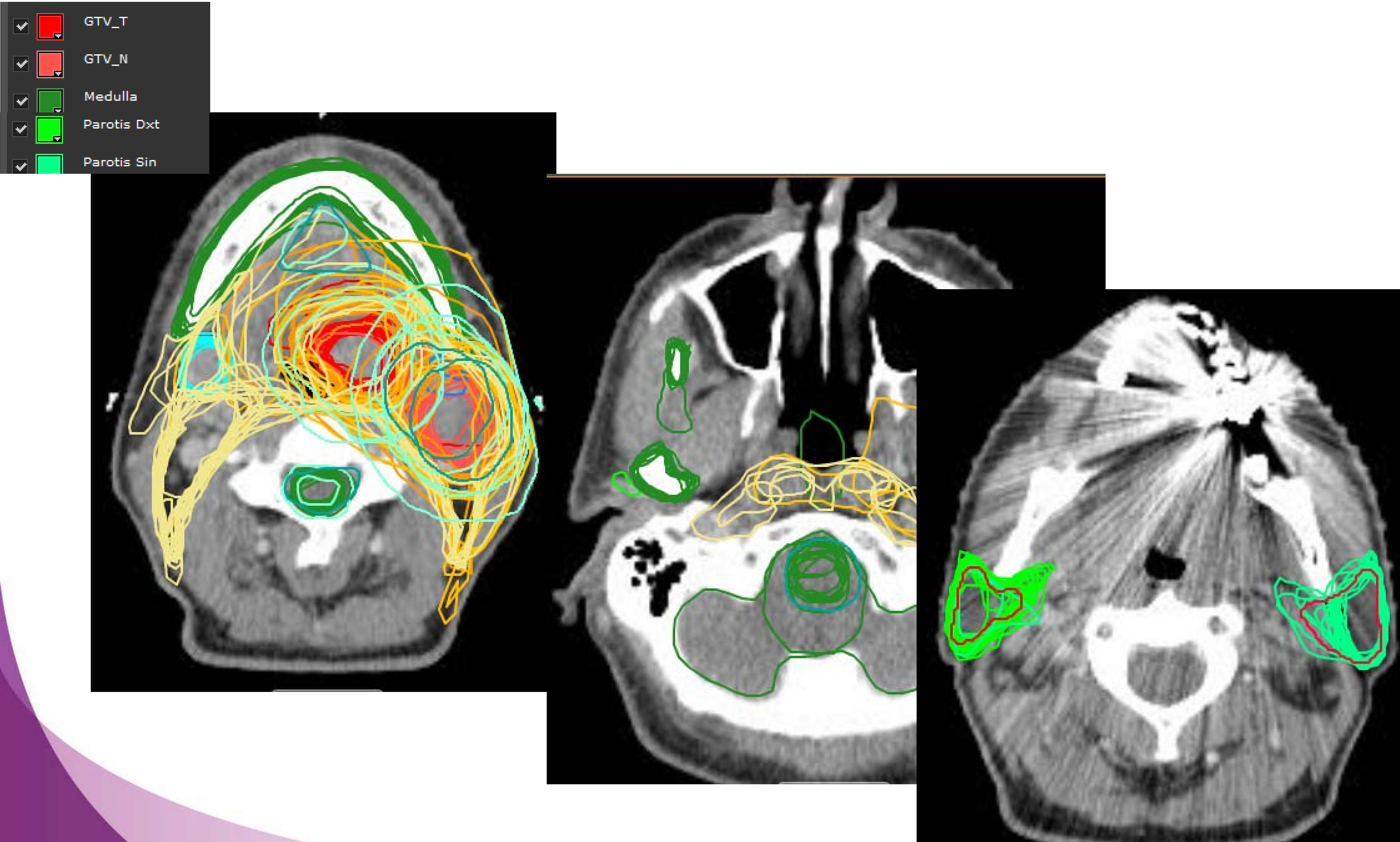
Case used for H&N Falcon online WS



Take home messages:

- HPV positive tumors are changing H&N cancer traditional scenario

- Positioning remain key points for these highly conformal treatments (IMRT+++)

- Target and OAR contouring remains an issue: Highly heterogeneous contours

- Crucial need for contouring guidelines and training

H&N case – Physics considerations

Peter Remeijer

Head and neck

- Complex target volume (GTV, CTV, lymph nodes, PTV)

- Many organs at risk (OARs)
  - Spine
  - Brainstem
  - Salivary glands
  - …

- OARs often close to PTV

Delineation and planning

- Multi-modality imaging (PET/MR) has a large impact on delineation uncertainties
- Image registration becomes important
- PET/MR scans preferably in treatment pose
  - Minimizes errors due to deformations

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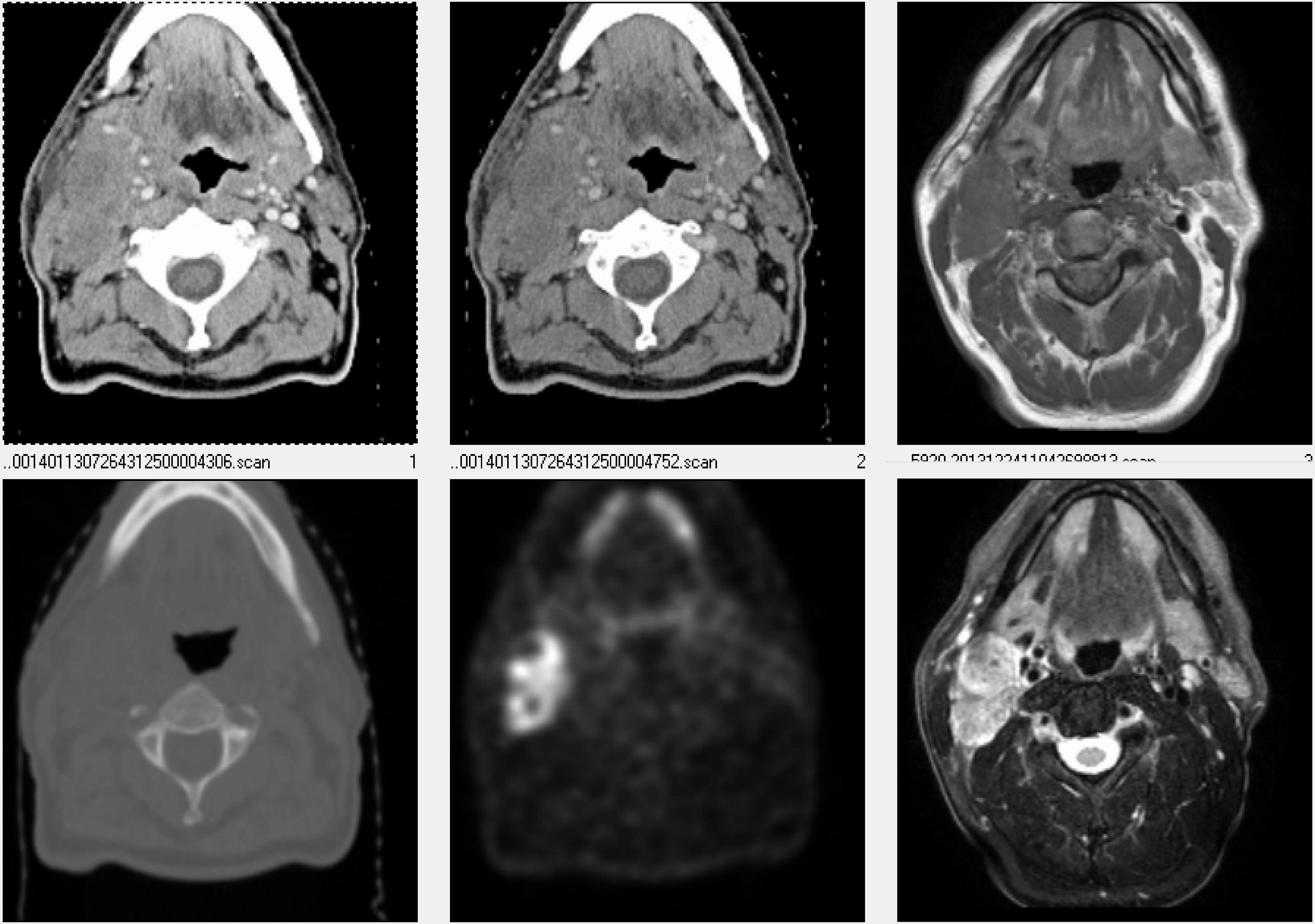
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1
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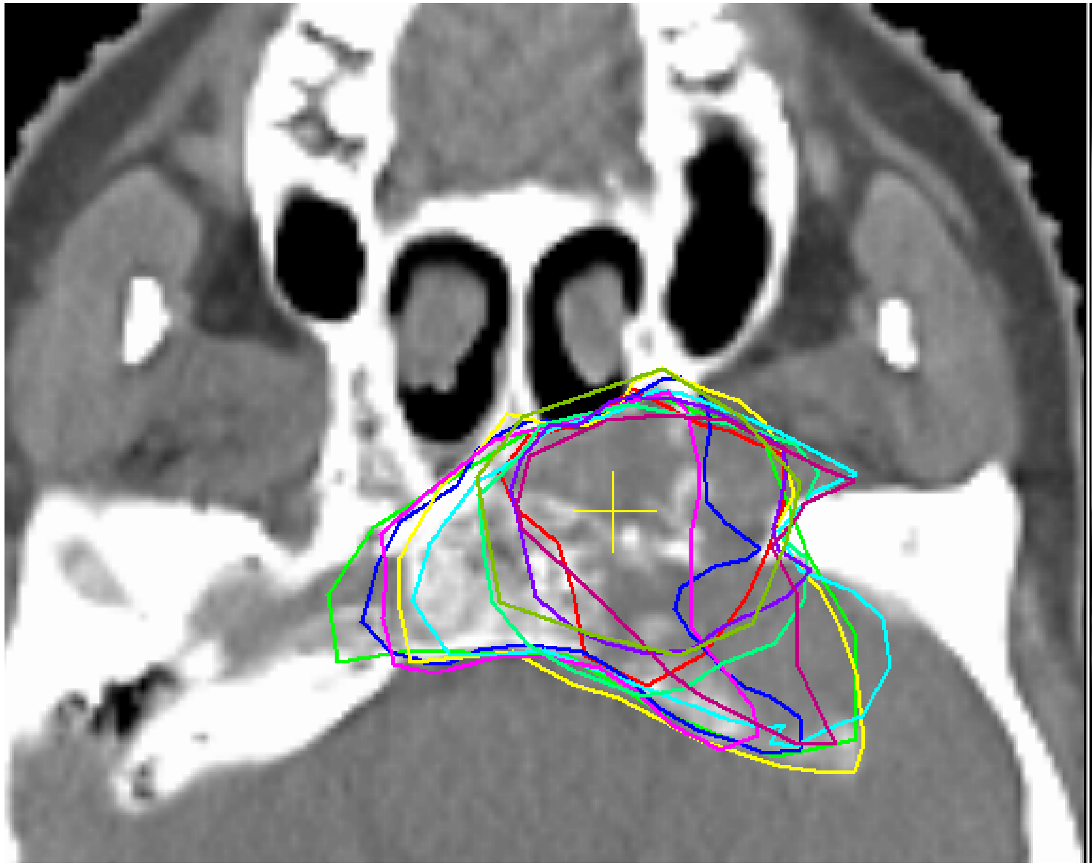
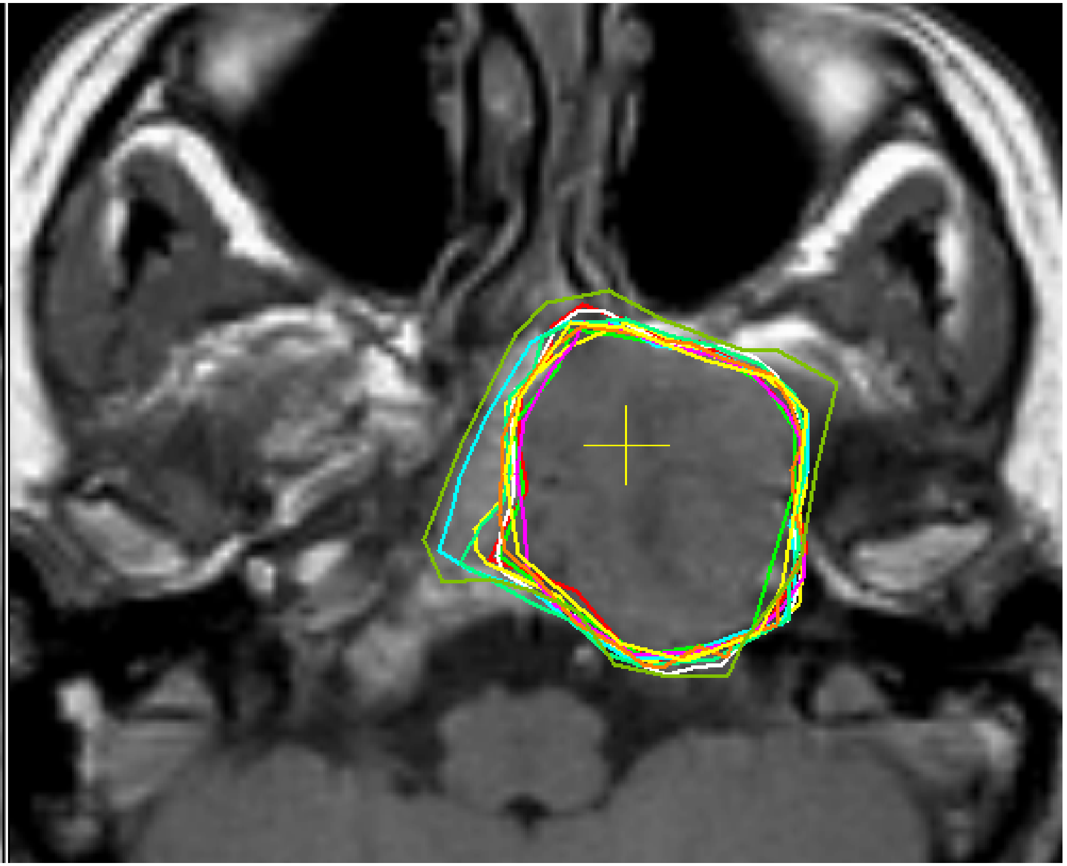
2

Multiple modalities improve H&N delineation



CT

SD 4.4 mm



CT + MRI

SD 3.3 mm

Steenbakkers *et al*

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Delineation and planning

- Multi-modality imaging (PET/MR) has a large impact on delineation uncertainties
- Image registration becomes important
- PET/MR scans preferably in treatment pose
  - Minimizes errors due to deformations
  - Focus on the main region of interest
- Planning: IMRT or VMAT

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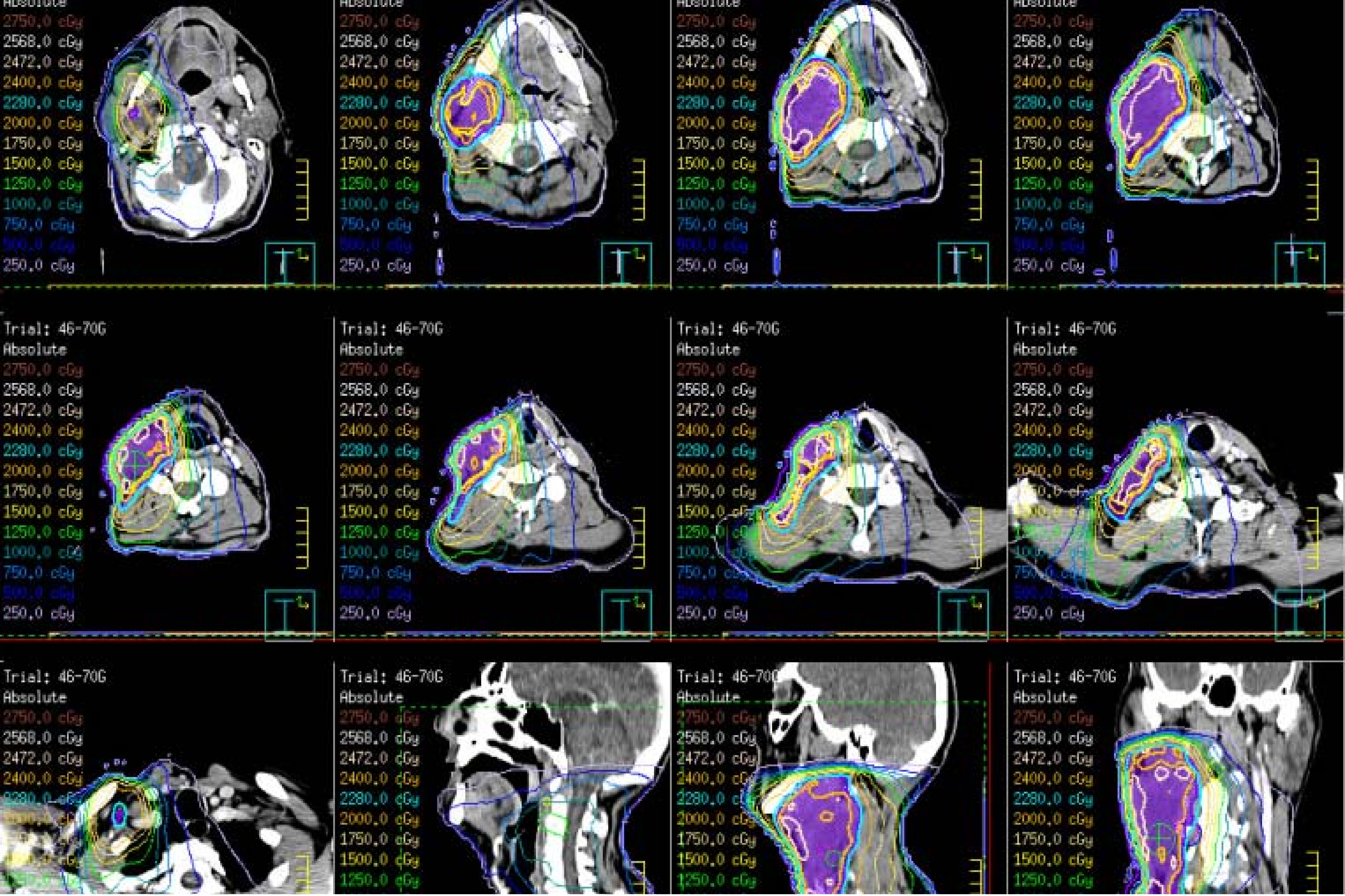

Complex planning techniques → Margin becomes more critical

Treatment - All is well?

# Patients	# Images	Direction	σ_{sys} (mm)	σ_{random} (mm)	Reference
31		ml cc ap	1.8 1.7 2.0	1.5 1.1 1.6	(Bel et al., 1995)
26	356	ml cc ap rot ant rot lat	1.8 2.7 1.7 1.2° 0.7°	1.6 1.5 1.2 0.8° 1.0°	(Vos et al., 1997)
12	192	cc ap	2.0 1.3	1.4 1.7	(Yan et al., 1997b)
12	290	ml cc ap	1.8 [a] 2.2 [a] 1.7 [a]	1.4 1.4 1.4	(Gildersleve et al., 1995)

Portal imaging data from a long time ago…

- Systematic errors: 1 to 2 mm (SD)
- Random errors: 1 to 2 mm (SD)

Hurkmans *et al*

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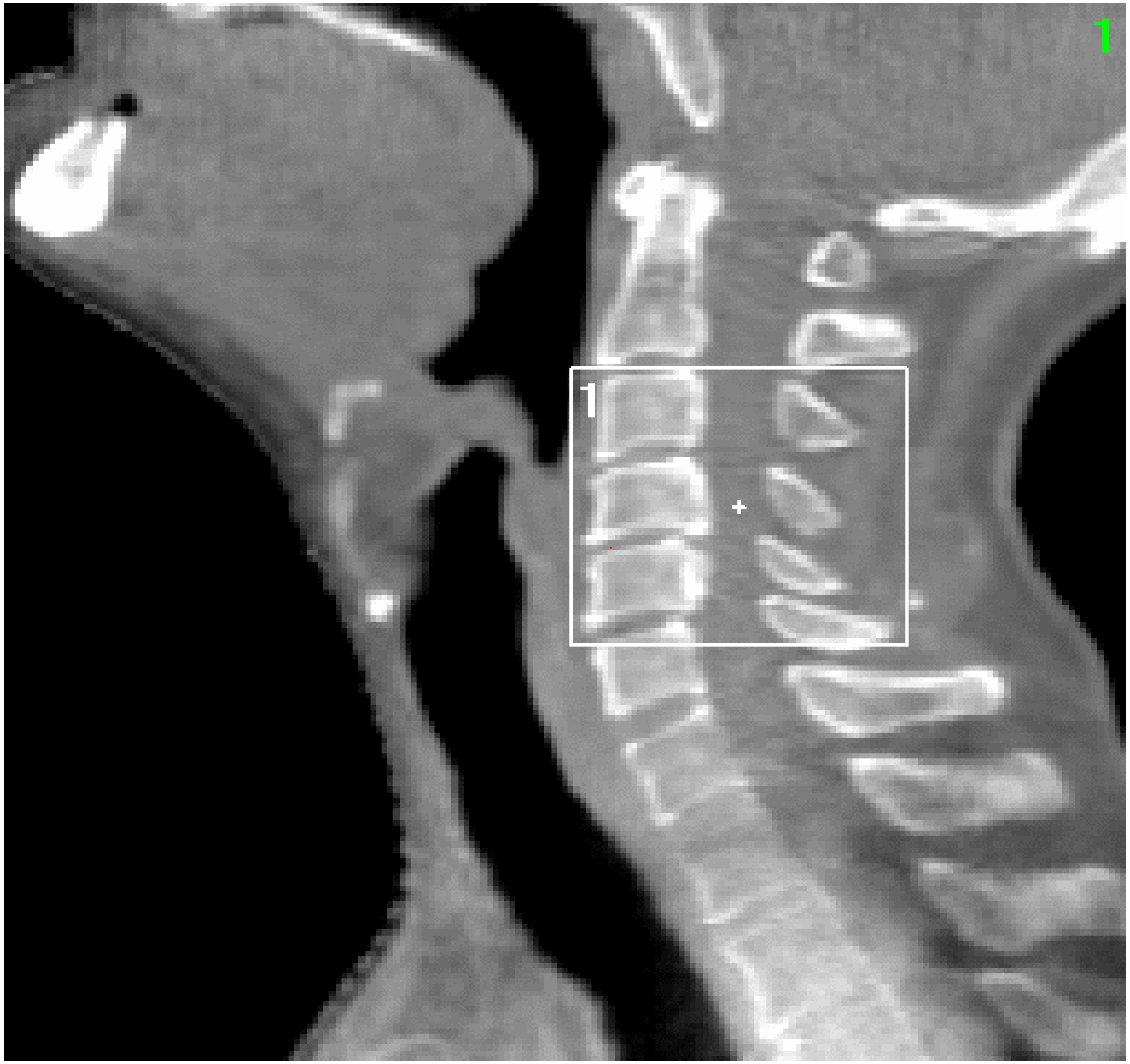
Cone beam CT → Shape changes!

- Pose
- Weight loss
- Tumor regression
- …

→ Non rigid



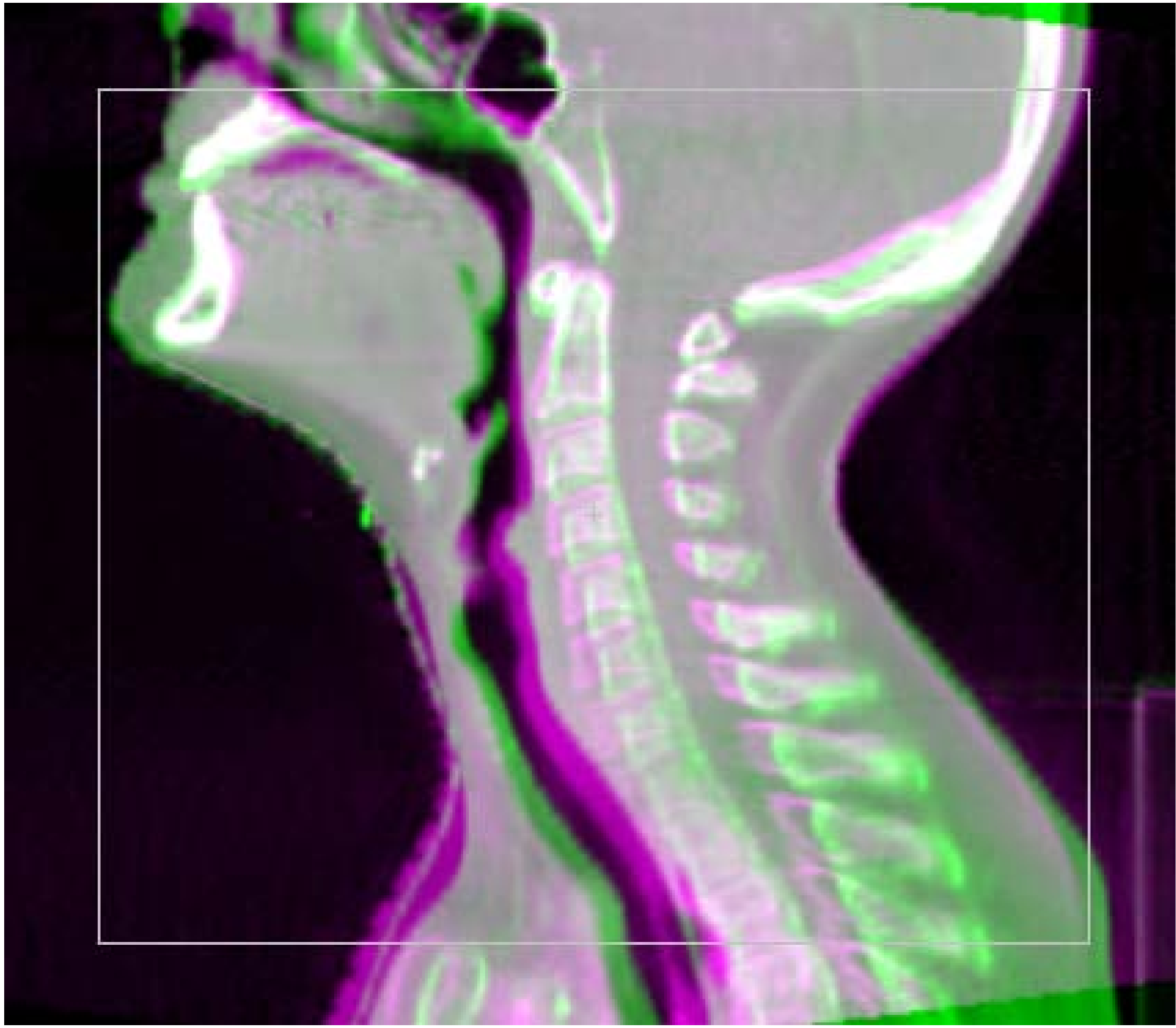
Treatment – image registration

Single ROI

ROI encompasses:

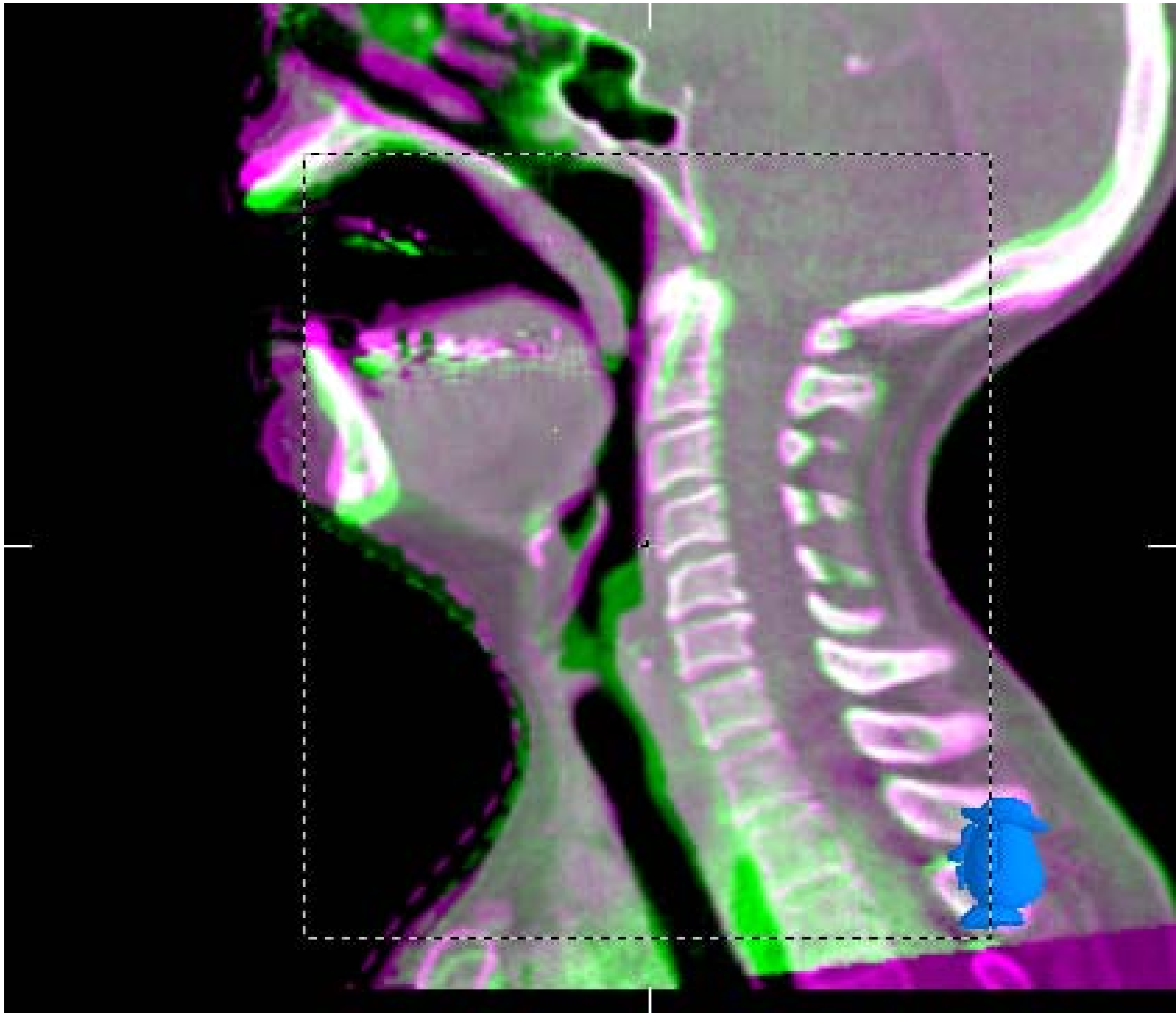
- PTV
- Vertebrae
- Base of skull
- Jaw

Purple: CBCT
Green: planning CT
Overlay: white = match



Single ROI registration

- Match inaccurate
  - ➢ Misregistration?
  - ➢ Deformation?



Use multiple ROIs

Allows:

- Accurate local registration
- Assessment of local setup errors

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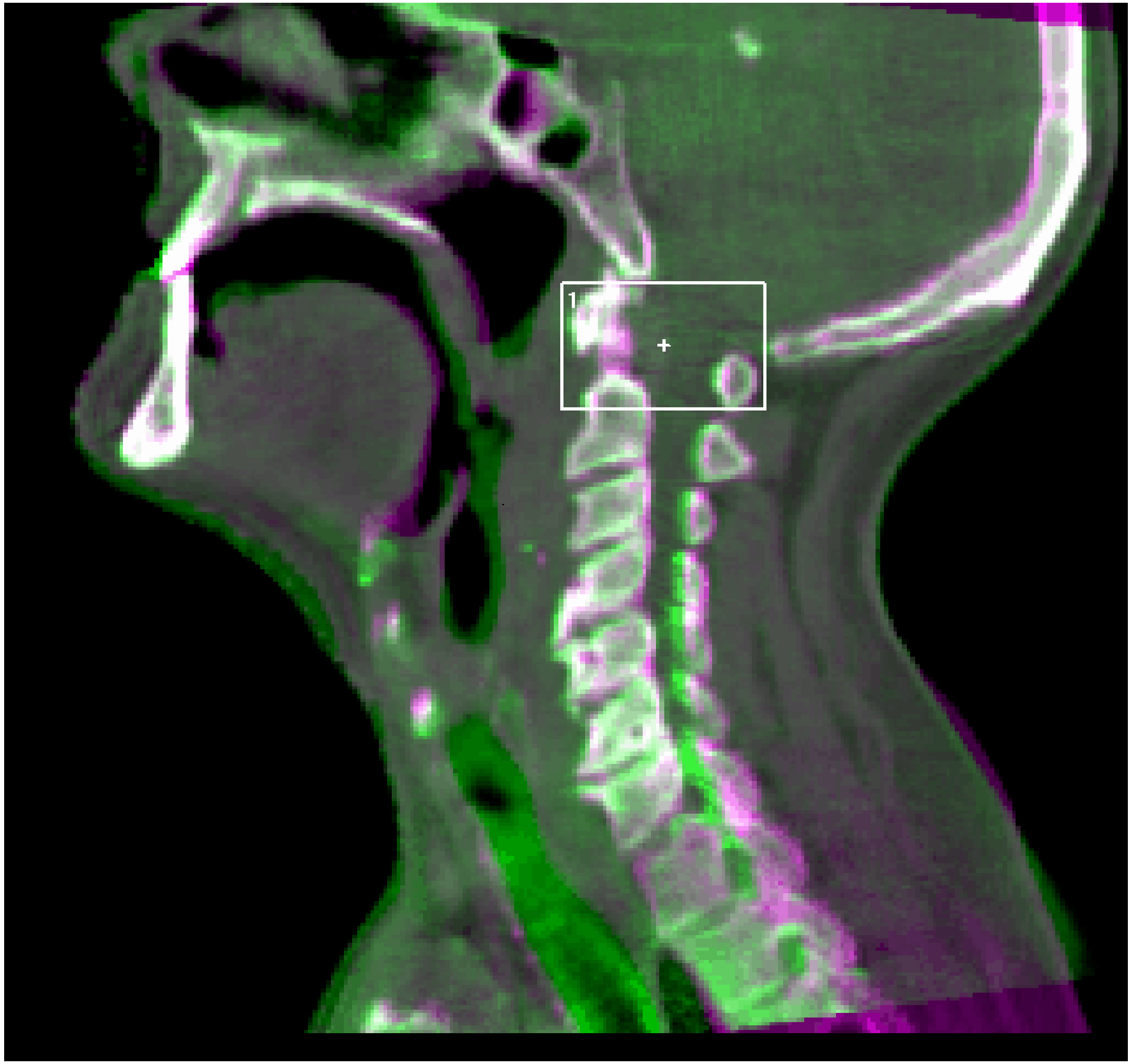
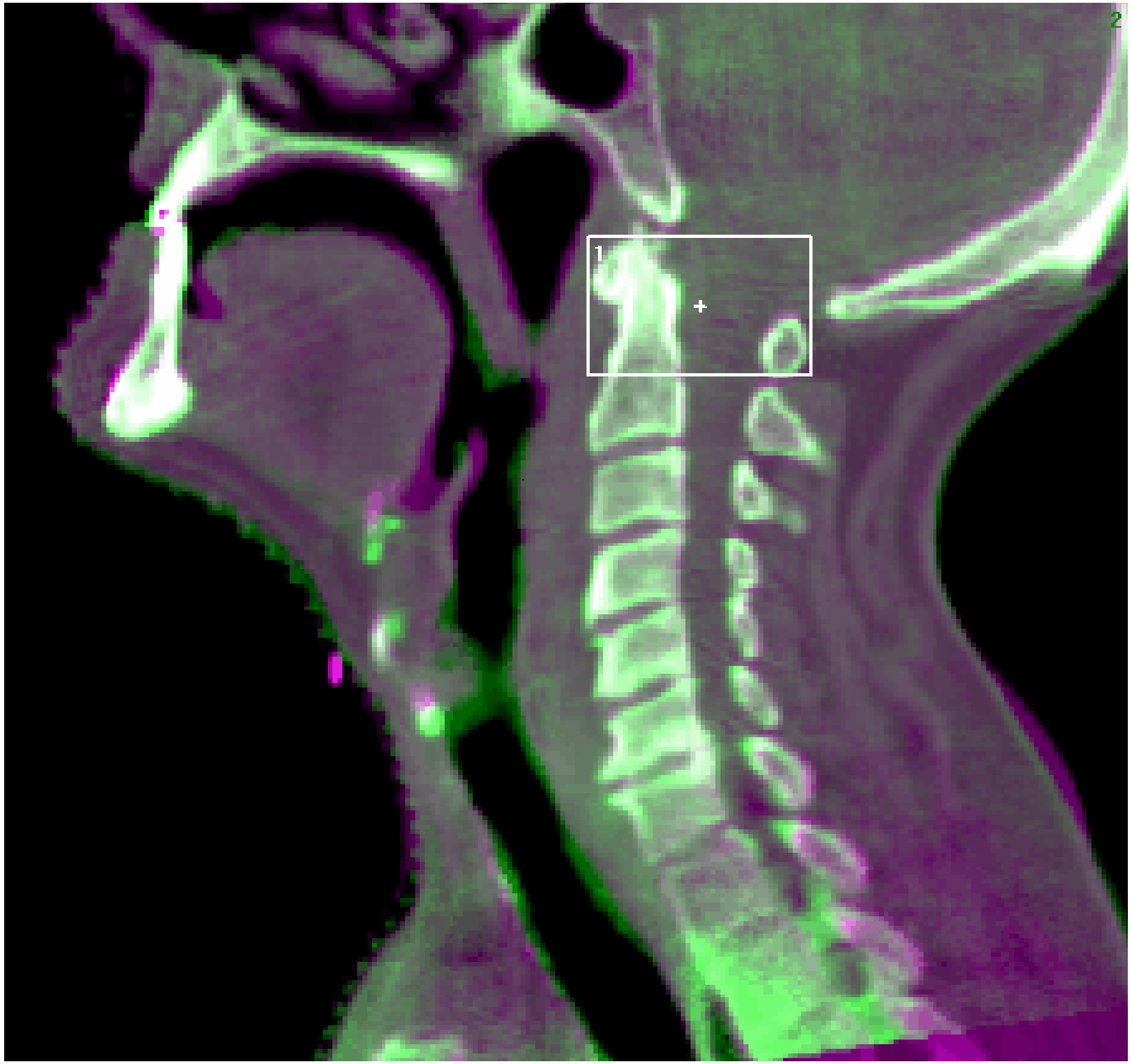
Image registration



- bony anatomy registration
- Loop over ROIs

Purple: planning CT
Green: CBCT

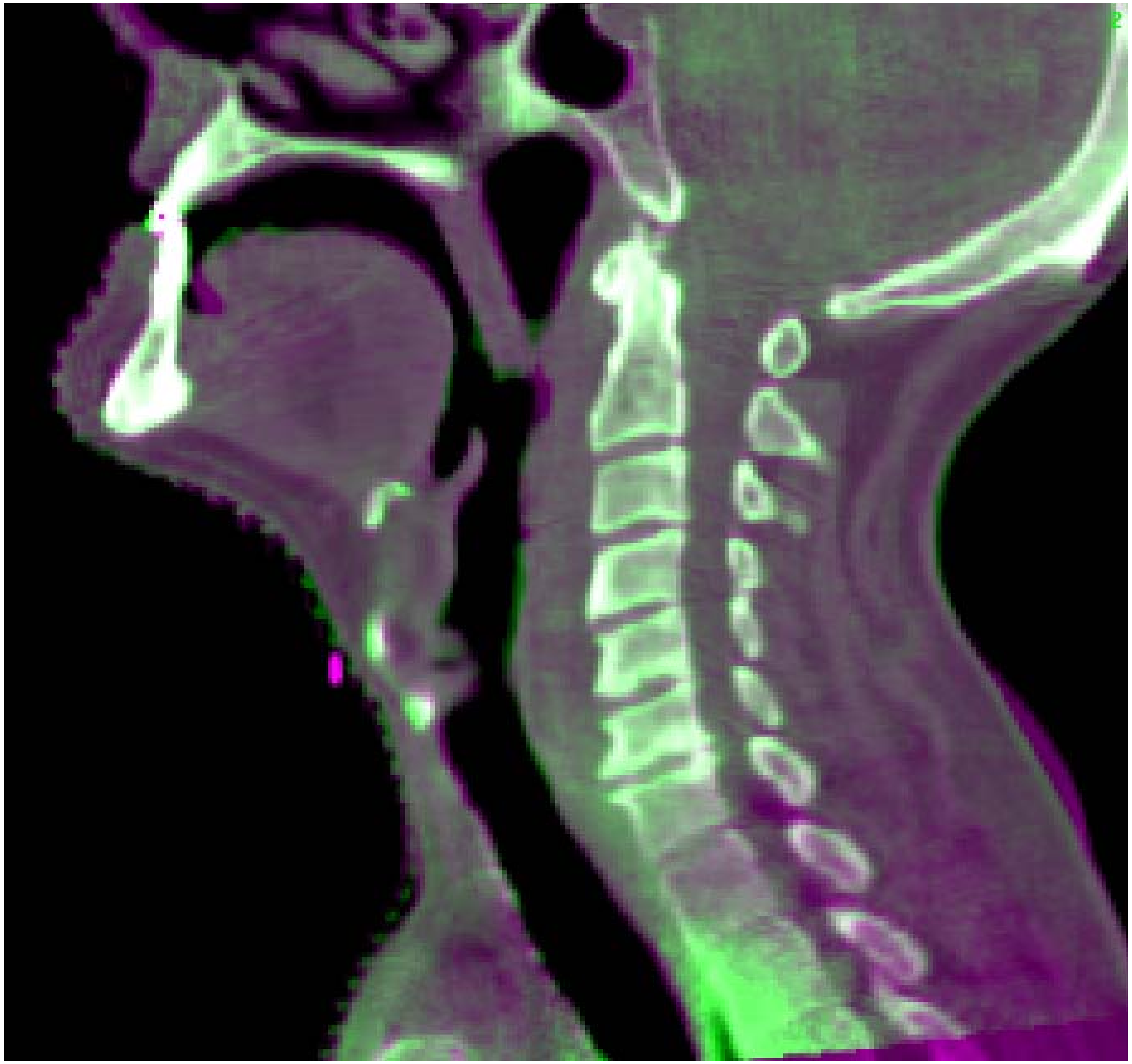
Validation of registration



All registrations separately

→ Easy

Validation of registration

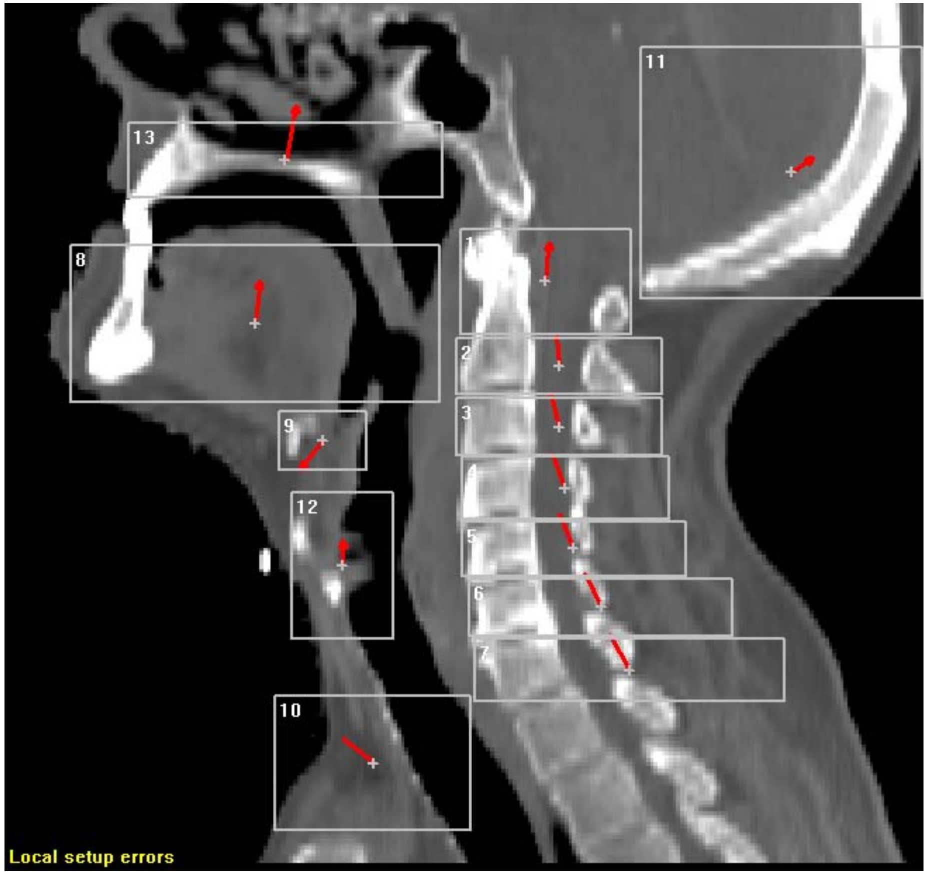


All registrations at once by warping

→Fast

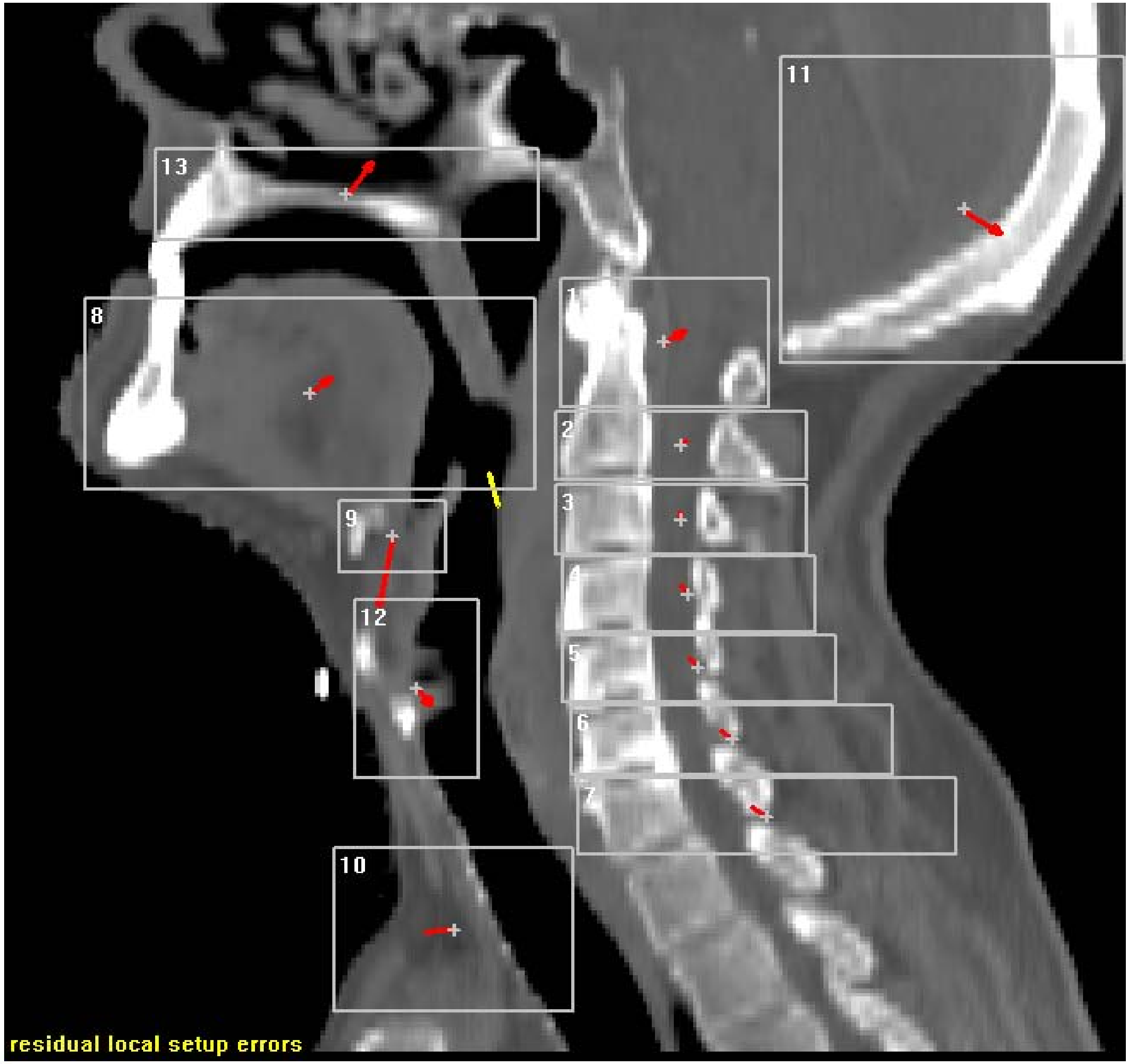
Corrections

Couch shift: Average setup errors



Correct average

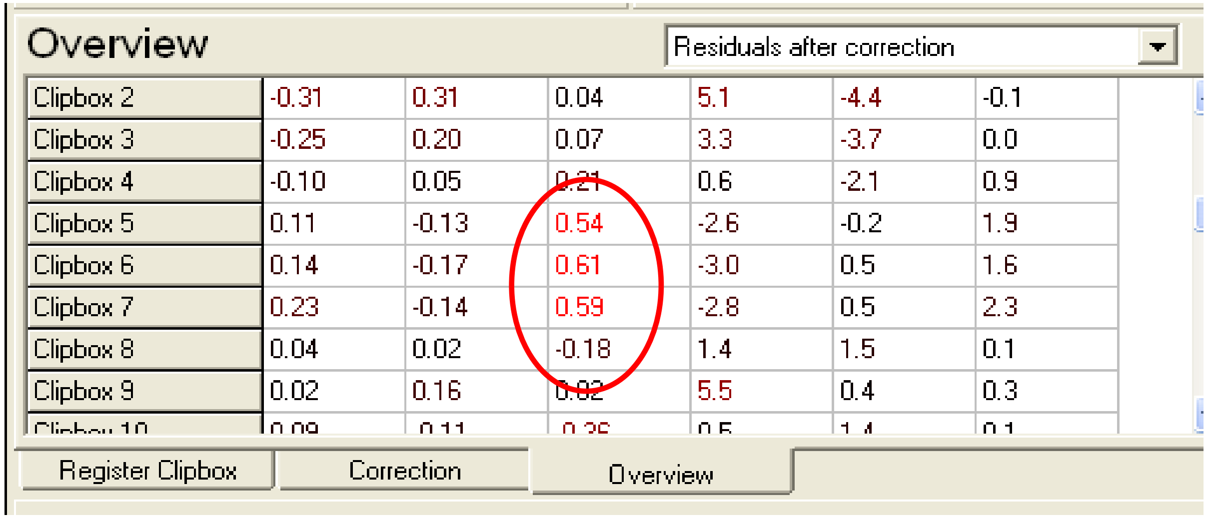
Corrections



- Residual errors!

Corrections

- Residual errors



Clipbox 2	-0.31	0.31	0.04	5.1	-4.4	-0.1
Clipbox 3	-0.25	0.20	0.07	3.3	-3.7	0.0
Clipbox 4	-0.10	0.05	0.21	0.6	-2.1	0.9
Clipbox 5	0.11	-0.13	0.54	-2.6	-0.2	1.9
Clipbox 6	0.14	-0.17	0.61	-3.0	0.5	1.6
Clipbox 7	0.23	-0.14	0.59	-2.8	0.5	2.3
Clipbox 8	0.04	0.02	-0.18	1.4	1.5	0.1
Clipbox 9	0.02	0.16	0.02	5.5	0.4	0.3

- Warnings:

  5 mm or 5°

- 3 consecutive warnings:

→ Evaluate → Possible re-plan

Alternatives?

- If only one region of interest
  - ➢ Limit size to most important structures – e.g. the boost area
  - ➢ If deviations are visible outside this area...
    → Retrospectively register and discuss

- If two regions of interest (Dual registration in XVI)
  - ➢ Use one region of interest for most important structures – e.g. the boost area
  - ➢ Use other region of interest for larger area and specify tolerance limits. When limit is exceeded...
    → Discuss

- Re-plan if deformation is persistent → ART

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Margins

- Delineation: 2-3 mm SD
- Setup: 1-2 mm SD (Portal imaging)

	Systematic	Random
Delineation	2-3 mm	-
Setup	1-2 / 1-4 mm	1-2 / 1-4 mm
Organ motion	Depends on tumor location	Depends on tumor location
Total	2-4	1-4 mm

- Margin: 5 mm (best case) ……. 13 mm (worst case)
- E.g. boost area → high precision/small margins

  Nodal regions → less precision/but CTV!

Take home messages

- Head and neck is a complex site
- Geometrical uncertainties are underestimated
  - Especially with portal imaging
  - Deformations are an important factor
- Margins will depend on correction strategy
- For persistent anatomical changes replanning is a good option
- Search for best correction strategy ongoing ☺

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Head and Neck IGRT: An RTT Perspective

Liz Forde, RTT
Assistant Professor
The Discipline of Radiation Therapy
School of Medicine
Trinity College Dublin

Fundamental IGRT Questions

- ***When*** *should I image?*
  - *Frequency*
- ***How*** *should I image?*
  - *Technology*
  - *Projection*
- ***What*** *can I see?*
  - *What is my target*
- ***What*** *should I match to?*
  - *Surrogate for target position*

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Site Specific Points to Consider

- The head and neck is a regions rich in radiosensitive structures (serial organs)

- Margins are typically tight
  - 0.3cm -0.5cm

- IMRT or VMAT are now standard and carry with them highly conformal dose distributions and multiple targets

Site Specific Points to Consider

- In addition to standard match structures also review:

- Position of mouth bung (if used) is correctly in place

- Bolus is positioned correctly (no gaps)

- Change in tumour size

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Site Specific Points to Consider

- Gaps between skin and mask
- Shoulder position
  - Neubauer *et al.*, 2012
- Direct clinical impact of translations and rotations have on adjacent structures
  - True OAR
  - OAR PRV

Pre Treatment

CT Simulation

Slice thickness

- Accurate delineation
- Accurate dose calculation
- Improved DRR resolution
- 2.5-3.0mm

Registration of diagnostic imaging

Contrast

IV

No pre contrast scan

Bolus

Scan with bolus on

Planning

3DCRT

IMRT

VMAT

Standard for this patient group

Beware the steep dose gradients

Shoulders

Avoid?

Match Anatomy

- Bony landmarks

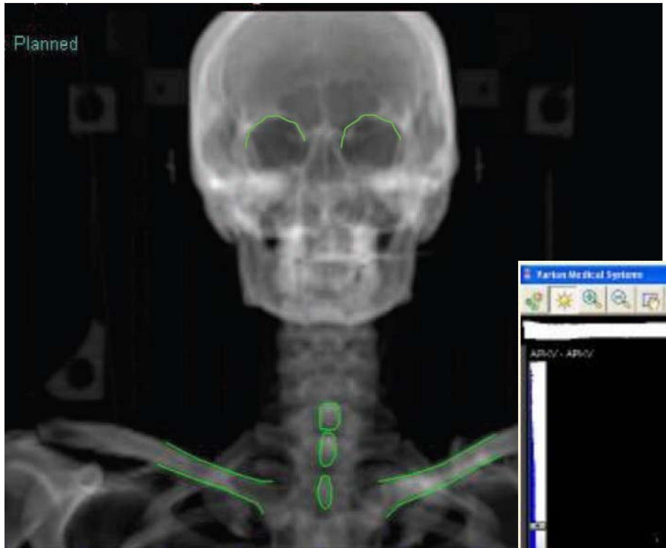
- Vertebrae
- Angle of mandible
- Orbital rim
- Frontal sinus
- Pituitary fossa

2D

- MV (EPI) is adequate for visualisation of bony anatomy
- Single projection ***not*** recommended for H&N
- Need to confirm isocentre in two planes
- Of less value when treating with IMRT
  - Field borders
  - Ciao images
- Impact of dose when imaging daily with MV

2D/2D

- Improved visualisation and image quality
- Large FOV assess anatomy across whole target volumes and patient straightening

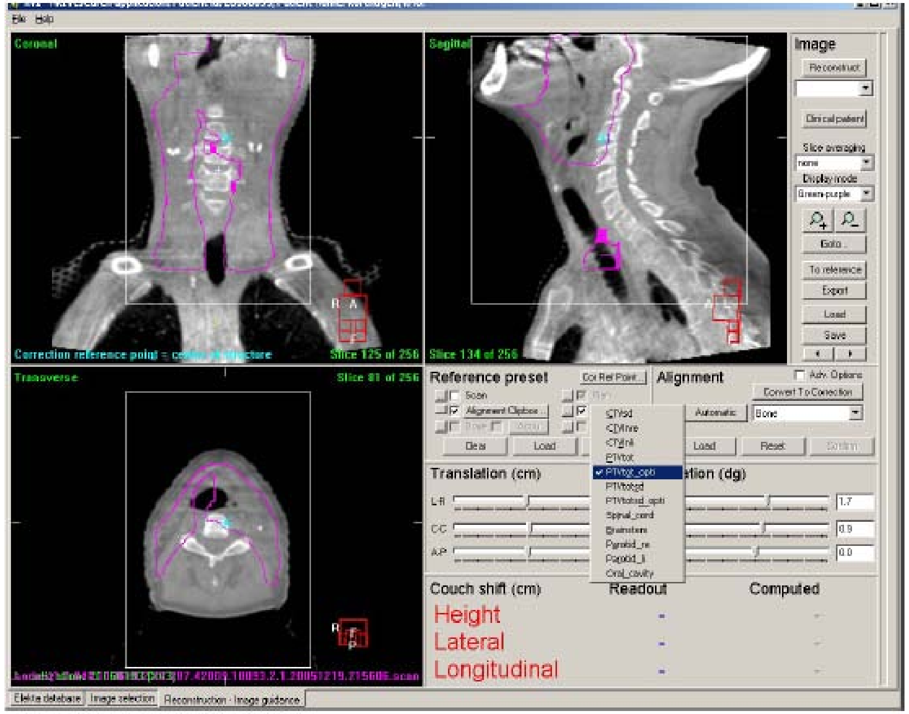


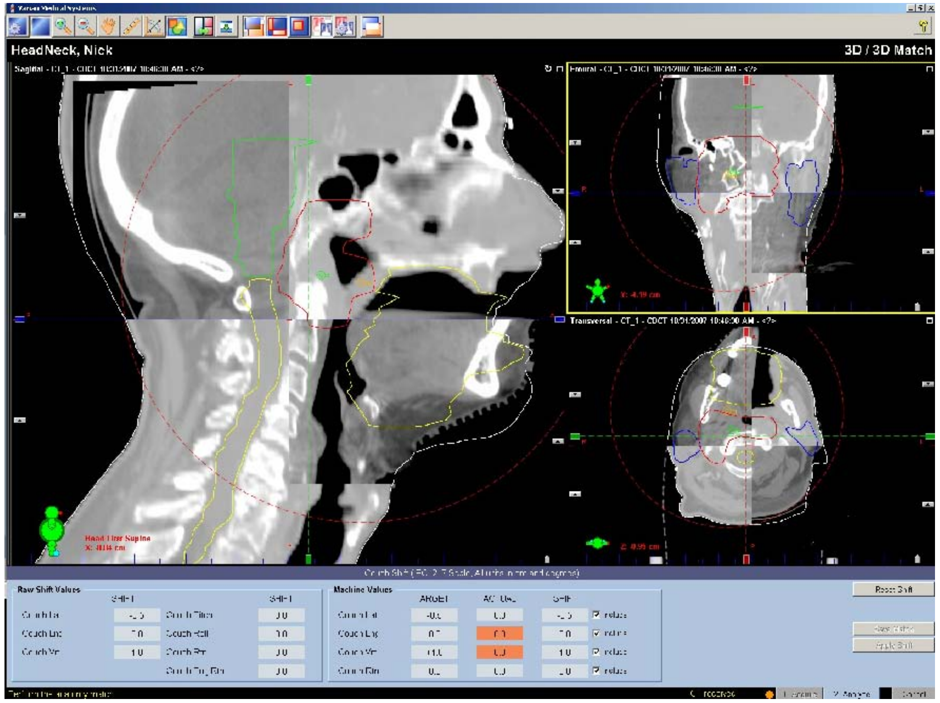
Mechalakos et al., 2007

3D

- Peter has covered this in excellent detail!

- Consider other structures to review
  - 45Gy isodose line





All Very Straightforward!

- But wait…there's more…

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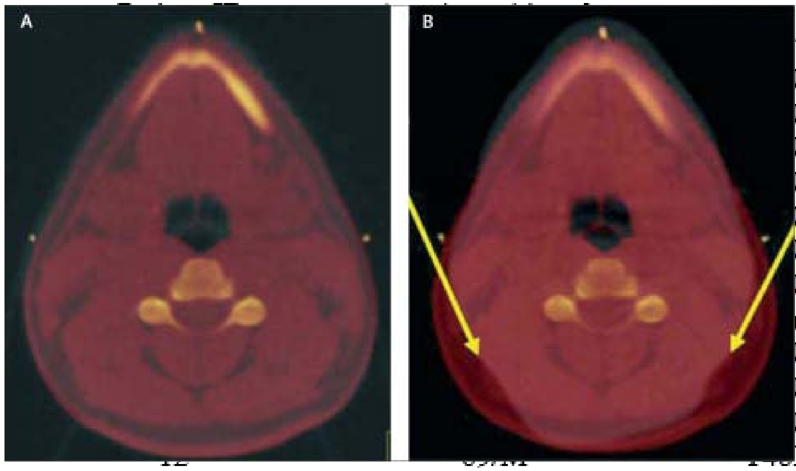
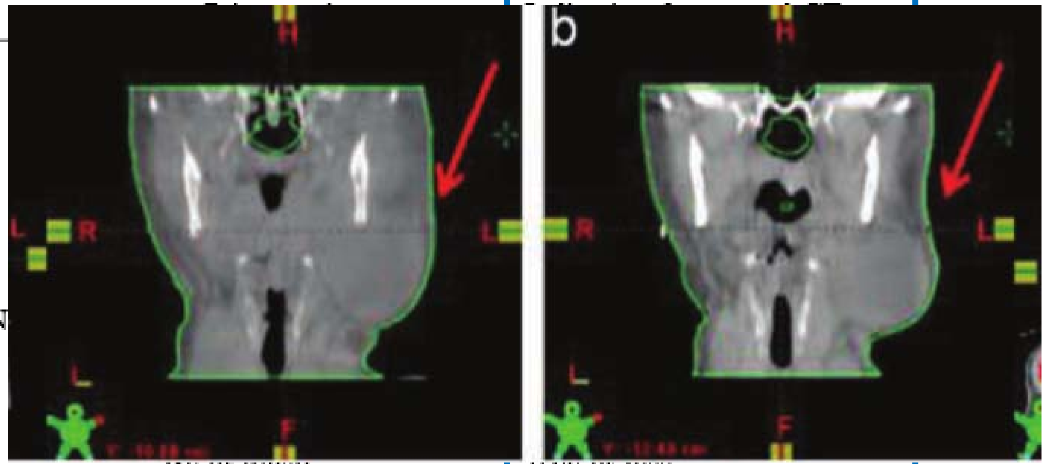
Tumour Shrinkage and Weight Loss

- Despite nutritional support these patients typically suffer significant weight loss during treatment
  - ➢ Impact on setup accuracy
  - ➢ Role of prophylactic PEG

Table 1. Patient characteristics





		Stage		
13	54/M	TXN2b	Unknown primary	Weight loss, tumor shrinkage

Abbreviations: ID = identification number; M = male; F = female; NPX = nasopharynx; BOT = base of tongue.
* Patient died of pneumonia after completing 23 fractions.

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Tumour Shrinkage and Weight Loss

- Dosimetric Impact!

Replanning during IMRT for H&N cancer ● E. K. HANSEN *et al.*

Table 3. Dosimetric comparisons of the 2nd portion of treatment with and without replanning

Dosimetric end point (mean values)	1st portion of treatment (1st CT/1st plan)	2nd portion of treatment: Replanned (2nd CT/2nd plan)	2nd portion of treatment: Not replanned (2nd CT/1st plan)	*p* value
PTV_{GTV}				
D_{99}	38.1 Gy	28.3 Gy	26.0 Gy	0.05
D_{95}	40.3 Gy	30.3 Gy	28.1 Gy	0.02
V_{93}	99.5%	99.4%	92.5%	<0.001
PTV_{CTV}				
D_{99}	30.9 Gy	22.9 Gy	18.3 Gy	<0.001
D_{95}	34.0 Gy	25.7 Gy	22.7 Gy	0.003
V_{93}	98.7%	98.7%	90.5%	<0.001
Spinal cord				
D_{max}	25.7 Gy	19.3 Gy	23.3 Gy	0.003
$D_{1\ cc}$	23.0 Gy	17.1 Gy	20.2 Gy	0.04
Brainstem				
D_{max}	28.2 Gy	22.3 Gy	24.9 Gy	0.007
$D_{1\ cc}$	25.0 Gy	19.4 Gy	21.7 Gy	0.20
$D_{1\%}$	26.1 Gy	20.2 Gy	22.9 Gy	0.12
Right parotid	($n = 12$)			
D_{mean}	15.5 Gy	12.0 Gy	14.9 Gy	0.05
D_{50}	13.0 Gy	10.6 Gy	13.6 Gy	0.06
V_{26}	44.6%	45.5%	55.5%	0.04
Left parotid				
D_{mean}	15.2 Gy	11.9 Gy	12.1 Gy	0.81
D_{50}	13.2 Gy	10.2 Gy	11.2 Gy	0.47
V_{26}	45.2%	42.9%	42.2%	0.89
Mandible ($n = 9$)				
D_{max}	39.2 Gy	29.6 Gy	31.3 Gy	0.01
V_{60}	11.0%	11.3%	18.2%	0.08
V_{70}	0.04%	0.05%	4.5%	0.32

Abbreviations: PTV_{GTV} PTV_{CTV} = planning target volumes of gross tumor volume and clinical tumor volume, respectively; D_{max} = maximum dose; D_{99} = dose to 99% of the volume; D_{95} = dose to 95% of the volume; V_{93} = percent of volume receiving ≥93% of the prescribed dose; $D_{1\ cc}$ = dose to 1 cc of the volume; $D_{1\%}$ = dose to 1% of the volume; D_{mean} = mean dose; D_{50} = dose to 50% of the volume; V_{26}, V_{60}, and V_{70} = percent of volume receiving ≥26 Gy, ≥60 Gy, and ≥70 Gy, respectively.

Assessed impact on OAR doses not target dose

Contoured OARs on CBCTs and recalc'd with correction for HU differences

Clinical Investigation: Head-and-Neck Cancer

Monitoring Dosimetric Impact of Weight Loss With Kilovoltage (KV) Cone Beam CT (CBCT) During Parotid-Sparing IMRT and Concurrent Chemotherapy

Kean Fatt Ho, F.R.C.R.,[*] Tom Marchant, Ph.D.,[†] Chris Moore, Ph.D.,[†] Gareth Webster, Ph.D.,[†] Carl Rowbottom, Ph.D.,[†] Hazel Penington, B.Sc.,[‡] Lip Lee, F.R.C.R.,[§] Beng Yap, F.R.C.R.,[§] Andrew Sykes, F.R.C.R.,[§] and Nick Slevin, F.R.C.R.[§]

From [*]Academic Radiation Oncology, [†]North Western Medical Physics, [‡]Wade Radiotherapy Research Centre, and [§]Department of Clinical Oncology, The Christie NHS Foundation Trust, Manchester, UK

Received Oct 10, 2010. Accepted for publication Jul 6, 2011

Where did this weight loss occur?

Weight loss and parotid shrinking did occur, but insignificant impact on OAR doses

Results inconsistent with previous studies
Impact of neoadjuvant therapy?

Demonstrates the benefit of 3D imaging
Discusses options of dose calculation from CBCT

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Tumour Shrinkage and Weight Loss

- A lot of literature!!!
- Every patient is individual
  - ➢ RTTs treat them and can see these subtle changes
- Dosimetric (and clinical) impact will depend on original DVH results
- Without 3D imaging, you cannot accurately visualise or account for this
- "*The dosimetric impact of anatomic changes during radiotherapy was of lesser importance than the effects of IGRT repositioning*" (Graff et al., 2012)

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What Else?
Variation in Shoulder Position

- The shoulders move independently from the isocentre
- This shoulder motion changes the path length of the beam
- Superior shoulder shift results in target coverage loss

Table 3 Target coverage in the C6-C7 region

	IMRT			VMAT		
	100%	**98%**	**95%**	**100%**	**98%**	**95%**
C6-C7						
No shift	97	98	100	94	97	99
5 mm superior	90	98	100	84	96	99
15 mm superior	23	53	94	16	35	72
C7-T2						
No shift	98	100	100	–	–	–
15 mm posterior	89	99	100	–	–	–

Percentage of the clinical target volume (CTV) in the C6-C7 region covered by the 100%, 98%, and 95% isodose lines with no shift and with superior shifts for IMRT and VMAT plans, as well as the percent coverage of the CTV in the C7-T2 region with no shift and a 15 mm posterior shift. All percentages were evaluated for Patient 1.

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What Else?
Variation in Shoulder Position

- This positional variation cannot be corrected with translational correction

- This variation also caused an increase in OAR dose
  - Brachial Plexus increased by up to 7.2Gy

- In the absence of CBCT the angle of clavicle on AP EPI

Take Home Message

- *"Complex and multifactorial dosimetric variations occur during head and neck IMRT."* *(Graff et al., 2012)*

- Take caution due to tight margins, conformal techniques and proximity of radiosensitive structures

- Have an understanding of dosimetric impact of weight loss and shoulder motion

- Appropriate immobilisation is key. IGRT may help in assessment of this, but can not always correct for this.

- Recommend clear protocols to mandate imaging frequency and match structures

Case report: **Brain**

Jose Lopez, M.D., Ph.D
Radiation Oncology
University Hospital Virgen del Rocio
Seville, Spain

Advanced skills for modern radiotherapy
28 June-02 July, 2015
Copenhagen, Denmark

Outline of Talk

- General pearls for Pediatric (CNS) tumors
- Case report
- Discussion of current multidisciplinary (physician, phisyc and RTTs) management

Pearls

- The number one cause of death in children is accidents (44%), followed by cancer (10%).
- Of childhood cancers, leukemias are the most common followed by CNS neoplasms (~20%)
- Of pediatric CNS neoplasms, gliomas are most common (lowgrade astrocytomas ~35–50%, brainstem gliomas ~15%, malignant astrocytomas ~10%, optic pathway gliomas ~5%)

Inmovilization

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Planning images

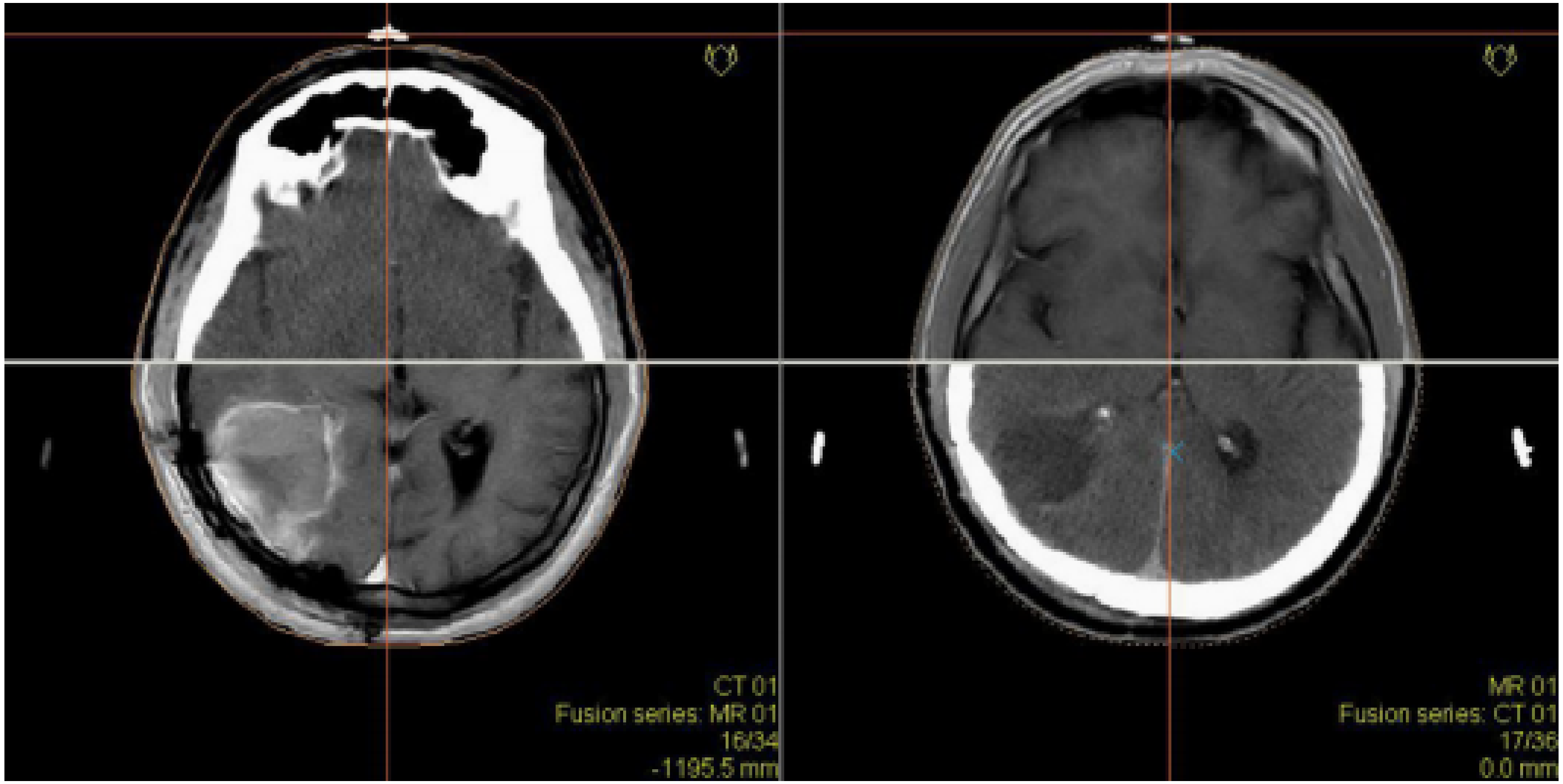

Fig. 2. Image registration of CT and MR image sets. Left image: top (CT), bottom (MR). Right image: top (MR), bottom (CT). The center of the middle fiducial marker pointed out on the left image is shown via registration on the right.

Radiotherapy and Oncology 87 (2008) 100–109

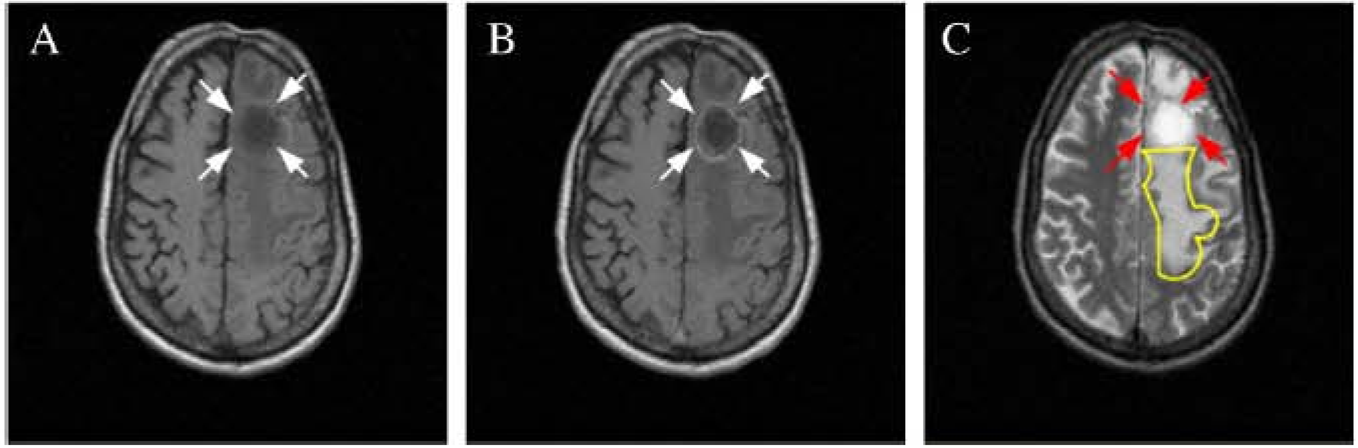

Fig. 4. Appearance of astrocytoma tumor on three sequences. (A) Isointense tumor (diffused) on T1-weighted image. (B) Isointense, peripherally enhanced homogeneous tumor on postcontrast T1-weighted image. (C) The tumor is seen as a homogeneous, hyperintense mass on T2-weighted image (in red) as is the edema, which, however, is less bright (in yellow).

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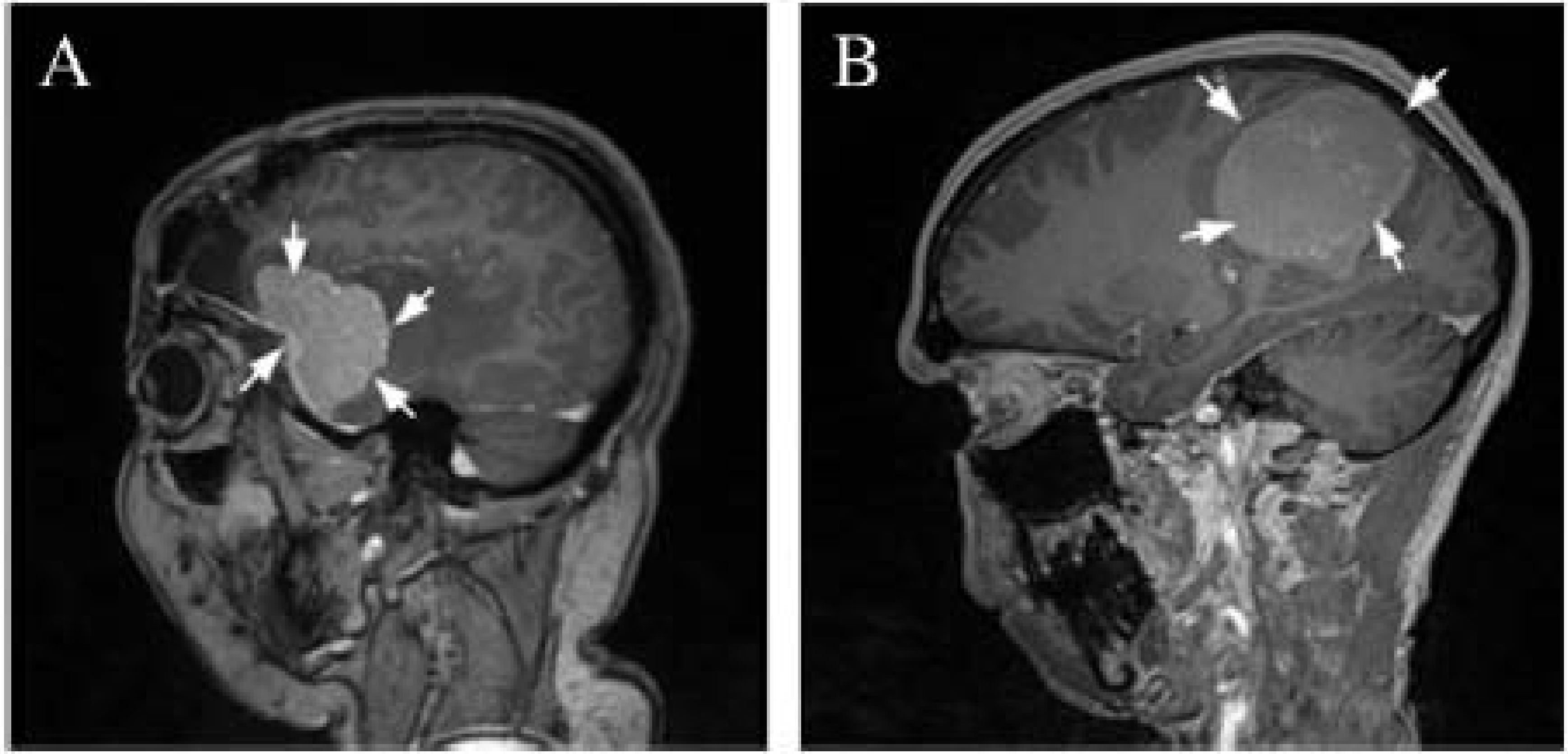

Fig. 2. Degree of enhancement of same tumor (meningioma) of different patients on postcontrast T1-weighted images. (A) Full enhancement of meningioma tumor (hyperintense signal). (B) No enhancement of meningioma tumor (isointense signal).

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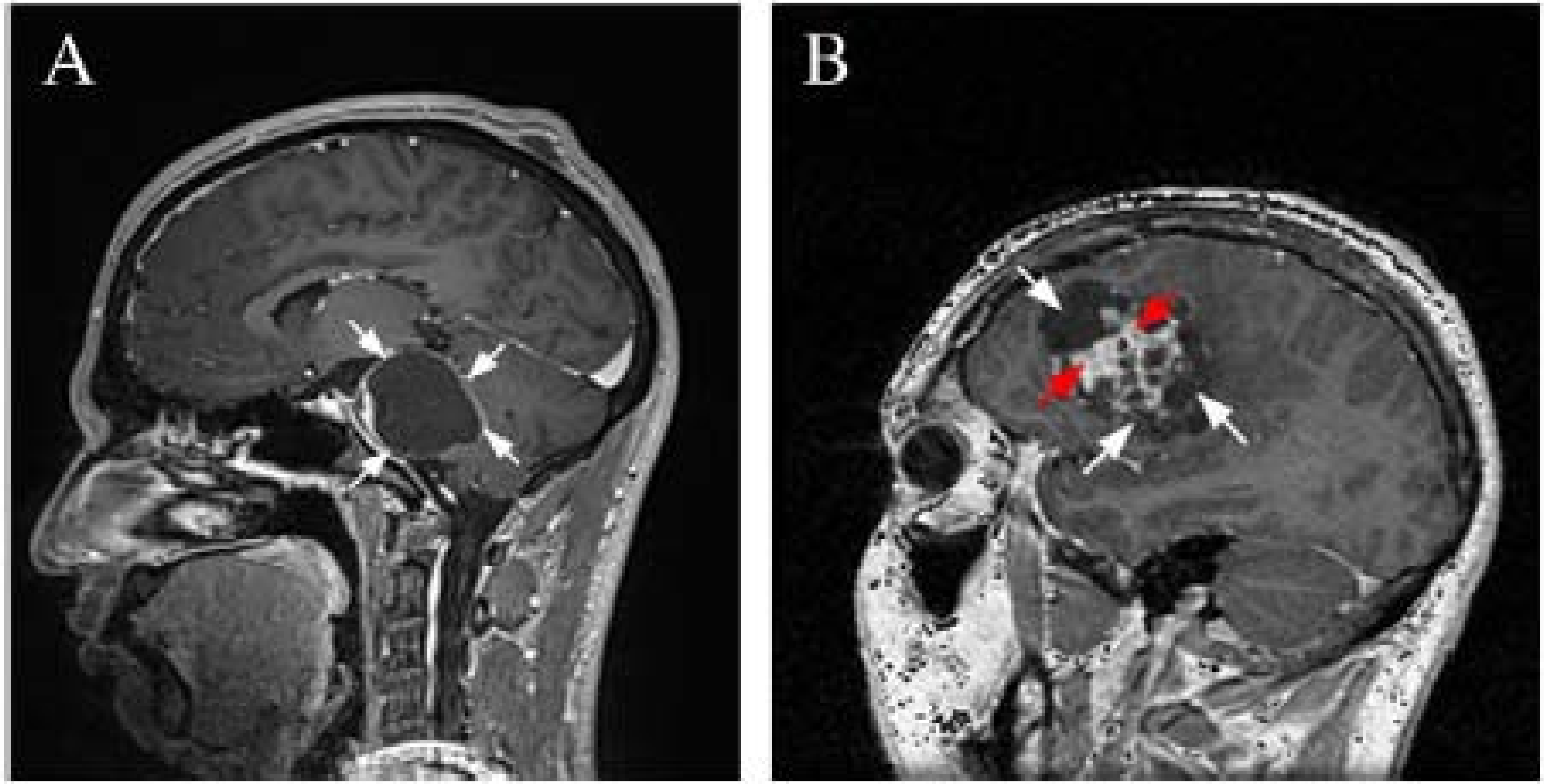

Fig. 3. Homogeneous and heterogeneous tumors. (A) Homogeneous astrocytoma tumor — hypointense signal, peripheral enhancement. (B) Heterogeneous glioma tumor with hypointense necrotic part (in red) and hyperintense-cystic components (in white).

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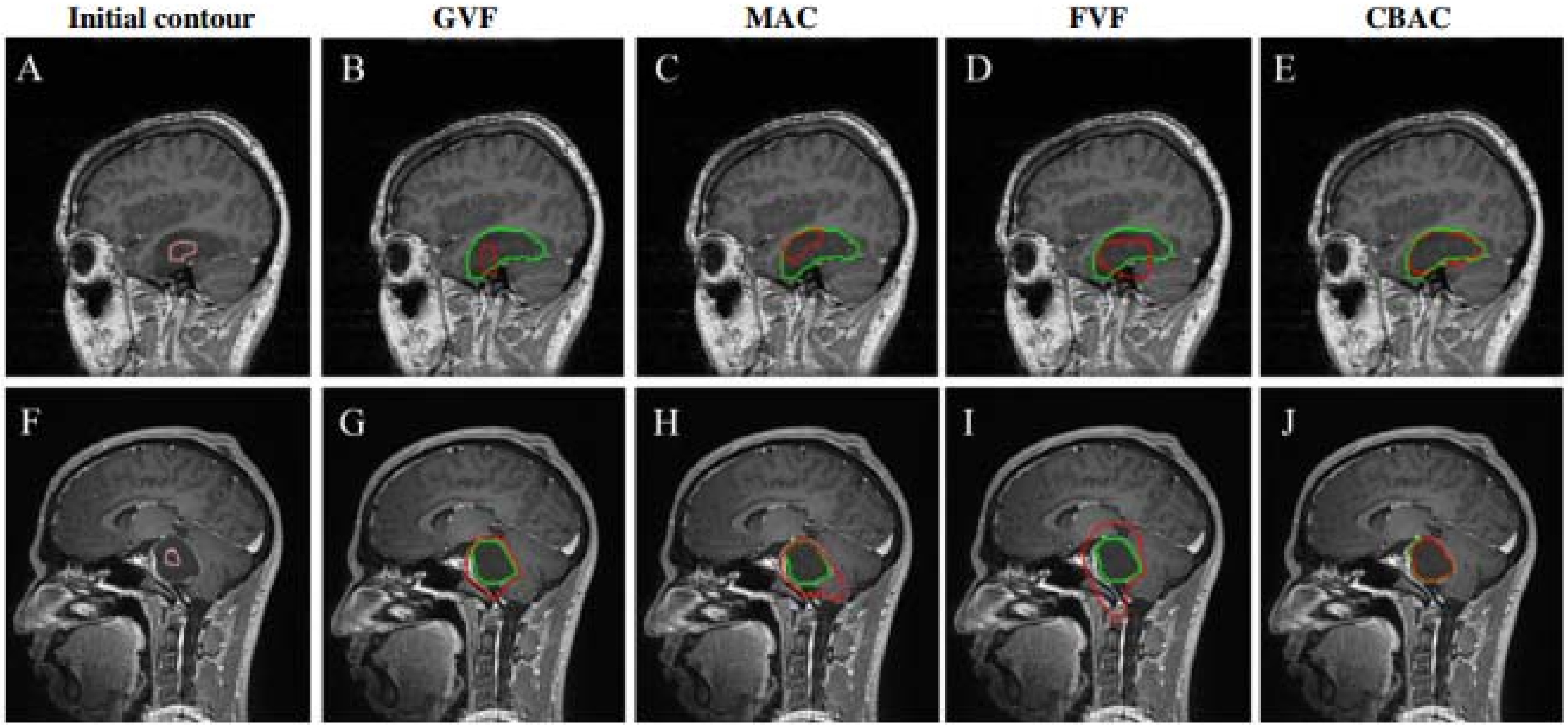
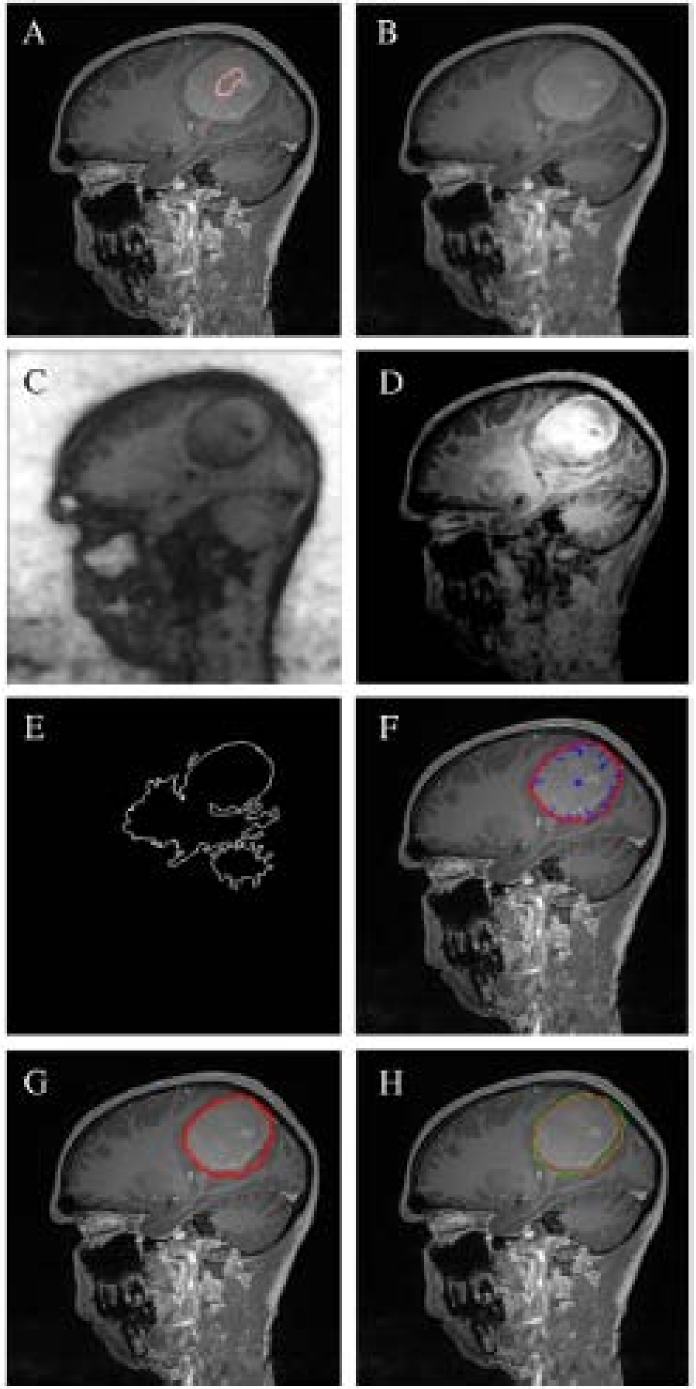


Fig. 10. Comparative segmentation results on postcontrast T1-weighted image. Green — ground truth marked by the radiologist; red — tumor boundary extracted by different methods. Row 1: tumor type, low-grade glioma; appearance, homogeneous tumor with isointense signal; the tumor shows no enhancement. Row 2: tumor type, astrocytoma; appearance, homogeneous tumor with hypointense signal; the tumor shows peripheral enhancement.

Magnetic Resonance Imaging 30 (2012) 694–715



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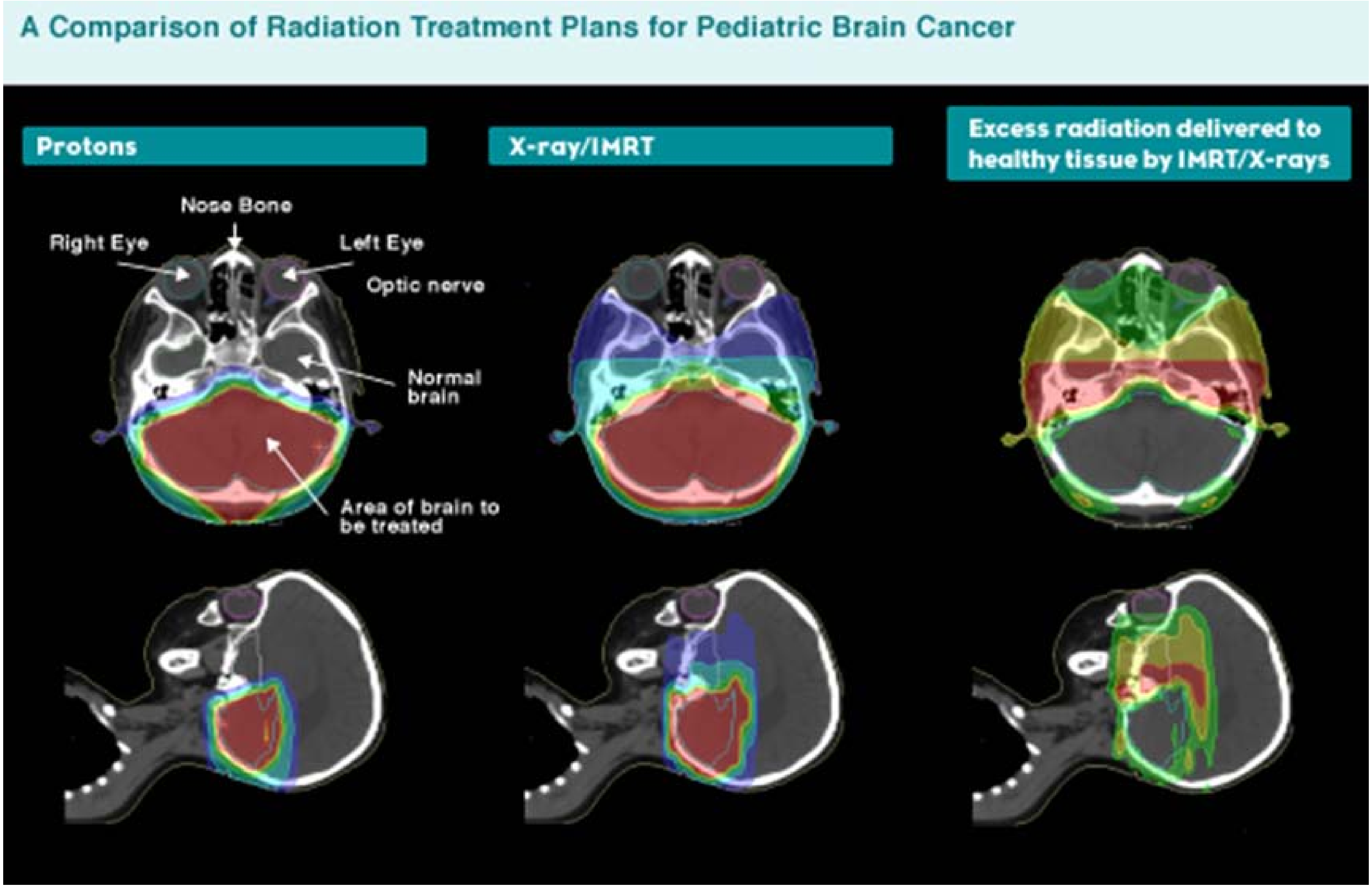


http://www.procure.com/ForMedicalProfessionals/ClinicalIndications.aspx

Technologies available for IGRT

Siemens PRIMATOM™

TomoTherapy Hi-Art™

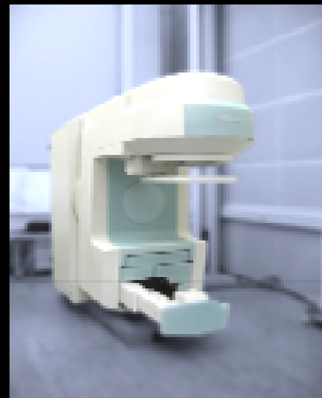
kV CT Approach

MV CT Approach

Elekta Synergy™

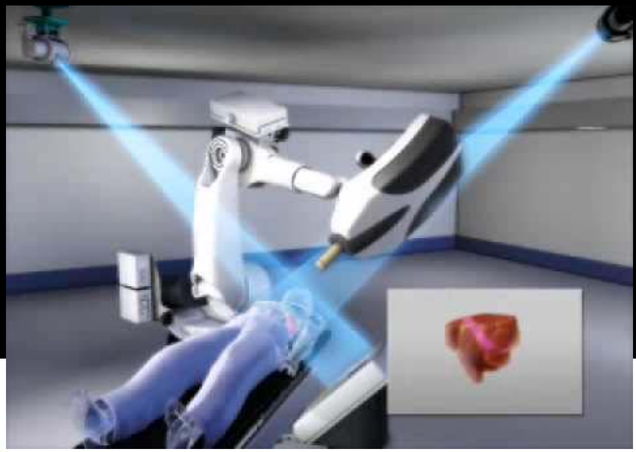
Siemens MVision™

Varian OBI™



Siemens Artiste™

MV Cone-beam CT Approach



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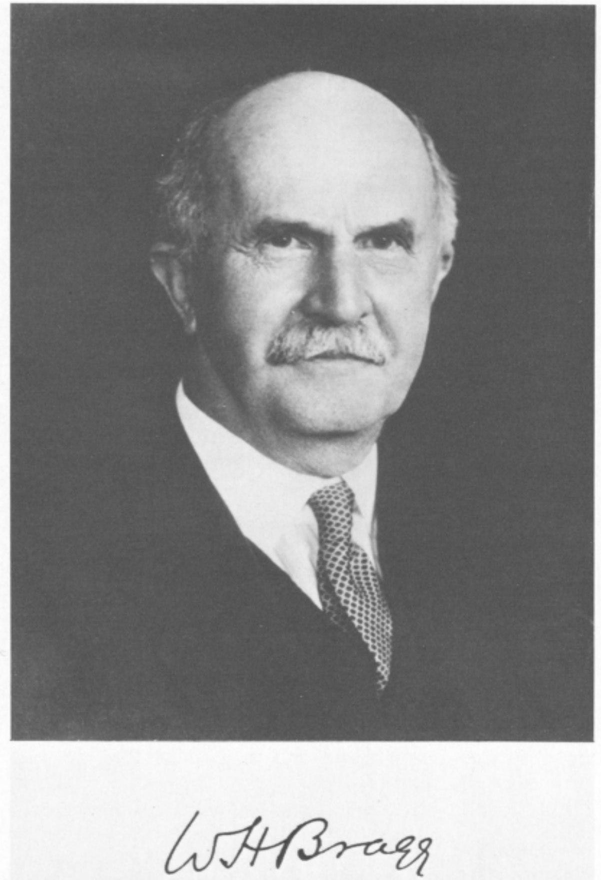
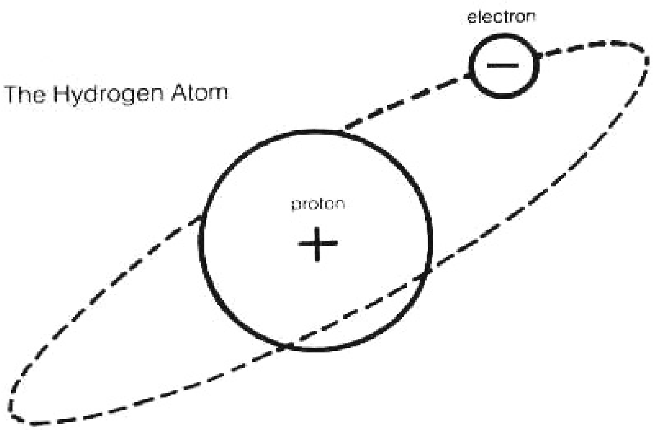
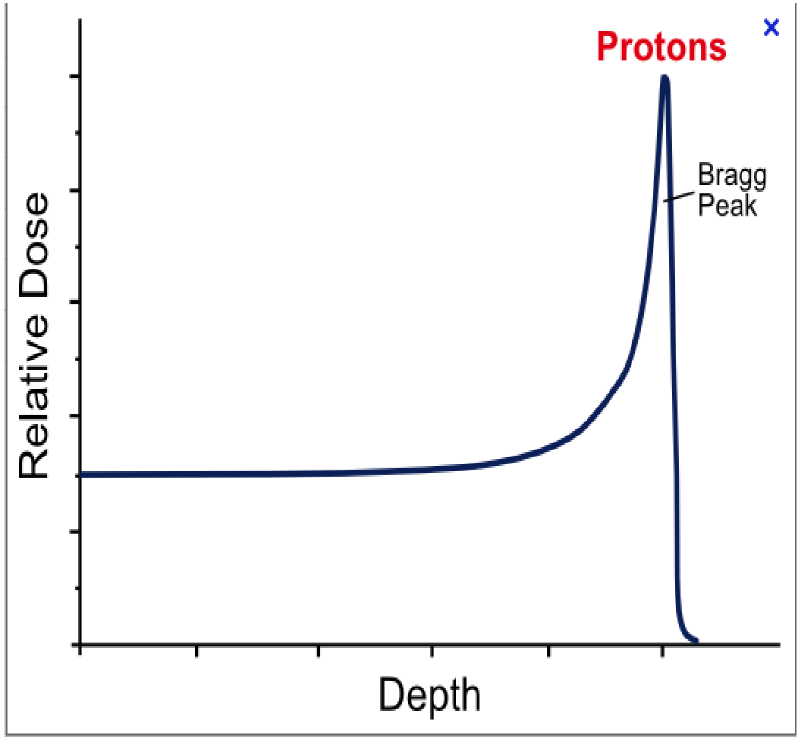
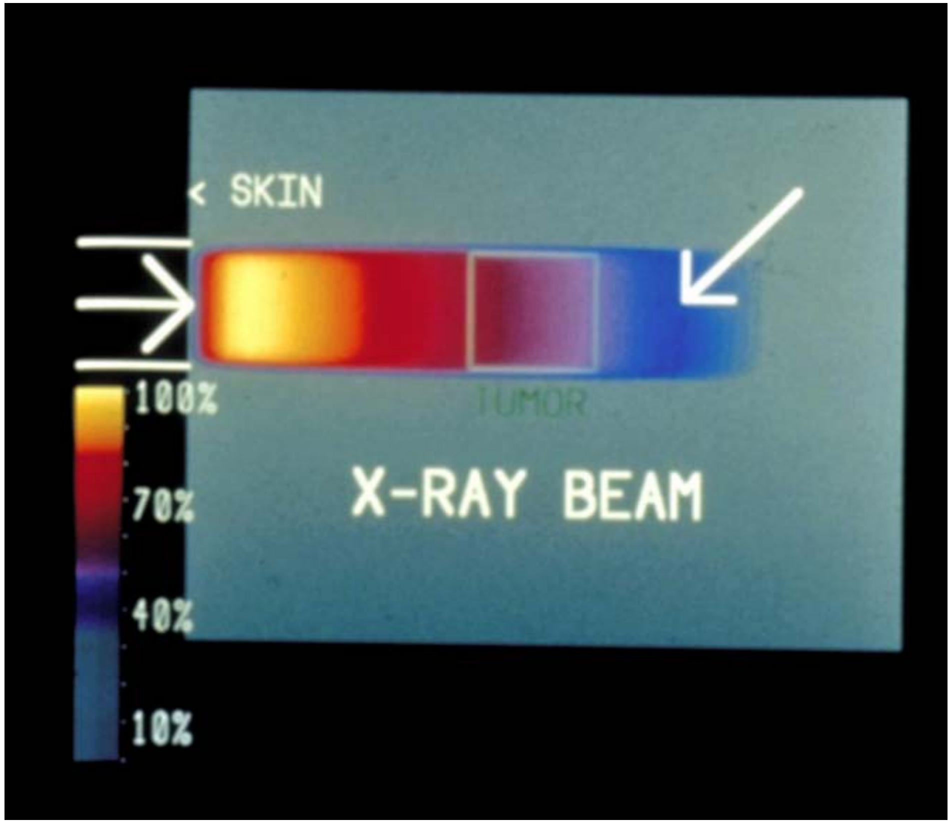
BRAGG PEAK

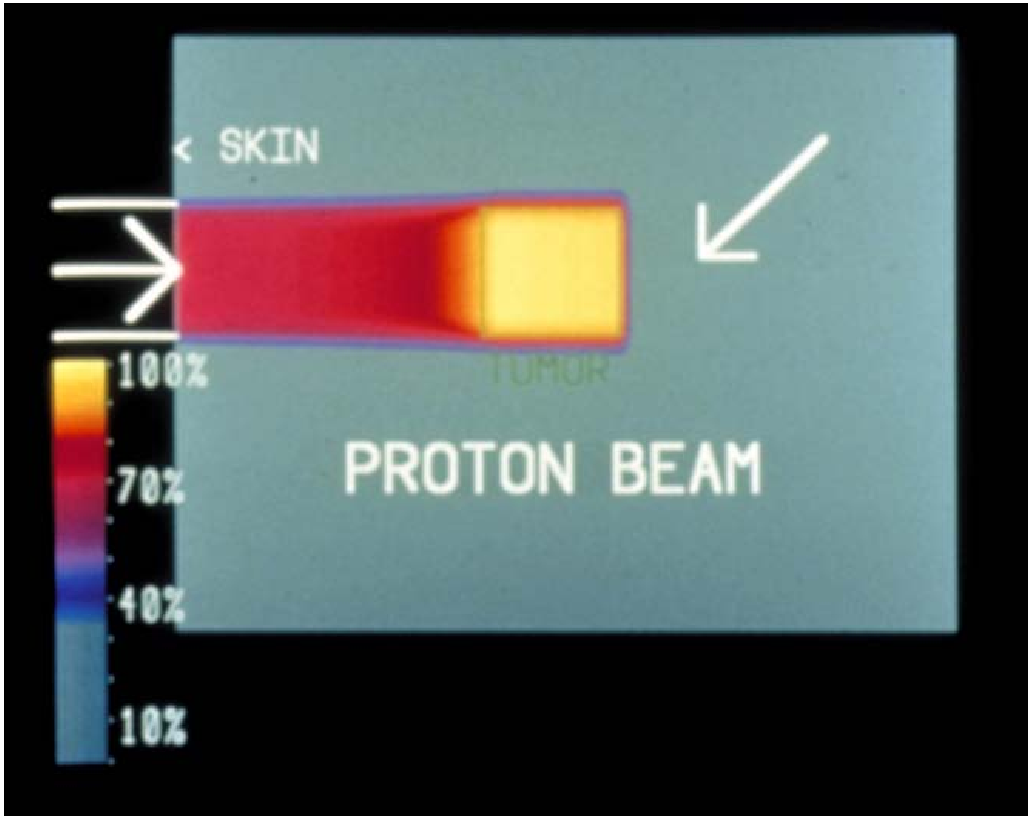



The Hydrogen Atom
electron
proton


Protons
Bragg Peak
Relative Dose
Depth



< SKIN
TUMOR
100%
70%
40%
10%
X-RAY BEAM



< SKIN
TUMOR
100%
70%
40%
10%
PROTON BEAM

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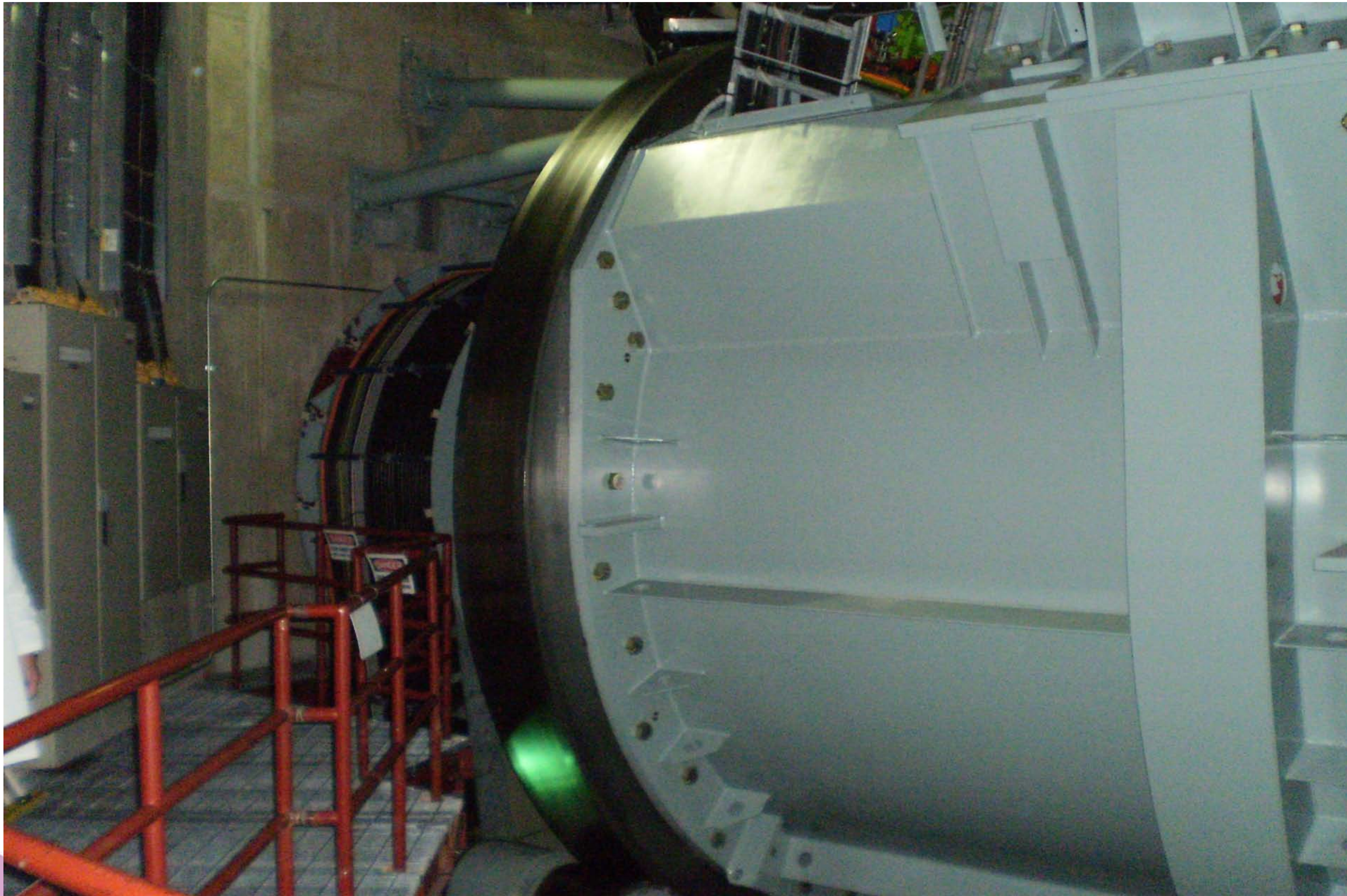
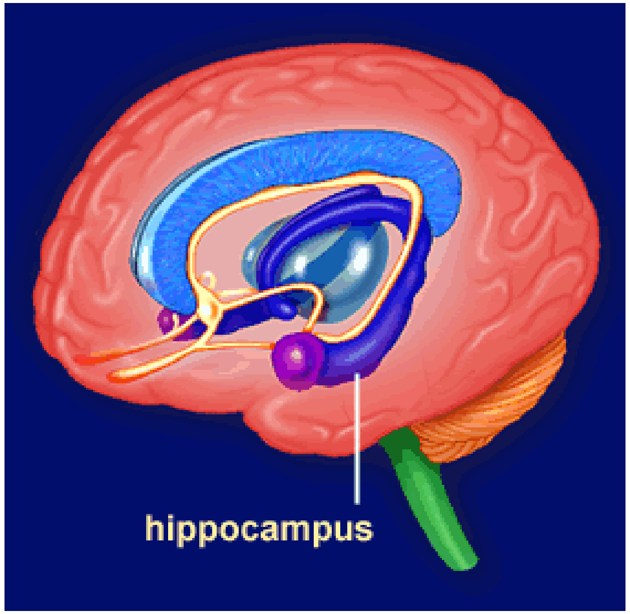
PTC



Association between hippocampal dosimetry and impairment in Wechsler Memory Scale-III Word Lists Delayed Recall at 18 months

Dosimetry	Dosimetric cut point	No impairment	Impairment*	*p* value
Bilateral hippocampi				
Maximum	≤24.7 Gy	66.7%	33.3%	0.500
	>24.7 Gy	55.6%	44.4%	
D30%	≤8.2 Gy	77.8%	22.2%	0.167
	>8.2 Gy	44.4%	55.6%	
D40%	≤7.3 Gy	88.9%	11.1%	0.025
	>7.3 Gy	33.3%	66.7%	
D50%	≤3.8 Gy	66.7%	33.3%	0.500
	>3.8 Gy	55.6%	44.4%	
D80%	≤0.5 Gy	55.6%	44.4%	0.500
	>0.5 Gy	66.7%	33.3%	
D100%	≤0.0 Gy	76.9%	23.1%	0.047
	>0.0 Gy	20.0%	80.0%	
Left hippocampus				
Maximum	≤15.0 Gy	55.6%	44.4%	0.500
	>15.0 Gy	66.7%	33.3%	

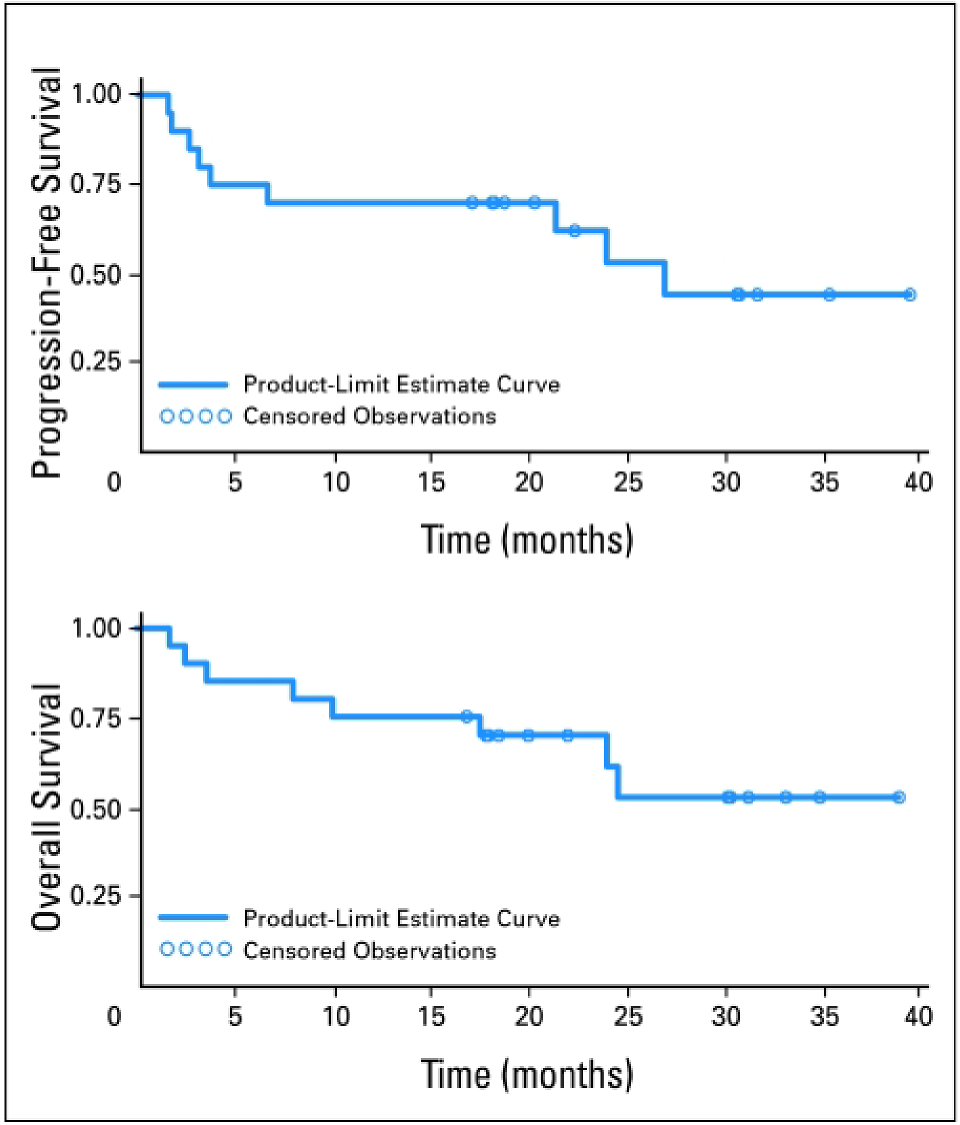


Int J Radiat Oncol Biol Phys. 2012 Jul 15;83(4):e487-93.

- N=25
- Period: 2004-2006
- Median age: 26 months
  (range, 2,4 months-19,5 years)
- Multimodality treatment:
  (surgery+/-radiation therapy [54 Gy at 2 Gy/fraction, N=15]+/-chemo)

The objective **response rate observed after RT was 38%.**

The **2-year progression-free and overall survival** rates are **53%** ± 13% and **70%** ± 10%,



J Clin Oncol. 2009 January 20; 27(3): 385–389.

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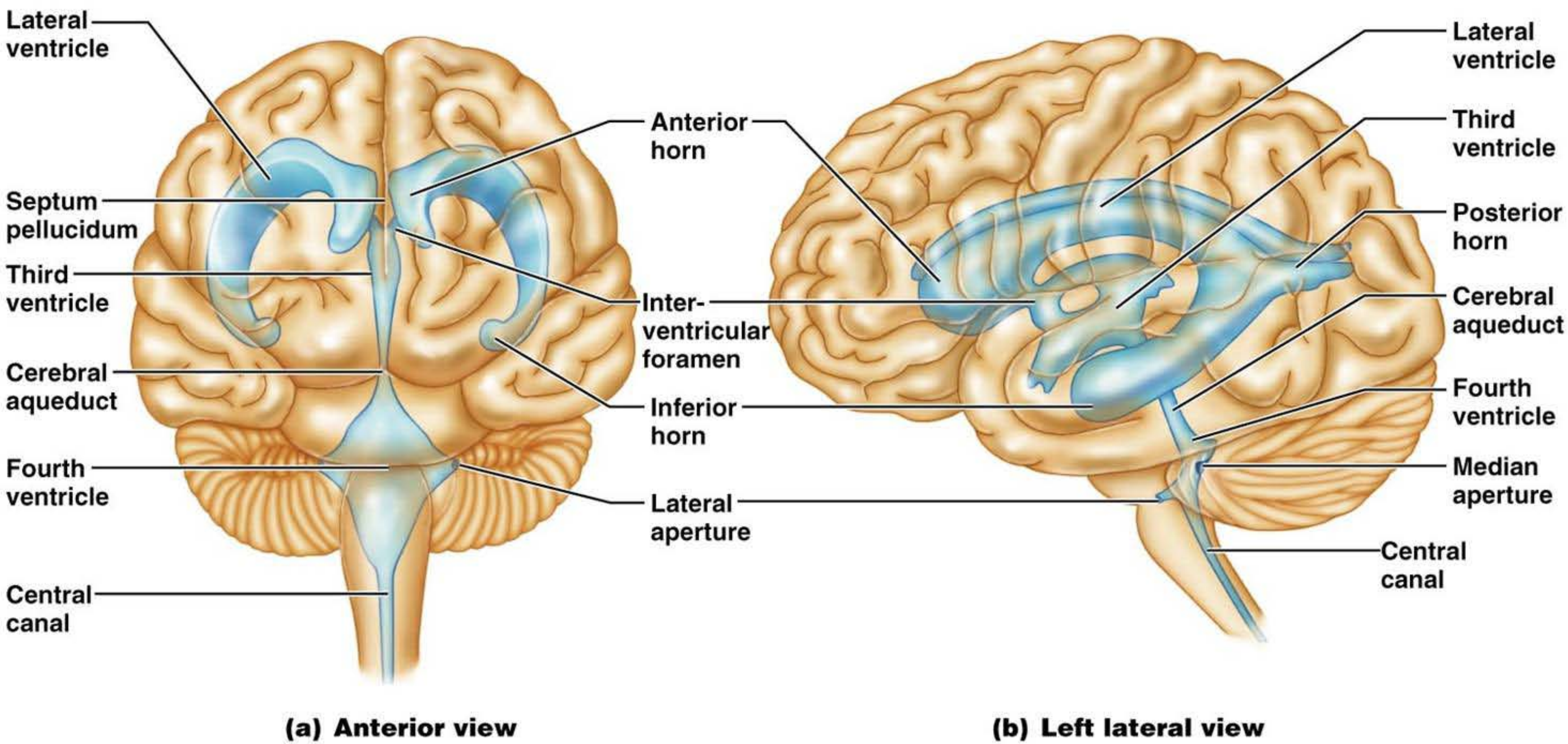
Case 1: patient with teratoid rhabdoid tumor

- A 19-month-old female infant was referred because of headache and weakness

- Magnetic resonance imaging revealed a mass that occupied the fourth ventricle



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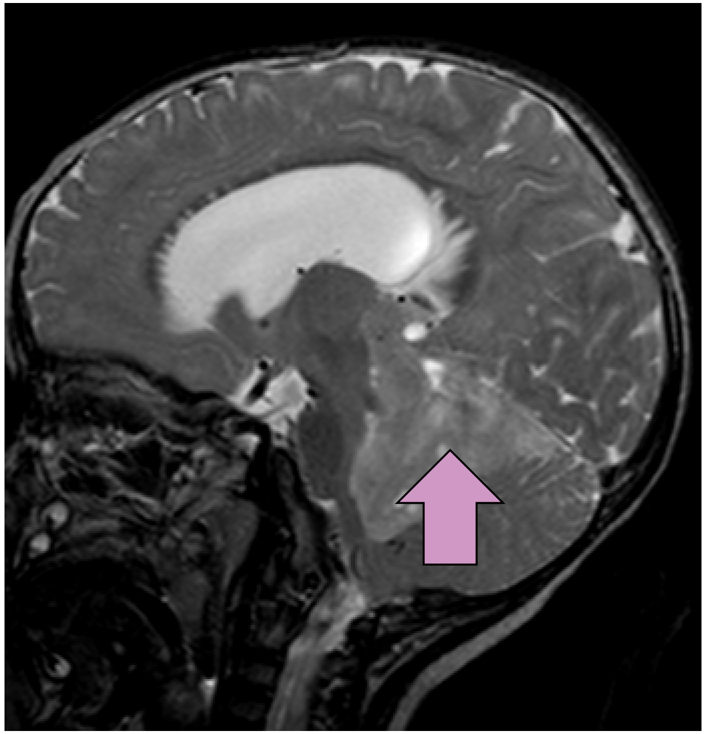
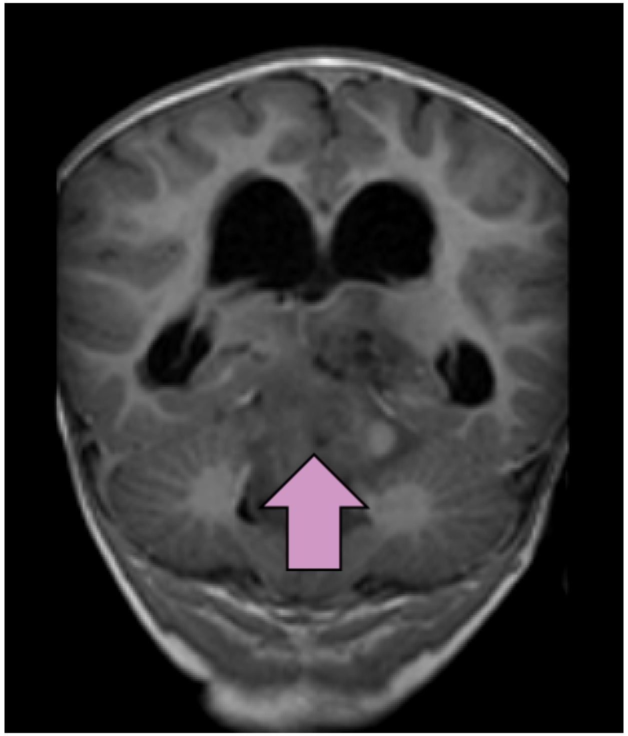
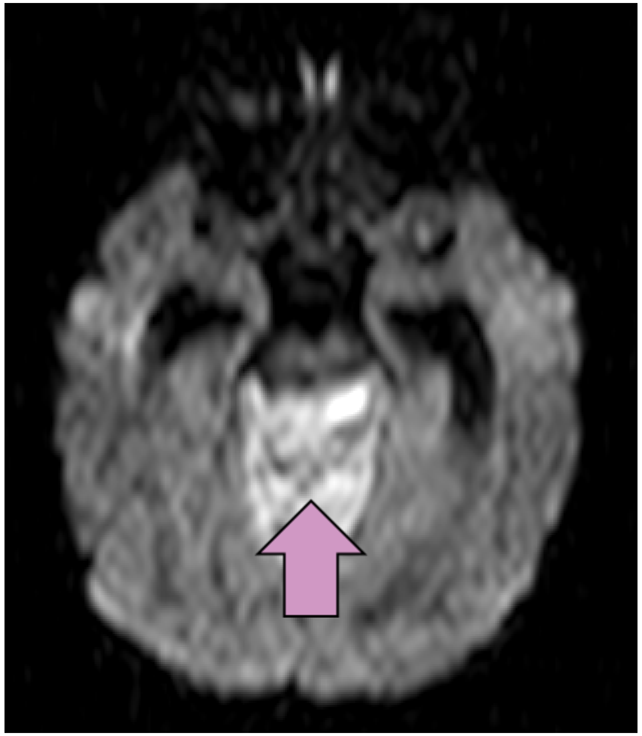
Mass at the fourth ventricle







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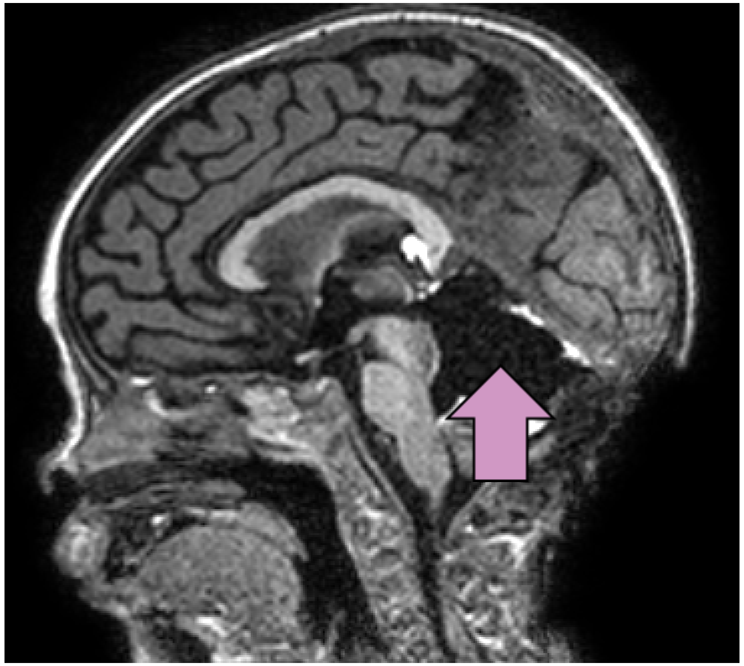
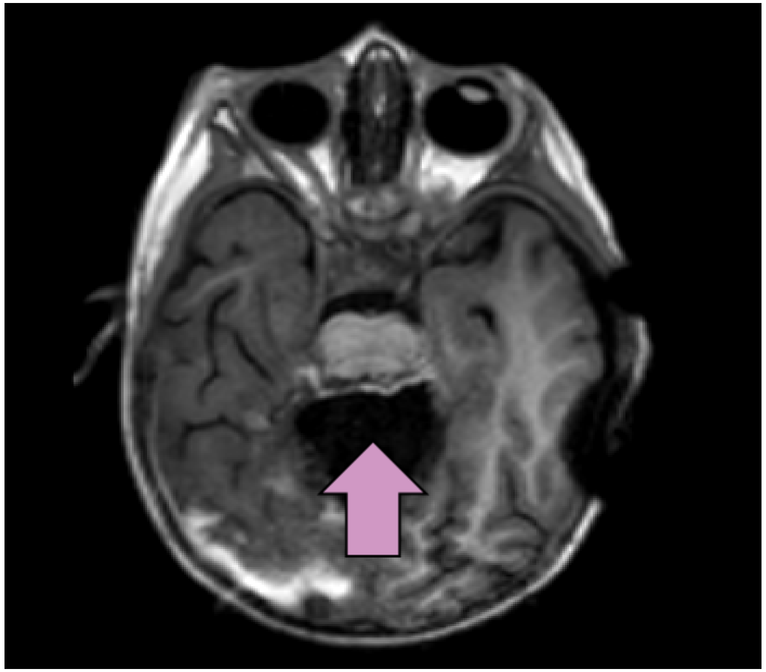
- The child underwent total removal of the tumor mass





- Pathological findings showed an **atypical teratoid/rhabdoid tumor**

- Diagnosis

- Atypical teratoid/rhabdoid tumor

- Treatment

- Chemotherapy + Surgery + Radiation Therapy

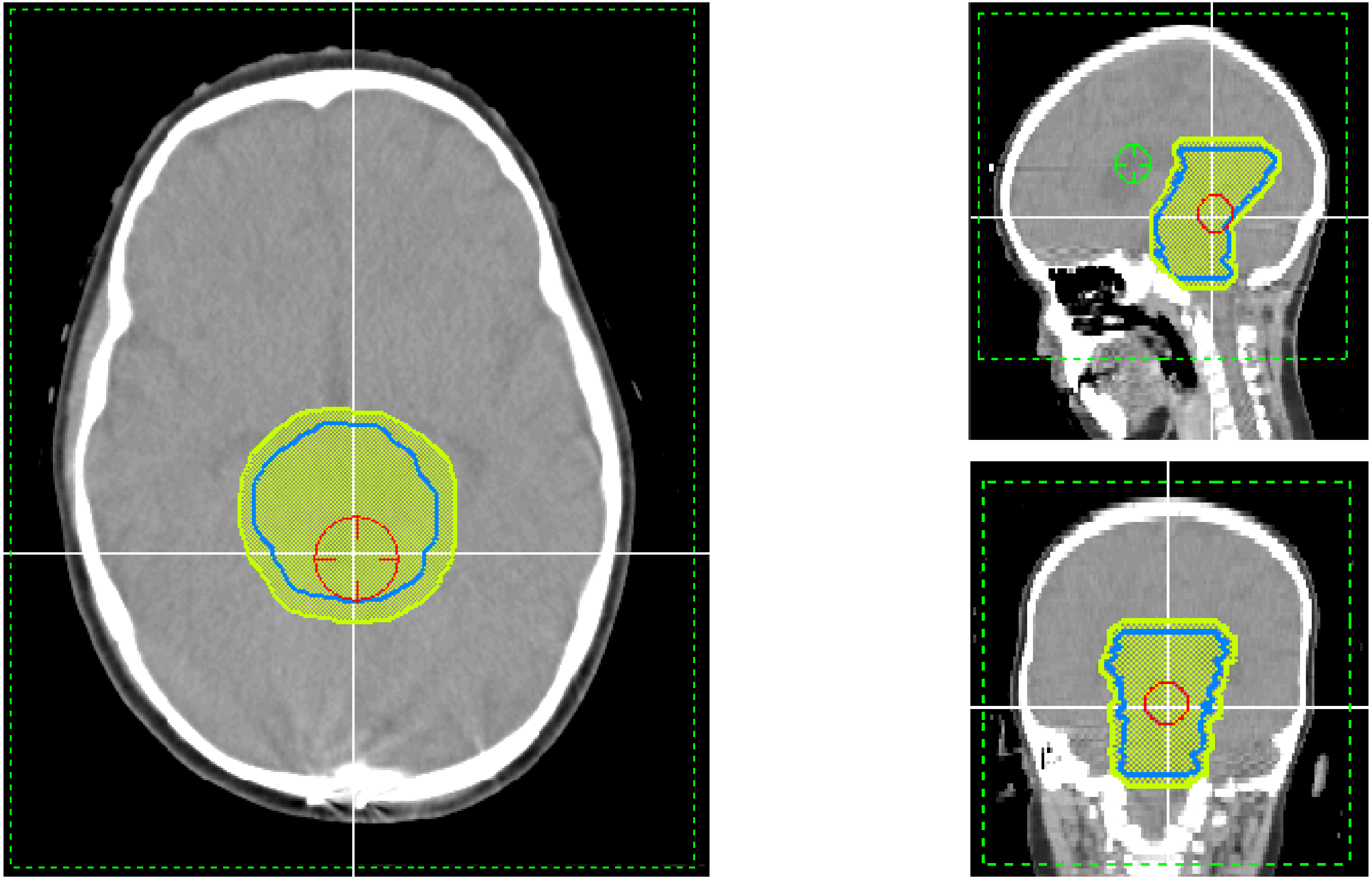
- Radiation Therapy Dose Prescription:

- PTV (surgical bed + 5mm margin): 54 Gy at 2 Gy/fraction

- **Organ at risk**

  Whole brain
  Braim stem
  Chiasm
  Pituitary
  Eyes
  Crystalline lens
  Nerve optic

PTV (surgical bed + 5 mm margin)



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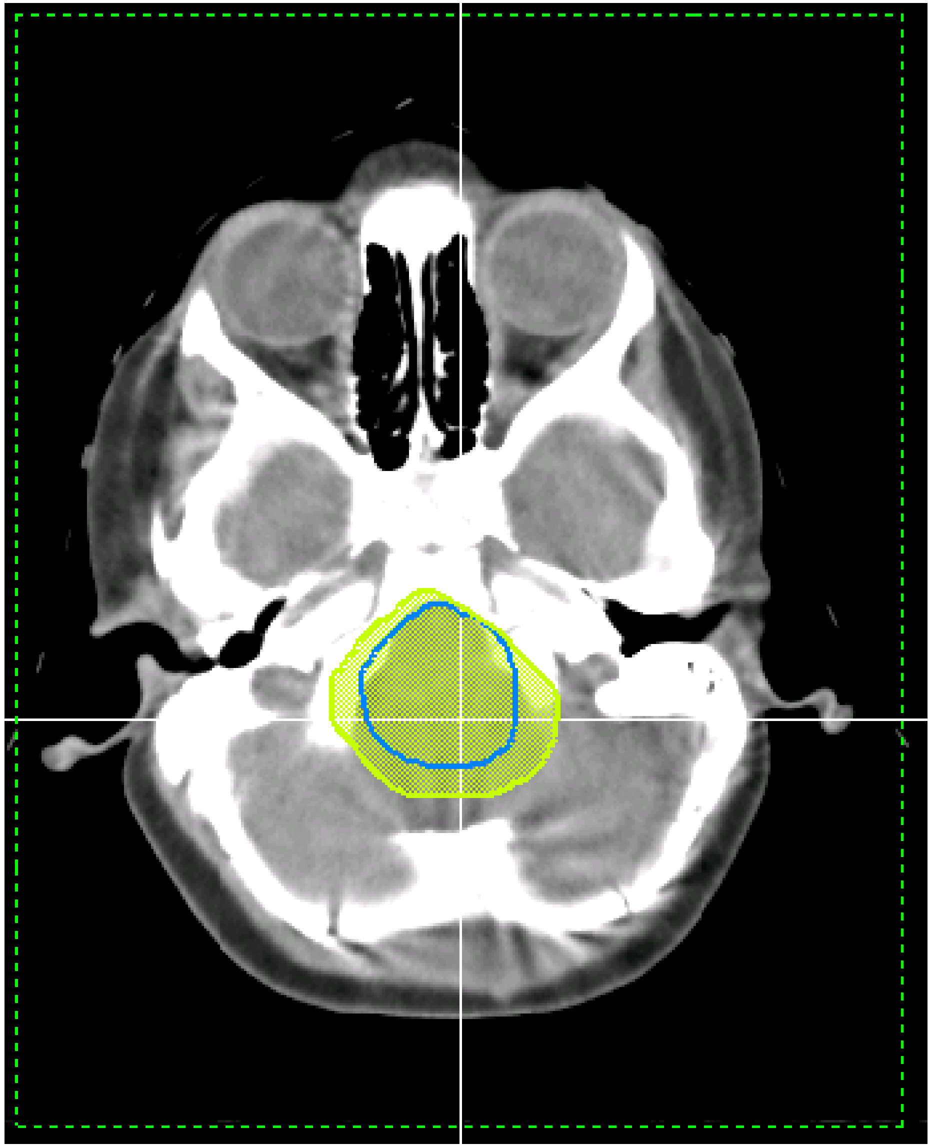
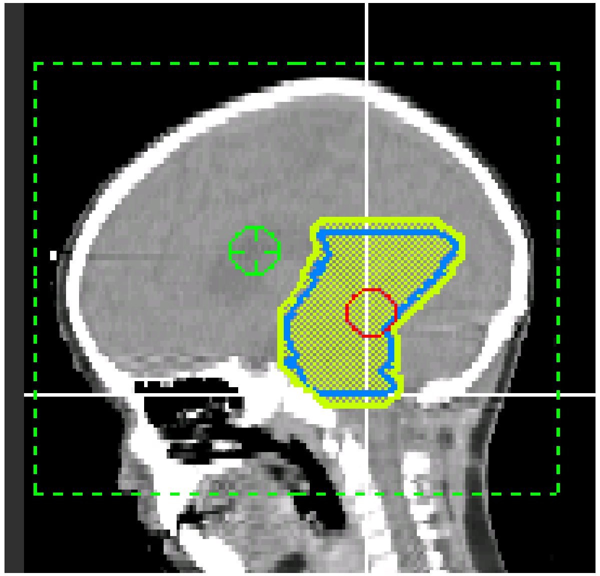
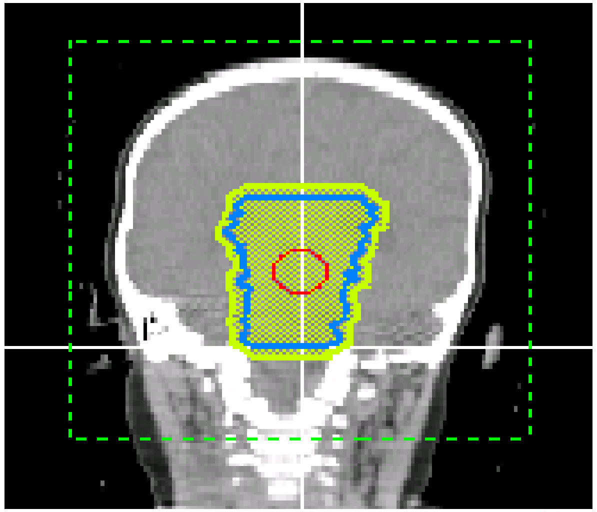
PTV(yellow)







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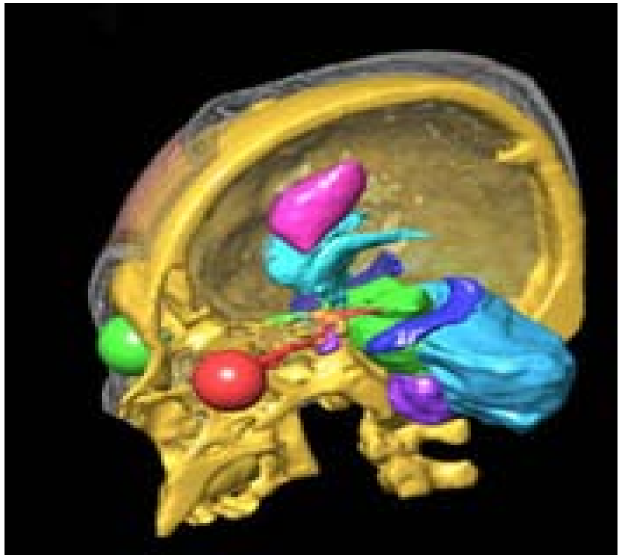
Take home message

- Inmovilization is crucial to reduce toxicity
- The addition of MRI gives vastly superior soft-tissue visualization
- The radiation technique (IMRT, Tomotherapy, Protons, Cyberknyfe) should be individualised for each patient



Questions:

- Preparation (thermoplastic mask)
- Positioning
- Organ at risk contouring
- Set-Up
- Verification
- Radiation technique

???

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WWW.ESTRO.ORG/SCHOOL

Case reports: **Brain**

Mirjana Josipovic
Dept. of Radiation Oncology,
Rigshospitalet
Copenhagen, Denmark

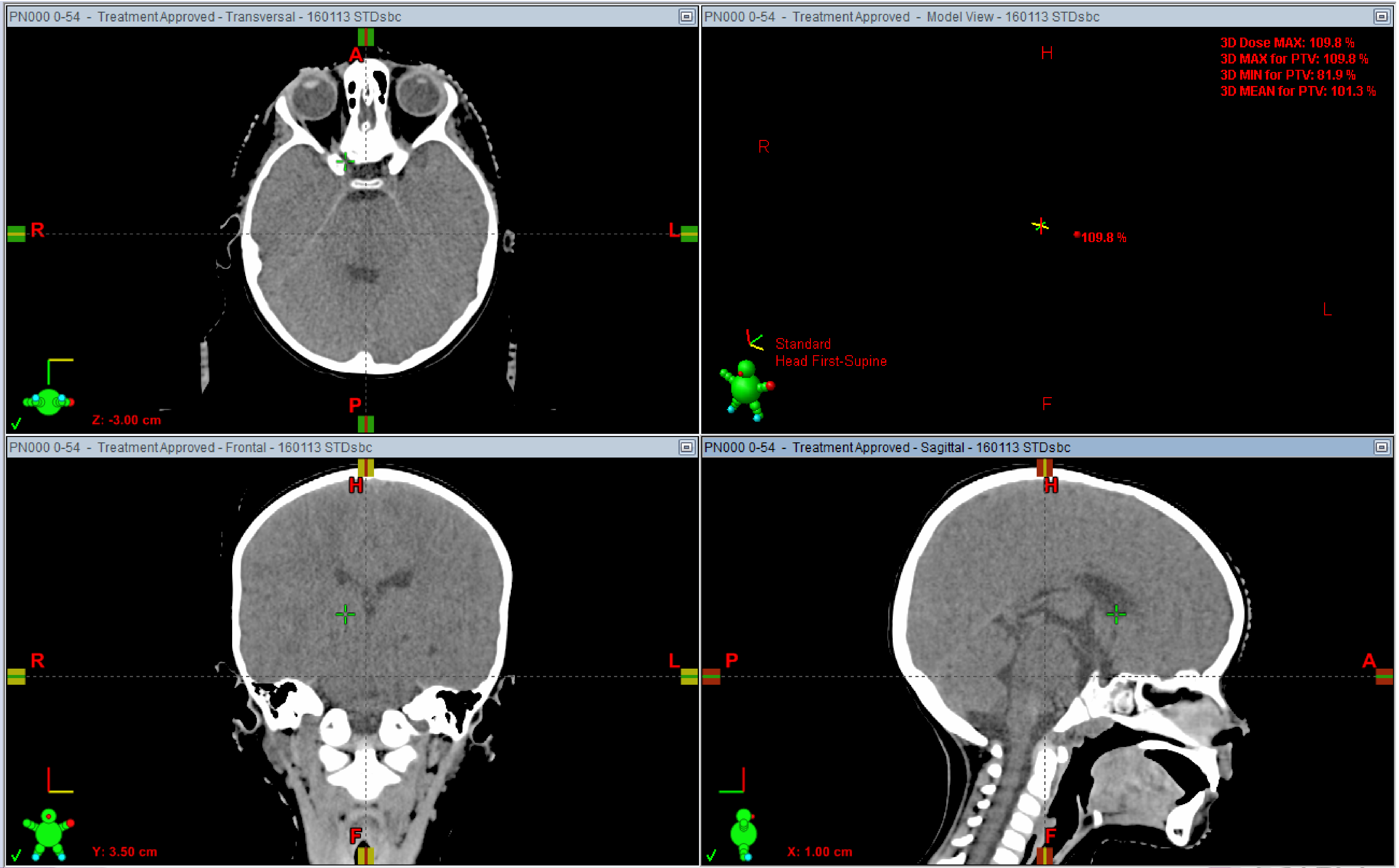
Advanced skills in modern radiotherapy
July 2015

Imaging for brain RT planning

Imaging immobilised patient in the treatment position

- CT scan
- MR scan
- Near future: functional MR

- Thin scan slices ~1 mm



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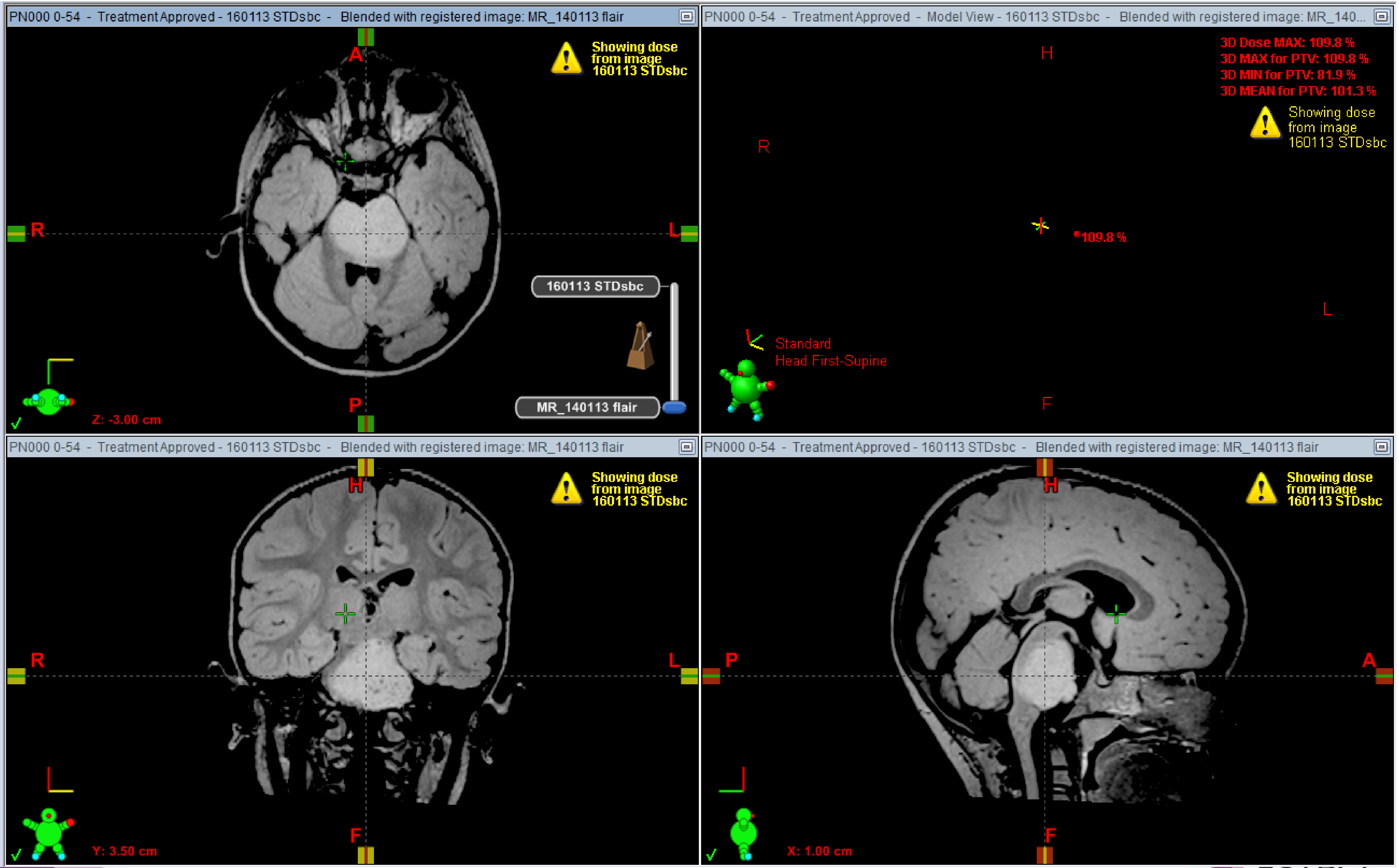

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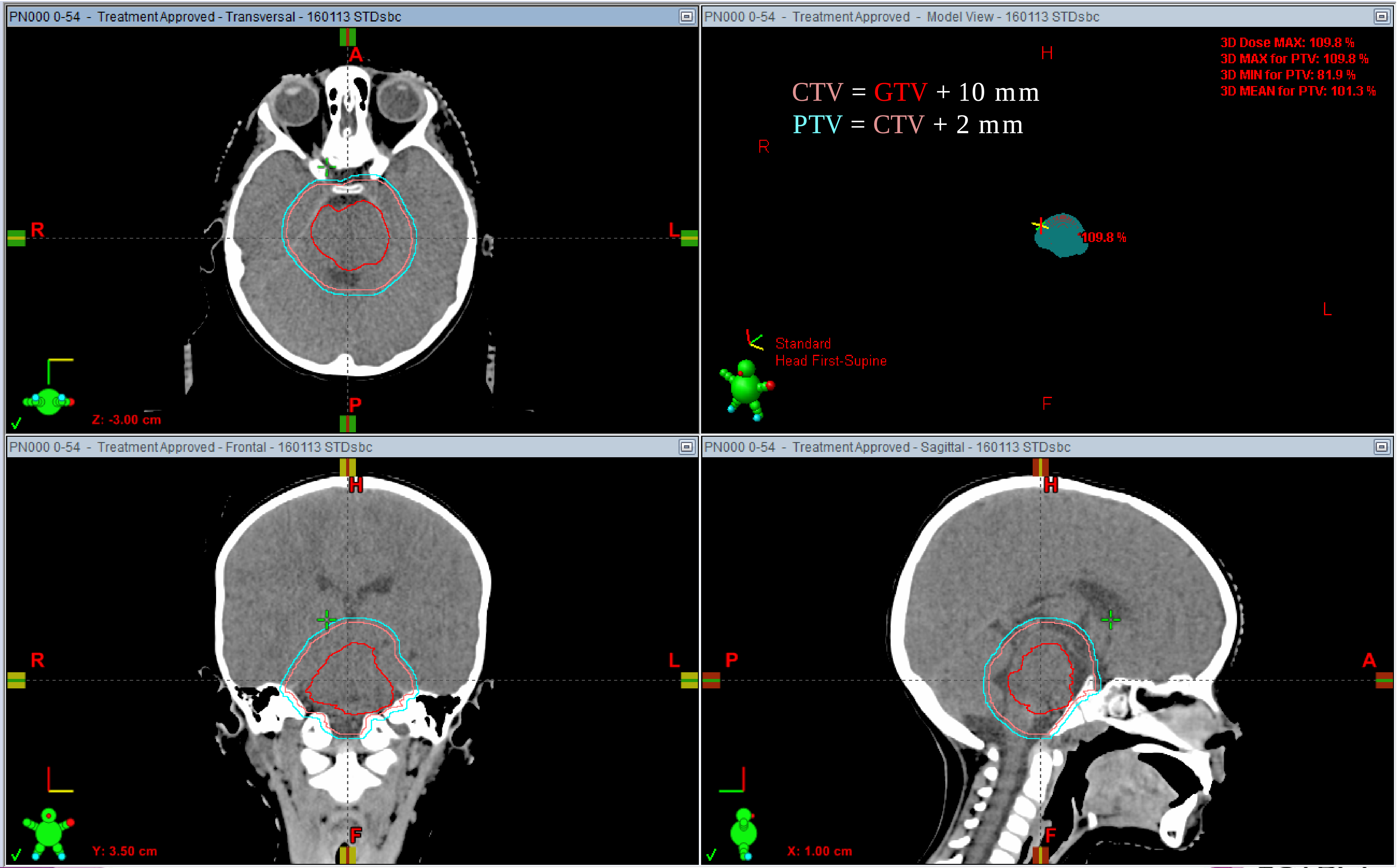

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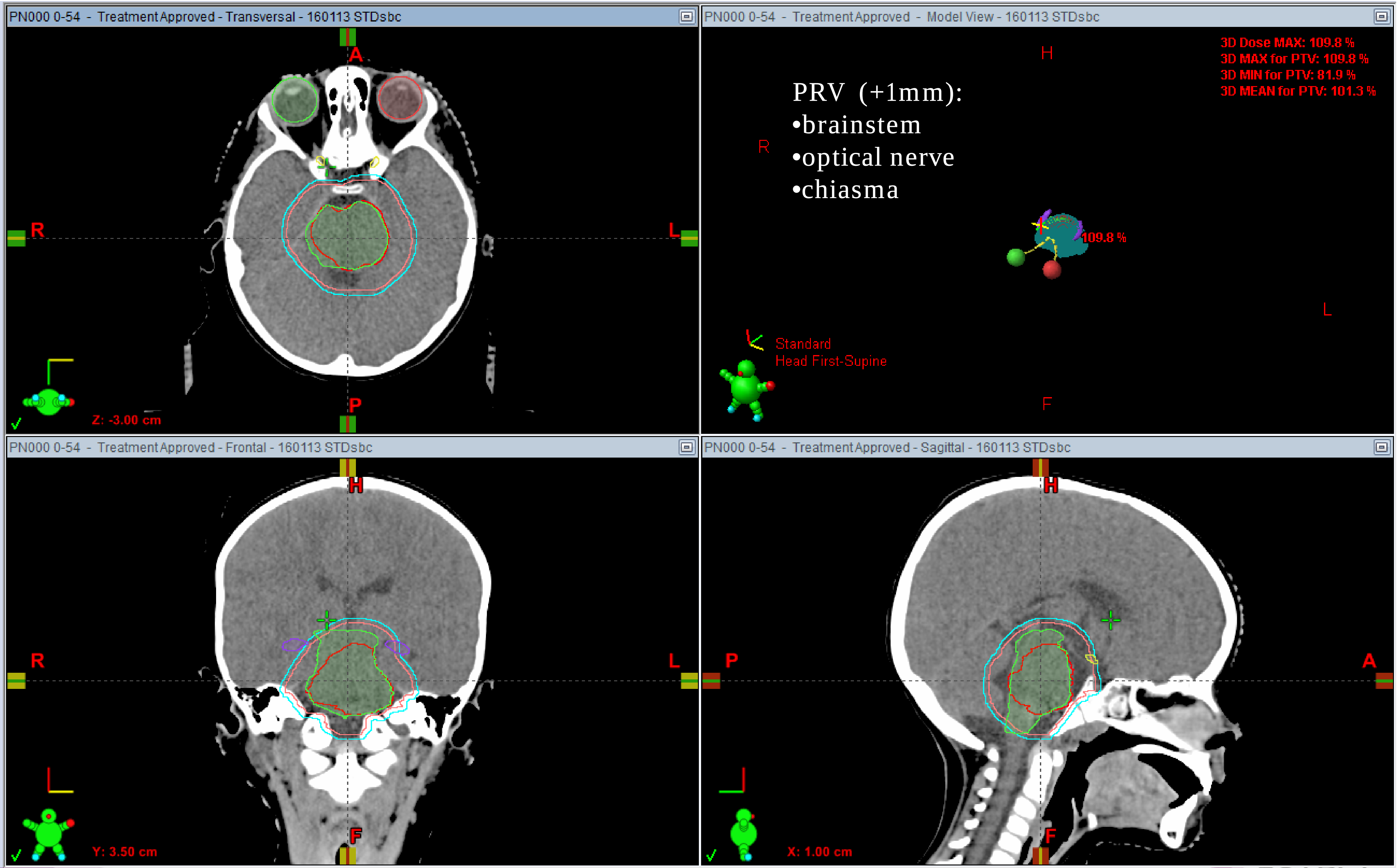
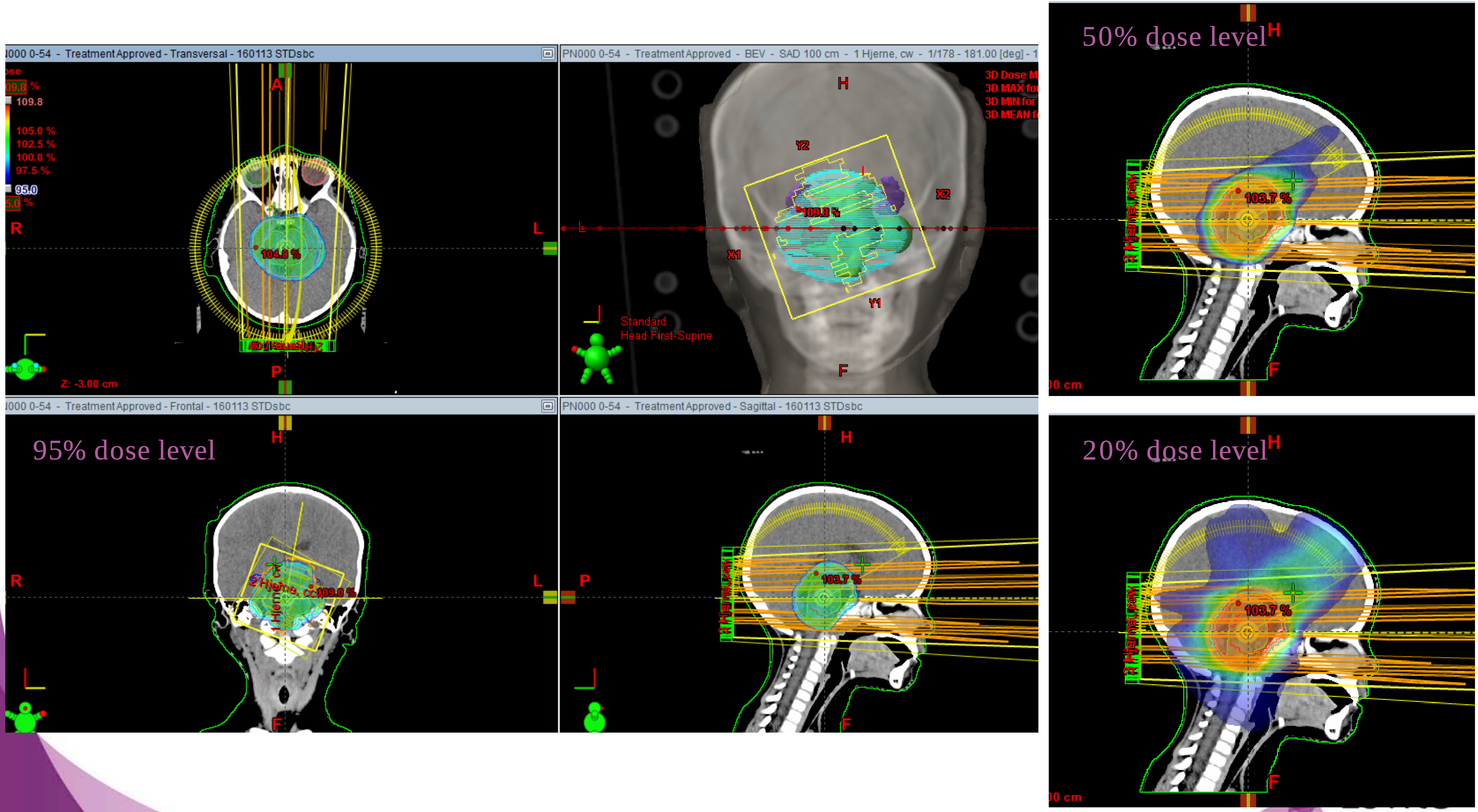

PN000 0-54 - TreatmentApproved - Transversal - 160113 STDsbc
PN000 0-54 - TreatmentApproved - Model View - 160113 STDsbc
PRV (+1mm):
•brainstem
•optical nerve
•chiasma
3D Dose MAX: 109.8 %
3D MAX for PTV: 109.8 %
3D MIN for PTV: 81.9 %
3D MEAN for PTV: 101.3 %
109.8 %
Standard
Head First-Supine
Z: -3.00 cm
PN000 0-54 - TreatmentApproved - Frontal - 160113 STDsbc
PN000 0-54 - TreatmentApproved - Sagittal - 160113 STDsbc
Y: 3.50 cm
X: 1.00 cm

VMAT plan – 2 arcs



School

Radiotherapy

Radiotherapy techniques

- 3DC
- IMRT
- VMAT
- Proton therapy

Fractionation schemes (Rigshospitalet, CPH)

- 2 Gy x 30
- 1.8 Gy x 30 (if brainstem is involved)

- 18 Gy x 1 (very small targets, stereotactic RT)

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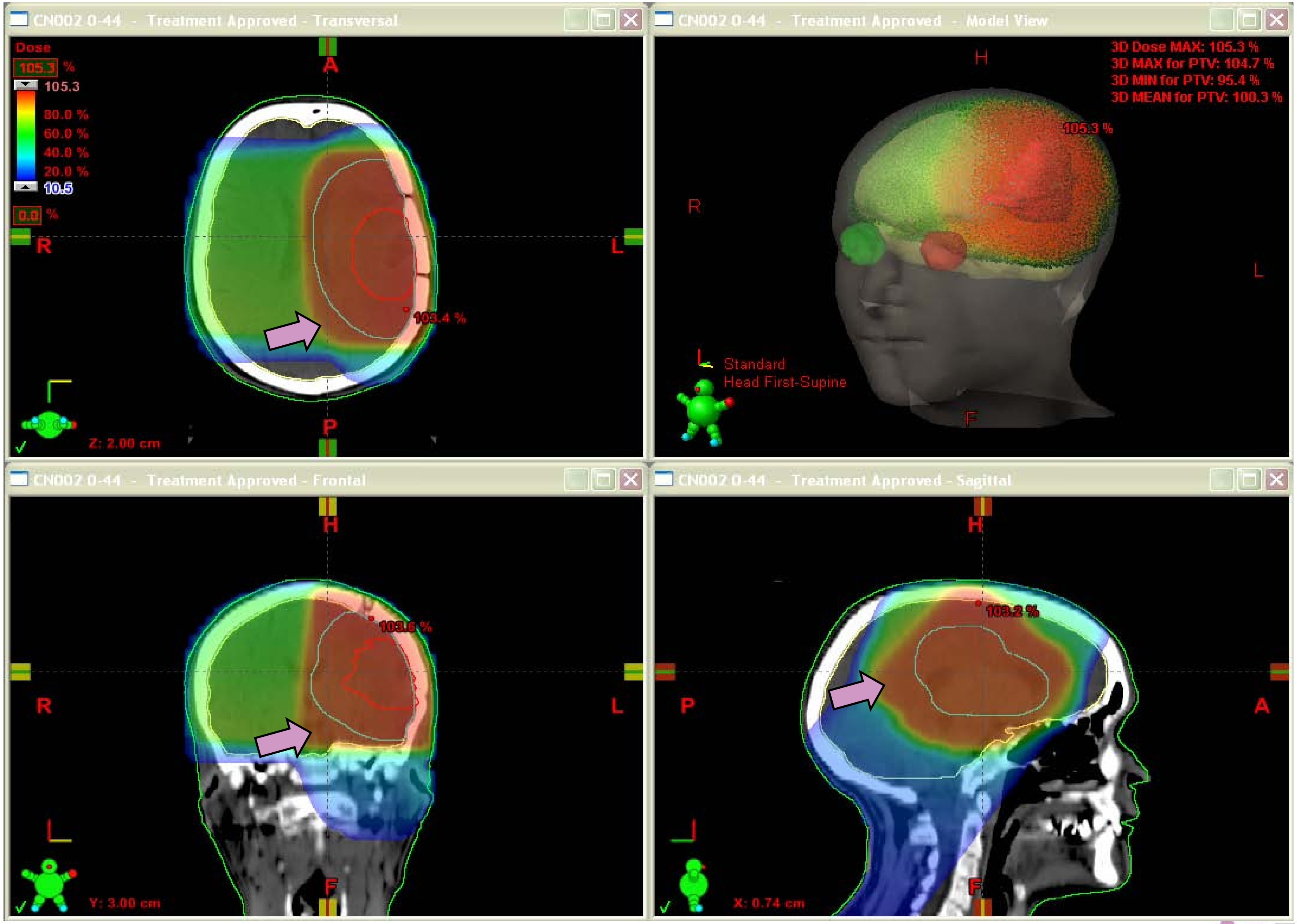
3DC plan



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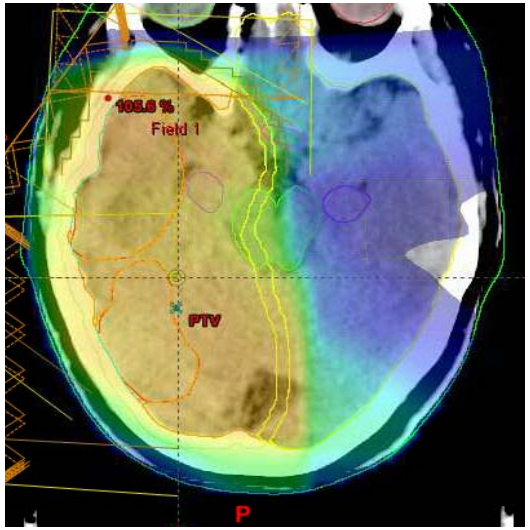
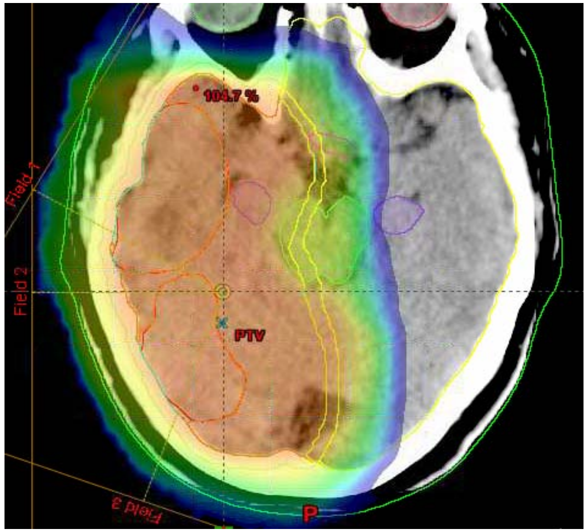
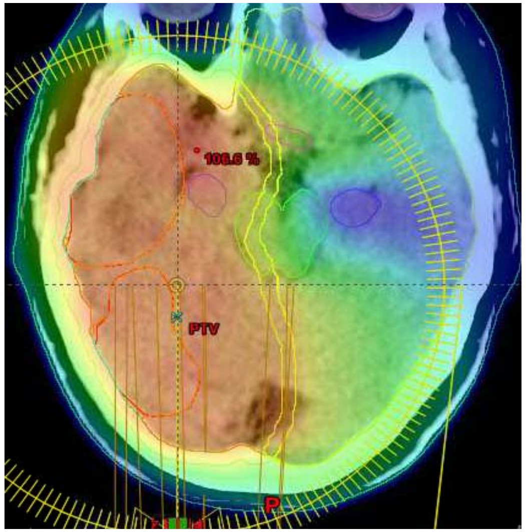
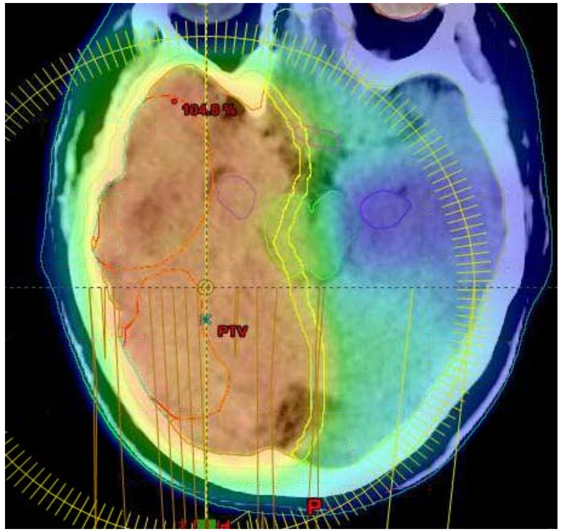
IMRT vs. protons vs. VMAT









IMRT	IMPT protons	VMAT (co-planar)	VMAT (non co-planar)
worst plan conformity	best plan conformity		

Courtesy of P Munck af Rosenschöld

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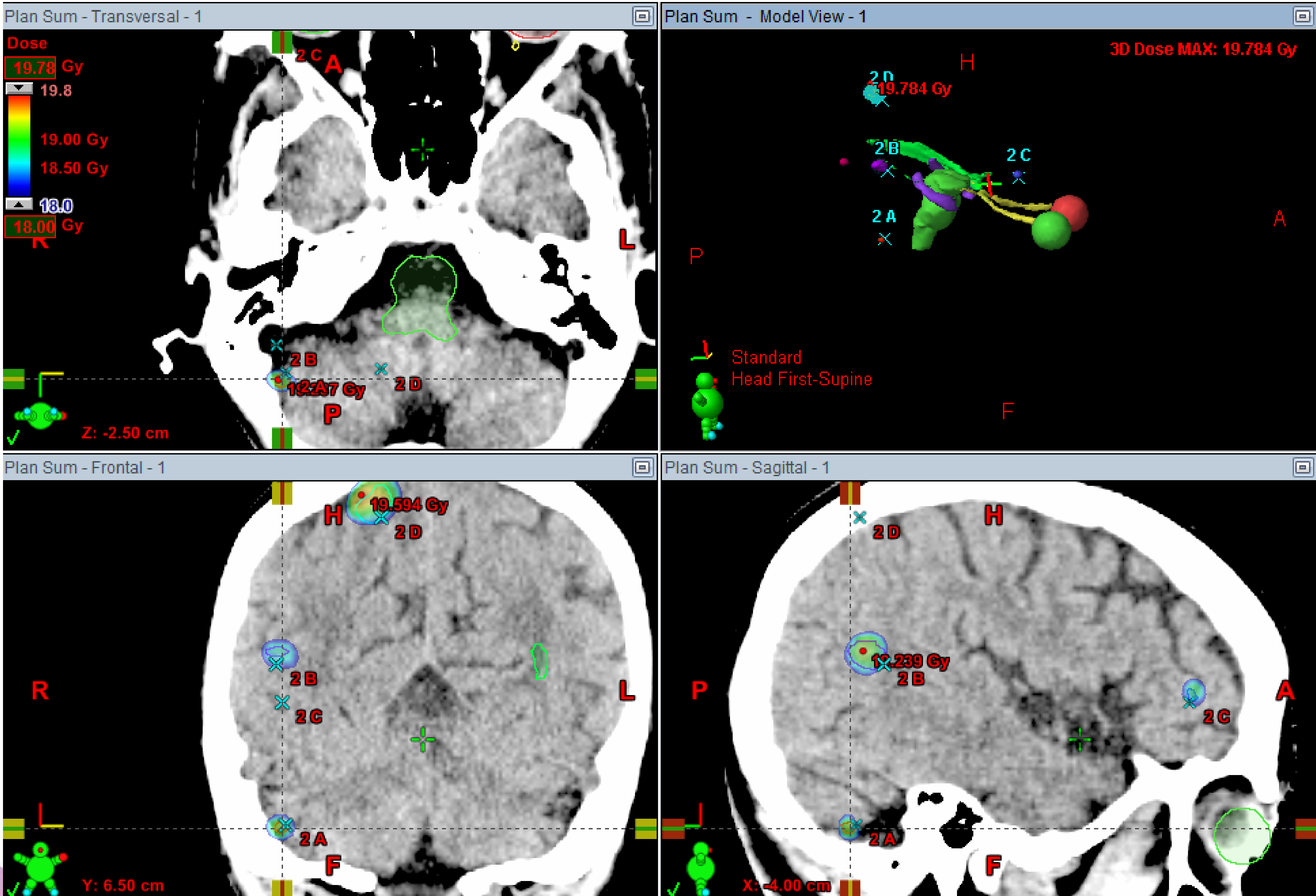
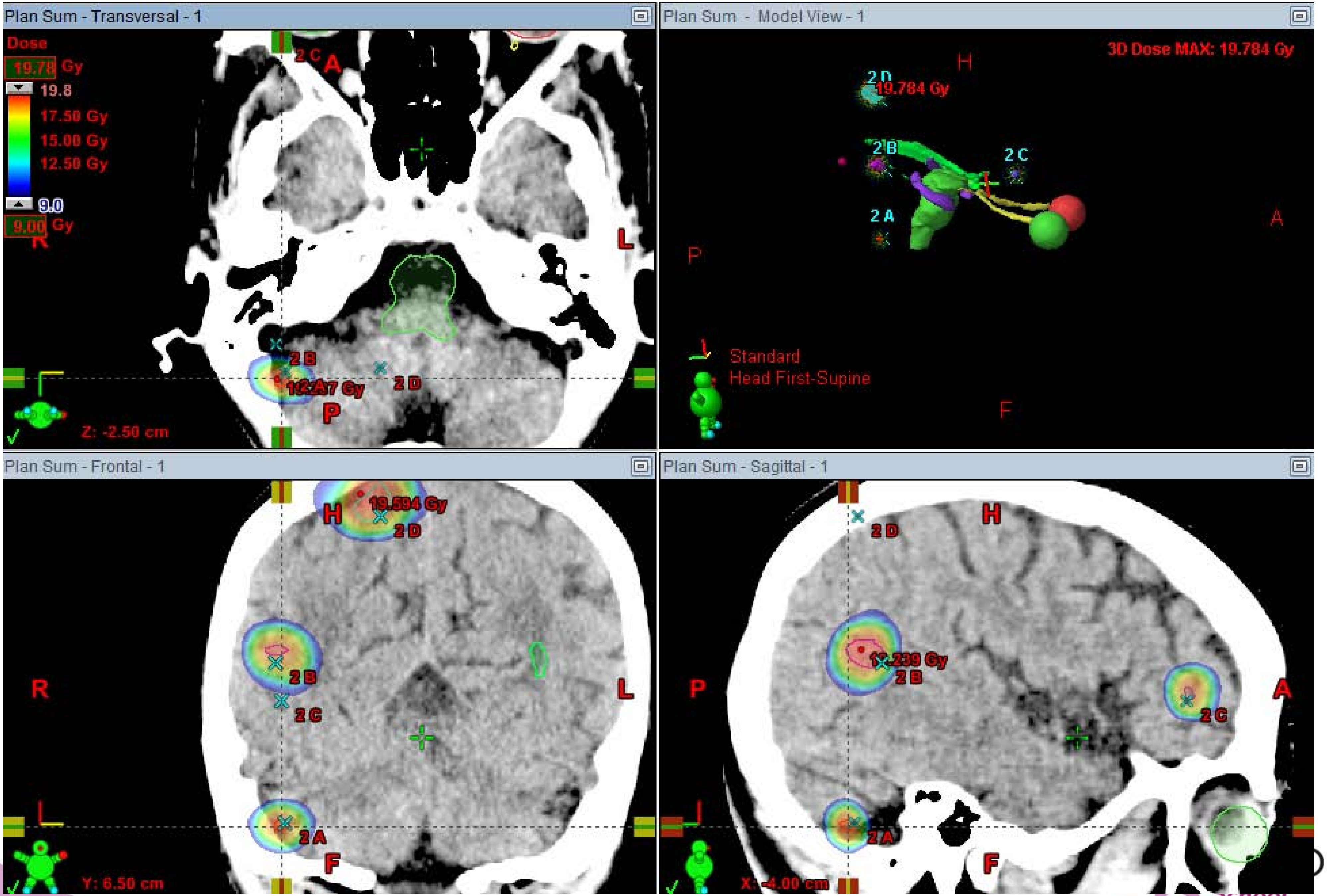
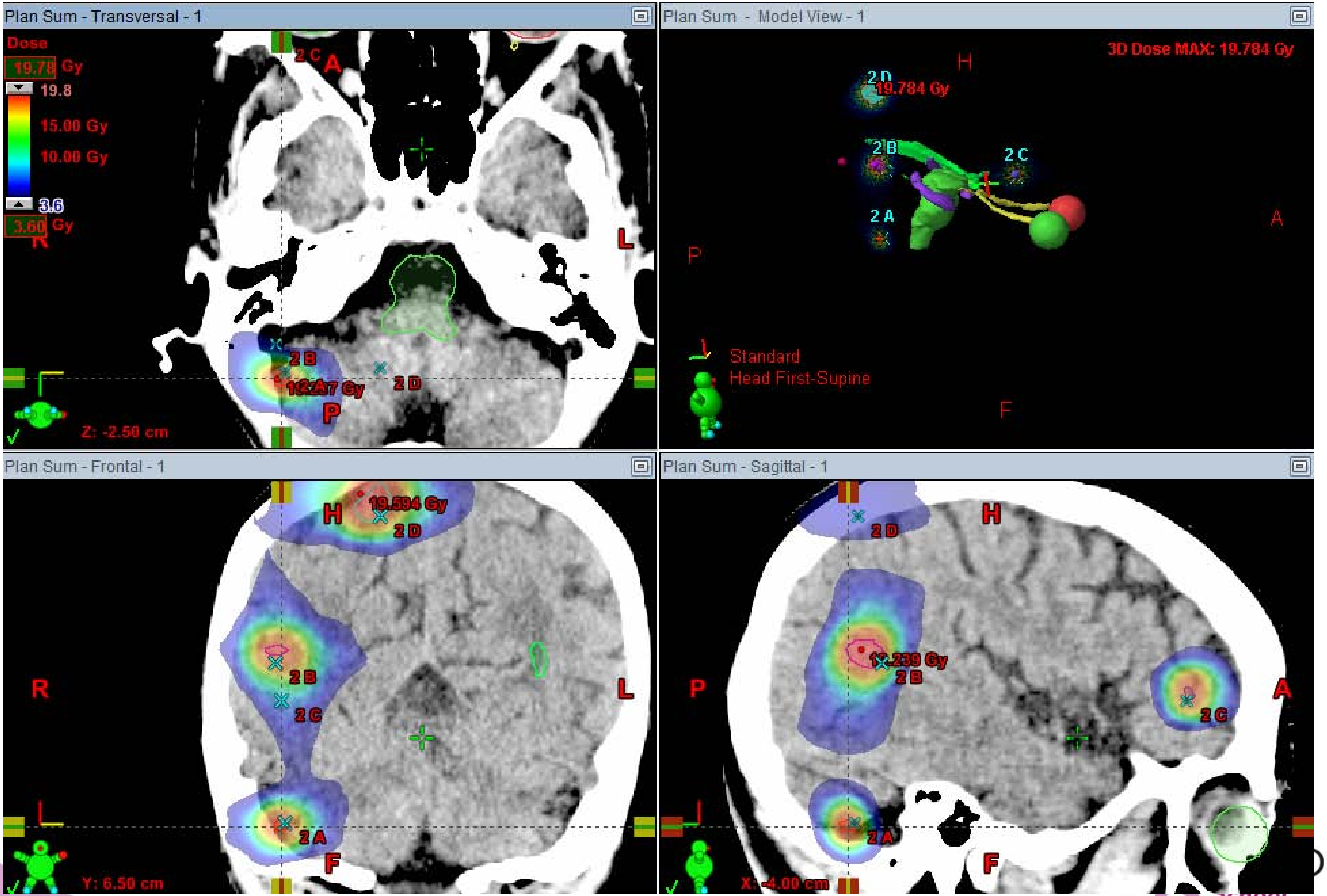
Stereotactic treatment – 4 targets!



Stereotactic treatment – 4 targets!



Stereotactic treatment – 4 targets!



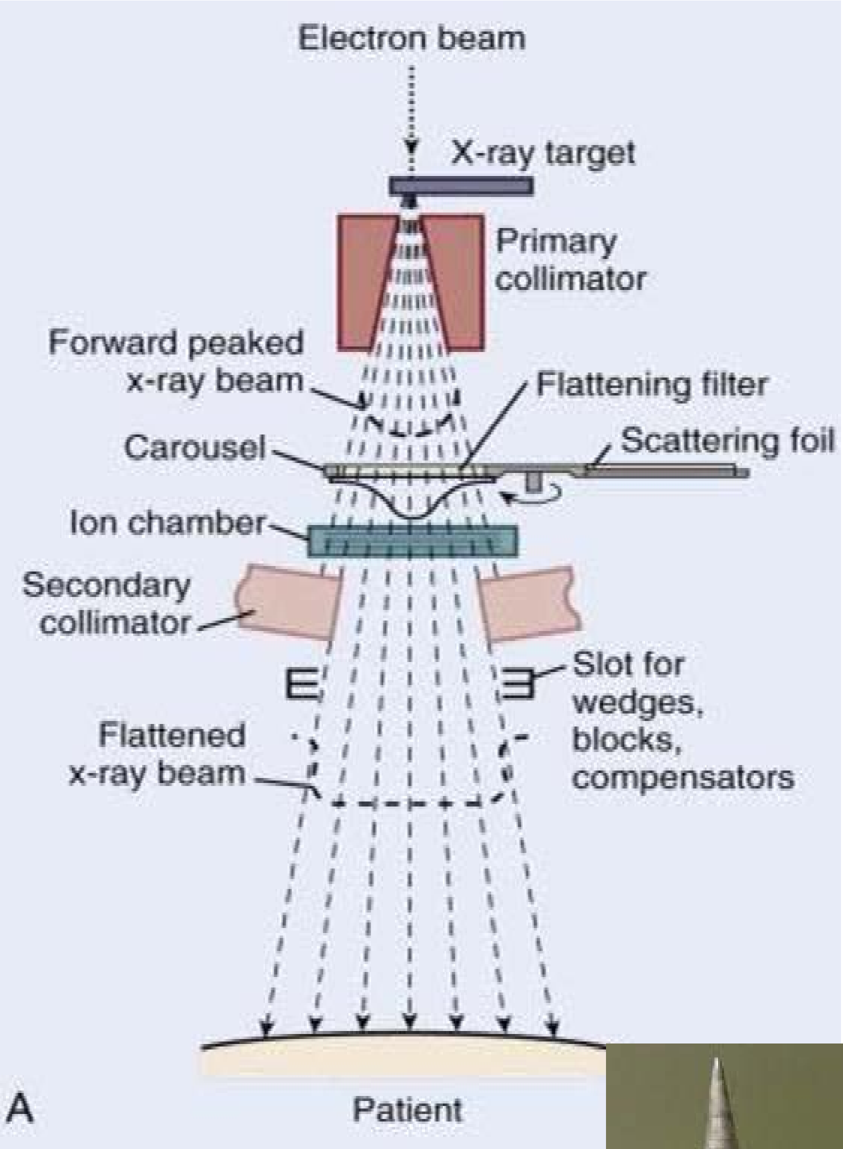
Delivery of stereotactic brain RT

It takes time …

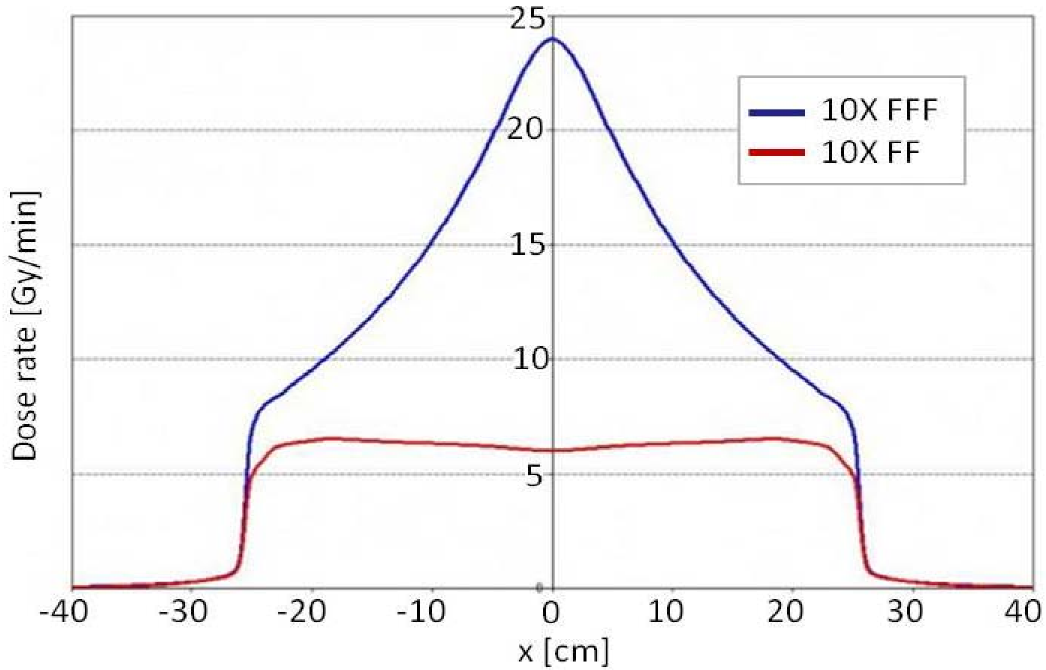
- Larger amount of MU to be delivered
- Non – coplanarity requires couch rotations

- Dose rate: 600 MU/min (Varian)
- #MU: ~2500-3000

FFF – flattening filter free



Intensity modulated RT does not necessitate flat beams



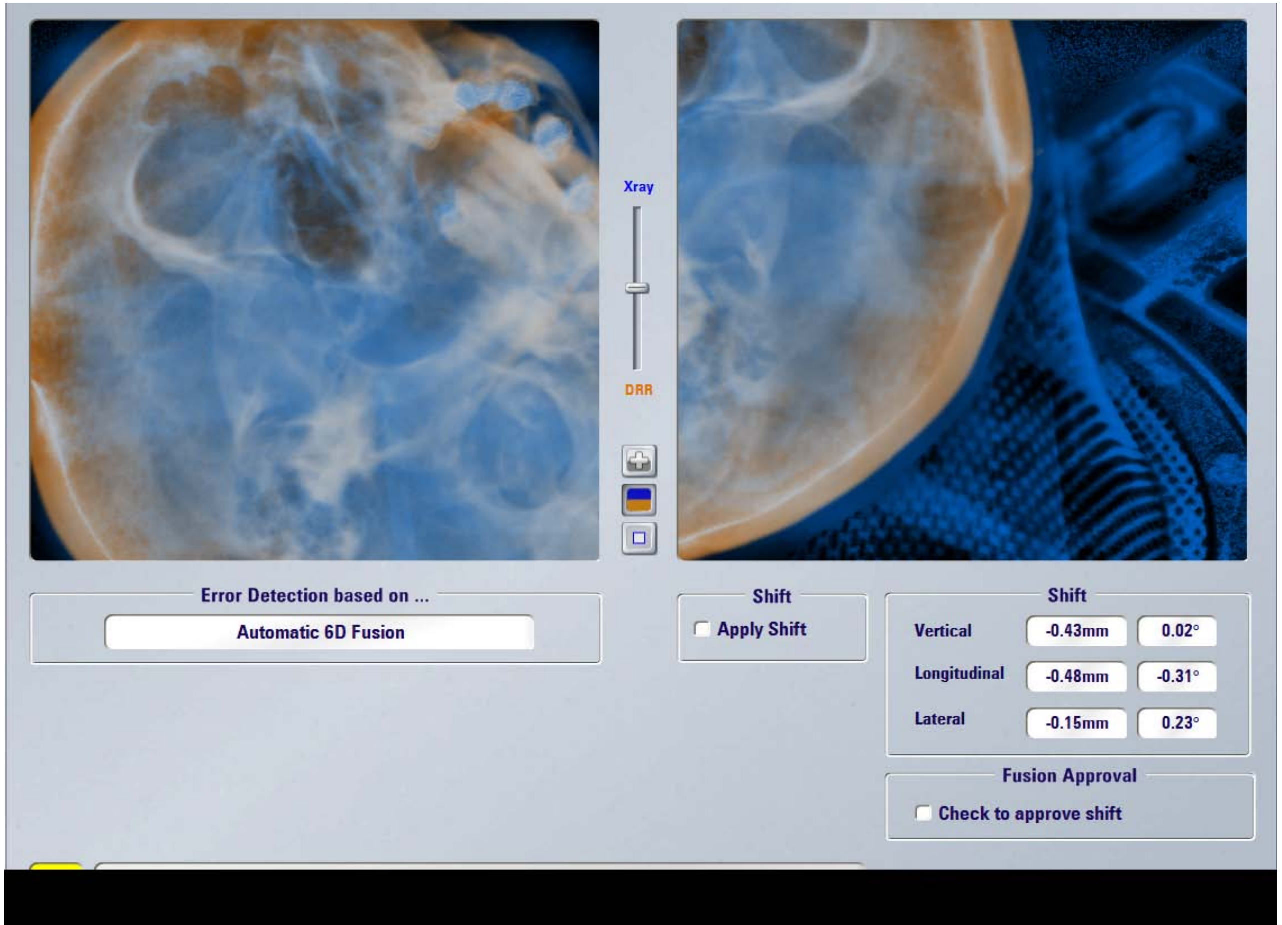
FFF facilitates increase in dose rate & decrease in beam time by a factor of up to 6

Delivery of stereotactic brain RT

IGRT

- Small PTV margins
- 6D corrections

- Rigs tolerance:
  - <1mm
  - <1°



A bit about the margins…

Margins depend on:

- RT technique
- IGRT strategy (Rianne's talk)

Example:

- 3DC RT & field verification at first treatment
  - 5 mm CTV-PTV margin

- VMAT & daily IGRT with 6D:
  - 1-2 mm CTV-PTV margin

Considering the margins vs. daily IGRT workload

margins of 5 mm increase the treated volume by 50%

D. Verellen et al. nature reviews | **cancer** volume 7 | december 2007 | 949

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Take home messages

- Optimal imaging for brain RT planning
  - ➢ MR + CT
  - ➢ Thin slices

- Challenging RT planning due to overlap of OAR & PTV

- Choice of treatment technique affects dose outside PTV
  - ➢ 3DC vs. VMAT
  - ➢ In stereotactic RT, FFF facilitates reduction of beam on time
  - ➢ Daily IGRT is optimal, maximal margin reduction with 6D corrections

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Brain

Rianne de Jong *RTT*,
Academic Medical Centre, Amsterdam
Copenhagen 2015

m.a.j.dejong@amc.uva.nl

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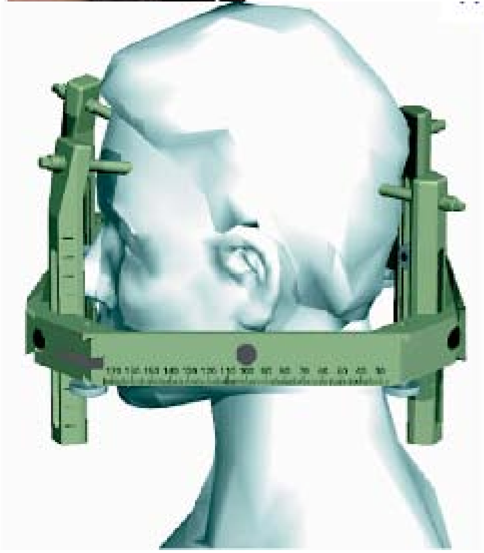
Brain @the treatment machine

- How well can we set up the patient?
- How well can we image the target volume?
- How well can we correct the patient position?
- How stable is the patient position?
- Imaging dose for children

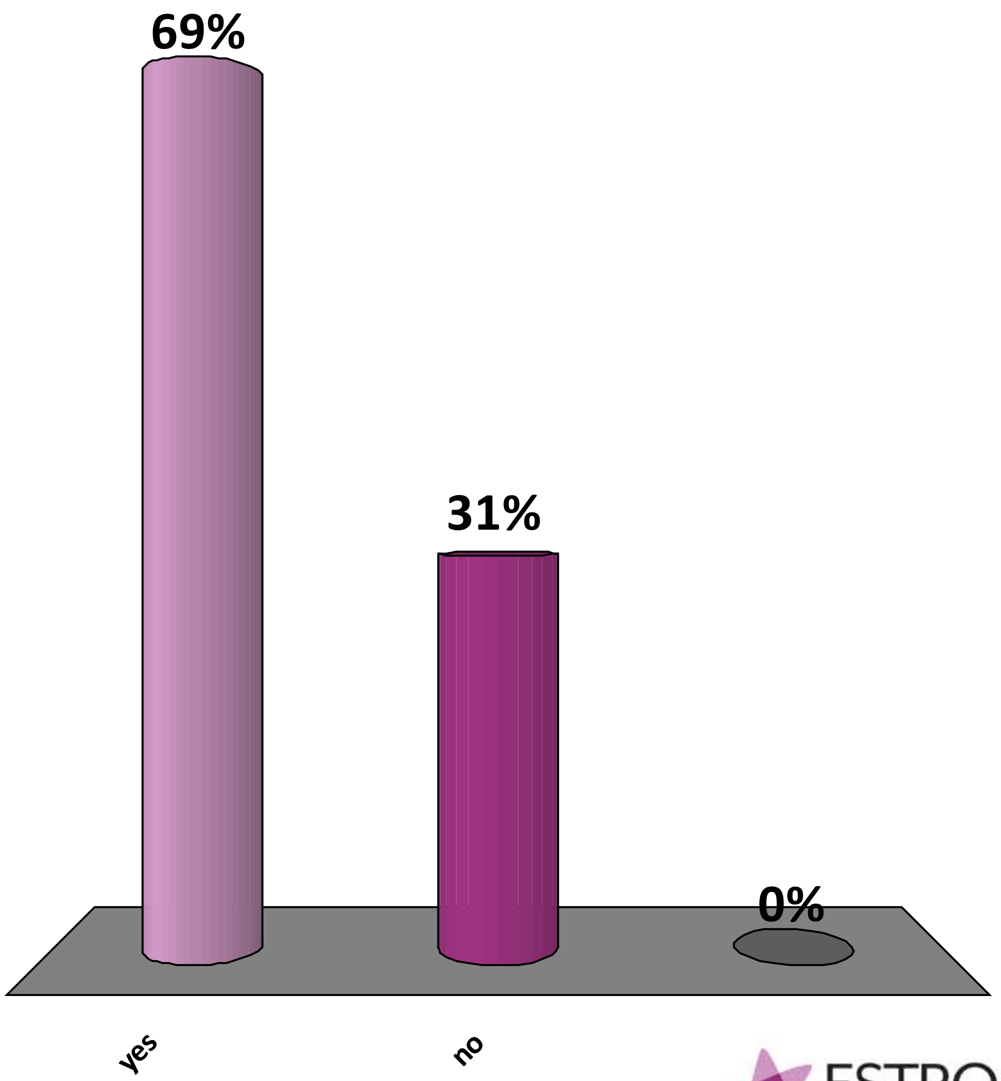
Commercial Immobilisation Options

- Thermoplastic mask
- Mask + bite block
- Frames
- Invasive frames



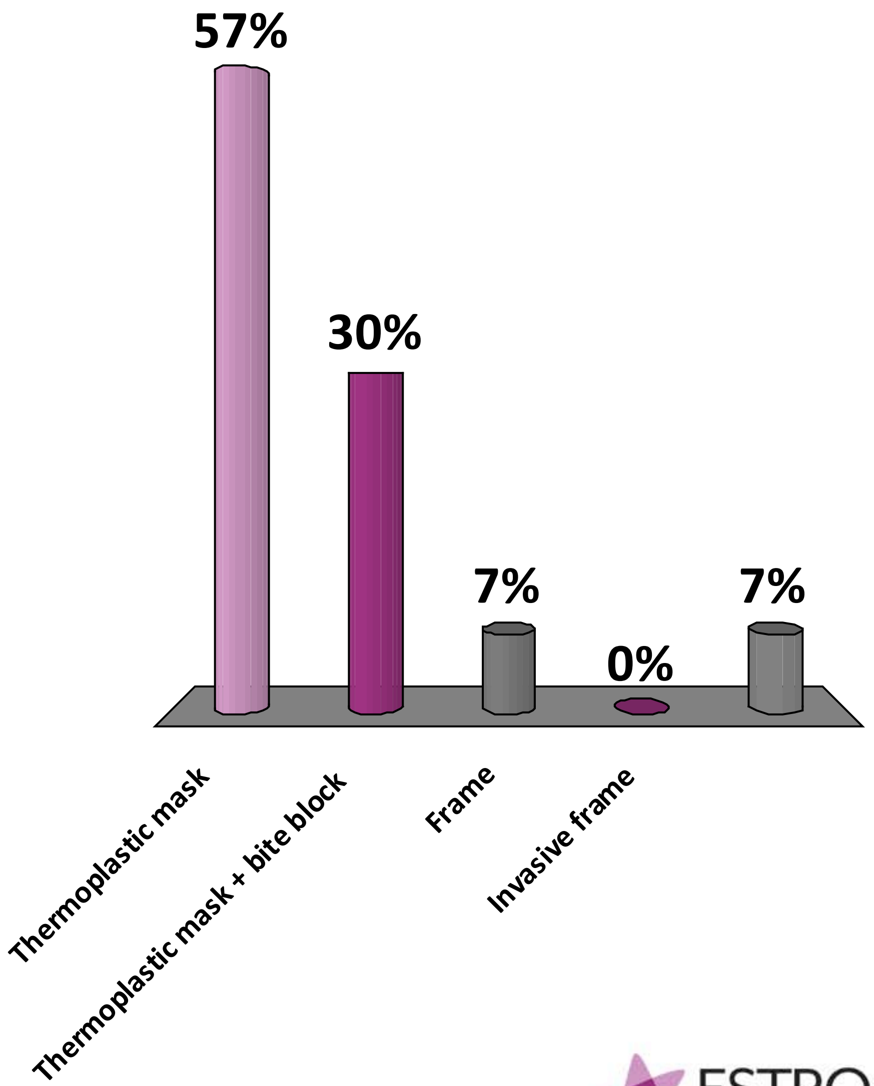
Do you treat with hypofractionation? (solitary metastasis)

A. yes
B. no
C.



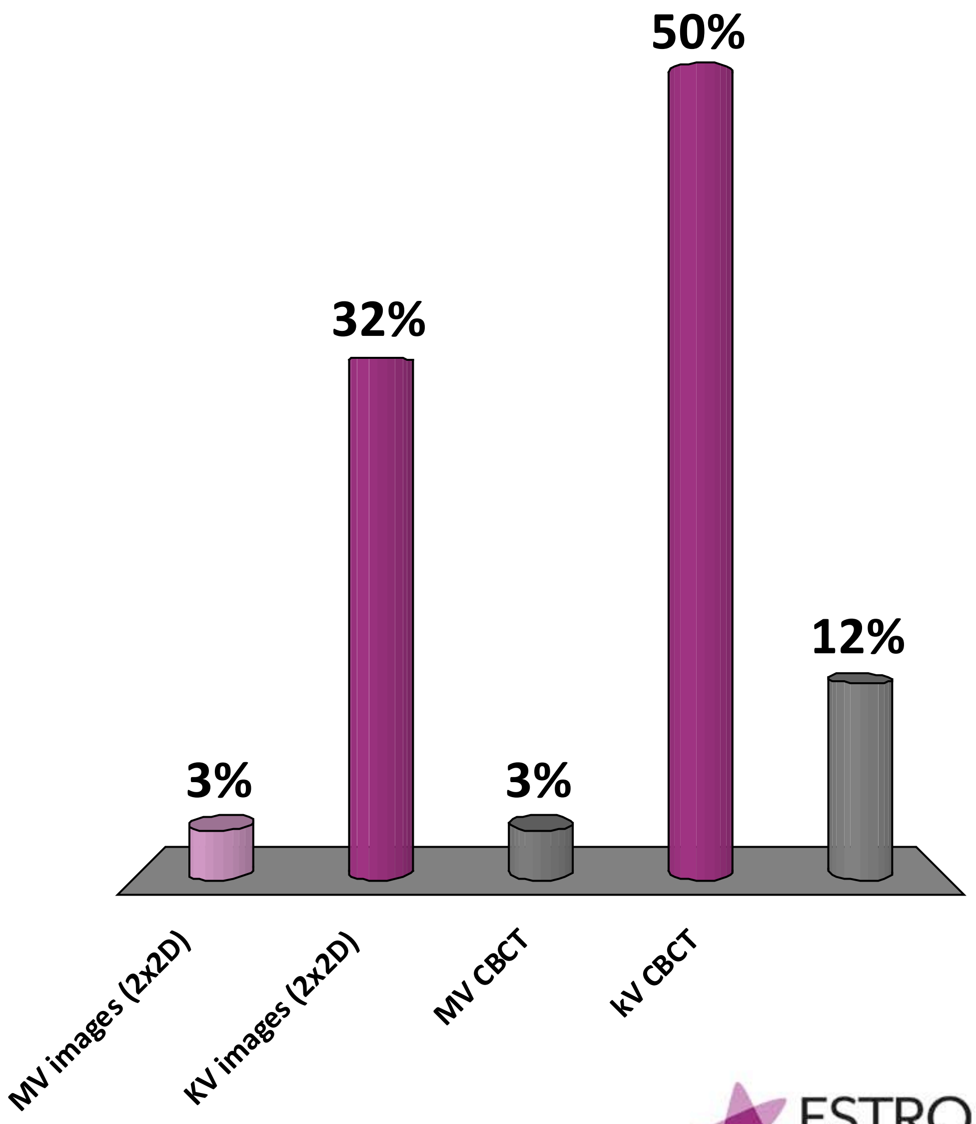
What immobilisation do you use?

A. Thermoplastic mask
B. Thermoplastic mask + bite block
C. Frame
D. Invasive frame
E.



What images do you use for registration?

A. MV images (2x2D)
B. KV images (2x2D)
C. MV CBCT
D. kV CBCT
E.

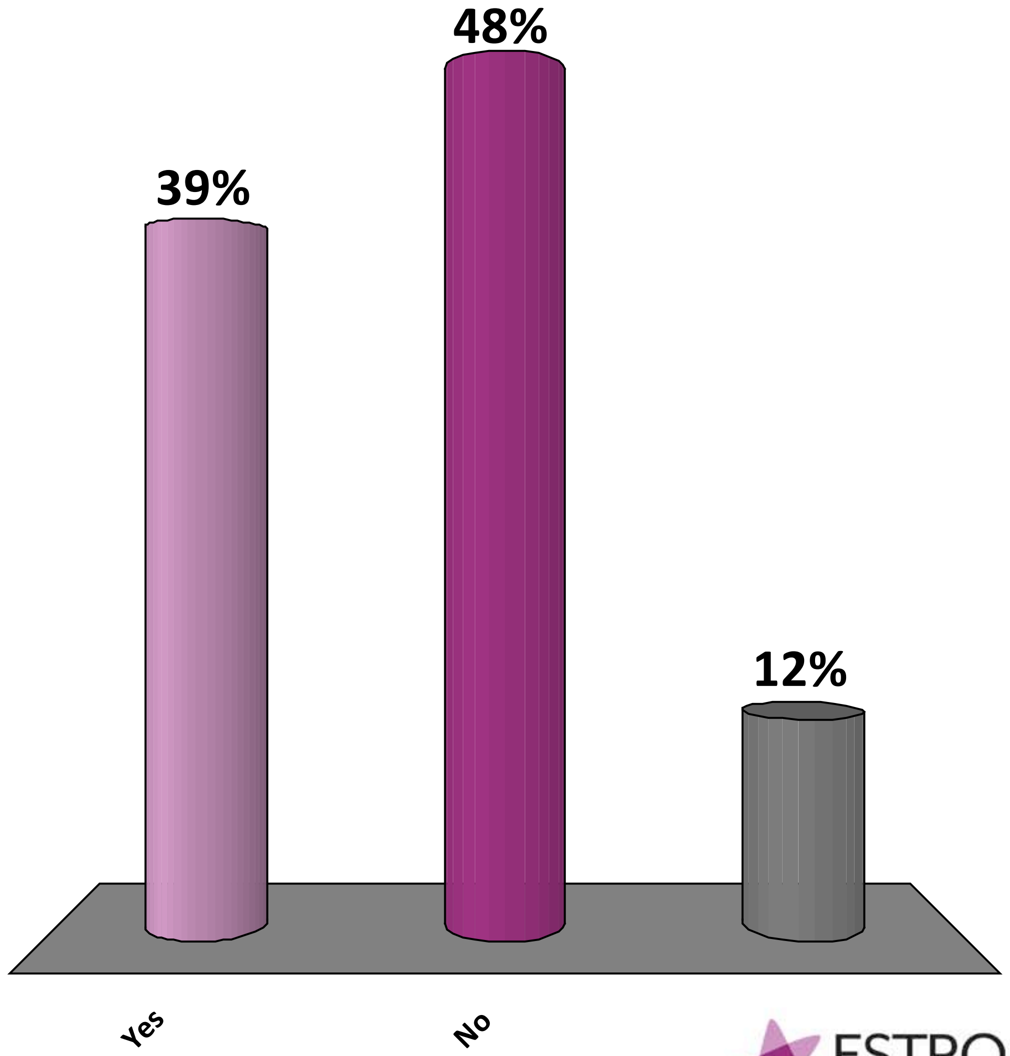


Are all images as accurate?

A. Yes

B. No

C.



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Set-up accuracy: interfraction motion
→ based on bony anatomy registration

Study	Positioning system	Imaging modality	Position error
2D-2D image registration for verification of set-up			
Rosenthal 1995	Dental fixation	Ortogonal radiographs	**2.3mm ±1.6mm**
Sweeny 2001	Vogely Bale Hohner head Holder	Portal imaging	**1.9mm ± 1.2mm**
Kumar 2005	Gill-Thomas-Cosman	Portal imaging	**1.8mm ± 0.8mm**
Georg 2006	Brain Lab Mask	Portal imaging	**1.3mm ± 0.9mm**
3D-3D image registration for verification of set-up			
Baumert 2005	Stereotactic mast	CT	**3.7mm ± 0.8mm**
Boda-Heggermann 2006	Scotch cast mask	CBCT	**3.1mm ± 1.5mm**
Guckenberger 2007	Scotch cast mask	CBCT	**3.0mm ± 1.7mm**
Masi 2008	Thermoplastic mask & Bite block	CBCT	**2.9mm ± 1.3mm**
	Bite-block	CBCT	**3.2mm ± 1.5mm**

Courtesy M. Guckenberger, ESTRO IGRT course

amc ESTRO School

Set-up accuracy: interfraction motion

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	Bite-block	CBCT	**3.2mm ± 1.5mm**

!

Courtesy M. Guckenberger, ESTRO IGRT course

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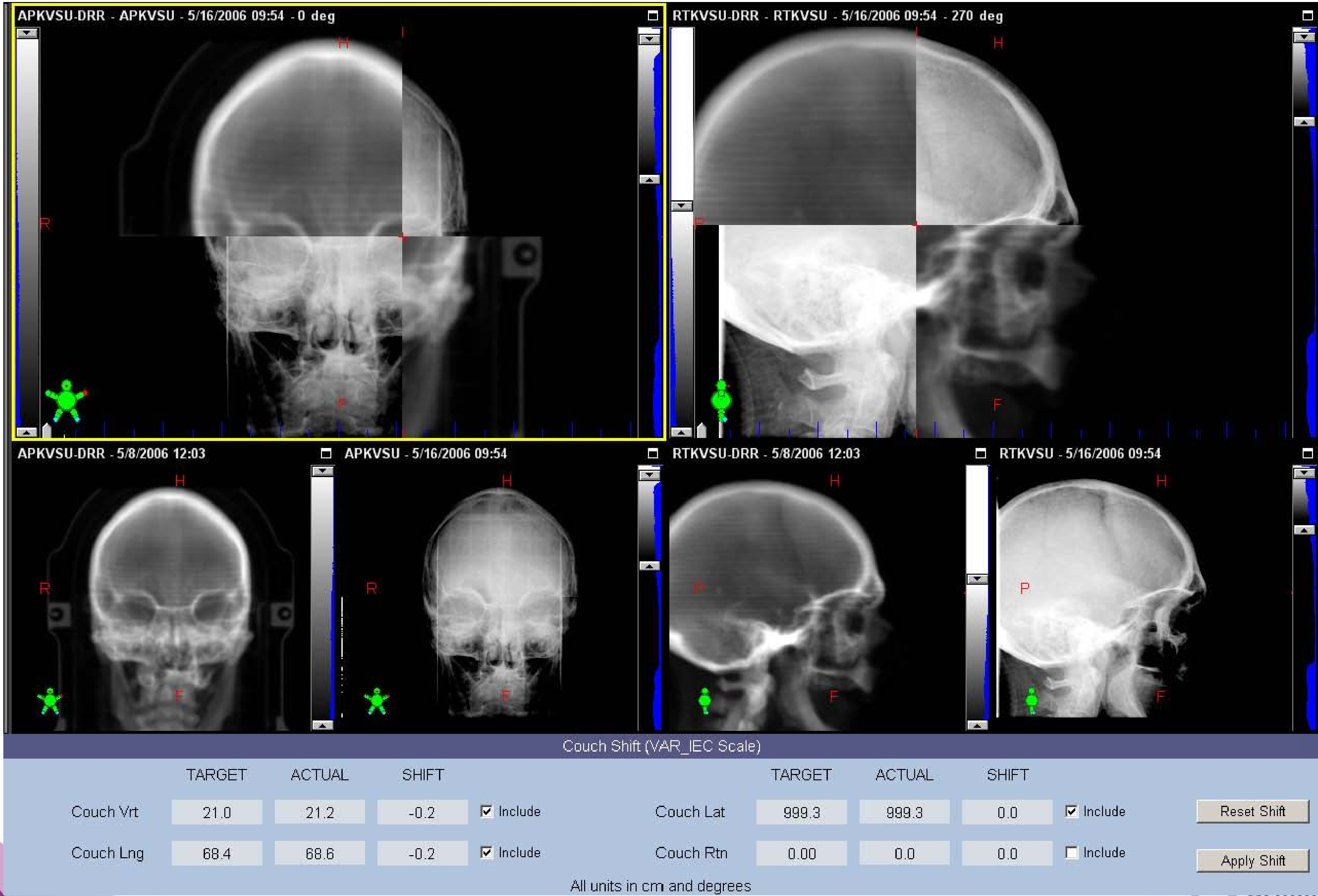
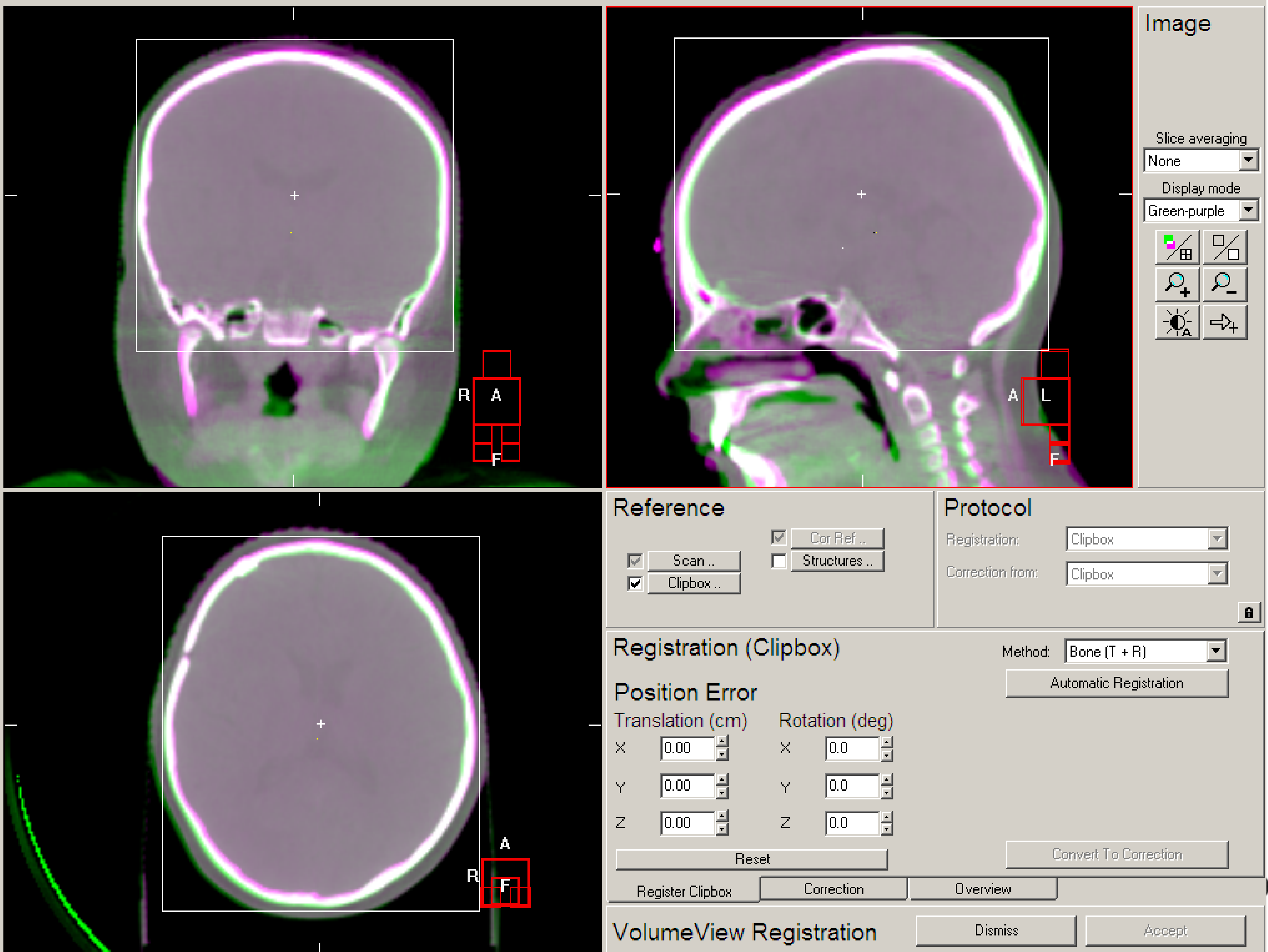

APKVSU-DRR - APKVSU - 5/16/2006 09:54 - 0 deg
RTKVSU-DRR - RTKVSU - 5/16/2006 09:54 - 270 deg
APKVSU-DRR - 5/8/2006 12:03
APKVSU - 5/16/2006 09:54
RTKVSU-DRR - 5/8/2006 12:03
RTKVSU - 5/16/2006 09:54
H
R
P
F
Couch Shift (VAR_IEC Scale)
TARGET
ACTUAL
SHIFT
Couch Vrt 21.0 21.2 -0.2 Include
Couch Lng 68.4 68.6 -0.2 Include
Couch Lat 999.3 999.3 0.0 Include
Couch Rtn 0.00 0.0 0.0 Include
Reset Shift
Apply Shift
All units in cm and degrees


R
A
F
A
L
F
A
R
F
Image
Slice averaging
None
Display mode
Green-purple
Reference
Cor Ref ..
Scan ..
Structures ..
Clipbox ..
Protocol
Registration:
Clipbox
Correction from:
Clipbox
Registration (Clipbox)
Method:
Bone (T + R)
Automatic Registration
Position Error
Translation (cm)
Rotation (deg)
X
0.00
0.0
Y
0.00
0.0
Z
0.00
0.0
Reset
Convert To Correction
Register Clipbox
Correction
Overview
VolumeView Registration
Dismiss
Accept

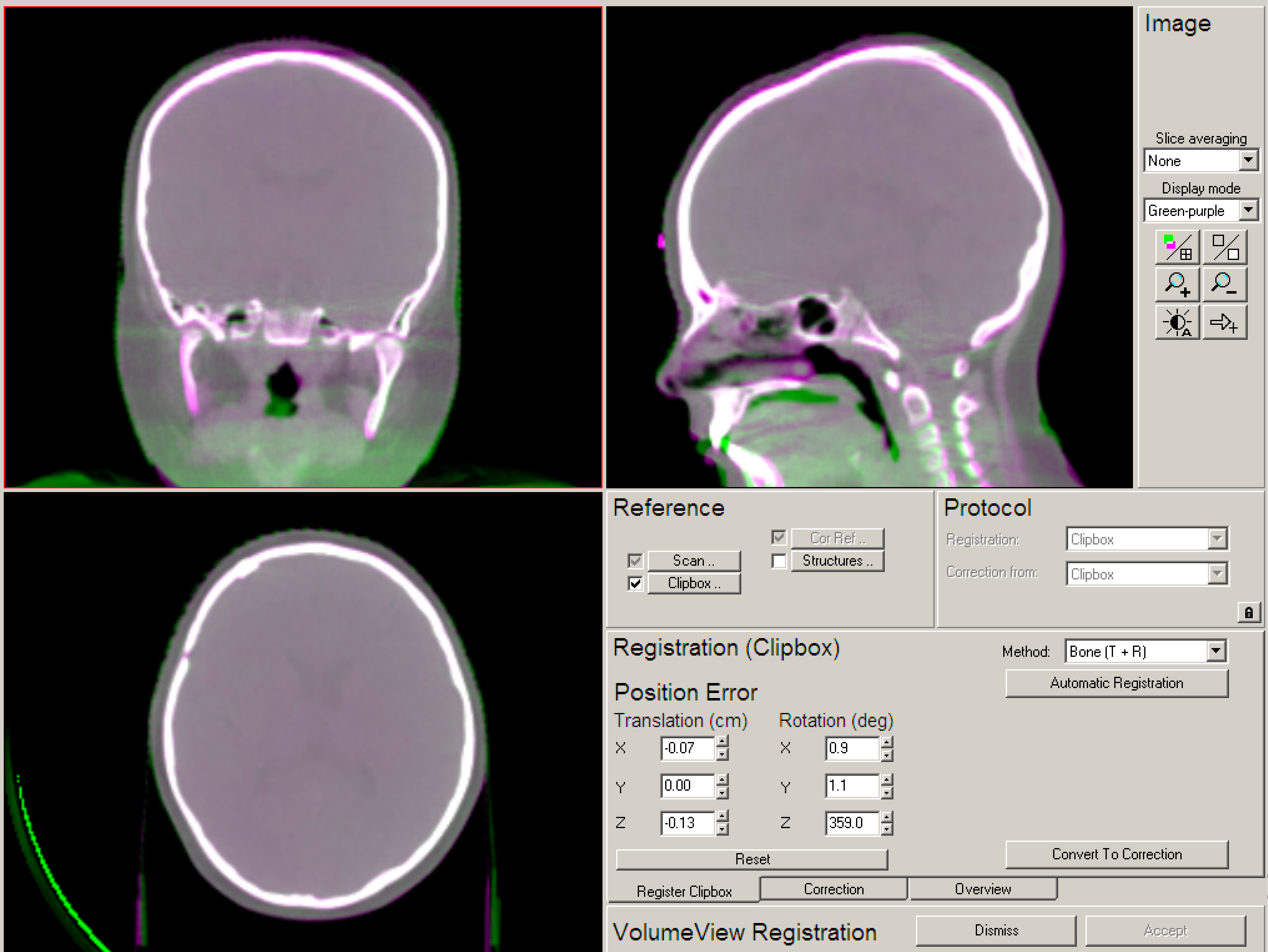


Image
Slice averaging
None
Display mode
Green-purple
Reference
Cor Ref ..
Scan ..
Structures ..
Clipbox ..
Protocol
Registration:
Clipbox
Correction from:
Clipbox
Registration (Clipbox)
Method:
Bone (T + R)
Automatic Registration
Position Error
Translation (cm)
Rotation (deg)
X
-0.07
X
0.9
Y
0.00
Y
1.1
Z
-0.13
Z
359.0
Reset
Convert To Correction
Register Clipbox
Correction
Overview
VolumeView Registration
Dismiss
Accept

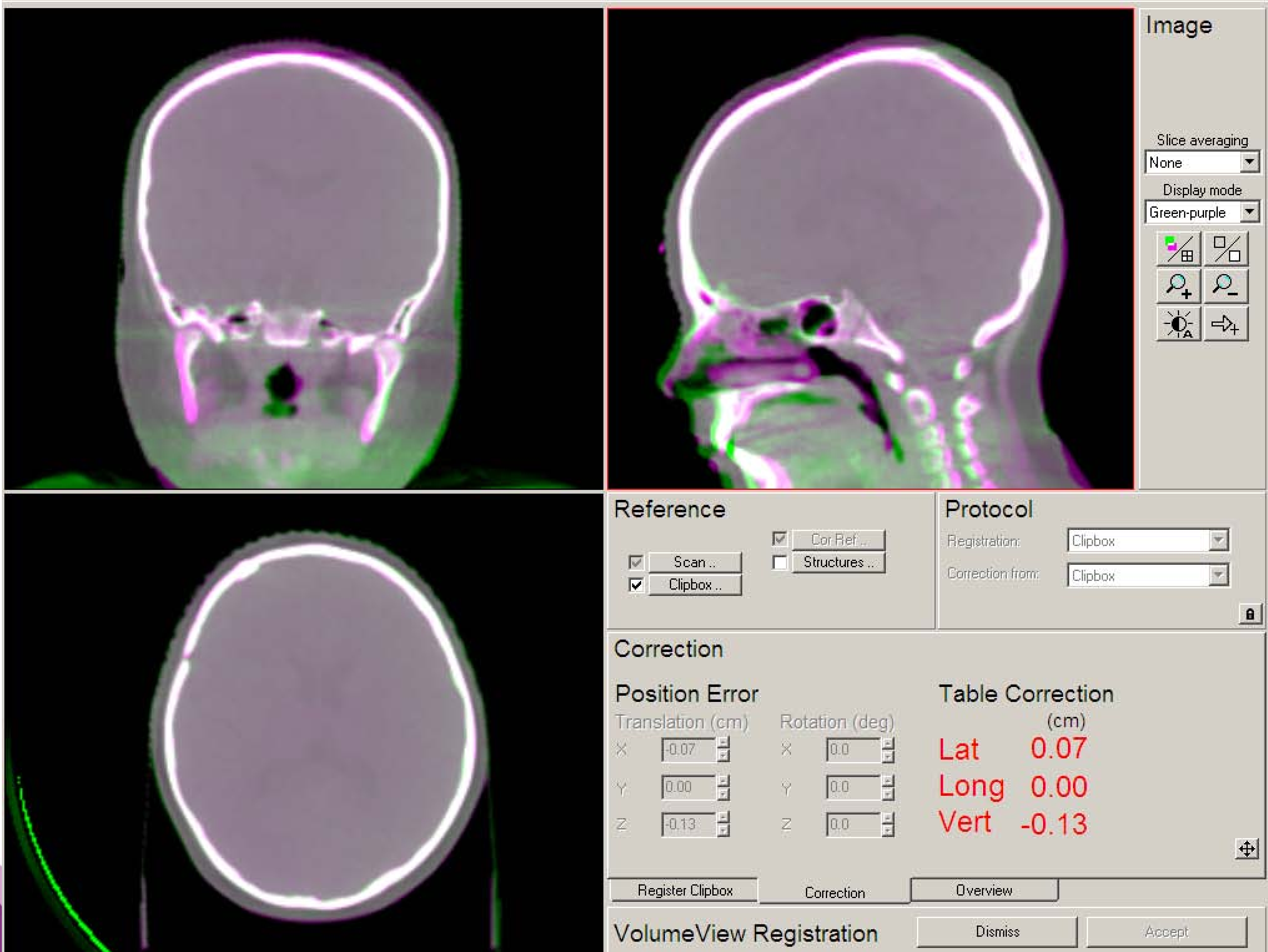


Image
Slice averaging
None
Display mode
Green-purple
Reference
Cor Ref ..
Scan ..
Structures ..
Clipbox ..
Protocol
Registration:
Clipbox
Correction from:
Clipbox
Correction
Position Error
Translation (cm)
Rotation (deg)
X -0.07
Y 0.00
Z -0.13
X 0.0
Y 0.0
Z 0.0
Table Correction
(cm)
Lat 0.07
Long 0.00
Vert -0.13
Register Clipbox
Correction
Overview
VolumeView Registration
Dismiss
Accept

Image registration
→ Bony anatomy a good surrogate?

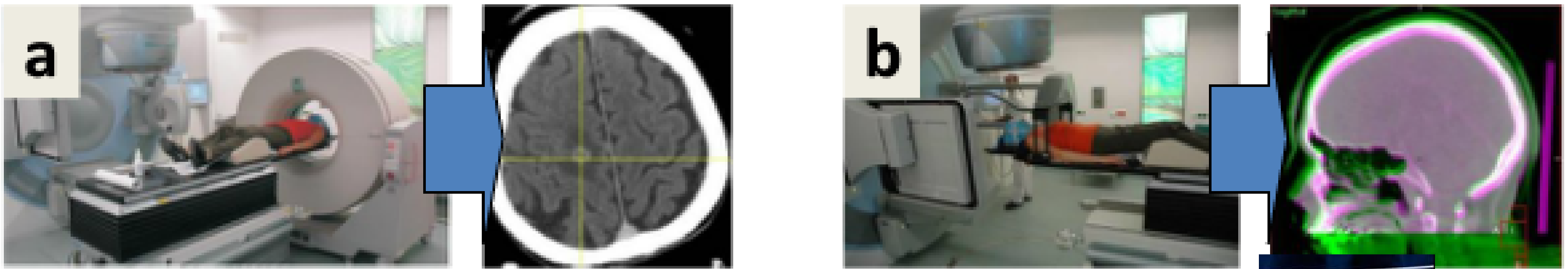
Internal motion of the intra cerebral tumor could be caused by

- Tumor progression
- Tumor shrinkage
- Changes of peritumoral edema

Set-up prior to treatment was verified based on the

a) position of the metastasis (soft tissue match): imaging using an in-room CT scanner after application of iv contrast

b) position of the bony anatomy (bone match): imaging using cone-beam CT



M. Guckenberger 2007

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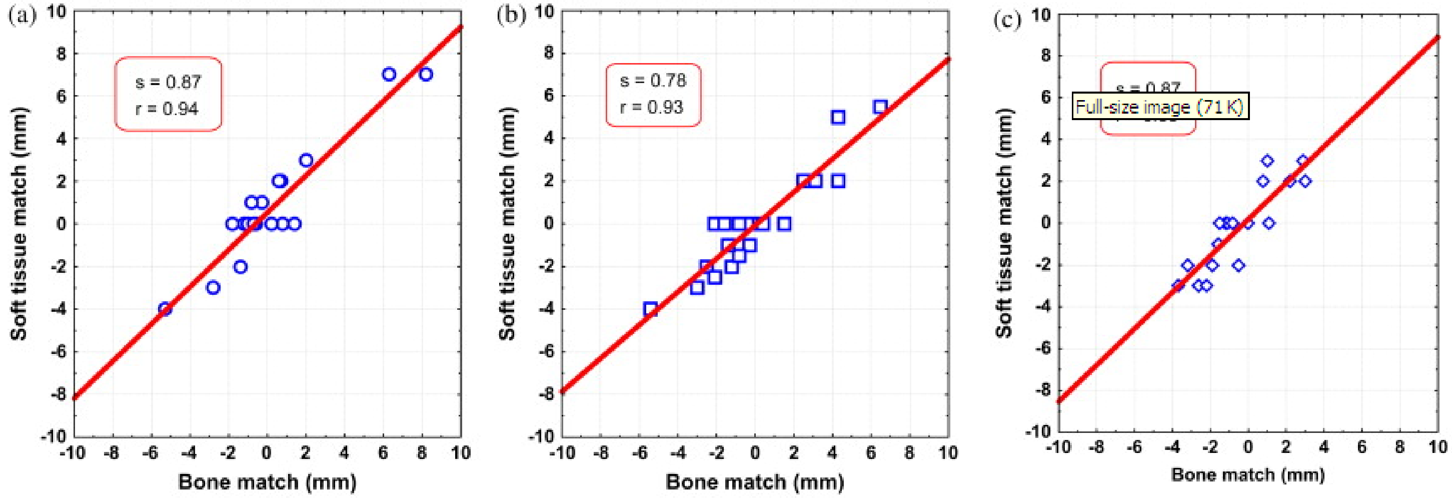
Image registration

→ Bony anatomy a good surrogate?

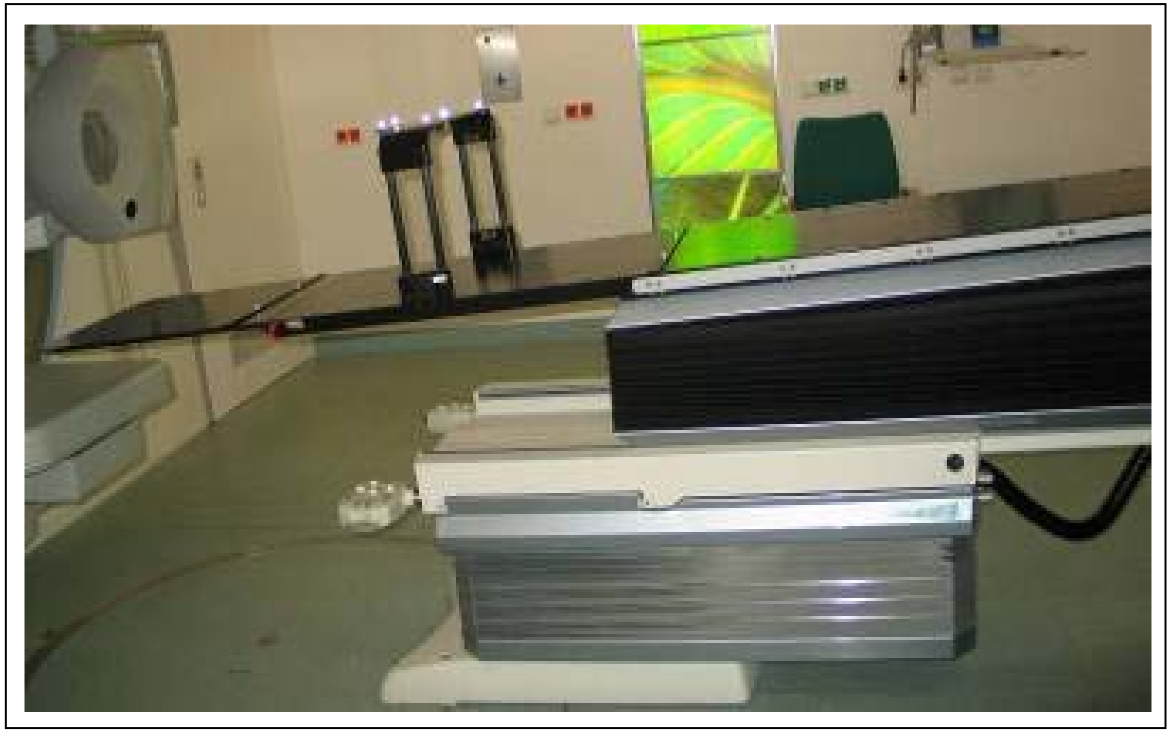


	Difference between bone match and tumor match (mm)		
	LR	SI	AP
Mean ± SD	-0.5 ± 1.0	0.1 ± 1.1	-0.2 ± 1.0
Maximum	1.8	2.3	2

M. Guckenberger 2007

Image registration

→ How well can we correct errors?



- Corrections up to 3°
- Target is often spherical

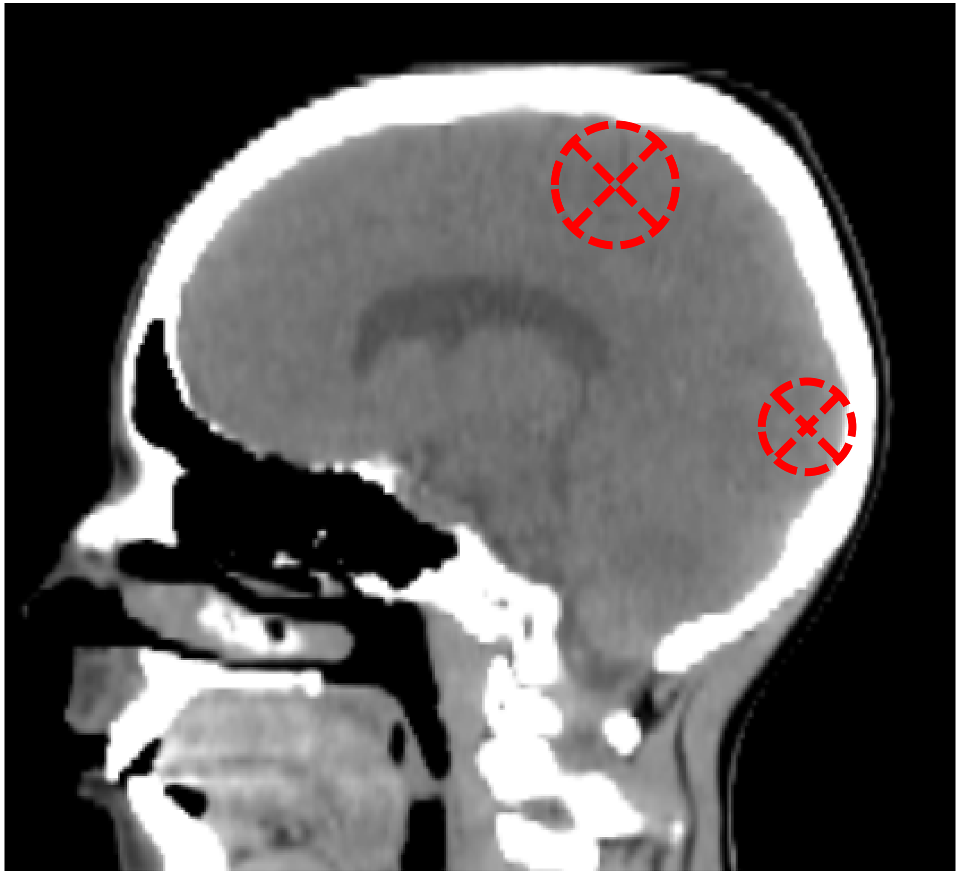
Residual errors after image guidance with CBCT and robotic couch:

< 0.3mm   <0.3°

Meyer 2008

Image registration

→ How well can we correct errors?

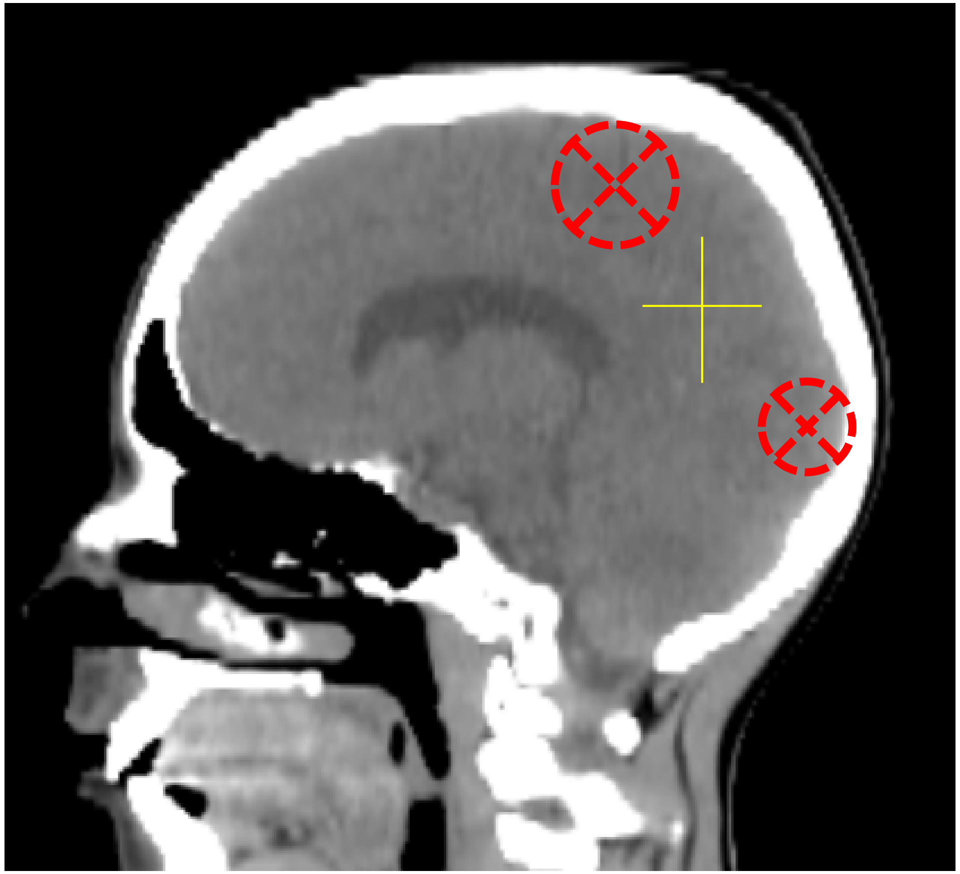


When multiple targets:

Rotations become important!

Image registration

→ How well can we correct errors?



When multiple targets:

Rotations become important!

Use limit on rotations !

Correcting Patient position
→ How stable is a mask?

Study	Immobilisation system	Imaging modality	Position error
Boda Heggeman 2006	Thermoplastic mask	CBCT	1.8mm ± 0.7mm1.3mm
	Scotsch cast mask		1.3mm ± 1.4mm
Masi 2008	Thermoplasic mask & Bite block	CBCT	<1.0mm
	Bite block		<1.0mm
Lamda 2009	BrainLab mask	2D kV images	0.5mm ± 0.3mm
Ramakrishna 2010	BrainLab mask	2D kV images	0.7mm ± 0.5mm
Guckenberger 2007	Scotsch cast mask	CBCT	0.8mm ± 0.4mm
	Thermoplastic mask		0.8mm ± 0.5mm

Courtesy M. Guckenberger, ESTRO IGRT course

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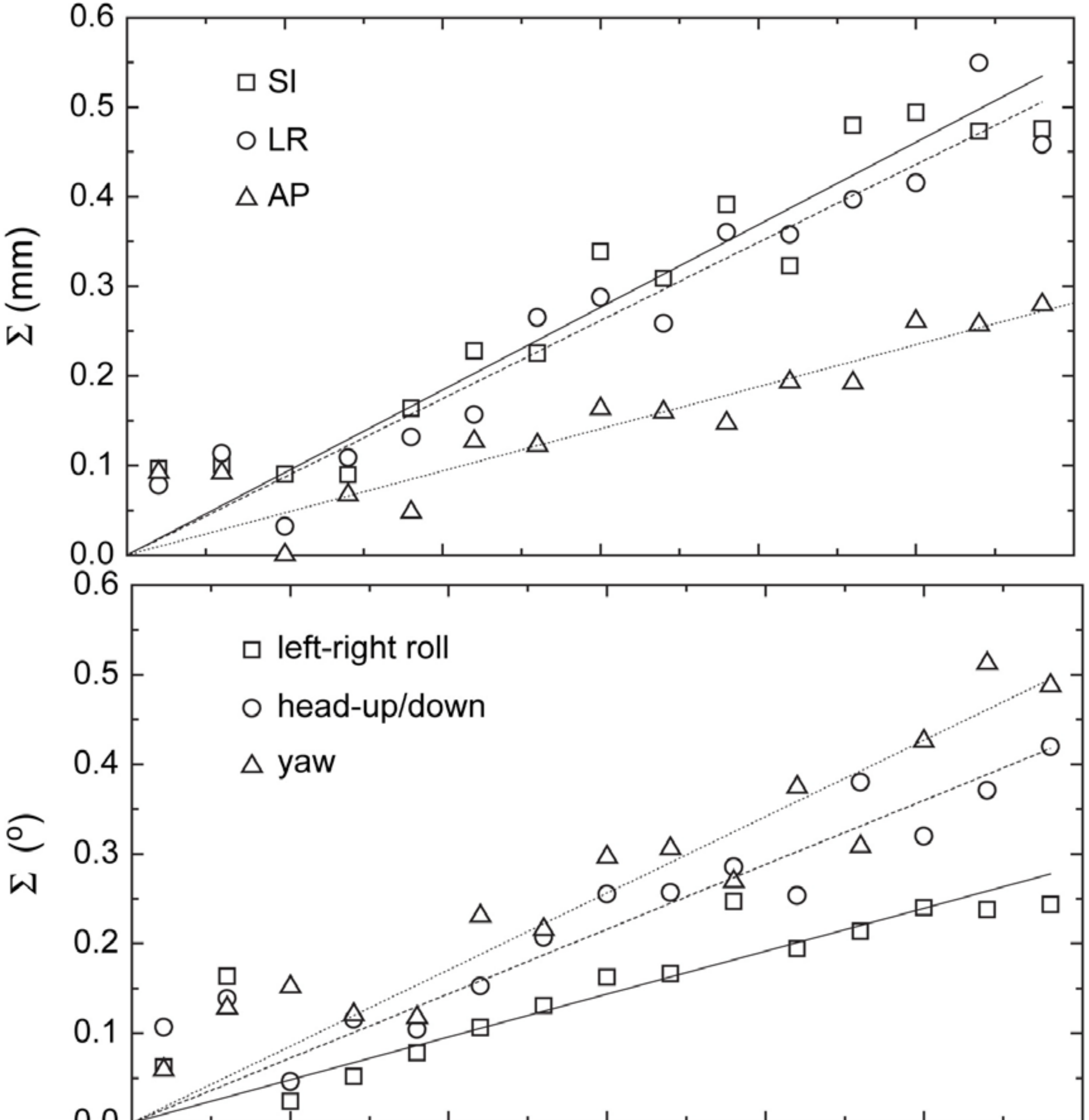
Correcting Patient position
→ How stable is a mask?



- 32 intracranial patients
- Cyberknife @ Rotterdam
- immobilized with a thermoplastic mask

Keep total treatment time as short as possible!

[redacted]ogeman 2008

Margins for small leasions hypo fractionated

Adding up some/al the errors:

Delineation uncertainty	2 mm
Residual set up error after imaging (2D or 3D)	
• bone registration	0.5 mm
• soft tissue changes	0.6 mm
Intrafraction motion	0.6 mm

PTV margin = $2.5\,\Sigma + 0.7\,\sigma$

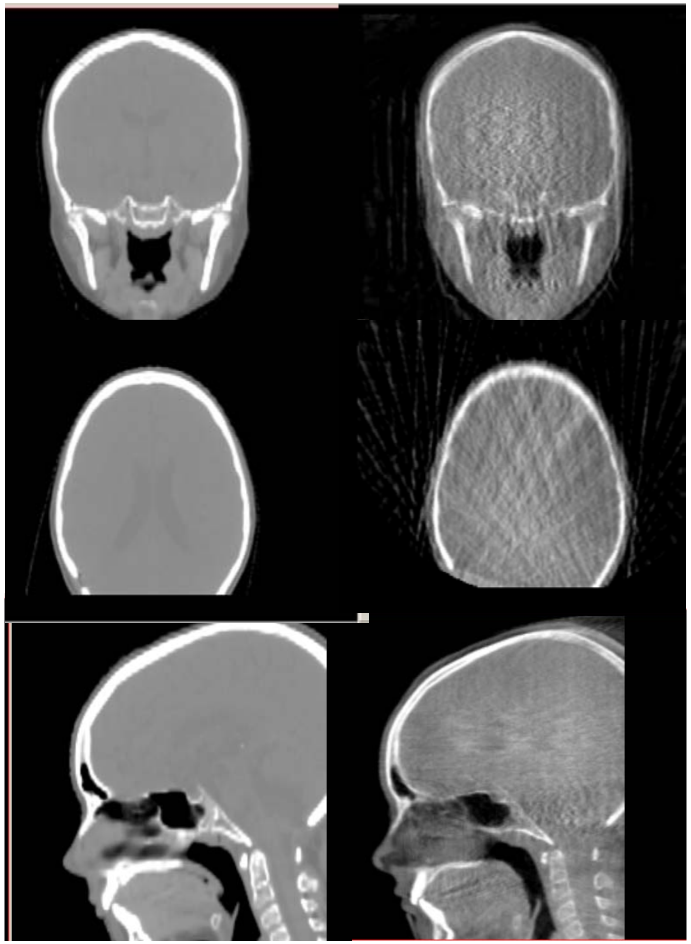
→ ***1mm margin/ 0mm margin??***

Literature show excellent local controle!

Imaging dose

→ Can we reduce dose for children?

100%, (0.5rpm)　　8%



Lowest exposure settings @XVI

10ms & 10mA

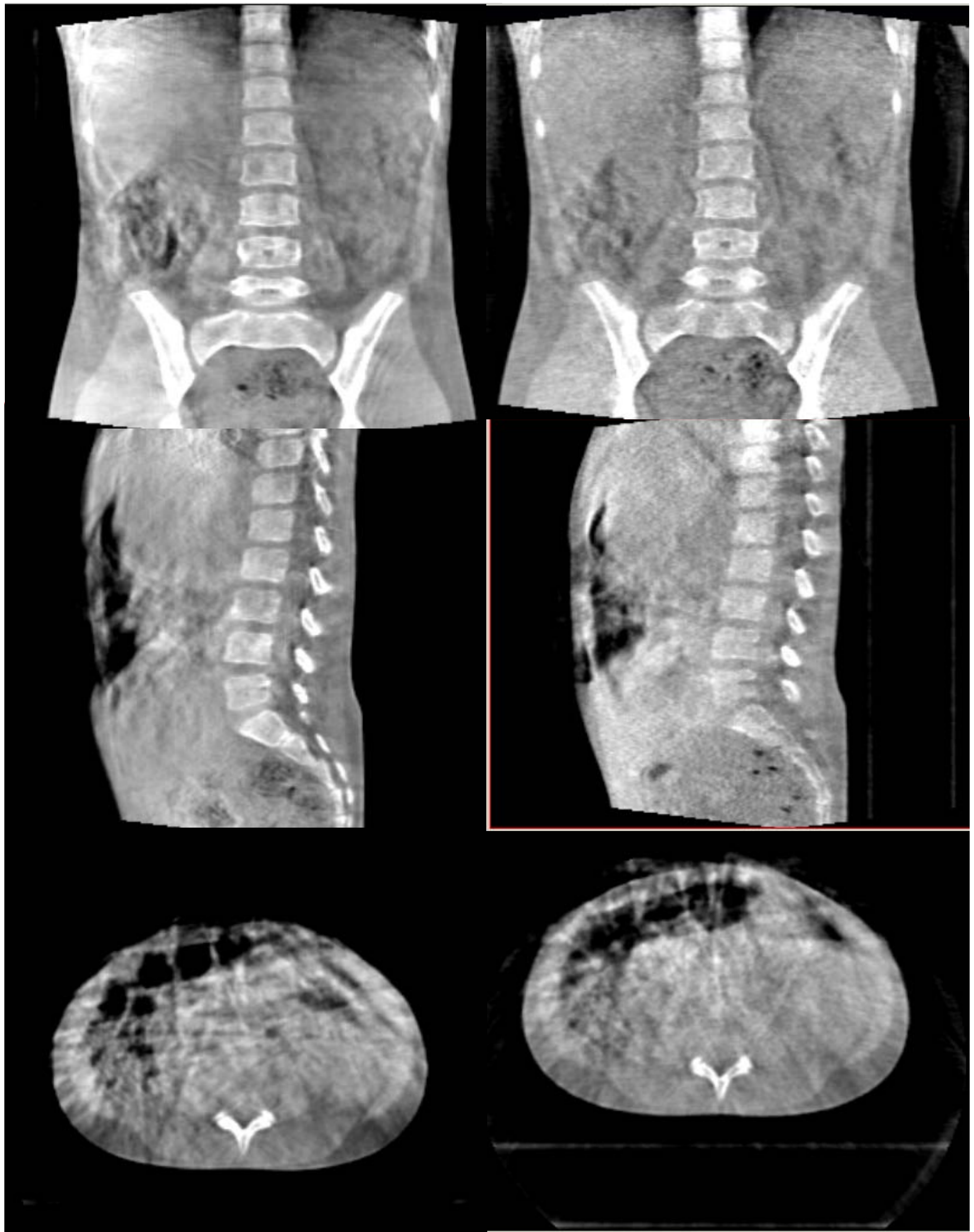
Using 'slice averaging' for display

	maximum deviation in outcome of registration			
	bony algorithm		grey value algorithm	
	translations (cm)	rotations (°)	translations (cm)	rotations (°)
skull	0.03	0.2	0.05	0.6
thoracic region	0.03	0.4	0.03	0.5
lumbar region	0.02	0.4	0.03	0.5

Imaging dose

→ Can we reduce dose for children?

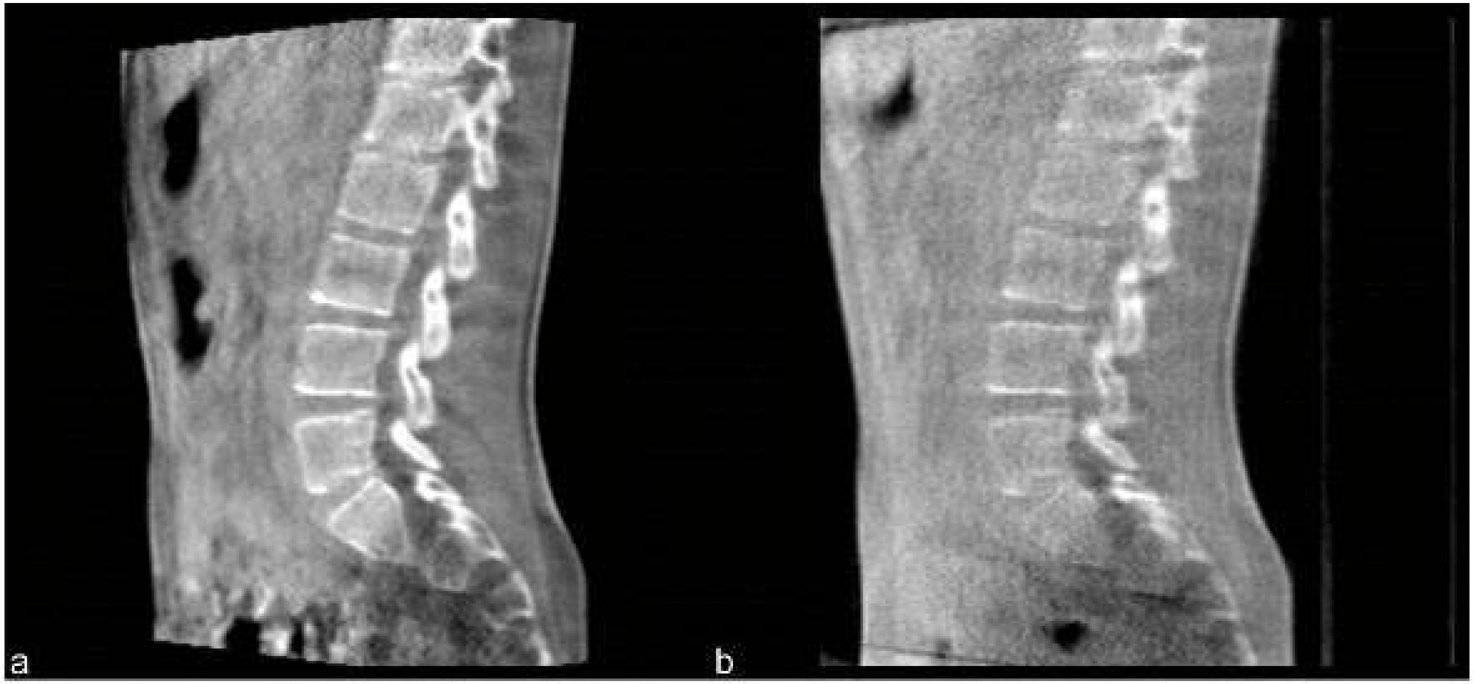
Adult exposure
40ms, 32mA



Kids exposure
10ms, 10mA

Imaging dose

→ Can we reduce dose for children?



40ms, 32mA, 0.5 rpm
Display using slice averaging

10ms, 10mA, 1.0 rpm
Display using slice averaging

5%

Rigshospitalet

Deep inspiration breath hold in thoracic tumours: imaging and treatment

Marianne C Aznar

Dept. of Radiation Oncology

With the help of the Dept. of Clinical Physiology, Nuclear Medicine and PET

Copenhagen University

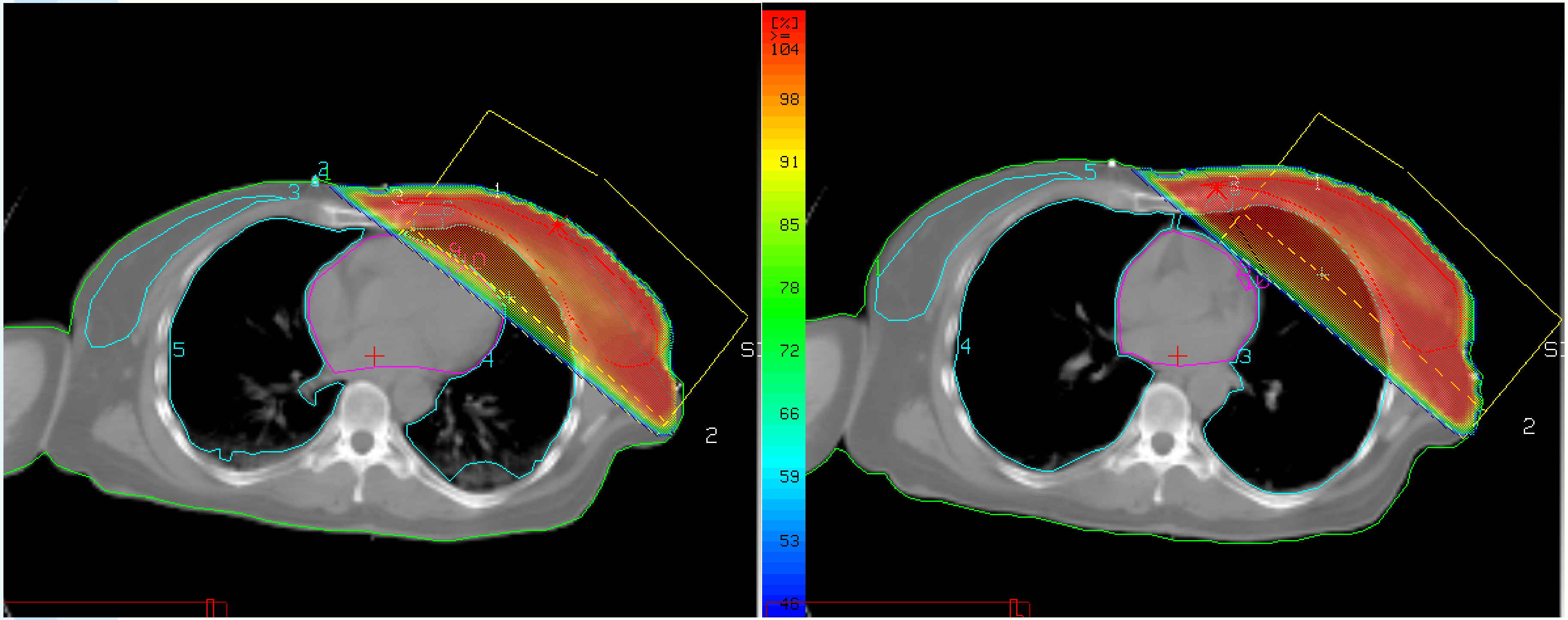
REGION H

LYMPHOMA: A SPECIAL CASE

Rigshospitalet

At Rigshospitalet

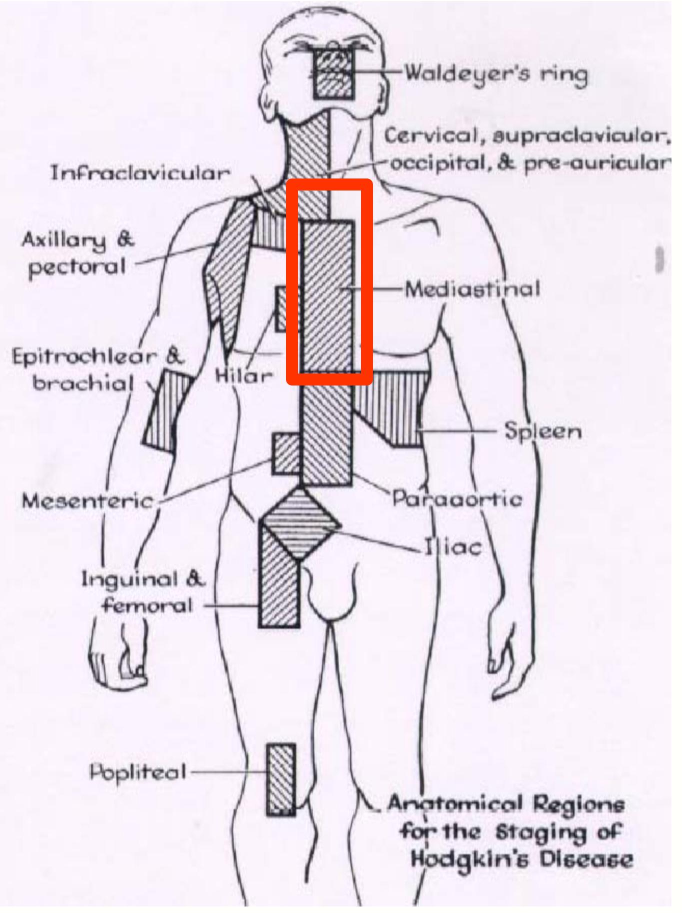
- Deep inspiration treatment since 2003 in left-sided breast cancer patients
- > 1000 patients



Hodgkin lymphoma

- Ca 130 cases/year in Denmark
- Excellent prognosis in the early stages

- Often young adults (20-30 y)
- High risk of radiation-related side-effects (cardiovascular toxicity, secondary lung cancer)



Methods

- Prospective phase II trial
- 22 patients
- <u>All</u> images in DIBH

Staging PET/CT

Chemotherapy (4-8 cycles)

Planning CT or PET/CT

Verification images at the linac

2-3 months

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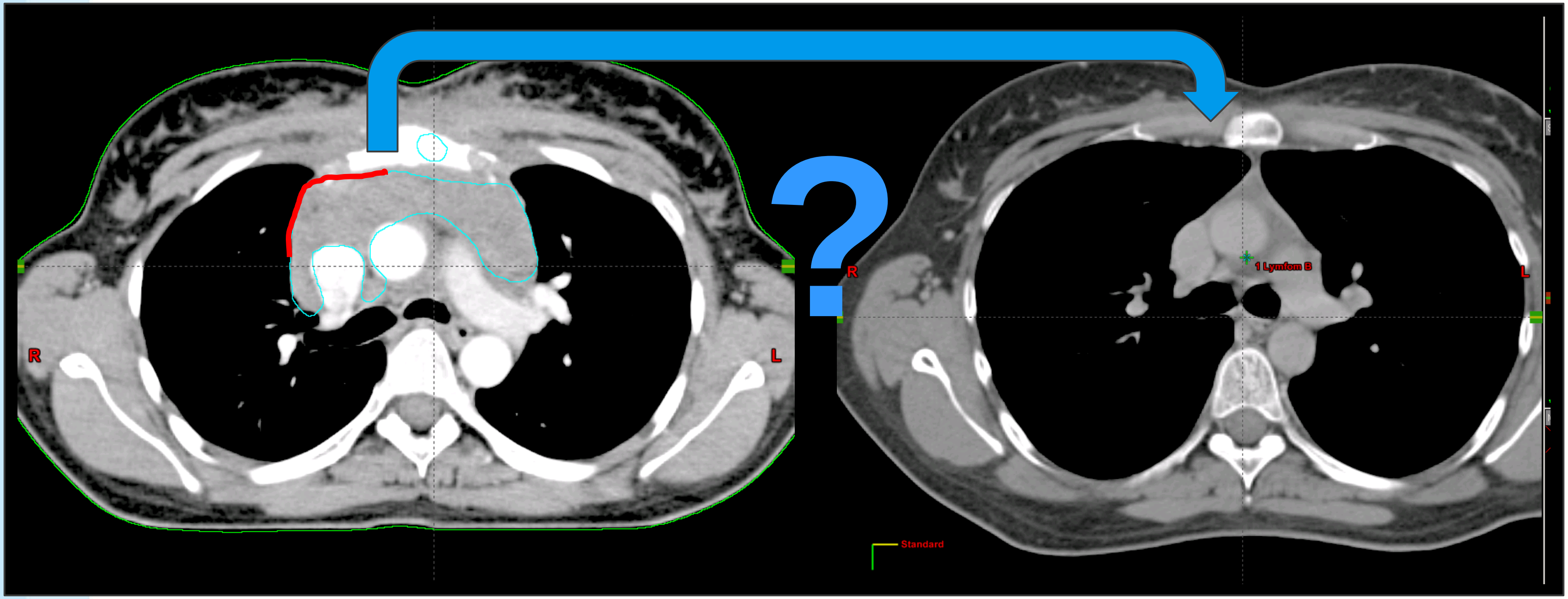
Fusing prechemo and planning images

Pre-chemo PET/CT

free breathing

Planning CT

at deep inspiration



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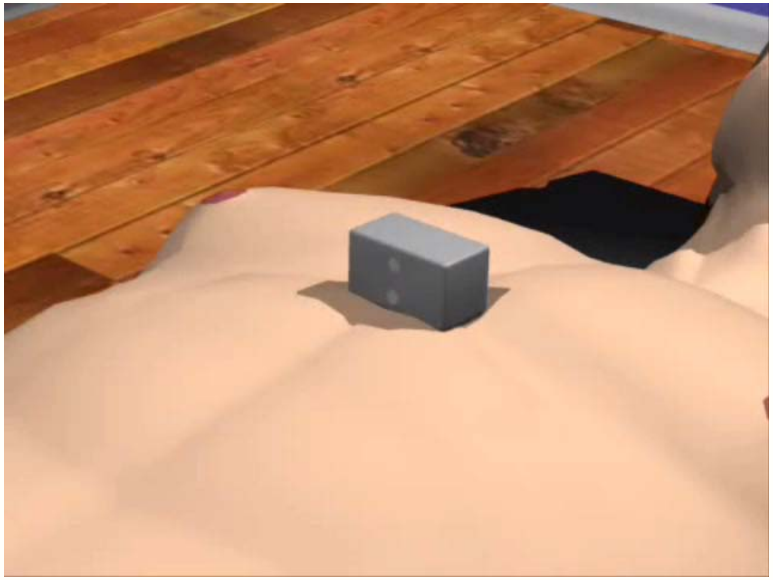
How to handle registration uncertainties ?

- Ensure a treatment-like position already at staging
  - Flat table top
  - Arms up
  - Chest board

- Provide DIBH PET/CT at staging

- All these take time, logistic effort, and a good collaboration with the PET department!

Respiration monitoring



<u>Varian RPM system:</u>
Deep inspiration breath hold
Gating
4D CT

On all linacs and scanners

Rigshospitalet

CT + PET/CT

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Visual guidance:
- Scanner
- linac

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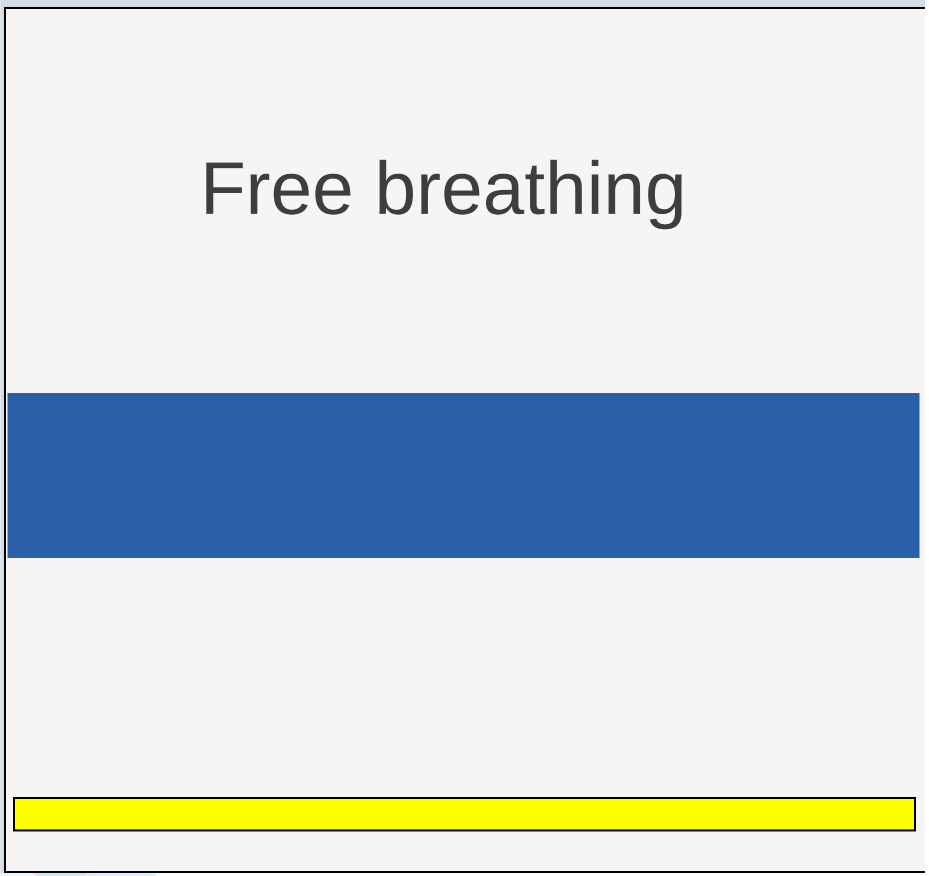

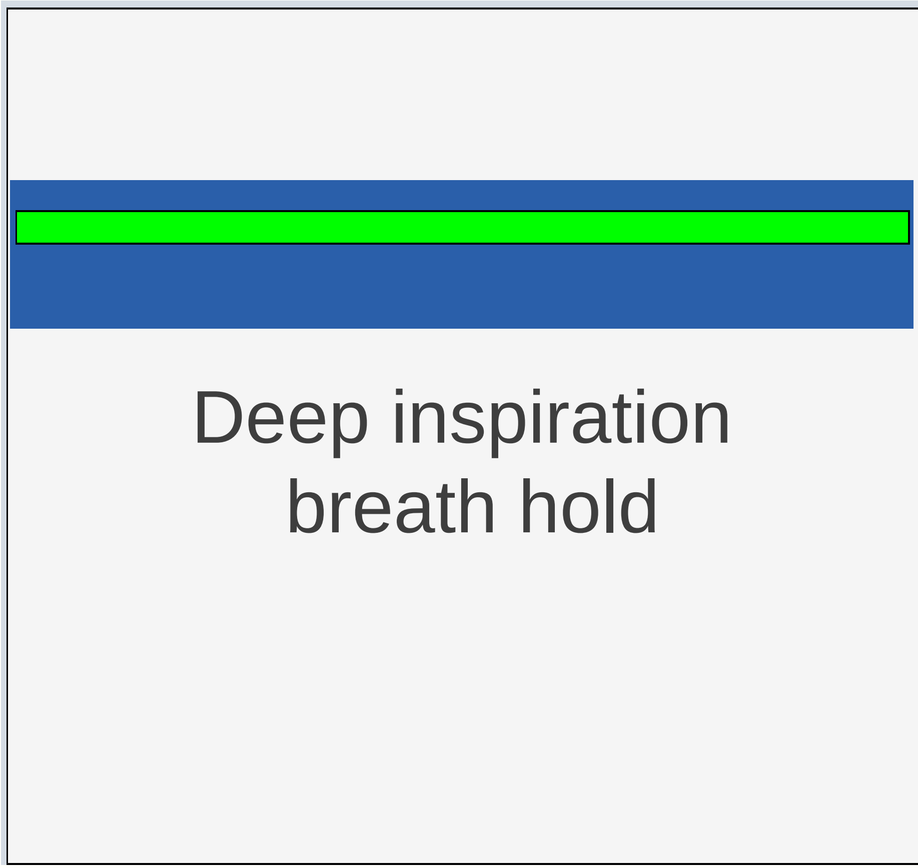

Take home message (1)

- Keep patient instruction and information as simple as possible
- Coach before scanning (30 min) or directly at the scanner (5-10 min): equivalent results !!
- Extra time necessary at the scanner (install equipement, etc… plus extra acquisition) : 15-30 min
- Good communication with PET extremely valuable !

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PET/CT acquisition in practice

- Pre chemo scan: *400 MBq* FDG on Siemens Biograph 40 PET/CT

- Free breathing scan followed by one FOV scan in breath hold

- 3 breath holds of 20 seconds each

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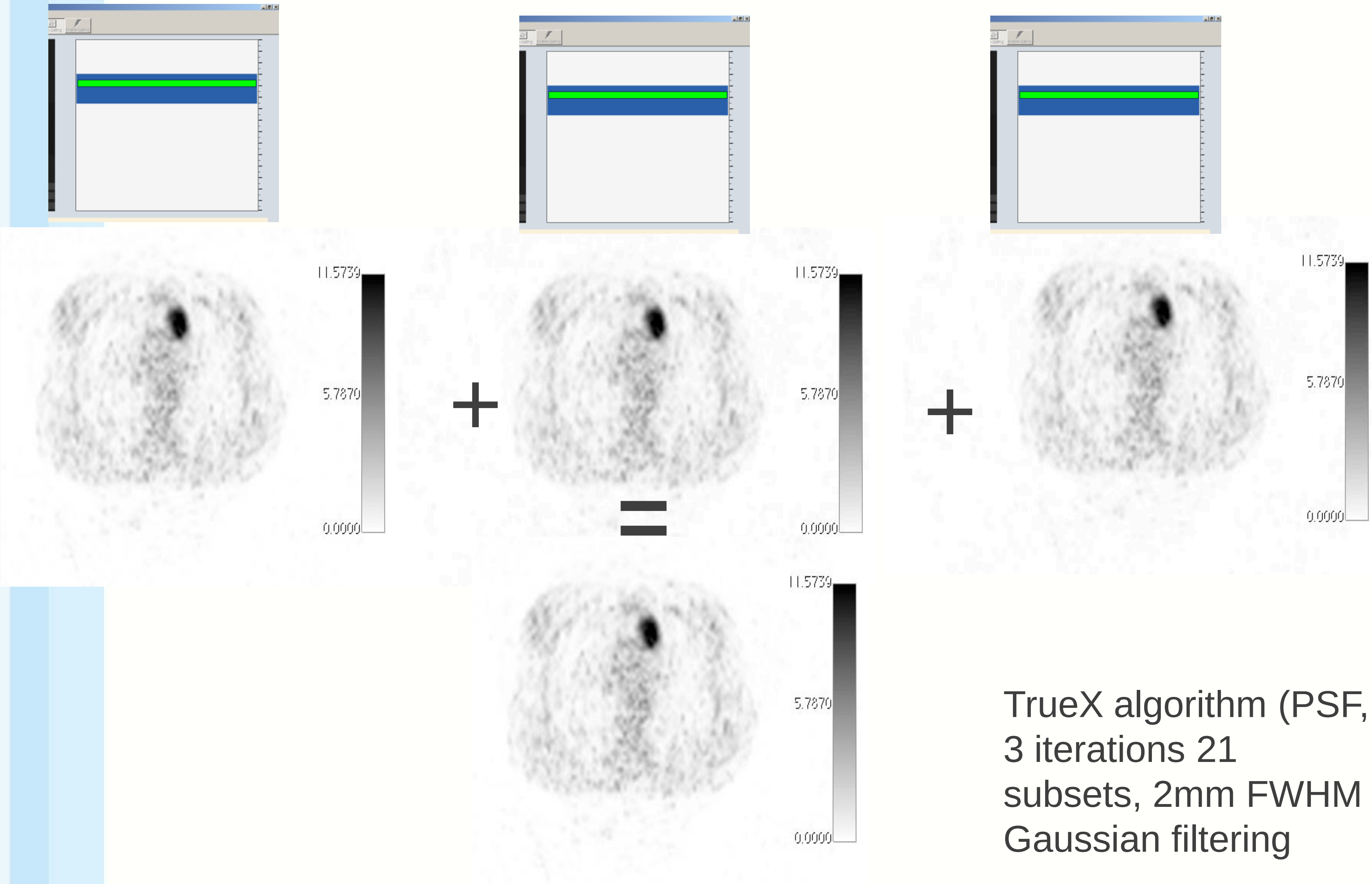
Methods: Image reconstruction



TrueX algorithm (PSF, 3 iterations 21 subsets, 2mm FWHM Gaussian filtering

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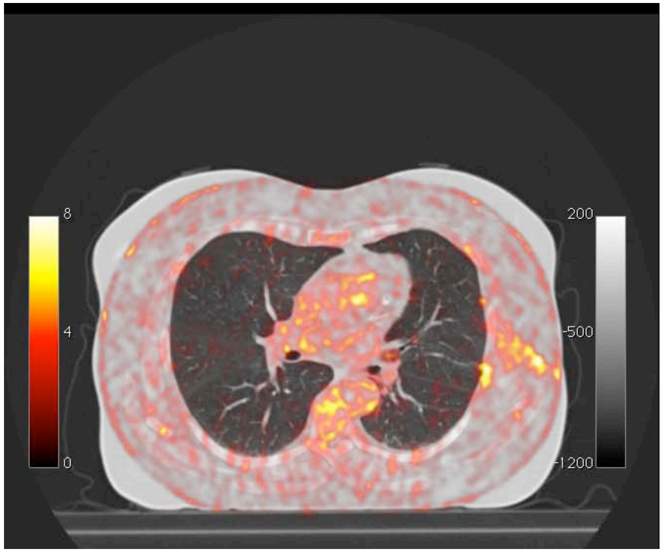
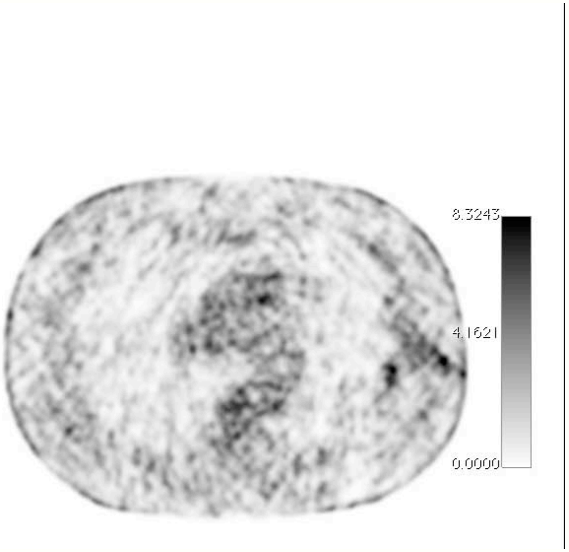
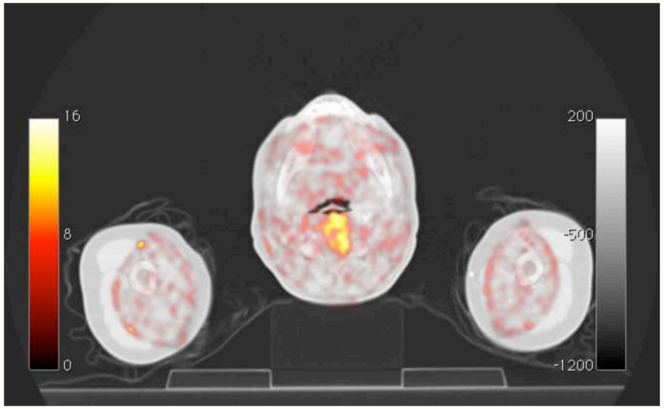
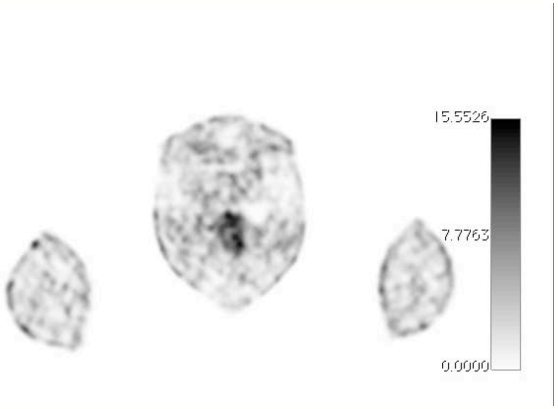
Some problems at start-up !!









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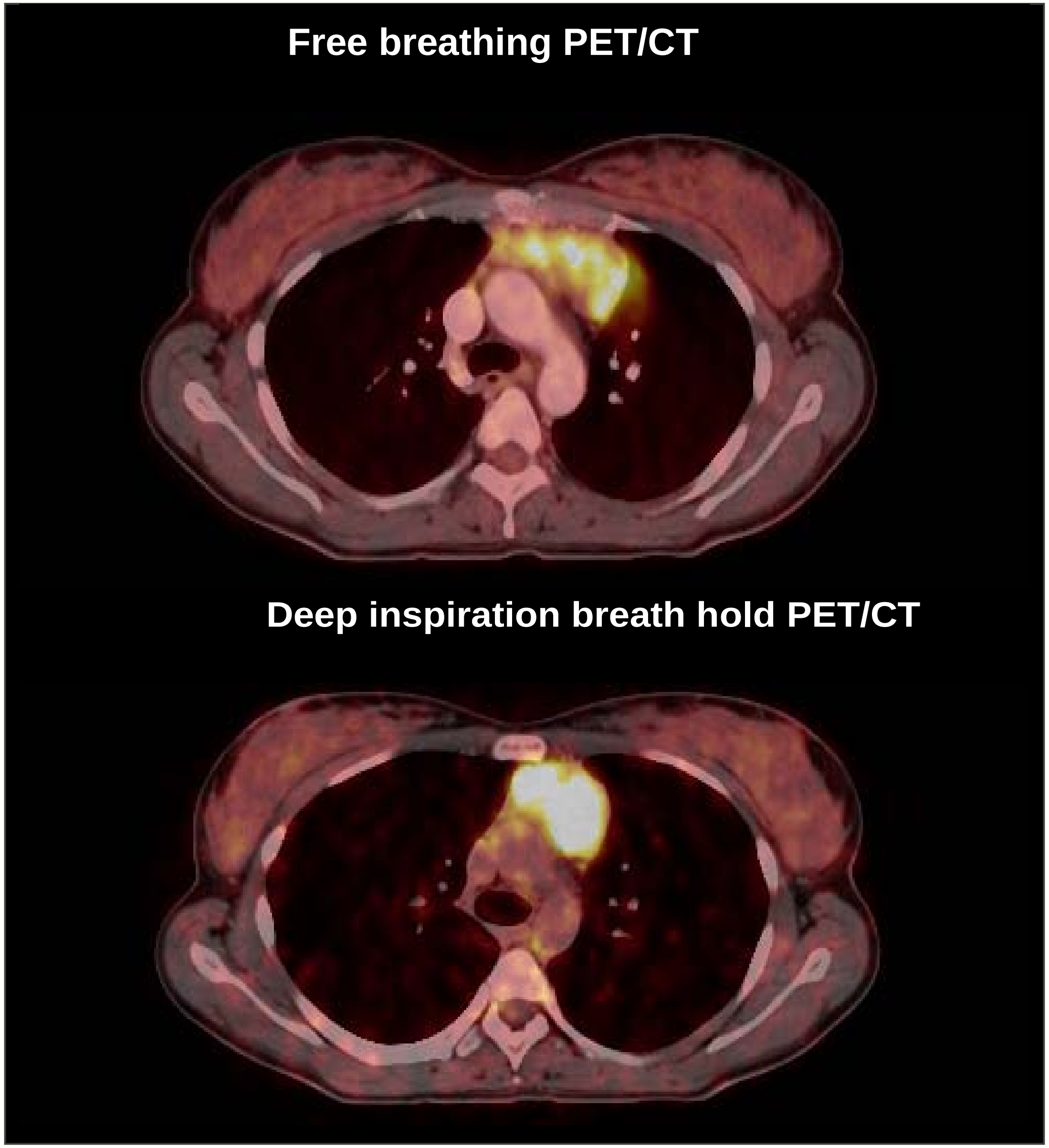
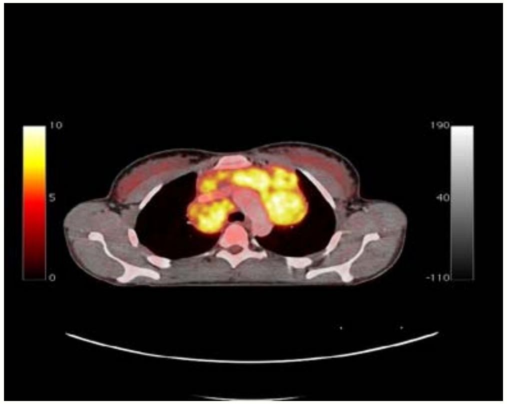
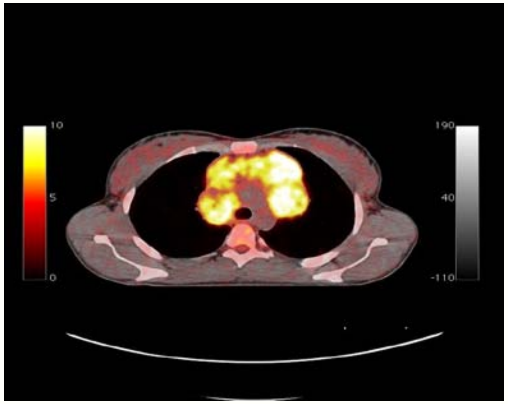
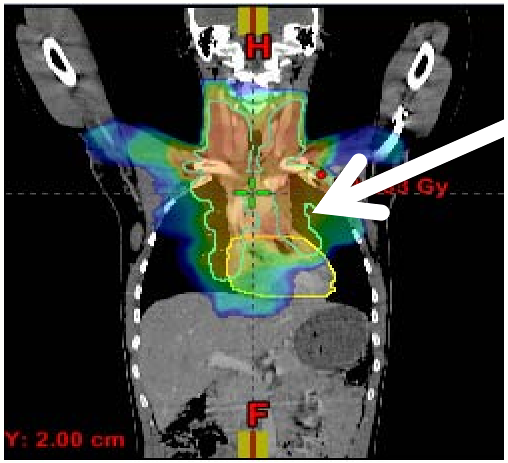
Results: reduced respiration artifacts

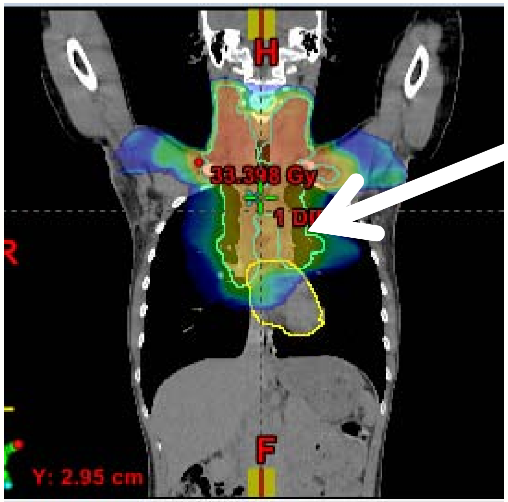


Mediastinal lymphoma
Free breathing vs. inspiration breath hold









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Breath hold decreases the exposure of healthy tissues

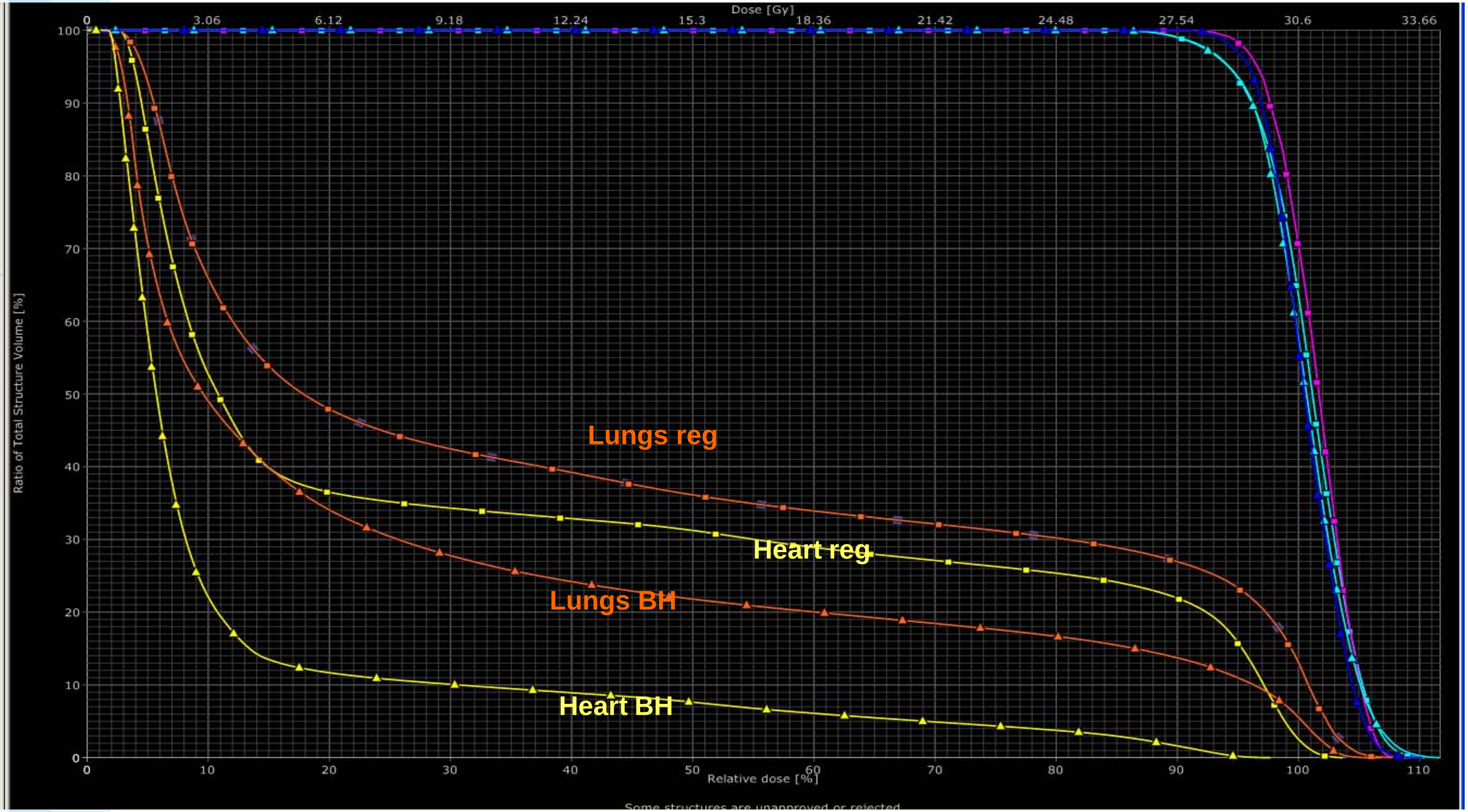
- Free breathing

- Deep inspiration breath-hold

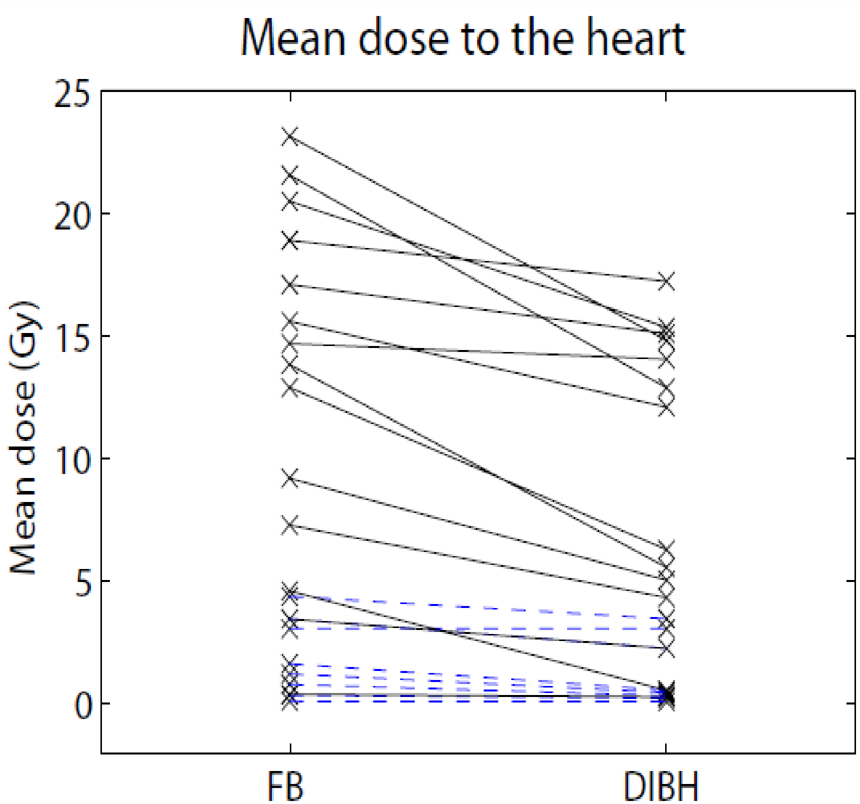
Notice lung volume and heart position

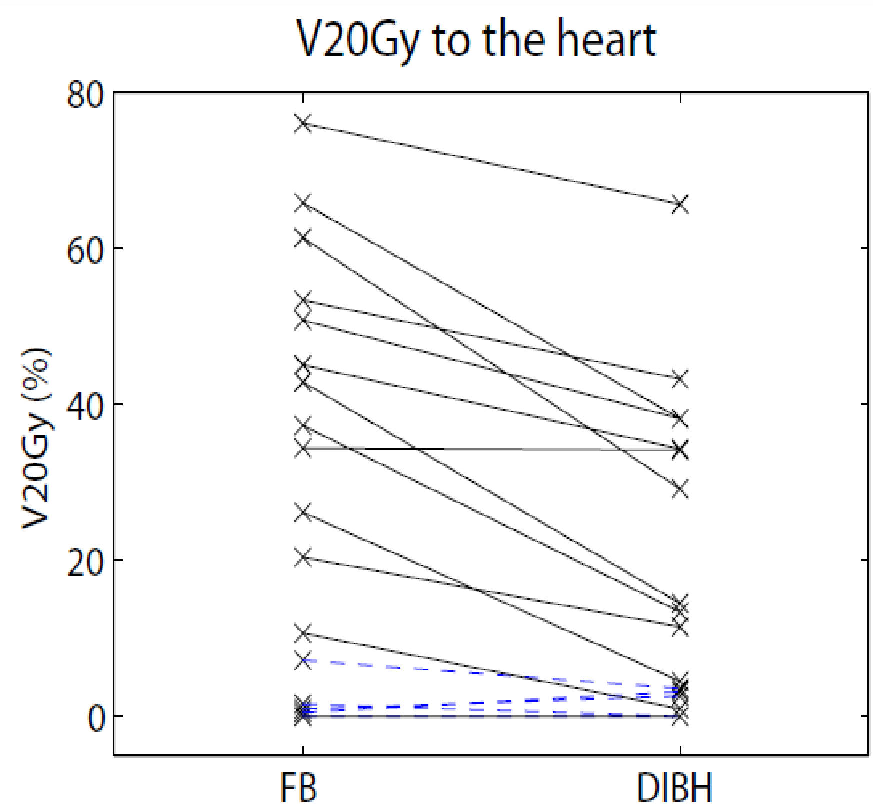
Rigshospitalet

Mean dose to lungs: 8.5Gy vs 12.8 Gy



Benefit: inter-patient variation

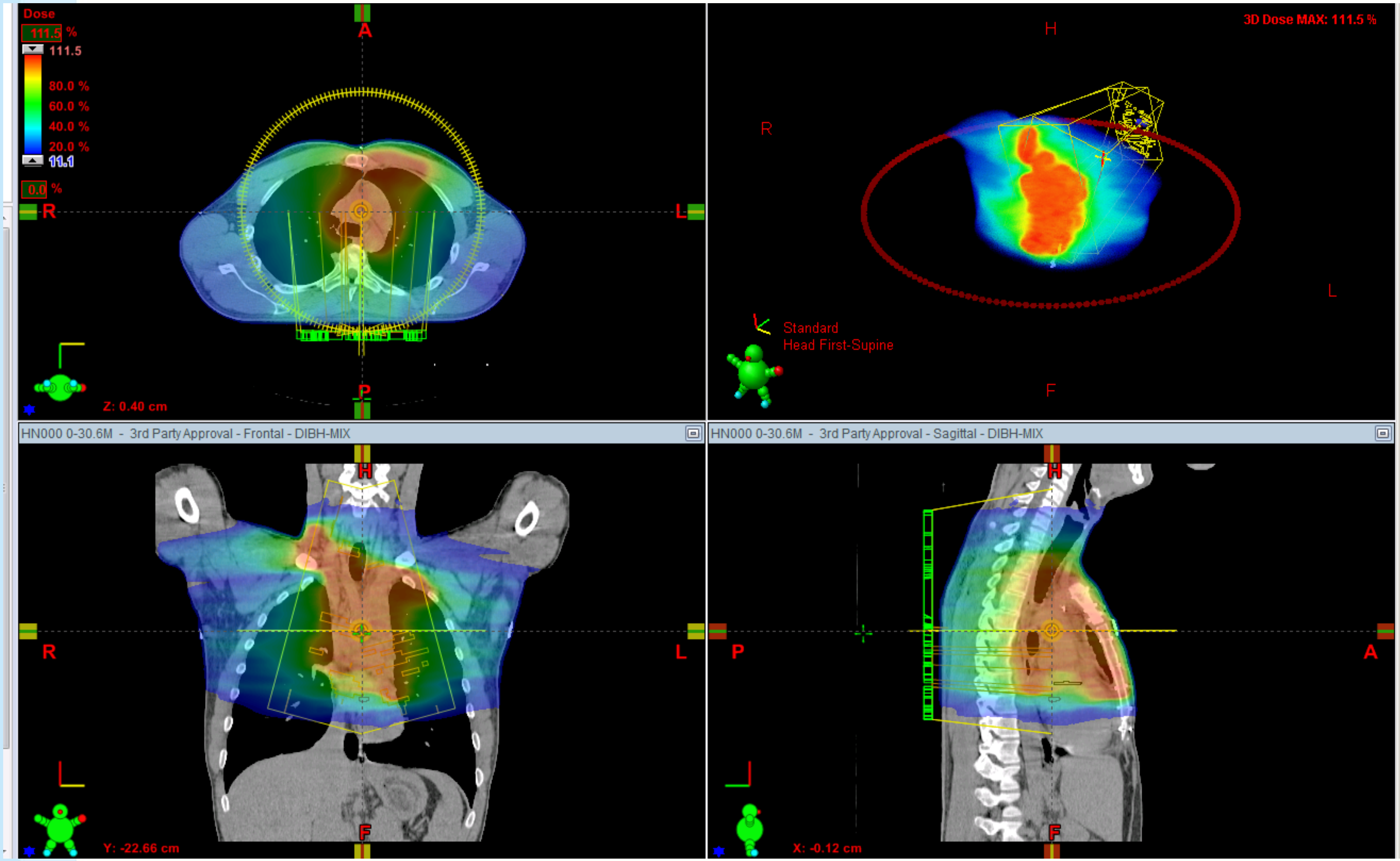




REGION

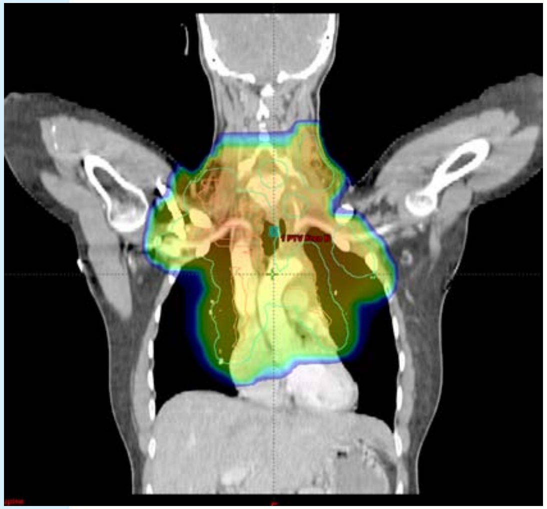
RPM integrated with linac
Beam switches on and off automatically

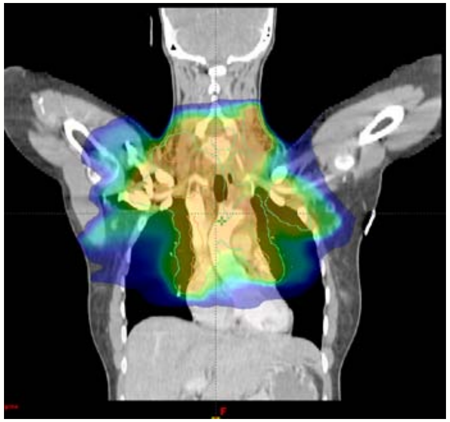
DIBH + VMAT/IMRT



What to choose: IMRT? DIBH or both?

- Free breathing (AP-PA)





•Intensity-modulated radiation therapy

NB: dose bath

- Deep inspiration breath-hold (AP-PA)

NB: lung and heart position

Conclusions DIBH vs IMRT

DIBH-3D was more effective to reduce heart and lung dose
IMRT tended to give a higher mean dose to the breasts

First choice: 3D-DIBH for young women, then IMRT only if the heart dose needs to be further reduced
Men: DIBH+IMRT could be a standard solution

Petersen et al Acta Oncologica 2015
Aznar at al IJROBP 2015

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Take home message (2): treatment planning

- Having the staging PET/CT in DIBH increased our physicians' confidence
- The dosimetric benefit was clear enough to make DIBH our standard treatment for HL
- However, we still acquire a free breathing planning CT on top of the DIBH planning CT
- Tendency to combine DIBH with VMAT

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IGRT

POSITION VERIFICATION IN DIBH

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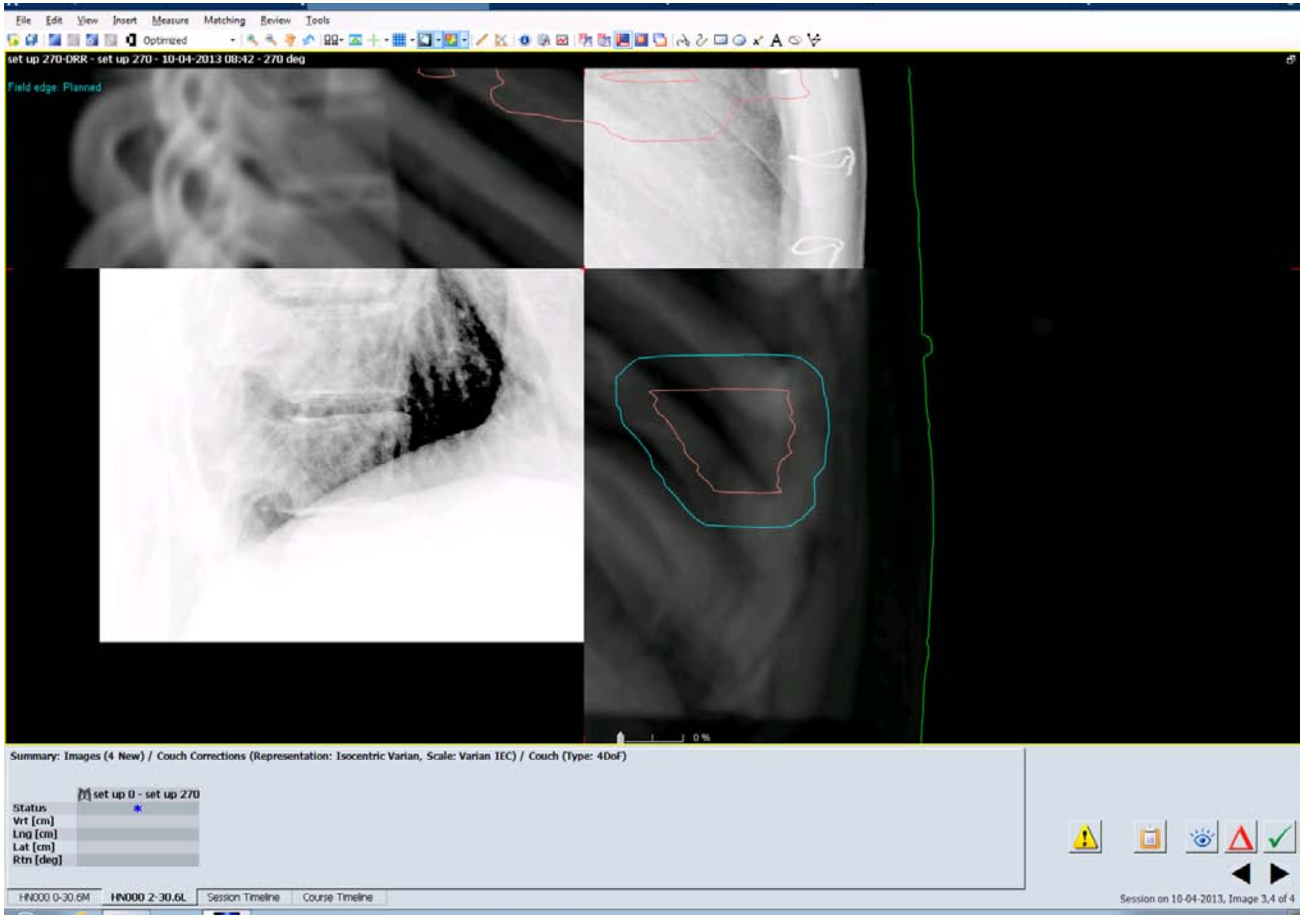
Daily 2D images: fuse on spine, check sternum



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Can check heart position and lung inflation

Some challenges with CBCT in DIBH

- Requires 2-3 additional breath holds
  - But remember: young/fit patients

- Manually operated

- Some resistance to introduce it as a daily modality !

Some possible compromises…

- Daily 2D DIBH images
- Daily 2D DIBH images + weekly DIBH CBCT (with/without a physicist present)
- Daily DIBH CBCT with a longer treatment slot

A note about margins…

- In free breathing: 1cm, 1.5 cm sup-inf

- In DIBH: 1 cm all around ?

- A study of interfraction variation demonstrated that margins could NOT be reduced with DIBH
  - Back to 1cm, 1.5 cm sup-inf

Take home message (3): treatment delivery

- Patient compliance is excellent
- DIBH CBCT is possible, but there is a learning curve

Conclusion

- DIBH implementation in lymphoma very succesful
- Protocol in lung cancer patients ongoing

- Clear dosimetric benefit, even when using VMAT/IMRT

- Ressource investment: the ”sore points” are
  - PET scanning time
  - IGRT
  - And even then, they remain very manageable !

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Acknowledgments

Department of radiation therapy, especially:

- Peter Meidahl Pedersen
- Maja Maraldo
- Lena Specht
- Ivan Vogelius
- Mirjana Josipovic
- Sidsel Damkjær
- Deborah Schut
- Patrik Brodin
- Gitte Persson

Department of Clinical Physiology Nuclear Medicine and PET, especially:

- Flemming Andersen
- Annika Loft
- Anne Kiil Berthelsen
- Thomas Levin Klausen
- Marianne Federspiel

REGION H Rigshospitalet

Keep breathing ☺

Quiet free breathing

Implementation of new protocols

Martijn Kamphuis MSc
Research Radiation Therapist IGRT

Department of Radiotherapy @AMC
Amsterdam, the Netherlands

ESTRO School

The Aim of the presentation

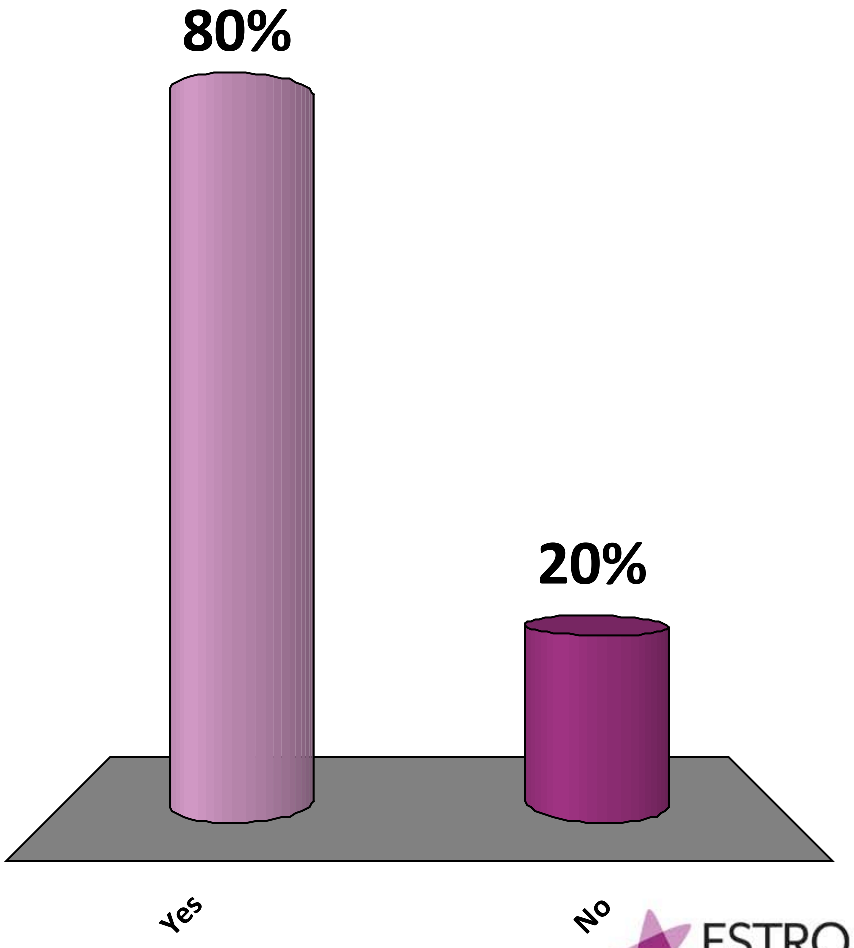
- Describing the process of implementing new technology and protocols
  - ➢ Illustrated with different examples

- Sharing experience, tips and tricks

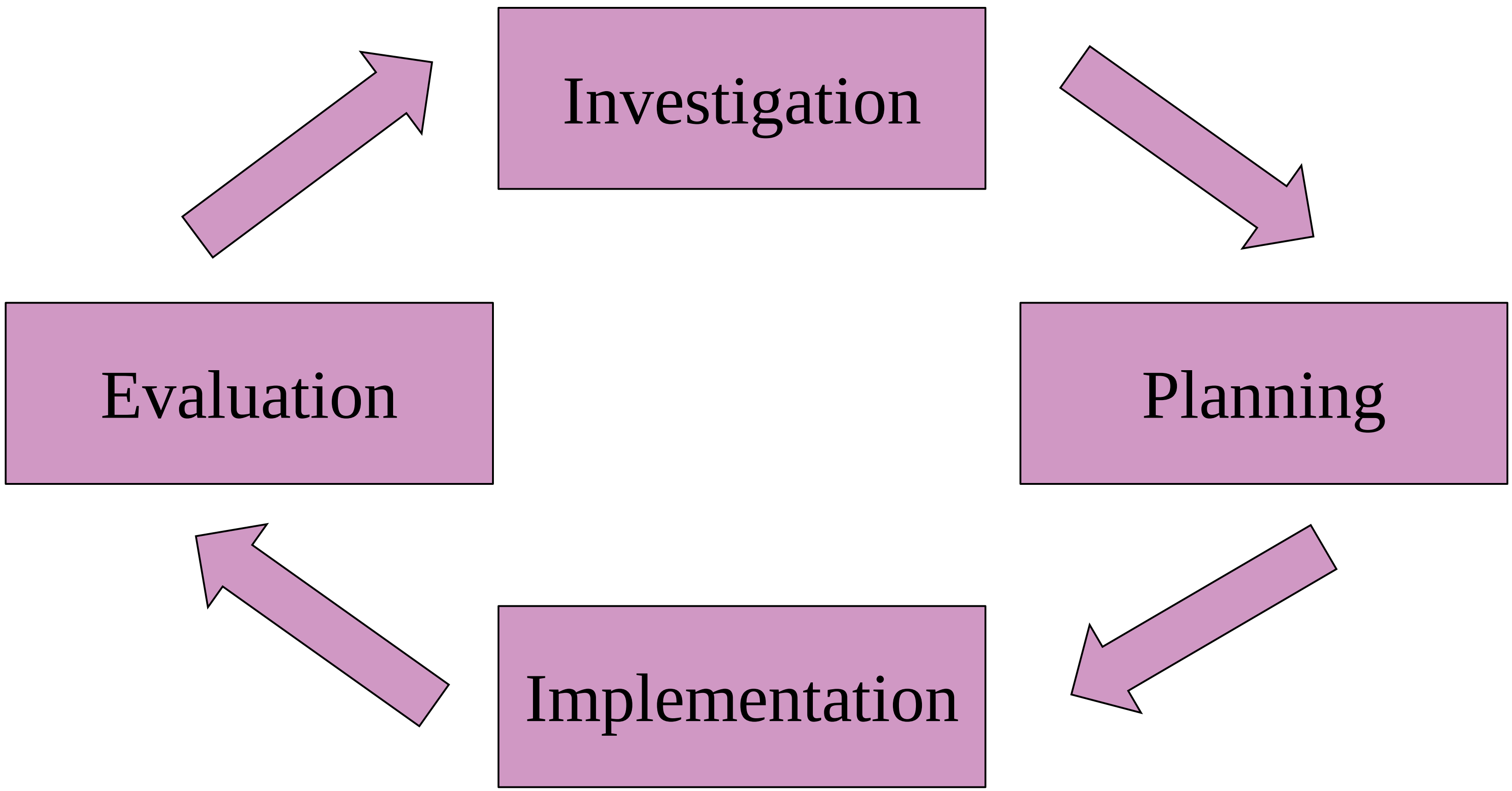
Have you ever been involved in clinical implementations of new protocols?

A. Yes

B. No



Protocol implementation



Preparation phase

- Defining your goal, make sure it's clear
  - E.g. Implementing hypofractioned radiotherapy in your department for stage one and two lung cancer
  - Implementing adaptive radiotherapy for bladder cancer using a library of plans

- Creating a multidisciplinary team
  - Include all stakeholders that will get involved
    - Not only MD, physicist and RTT, but also manager, technicians
  - Define roles of individual team members
    - Who is doing what?

Preparation phase: Investigate!

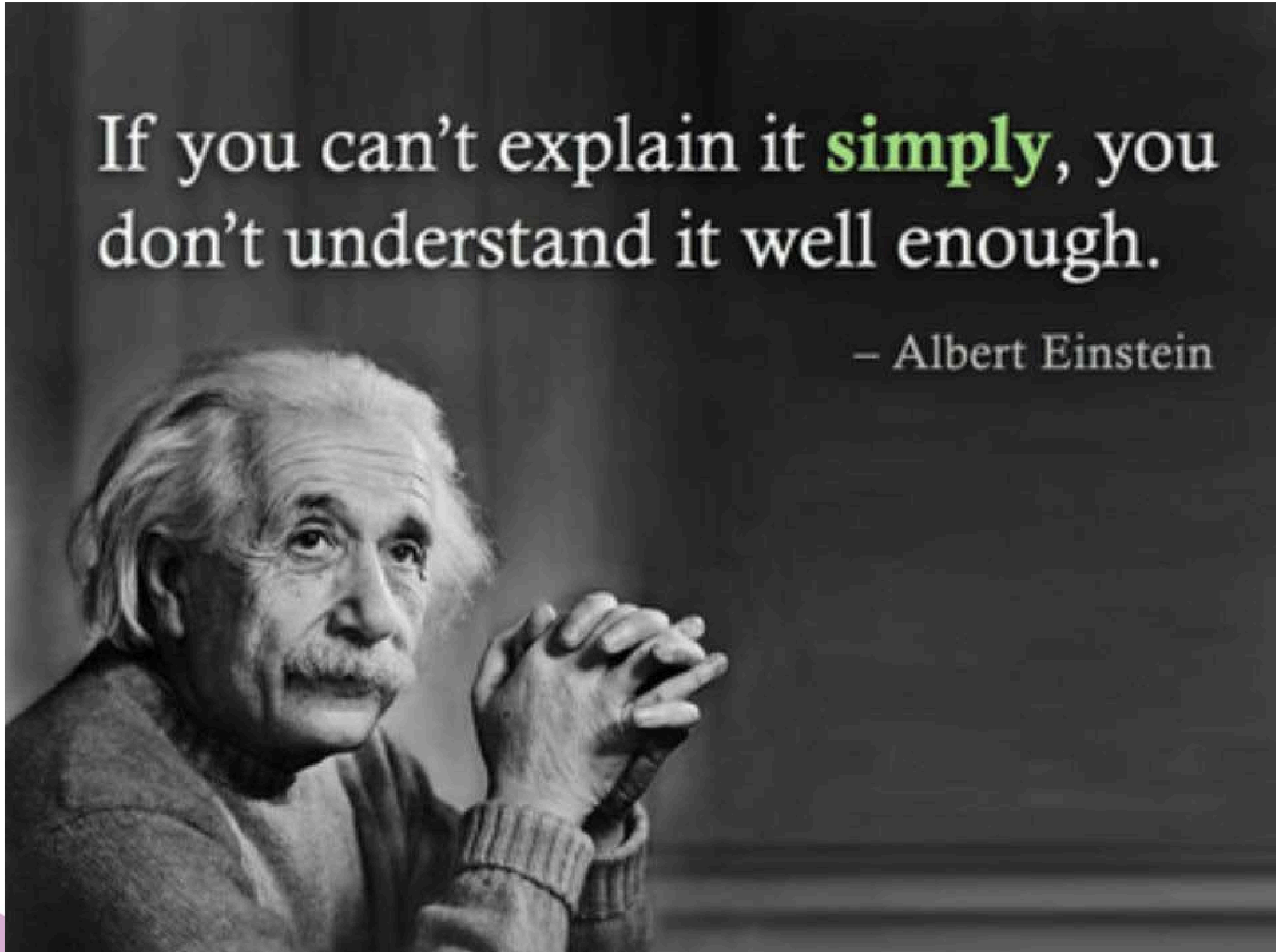
- Literature reading
  - ➢ Articles
  - ➢ Guidelines e.g. AAPM

- Join trails if possible

- Visit other institutes:
  - ➢ Learn from other ones' experience (and then do it better ☺)

- Follow vendor trainings/courses/workshops

- ESTRO
  - ➢ (Live) Courses
  - ➢ Dove (www.estro.org)
  - ➢ Technology transfer grant


If you can't explain it simply, you don't understand it well enough.
– Albert Einstein

Planning/protocol writing phase

- Organize multiple meetings to discus the protocol
  - Come to a shared vision

- Write a project plan/protocol
  - Define all tasks and responsibilities
  - Check weather task can be performed parallel
  - Create a timeline
    - Start from the deadline ☺
    - Decisions have to been made, sooner or later

- Prospective Risk Analyses
  - Helps to think ahead

Implementation Phase

Critical conditions for proper implementation

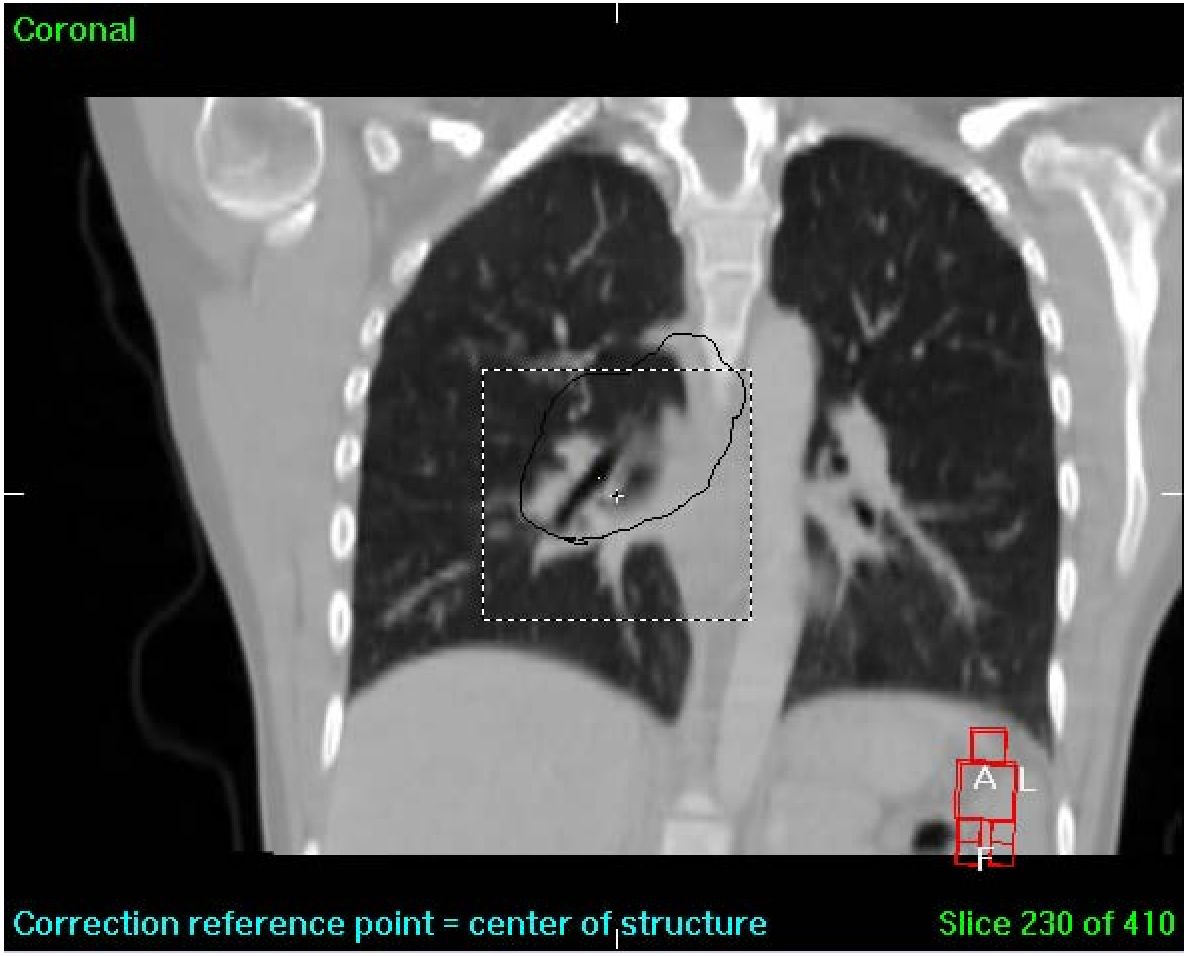
- Treatment protocol should be:
  - ➢ Well described and well defined task
  - ➢ Approved by staff
  - ➢ Available for everyone

Well described and well defined tasks

Example: protocol for dealing with anatomical changes

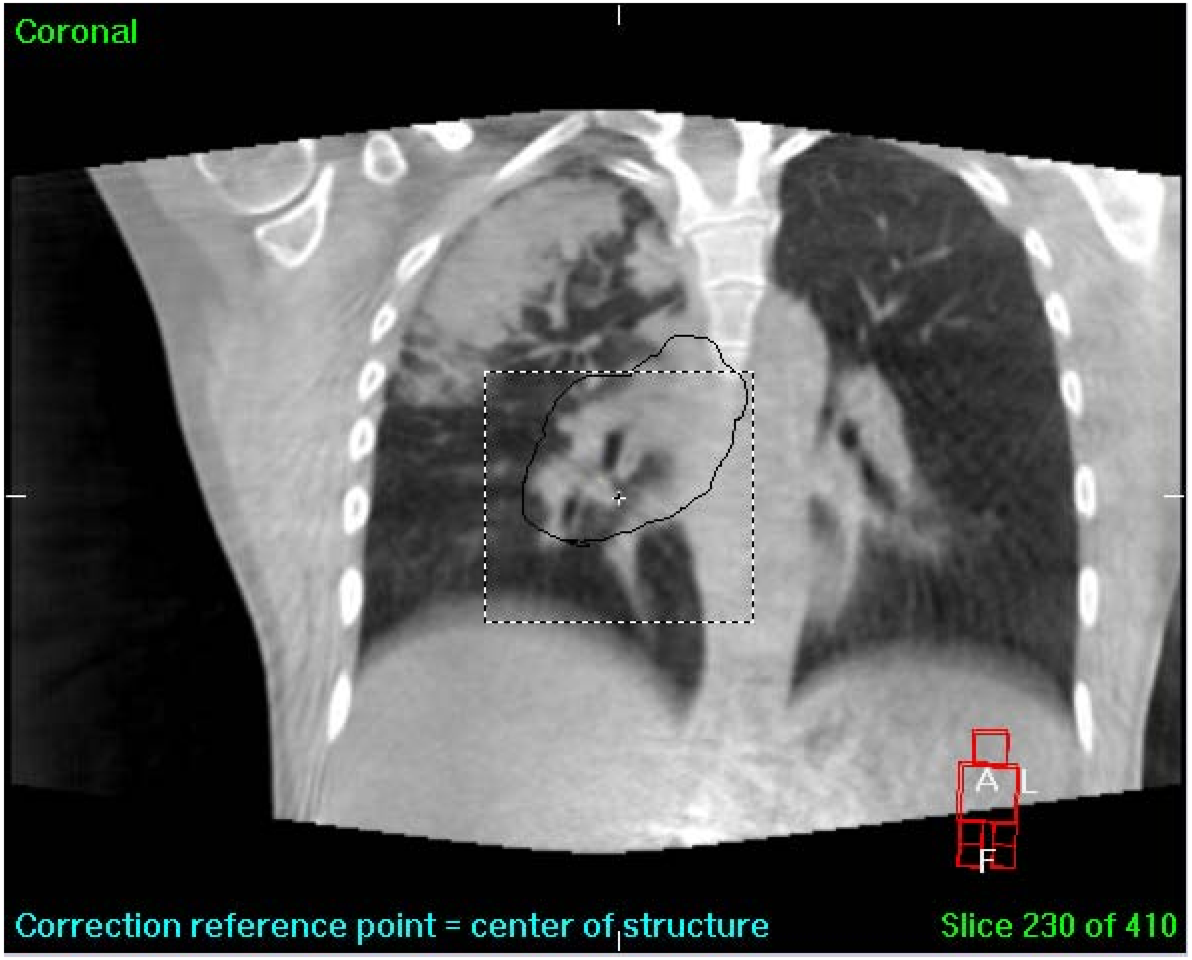
- In room imaging started off as a single check between CT and Linac
- Nowadays we are more aware of anatomical changes

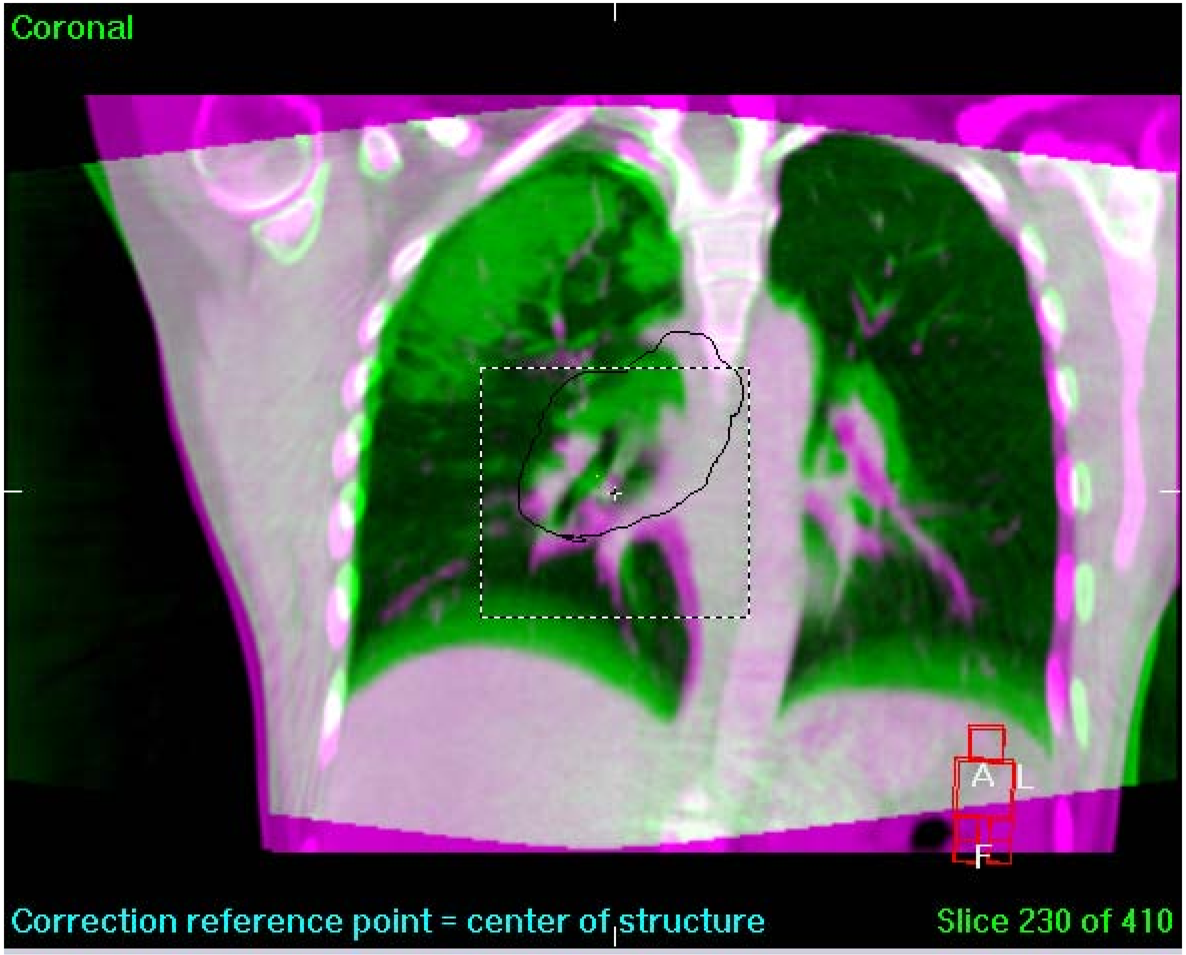
Anatomical changes



Ref-CT

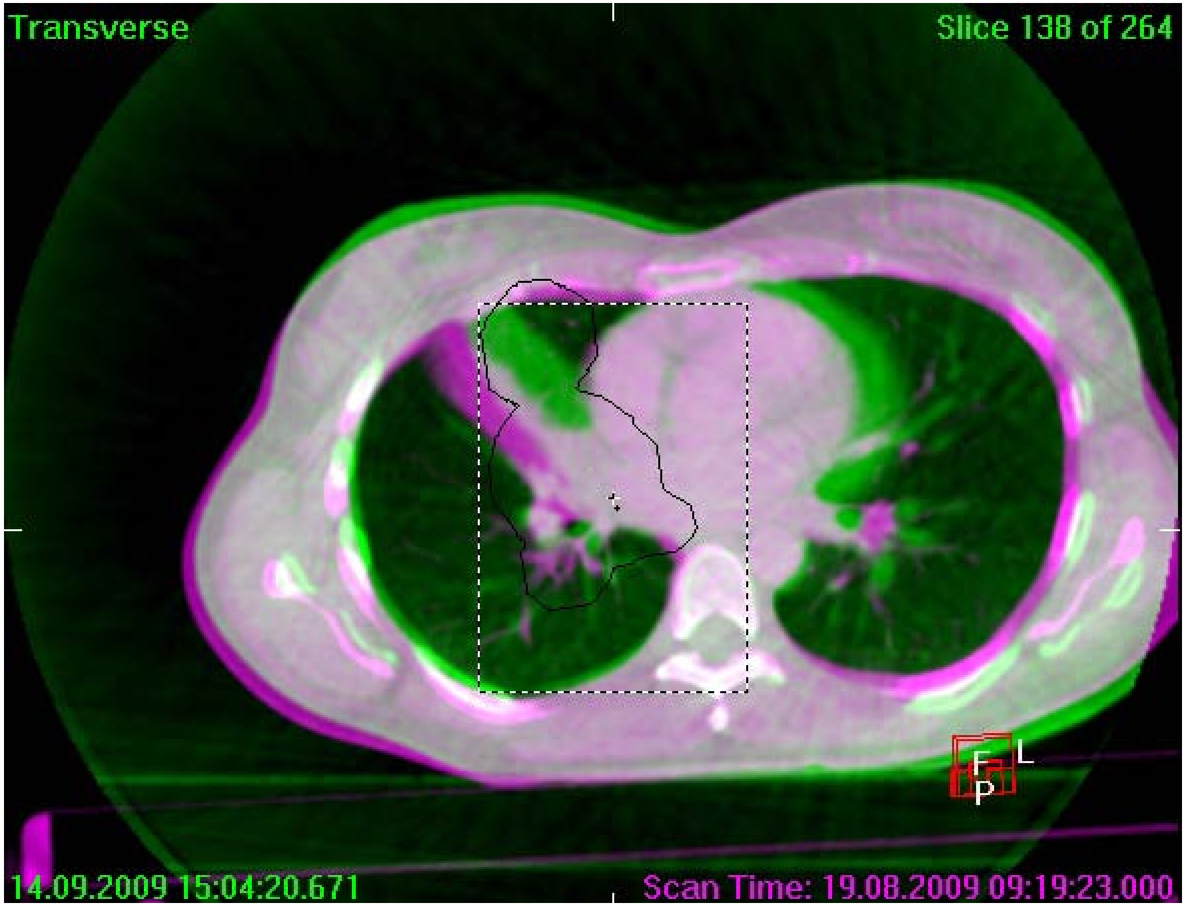
CBCT


Coronal
A
L
F
Correction reference point = center of structure
Slice 230 of 410


Coronal
A
L
F
Correction reference point = center of structure
Slice 230 of 410

CBCT

Ref-CT


Transverse
Slice 138 of 264
L
F
P
14.09.2009 15:04:20.671
Scan Time: 19.08.2009 09:19:23.000

CBCT

Ref-CT

Atelectases

- Dosimetry changes due to atelectases
- Tumor position changed

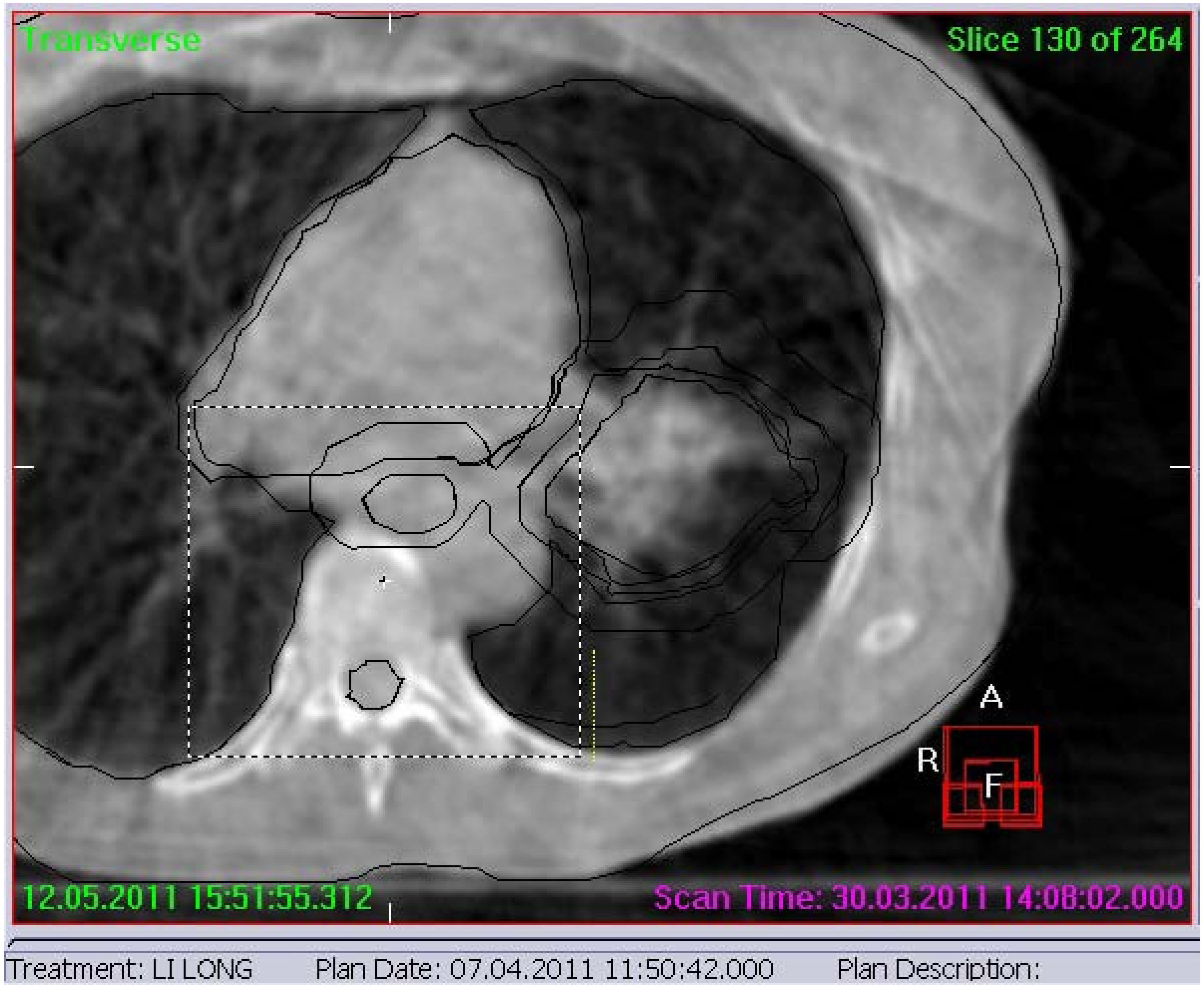
- Rescanning/replanning necessary


Coronal
Marker set
A
L
F
Correction reference point = center of structure
Slice 217 of 410

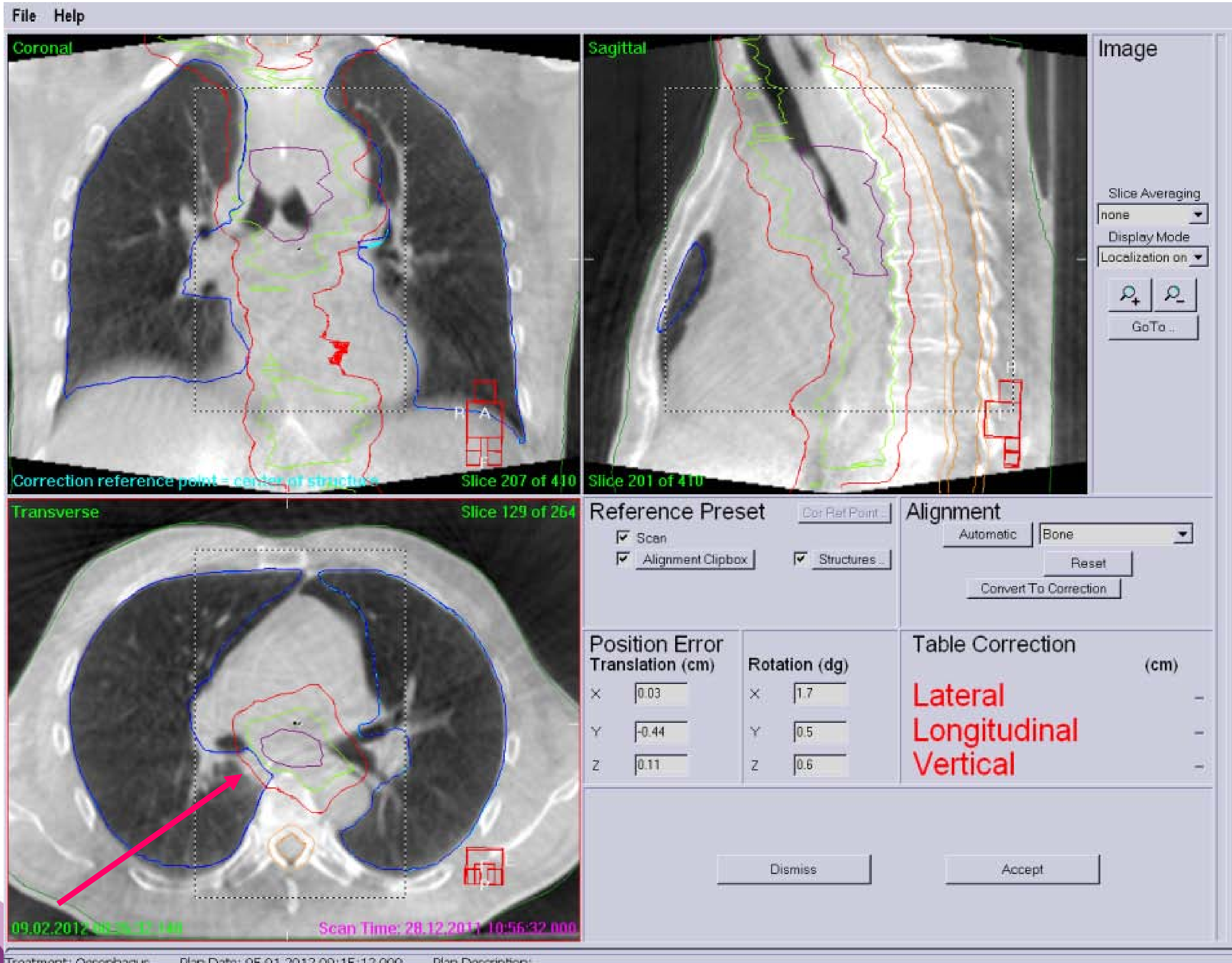
CBCT

Ref-CT

Tumor regression

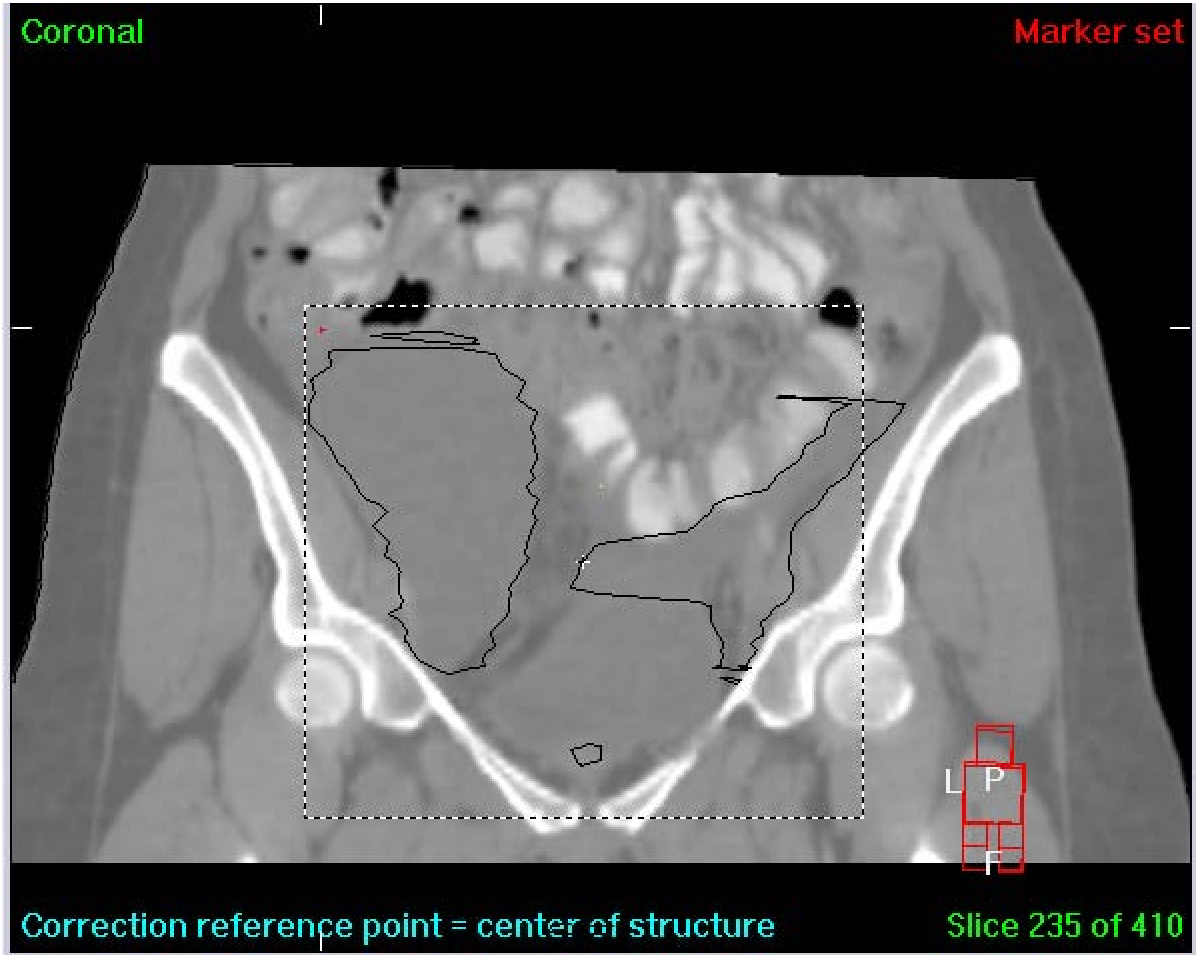


Tumor shift

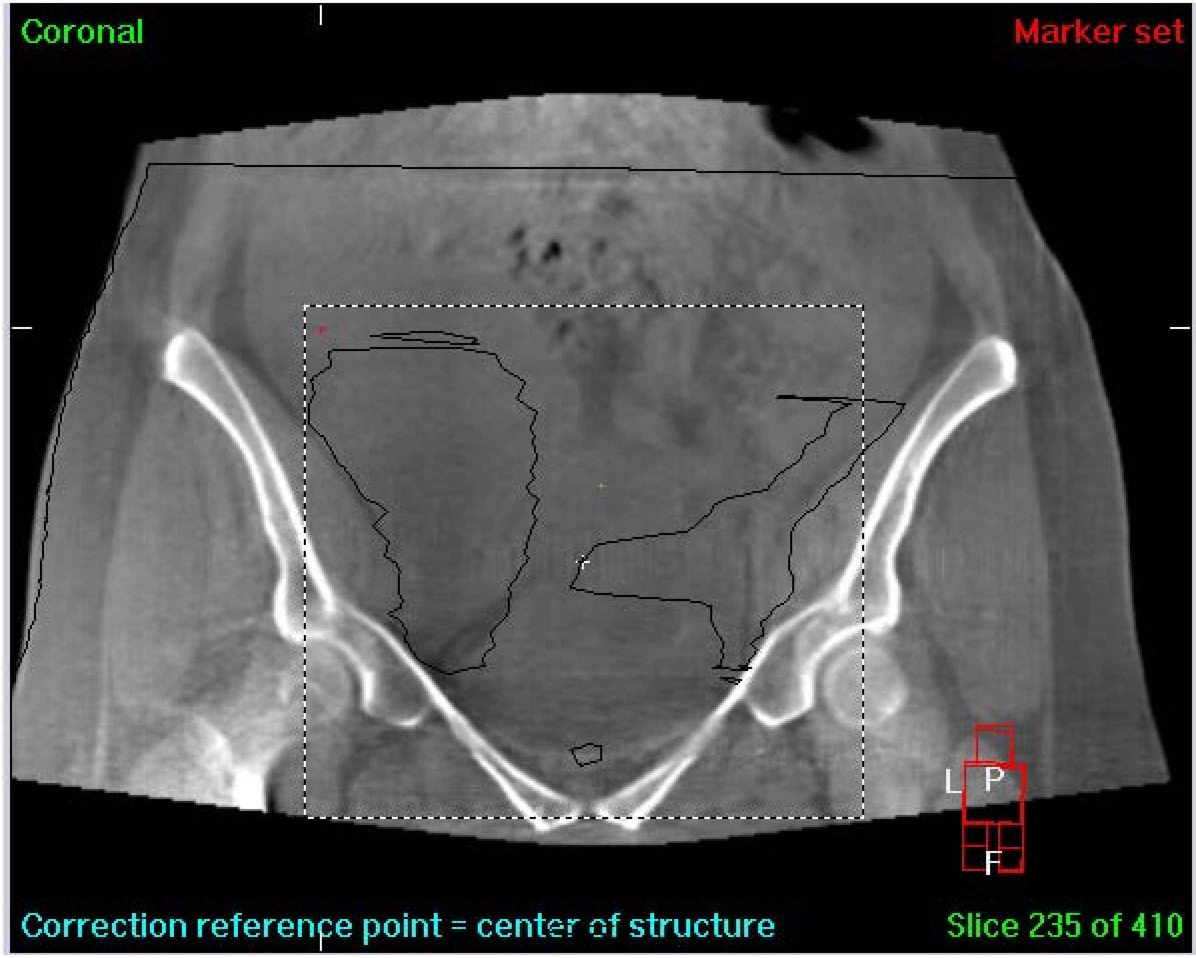

File
Help
Coronal
Correction reference point = center of structure
Slice 207 of 410
Sagittal
Slice 201 of 410
Image
Slice Averaging
none
Display Mode
Localization on
GoTo ..
Transverse
Slice 129 of 264
Scan Time: 28.12.2011 10:56:32.000
Reference Preset
Cor Ref Point
Scan
Alignment Clipbox
Structures ..
Alignment
Automatic
Bone
Reset
Convert To Correction
Position Error
Translation (cm)
X 0.03
Y -0.44
Z 0.11
Rotation (dg)
X 1.7
Y 0.5
Z 0.6
Table Correction
(cm)
Lateral
Longitudinal
Vertical
Dismiss
Accept
Treatment: Oesophagus
Plan Date: 05.01.2012 09:15:12.000
Plan Description:

Rare changes

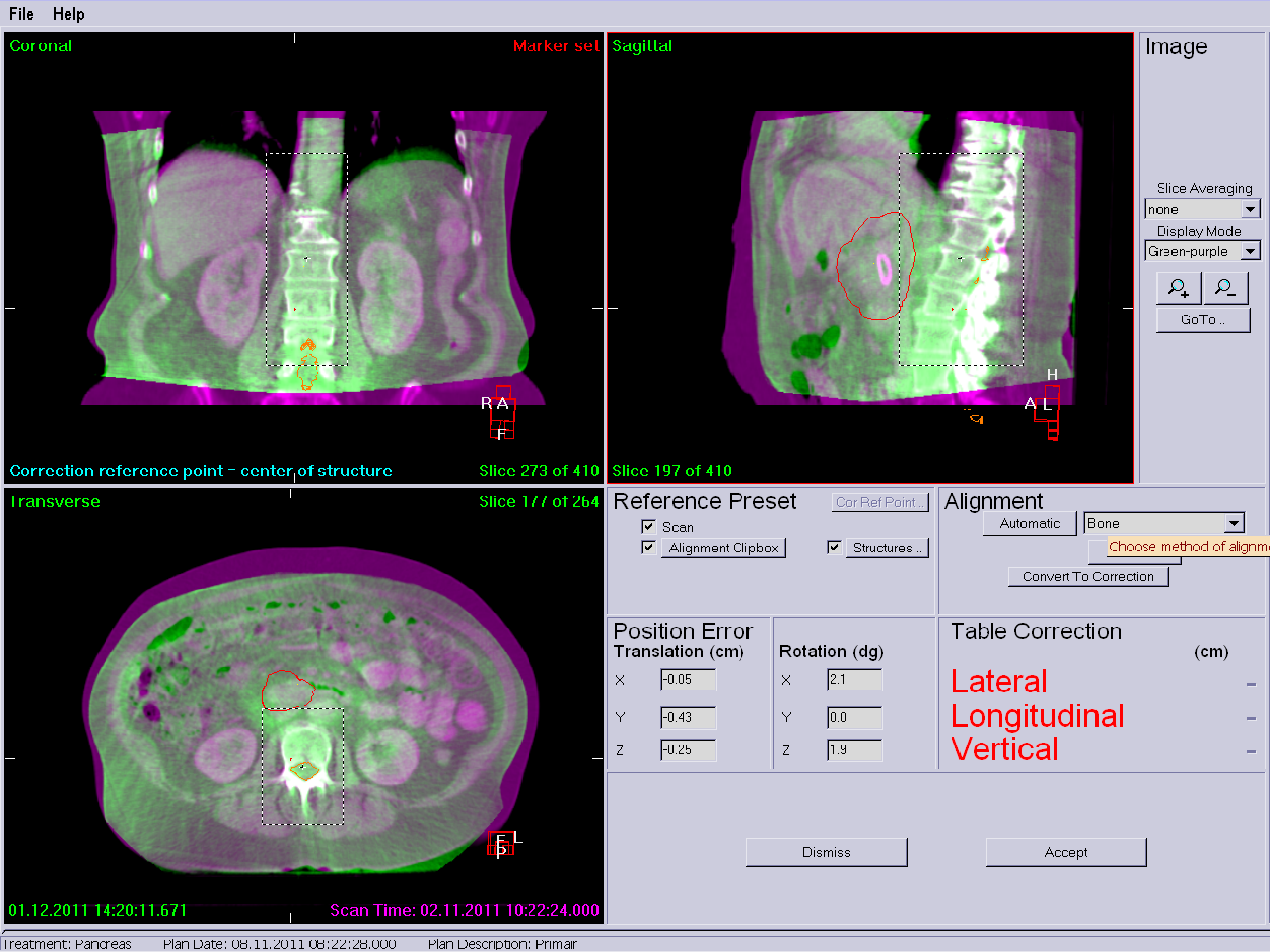
Rare changes



Change in lymphocele



Weight loss


File
Help
Coronal
Marker set
R A
F
Correction reference point = center of structure
Slice 273 of 410
Sagittal
H
A L
Slice 197 of 410
Image
Slice Averaging
none
Display Mode
Green-purple
GoTo ..
Transverse
Slice 177 of 264
F L
P
01.12.2011 14:20:11.671
Scan Time: 02.11.2011 10:22:24.000
Reference Preset
Cor Ref Point ..
Scan
Alignment Clipbox
Structures ..
Alignment
Automatic
Bone
Choose method of alignm
Convert To Correction
Position Error
Translation (cm)
X -0.05
Y -0.43
Z -0.25
Rotation (dg)
X 2.1
Y 0.0
Z 1.9
Table Correction
(cm)
Lateral
Longitudinal
Vertical
Dismiss
Accept
Treatment: Pancreas
Plan Date: 08.11.2011 08:22:28.000
Plan Description: Primair

Cardiac changes


Coronal
Marker set
H
A
L
Correction reference point - center of structure
Slice 163 of 410
Sagittal
L
P
F
Slice 253 of 410
Transverse
Slice 158 of 264
A
L
F
12/01/2012 09:28:12
Scan Time: 23/11/2011 10:33:06
Reference Preset
Cor Ref Point...
Scan
Alignment Clipbox
Structures ...
Alignment
Automatic
Bone
Res
Convert To Correcti
Position Error
Translation (cm)
X -0.19
Y 0.55
Z -0.12
Rotation (dg)
X 356.8
Y 358.9
Z 0.1
Table Correction
Lateral
Longitudinal
Vertical
Dismiss
Accept
Treatment: Oesophagus
Plan Date: 01/12/2011 14:03:22
Plan Description:

Summary

- Anatomy is changing during treatment

- RTT is the person most likely to detect
    - Should be her/his responsibility

- You can’t bother the doctor or physicist with everything…

How to deal with changing anatomy?*

- Call doctor before treatment
  - Change in atelectases
  - GTV and/or CTV outside PTV

- Contact doctor that day or the day after
  - Mild tumor progression
  - Tumor regression

- Contour changes (physicist)
  - >2 cm
  - >1cm H&N and extremities

***Inspired by:**

INTRA THORACIC ANATOMICAL CHANGES FOR LUNG CANCER PATIENTS DURING THE COURSE OF IRRADIATION: HOW TO RESPOND?

S. Conijn[1] , J. Belderbos[1] , J. Knegjens[1] , M. Rossi[1] , J. J. Sonke[1] , P. Remeijer[1]

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The protocol…

- *Describes were to look at*
- *Describes what do*
- *Describes who to contact*
- *Describes at what speed actions have to take place*

Implementation Phase

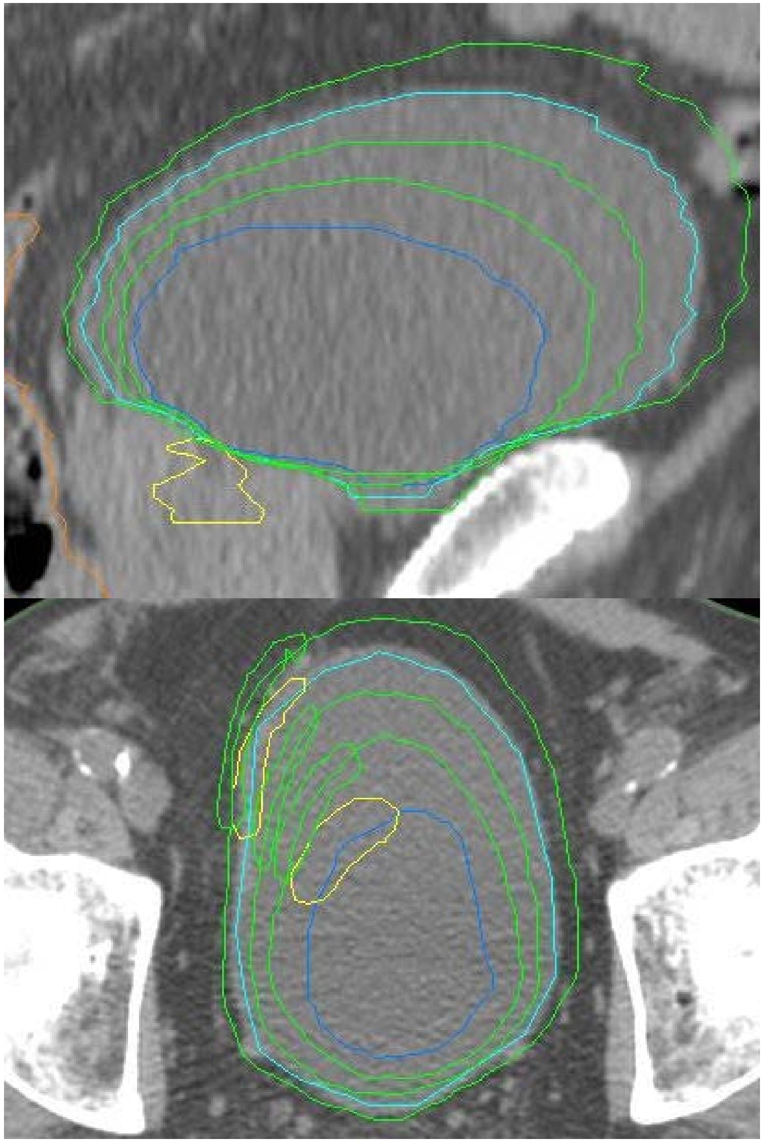
Critical conditions for proper implementation

- Treatment protocol should be:
  - ➢ Well described and tasks well defined
  - ➢ Approved by staff
  - ➢ Available for everyone
- Education and training of professionals:
  - ➢ Really depends on subject
  - ➢ Preferable as practical as possible
- Example: *Bladder ART*

Plan of the day

Inter- and extrapolation of bladder contours

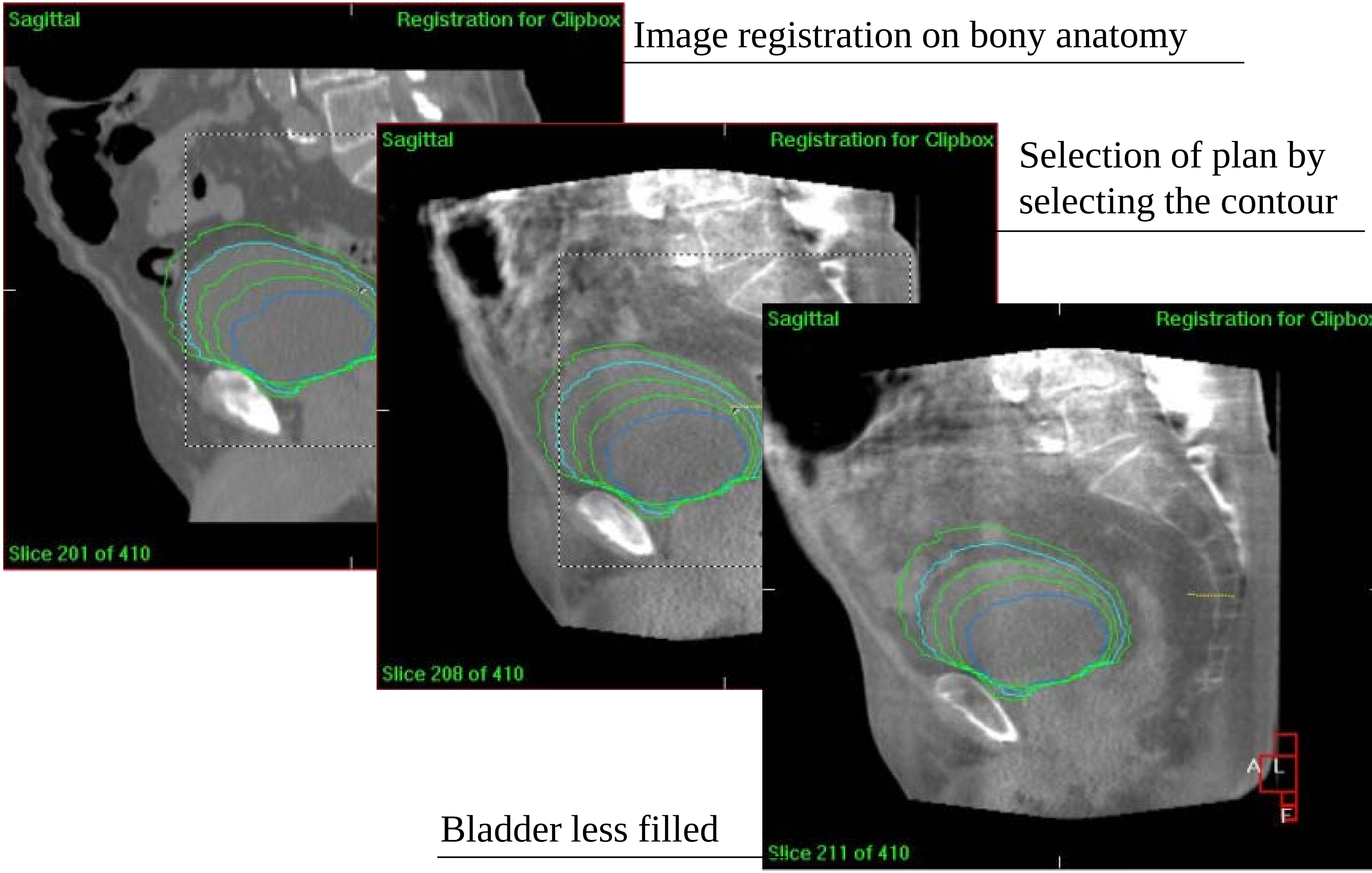
- 5 plans are generated on the TPS (Oncentra, Elekta)



Images: Jorrit Visser

Image registration on bony anatomy

Selection of plan by
selecting the contour



Bladder less filled

Images: Rianne de Jong

Demo database ART blaas

4 patients with two reference CT

82 Conebeam CT-scans

5 structures per patient/scan:

0 – 33 – 67 – 100 – 133%

12 observers

Interobserver study: *1e measurement*

workshop

2e measurement

Implementation Phase

Critical conditions for proper implementation

- Treatment protocol should be:
  - Well described and well defined task
  - Approved by staff
  - Available for everyone
- Education and training of professionals:
  - Really depends on subject
- **Implementation date**
  - **Properly communicated**
  - **Repeat communication just before start**
- **Use a predefined checklist**

Evaluation phase

- Phase that ignored often
  - The work just started....

- Space to correct for mistakes

- Evaluate
  - ➢ Ask for feedback from your colleagues:
    - Pro active: create a feedback session
  - ➢ Data to validate new procedure
    - publish

  - ➢ Monitor your processes

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Bladder ART: Safety-net plan selection

1^{e} week

- Doctor, physicist and IGART RTT on the linac
- Fixed moment

Starting of the 2^{e} week

- IGART RTT on the linac
- Fixed moment

After 10 patients

- evaluation and feedback - database oefenpatiënten? -

Once weekly one dedicated IGART RTT check all decisions:

- Was the “right” selected?
- Is the used model still valid?
- Was the used treatment plan in the R&V system selected?

Conclusions

Implementing protocols:

- Investigate
- Plan
- Implement
- Evaluate

Important:

- By failing to prepare, you are preparing to fail (Benjamin Franklin)
- You can never communicate to much…

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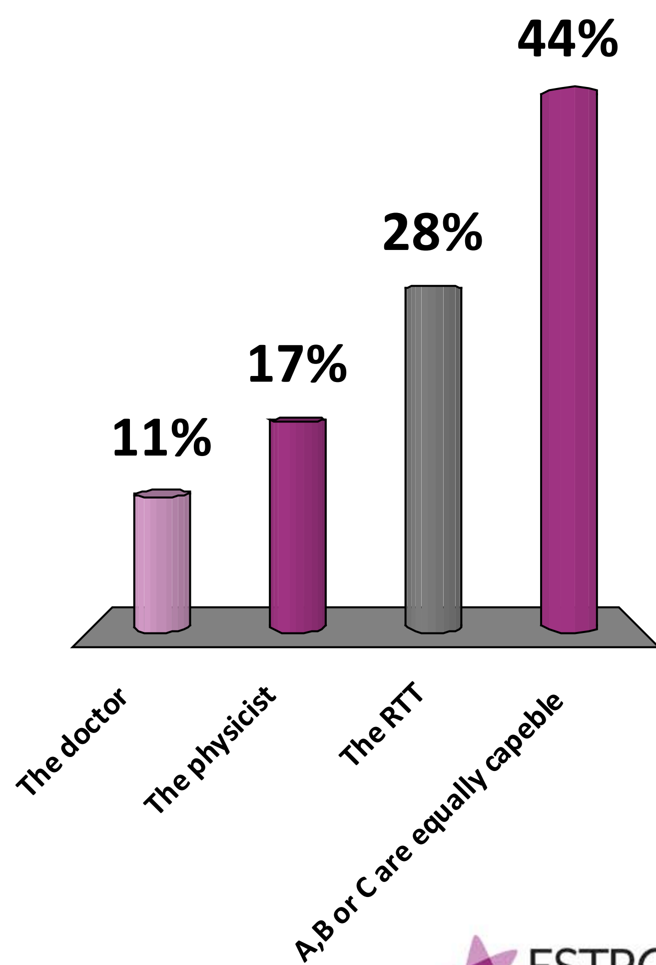
Who should coordinate clinical implementation of new protocols?

A. The doctor
B. The physicist
C. The RTT
D. A,B or C are equally capeble



Thank you for your attention!

Who is doing what in Radiation Therapy

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NKI-AVL
The Netherlands Cancer Institute
Antoni van Leeuwenhoek Hospital

Survey

Questionnaires to participants of ESTRO course on "IGRT in clinical practice" in 2006-2010:

48 hospitals

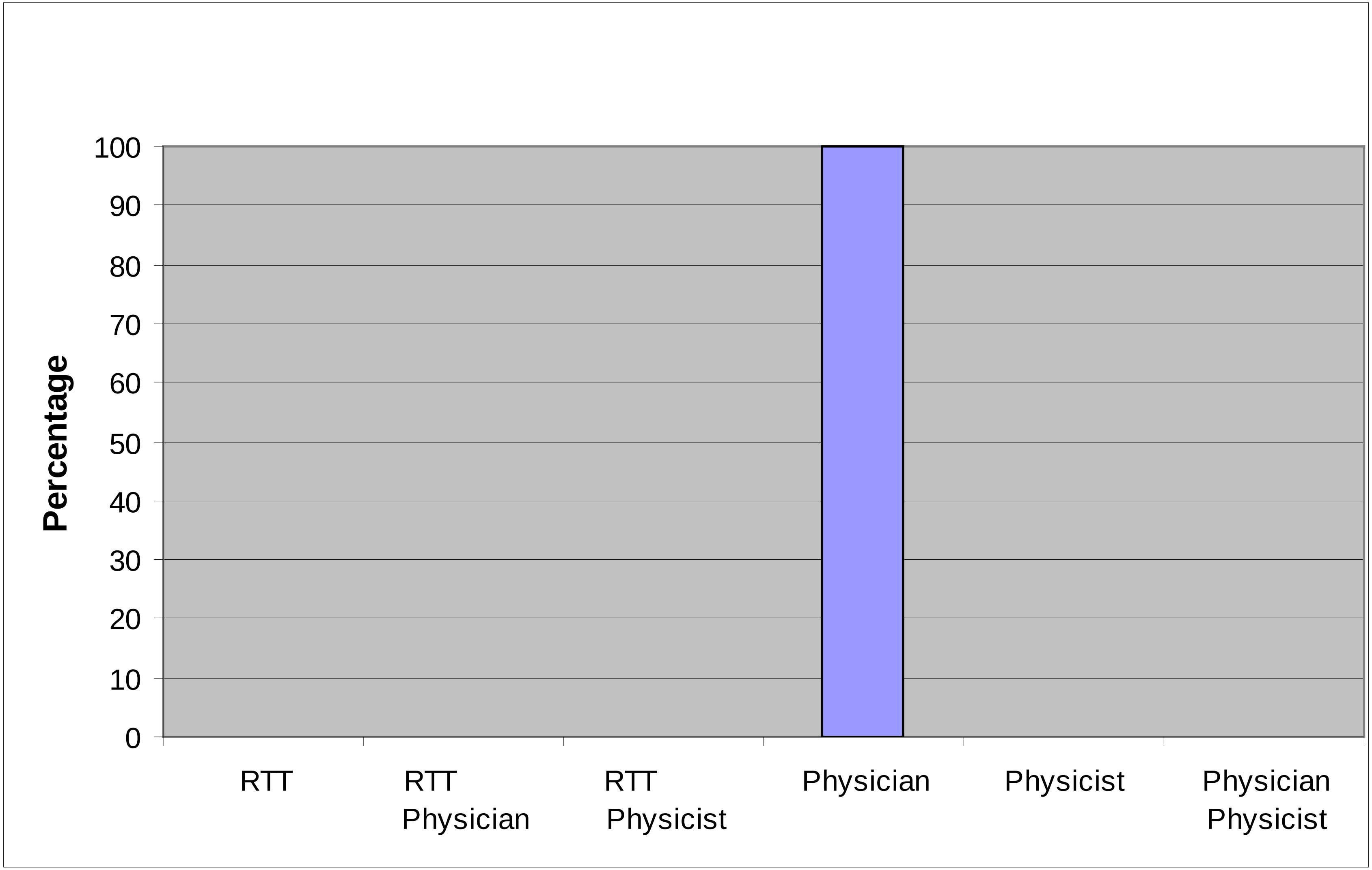
19 countries

Survey

1. Indication/Design of Radiation Treatment
2. Pre treatment imaging: CT/simulation
3. Delineation
4. Treatment Planning
5. Treatment
6. Image Guidance/Adaptation treatment

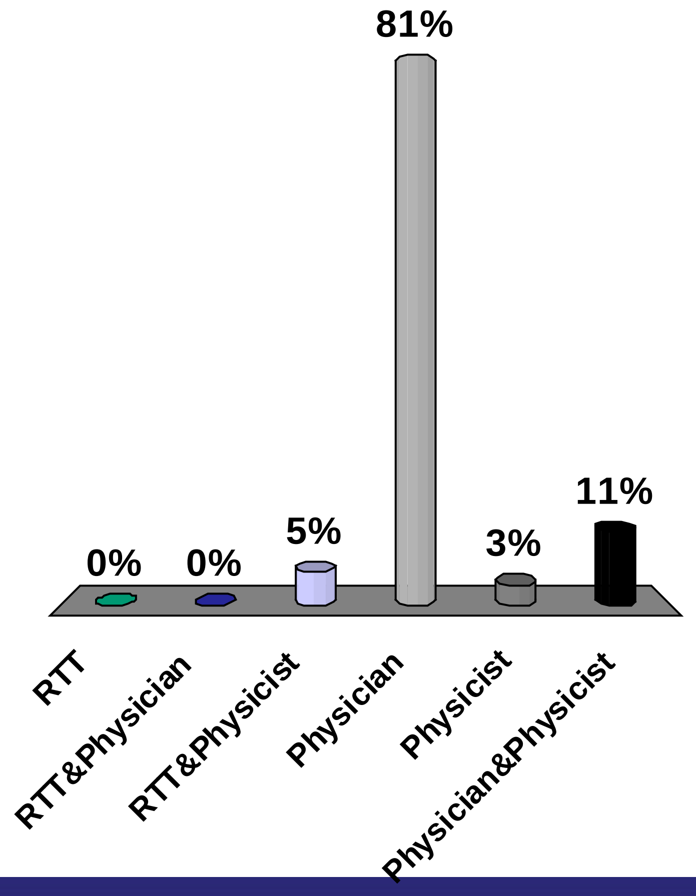
- Radiation Therapy Technicians (RTT)
- Physicians
- Physicists

1. Indication of treatment

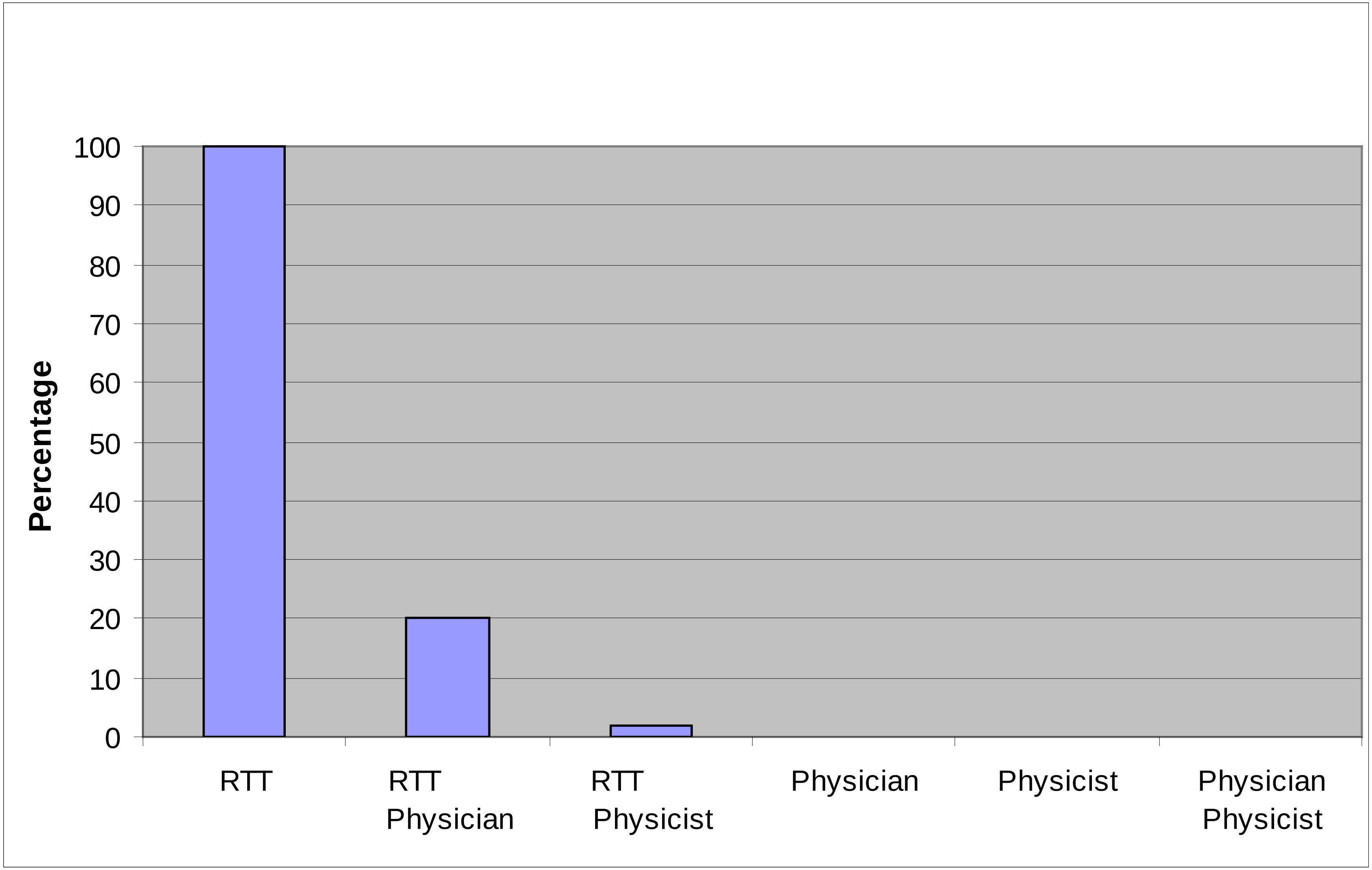


1. Indication of treatment

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist

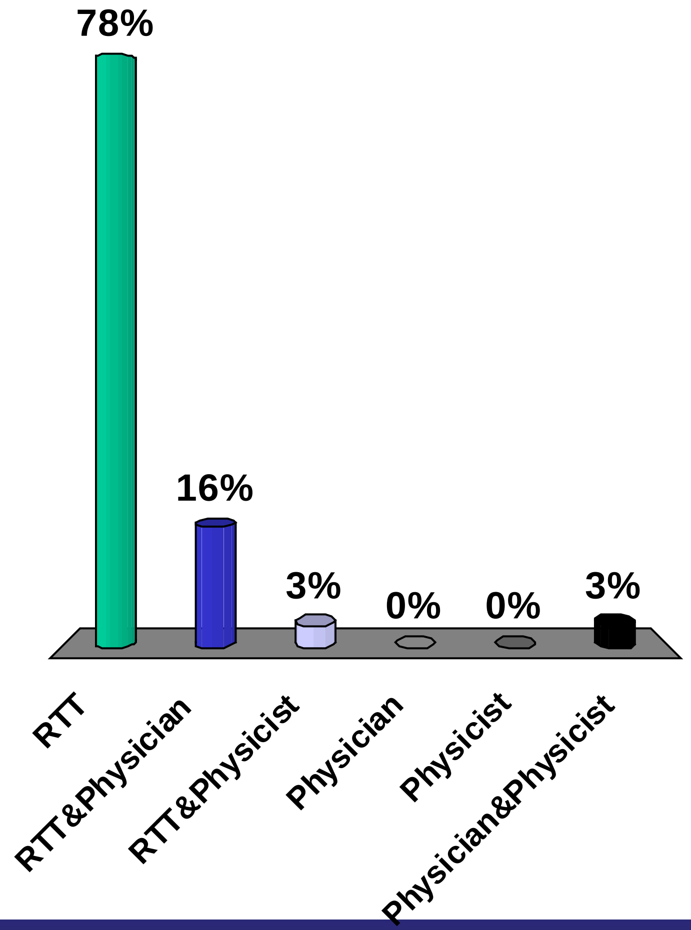


2. Pre-treatment Imaging

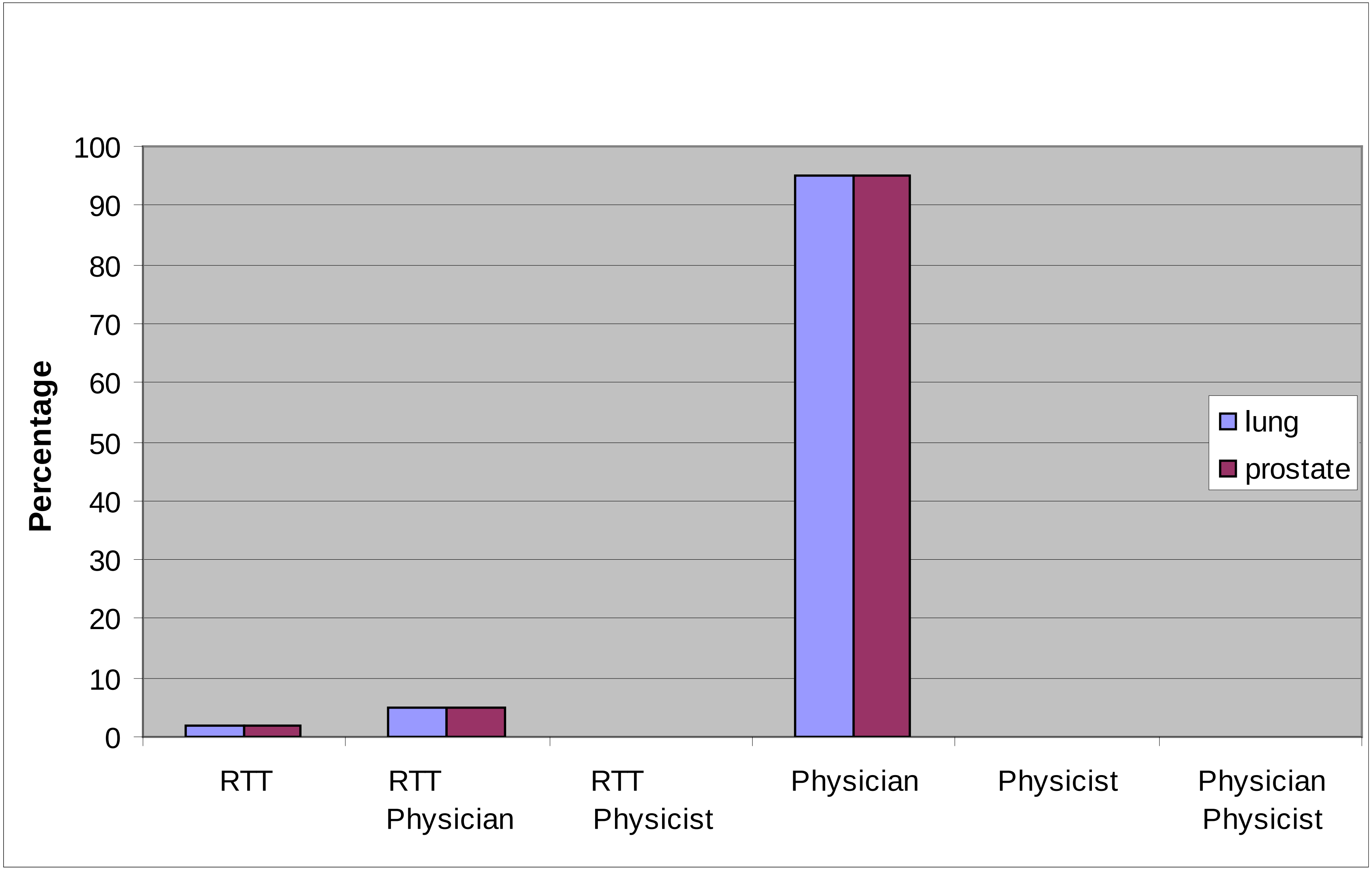


2. Pre treatment Imaging

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist

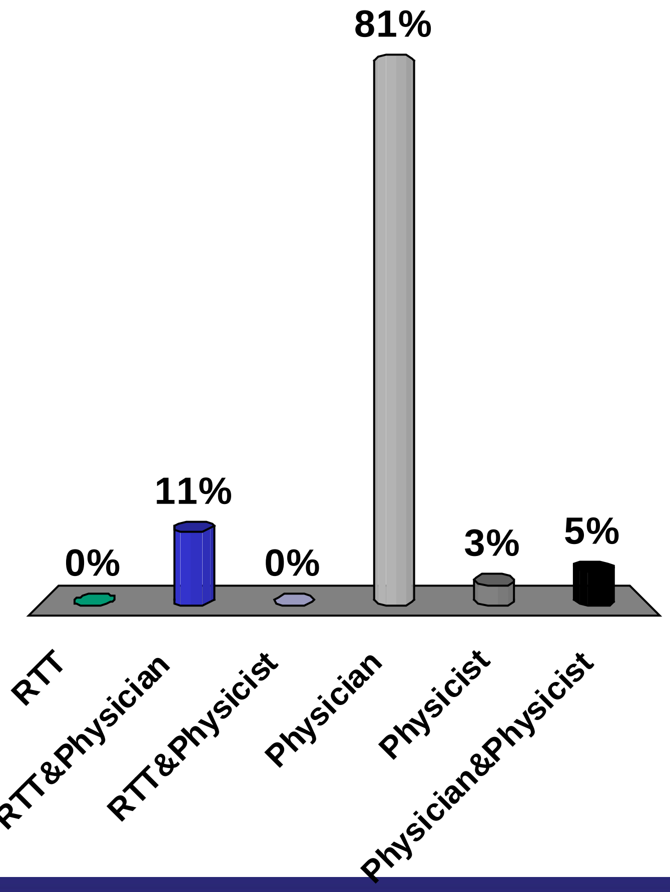


3. Delineation: Target Volume

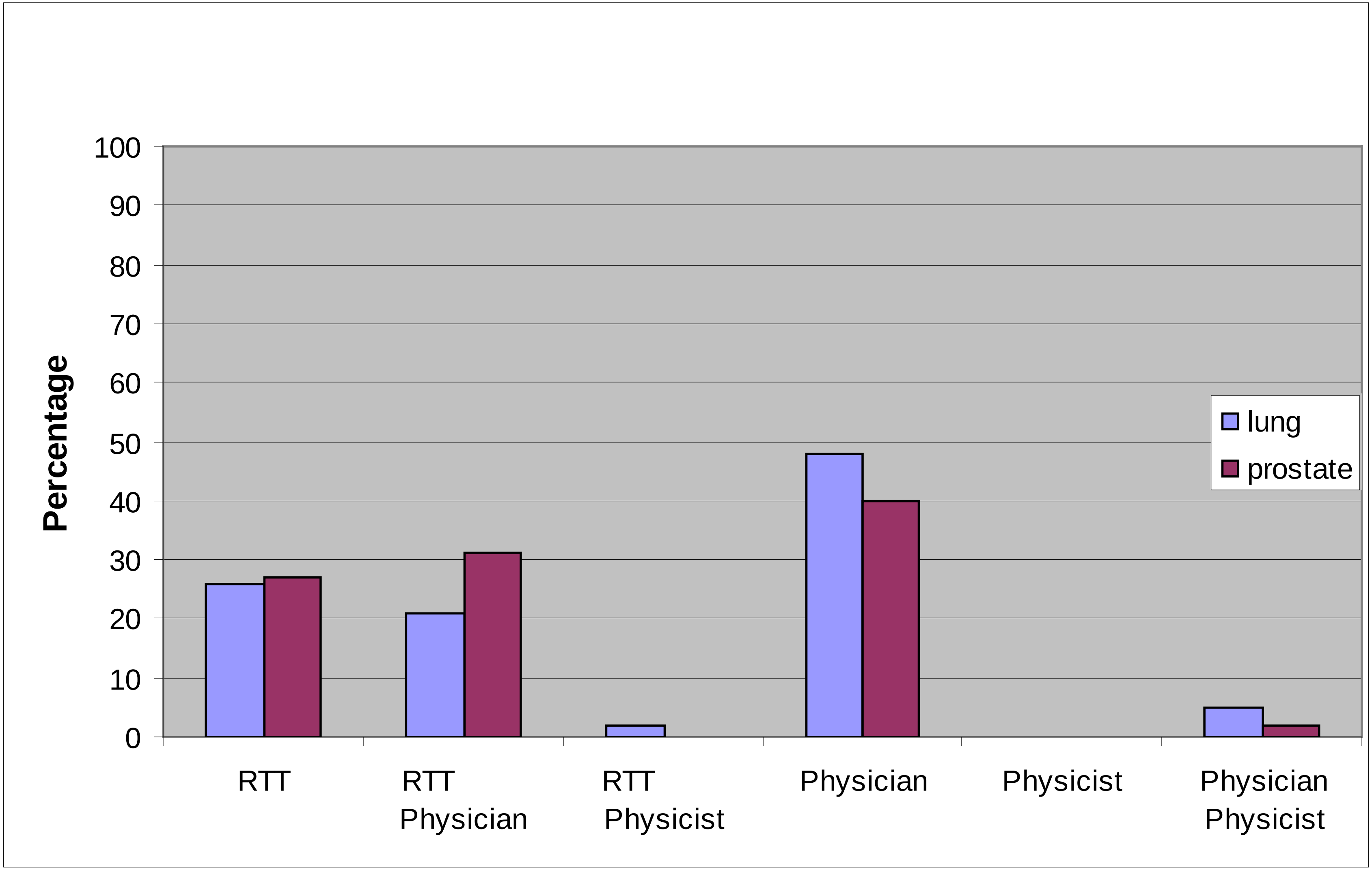


3. Delineation Target Volume

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist

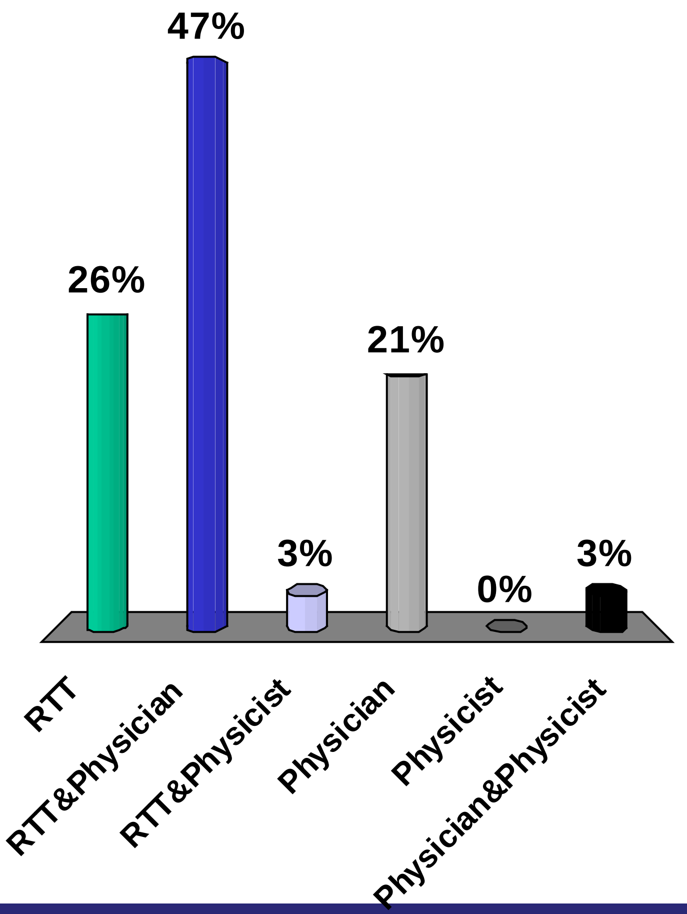


3. Delineation: Organs at Risk

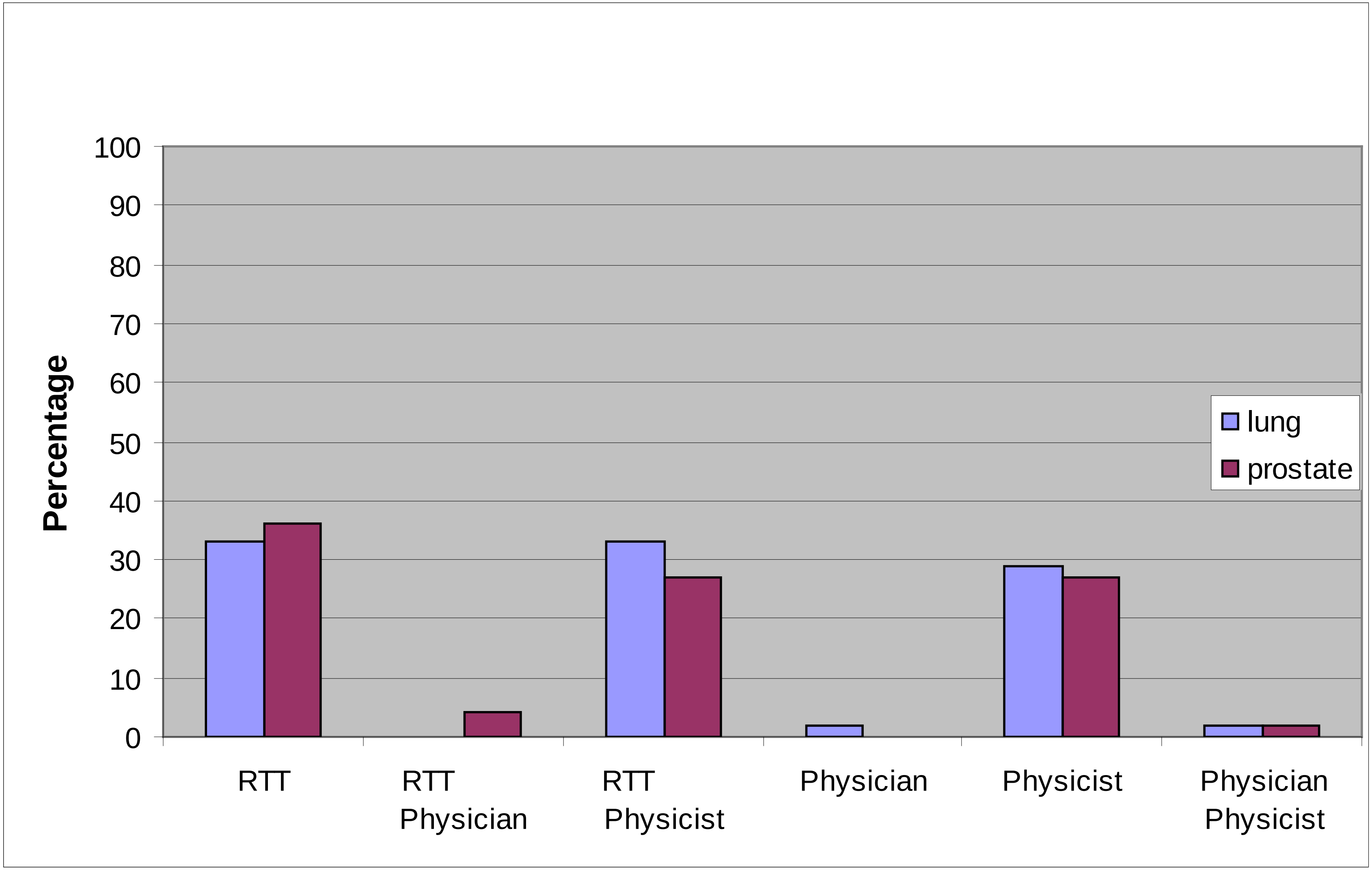


3. Delineation Organs at Risk

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist



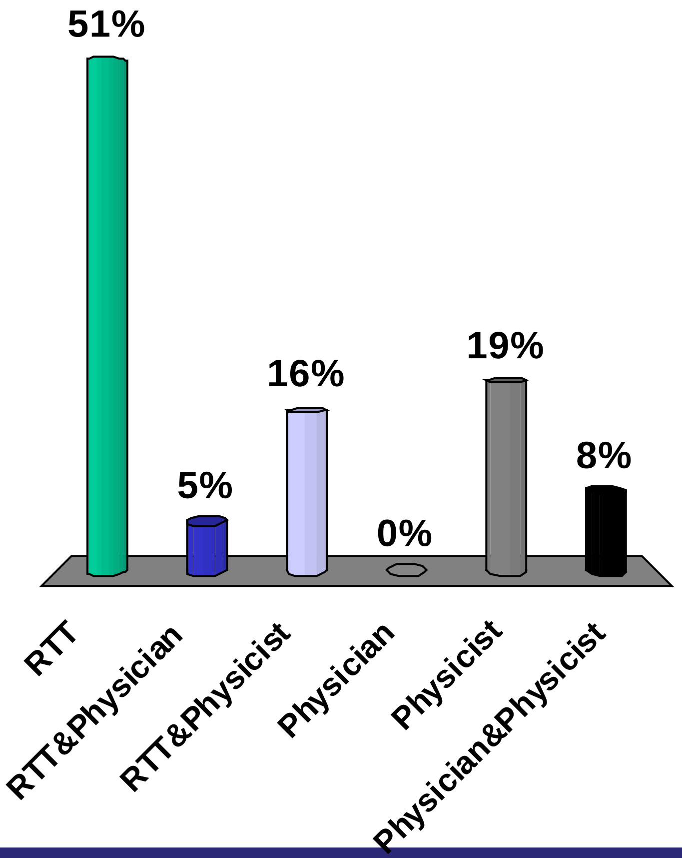
4. Treatment Planning



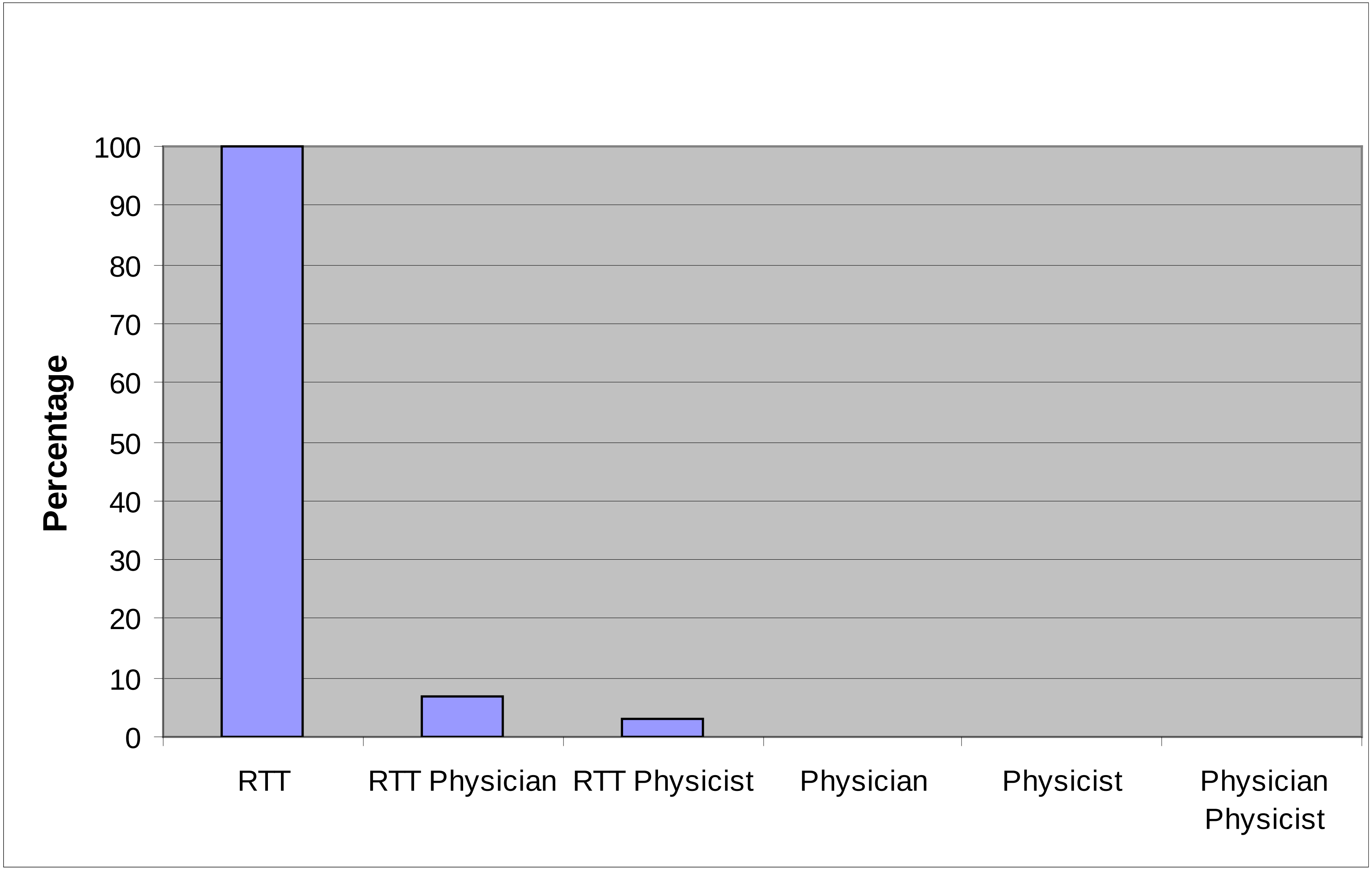
RTT: supervised and/or accepted by physician or physicist

4. Treatment Planning

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist

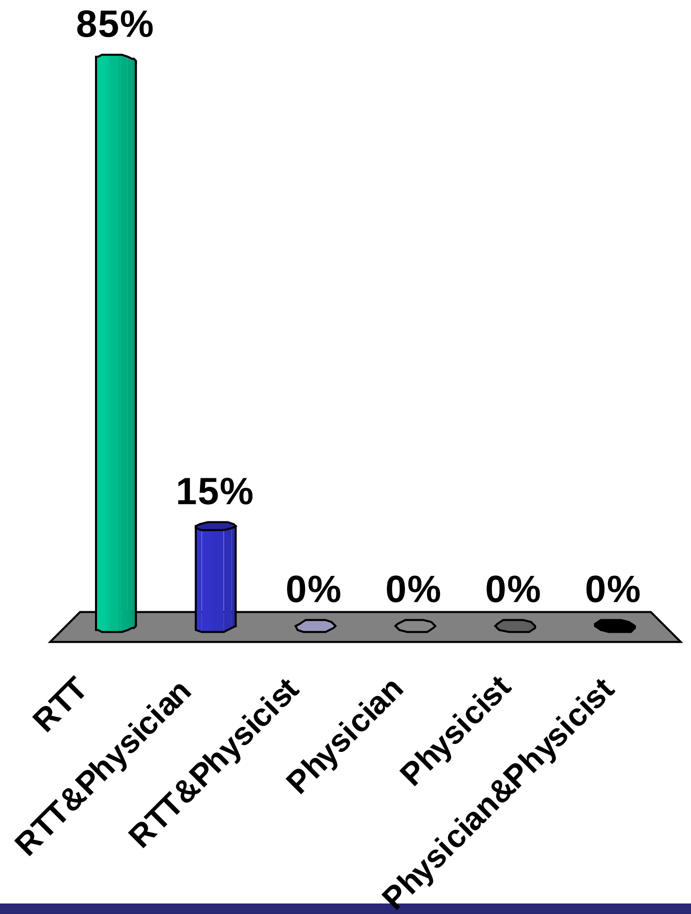


5. Treatment Delivery

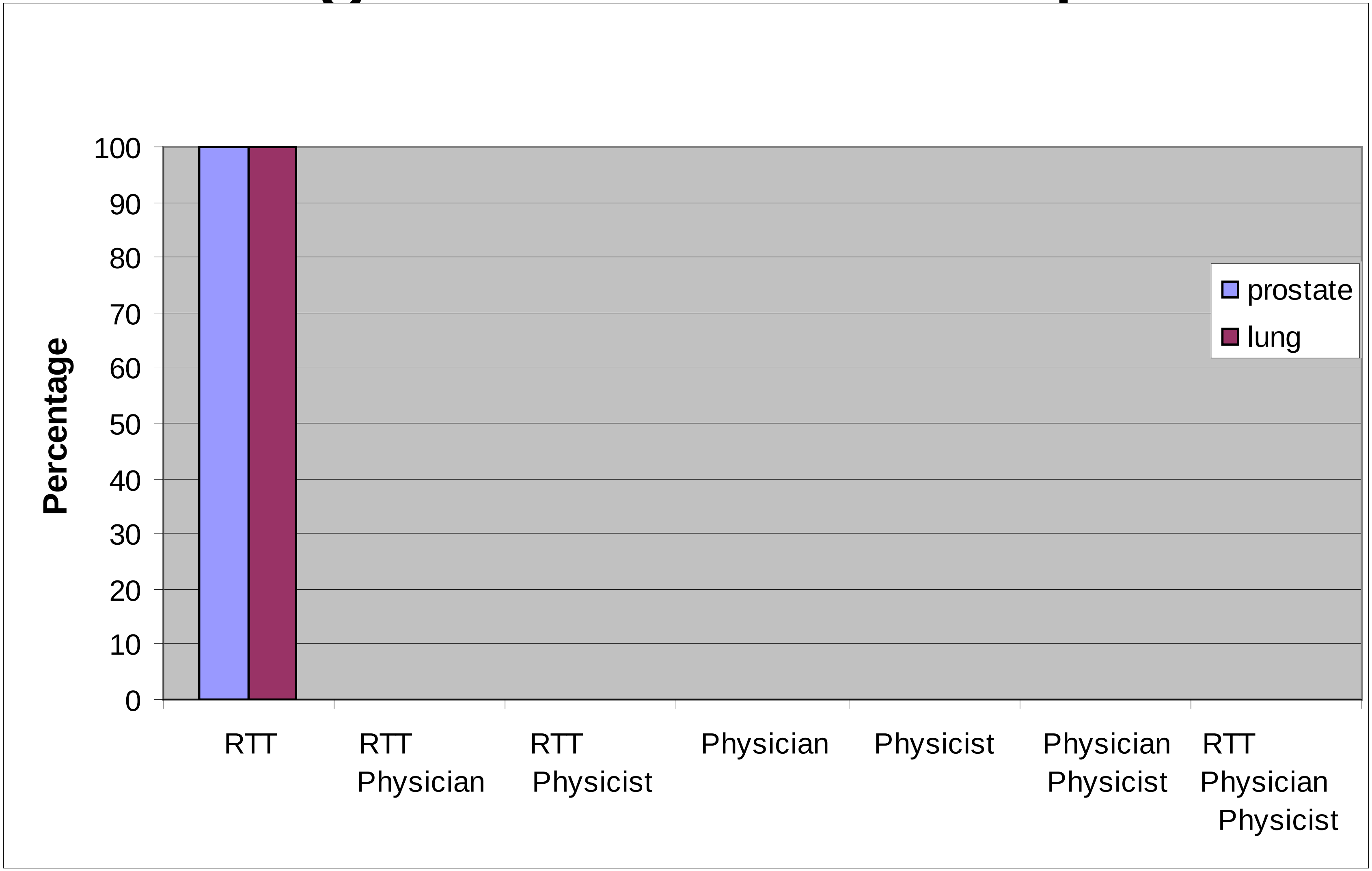


5. Treatment Delivery

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist

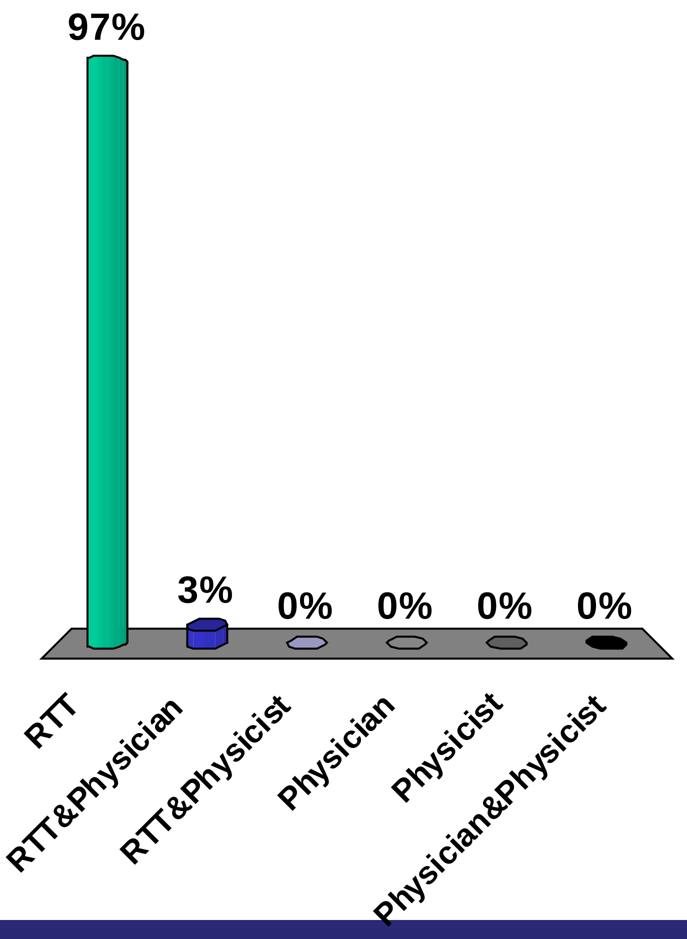


6a. Image Guidance: Acquisition

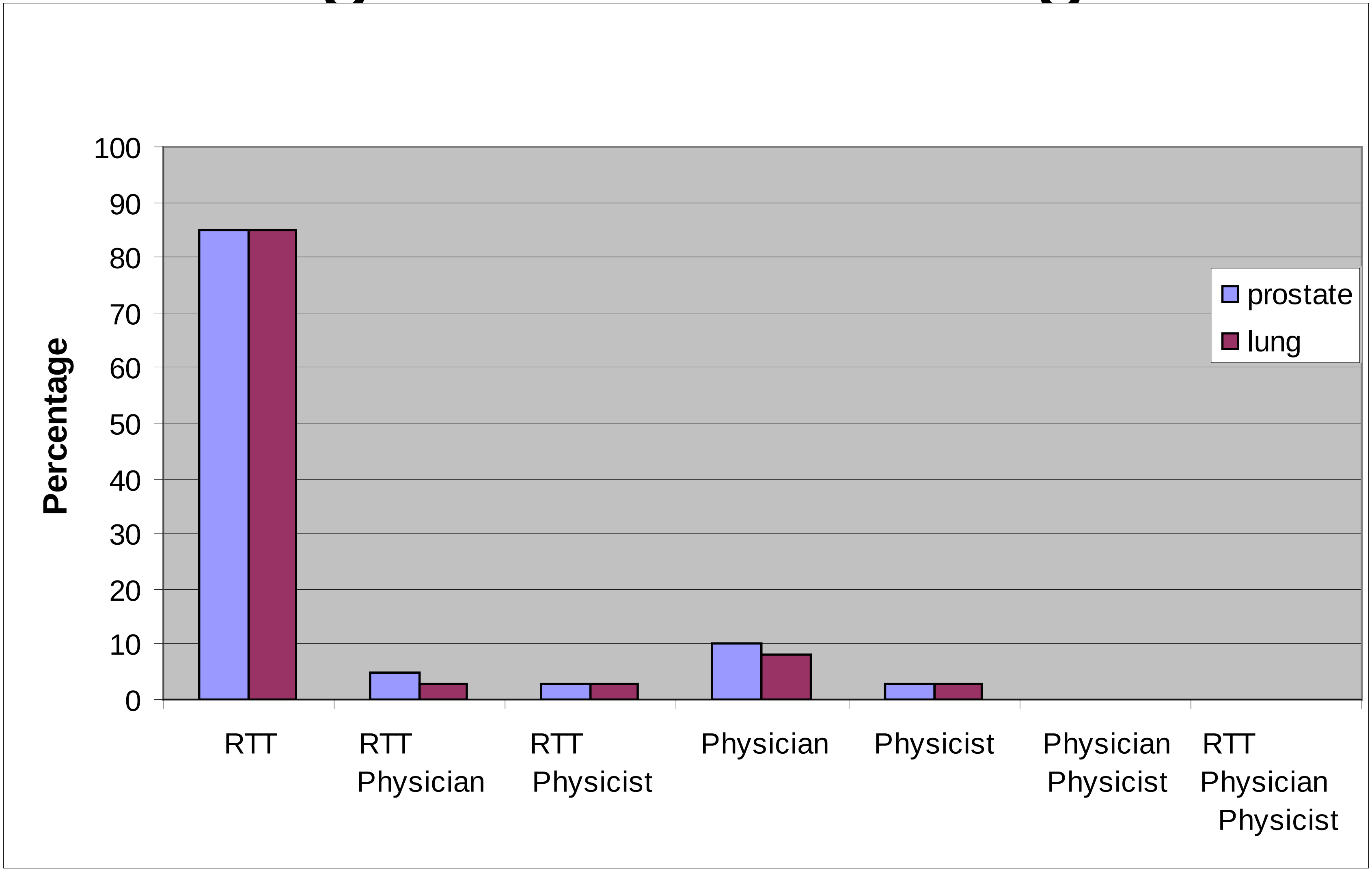


6a. Image guidance: Acquisition

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist

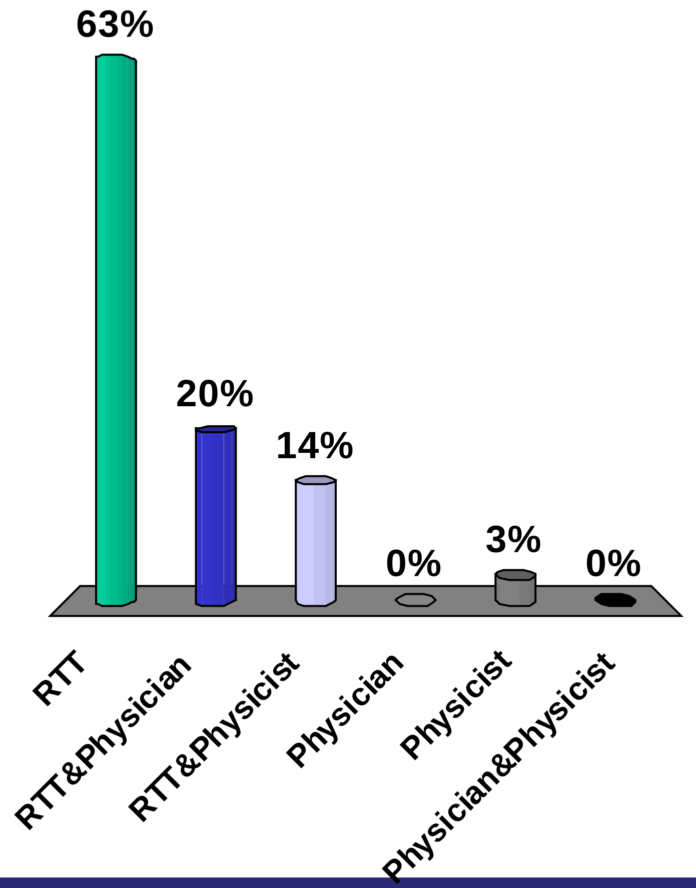


6b. Image Guidance: Registration

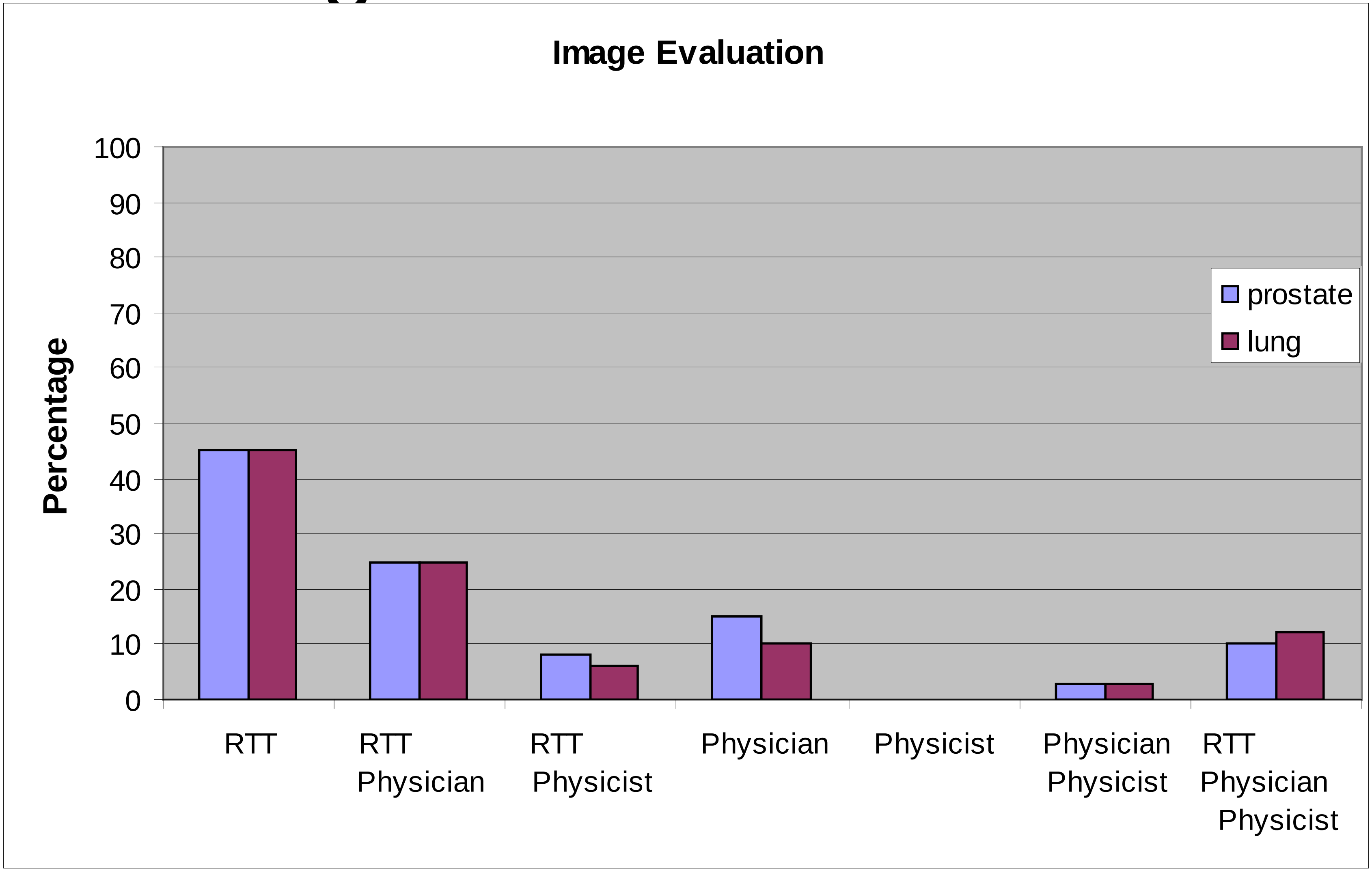


6b. Image Guidance: Registration

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist

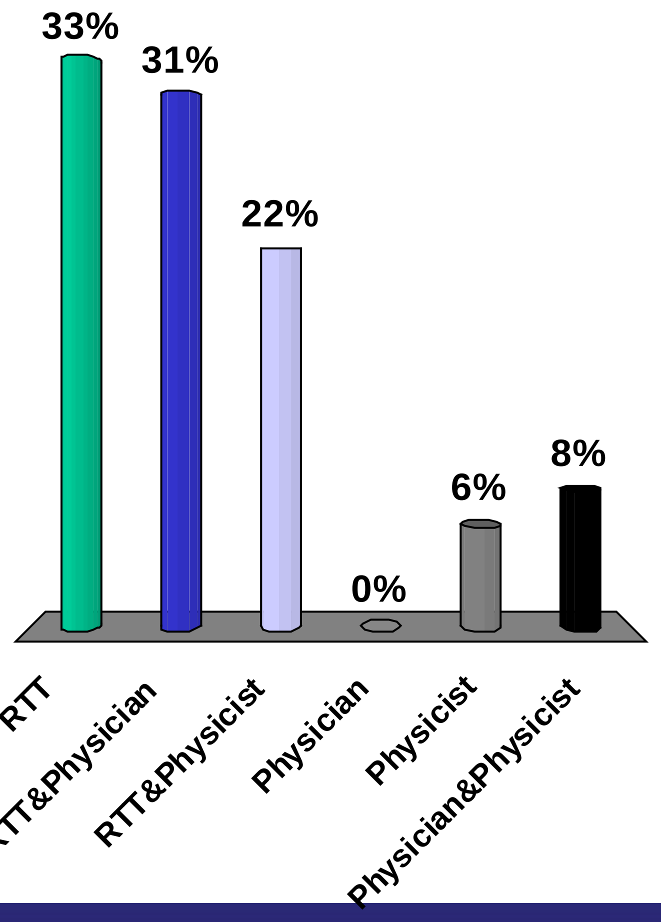


6c. Image Guidance: Evaluation



6c. Image Guidance: Evaluation

A. RTT
B. RTT&Physician
C. RTT&Physicist
D. Physician
E. Physicist
F. Physician&Physicist



Who is doing what?

Conclusion: Largest differences in ***Treatment Planning*** and ***Image Guidance***.

Why? What are the **variables** in the different departments that could have an influence on these differences?

- RTT – education / training
- Department size
- Resources per treatment machine
- IGRT modalities
- *Culture / History*
- *Money*

RTT training / Education

Majority:

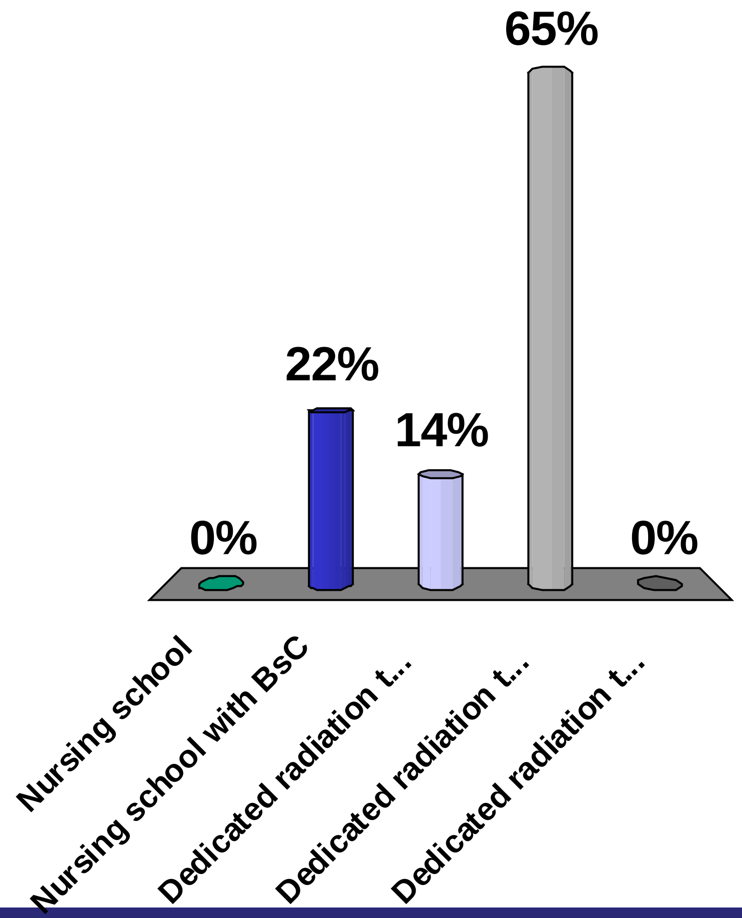
- 3 years of classroom combined with clinical intern hours
  → bachelor degree

Also:

- 2 or 4 years of classroom combined with clinical intern hours → bachelor degree
- 3 years of nursing school with bachelor degree with additional theoretical or clinical RTT training ~1 year.

Training & Education

A. Nursing school
B. Nursing school with BsC
C. Dedicated radiation therapy
D. Dedicated radiation therapy with Bsc
E. Dedicated radiation therapy with MsC



RTT training / Education

Majority:

- 3 years of classroom combined with clinical intern hours

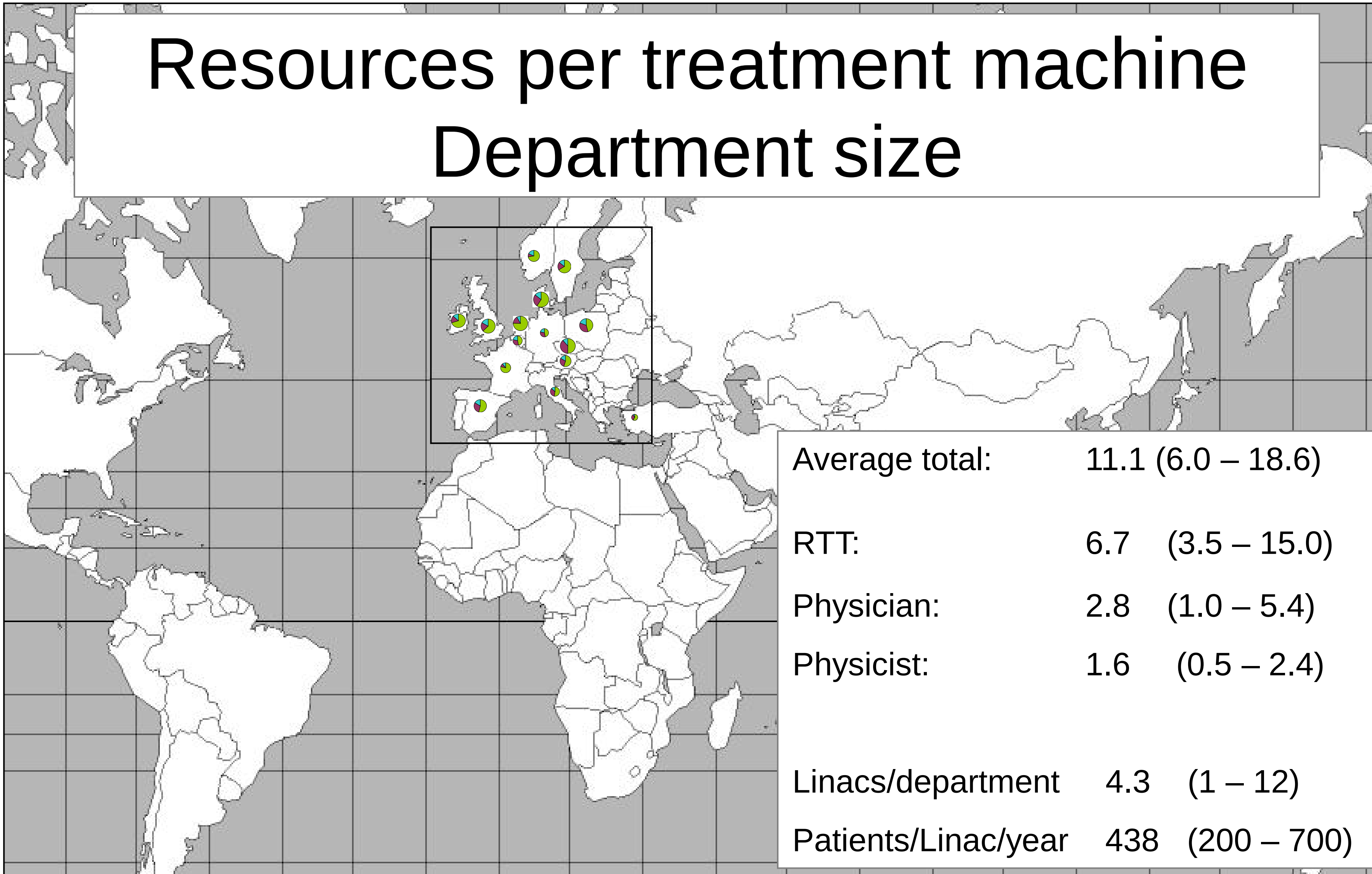
  → bachelor degree

Does not correlate

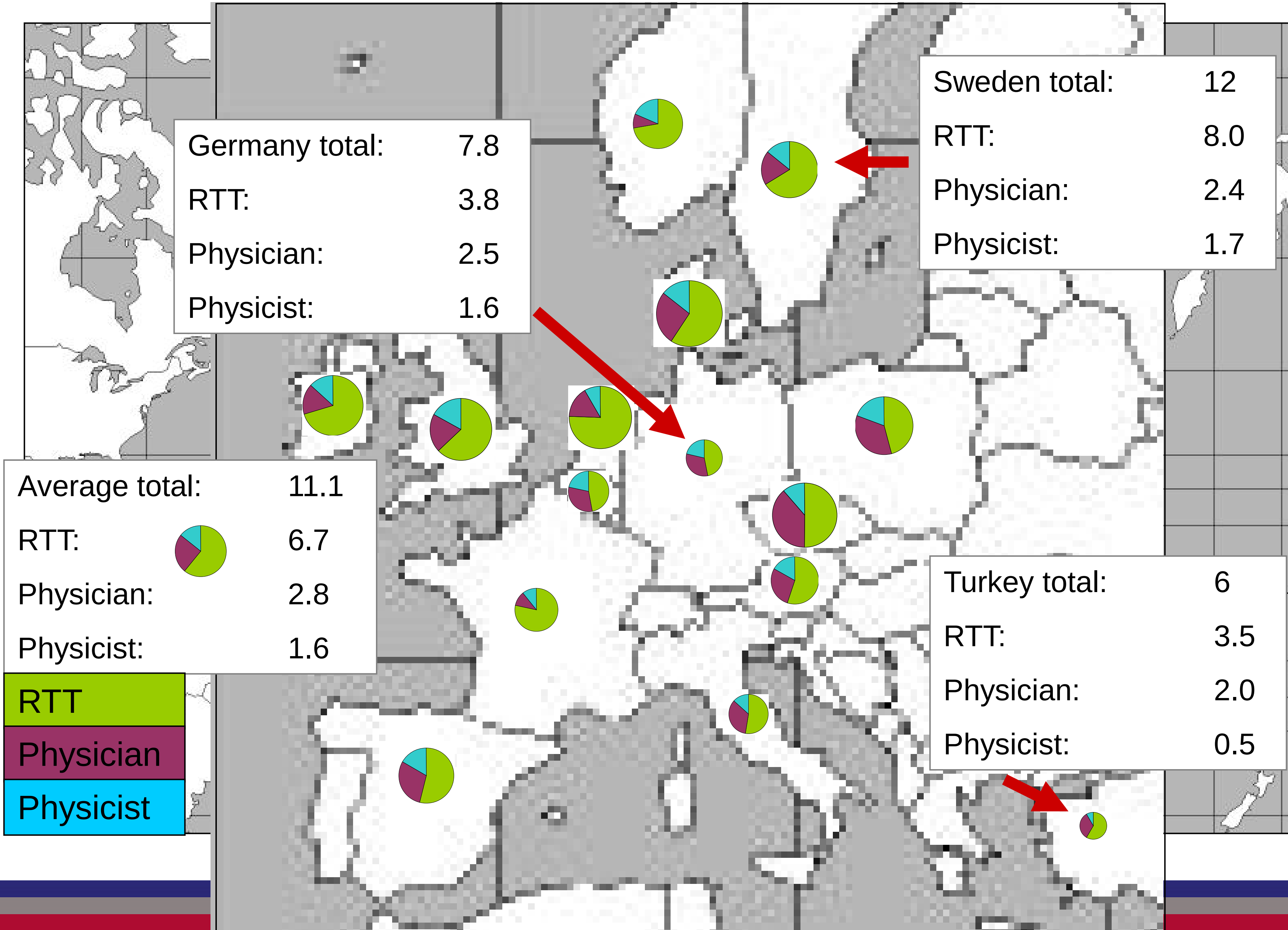
Also:

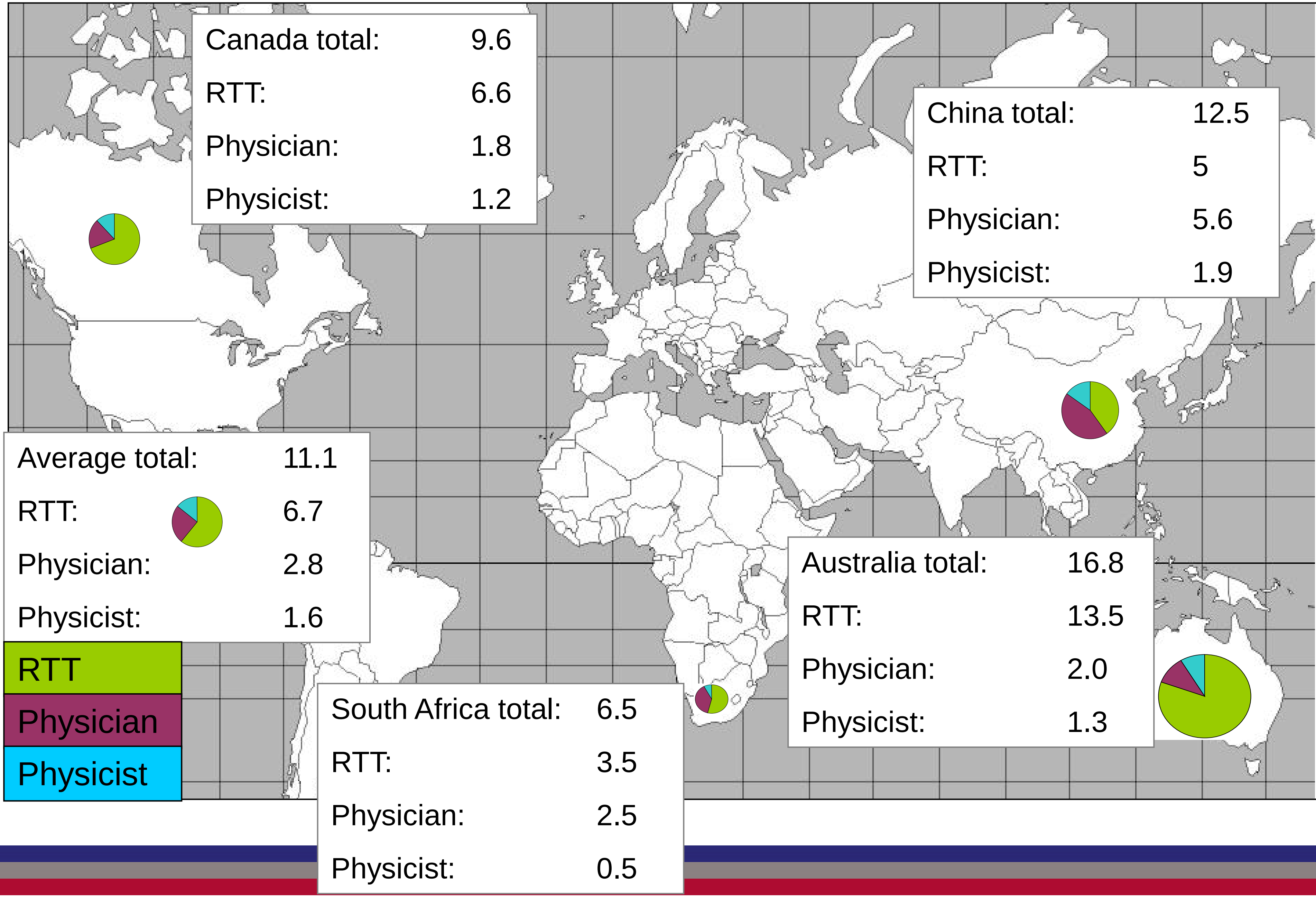
- 2 or 4 years of classroom combined with clinical intern hours → bachelor degree
- 3 years of nursing school with bachelor degree with additional theoretical or clinical RTT training ~1 year.

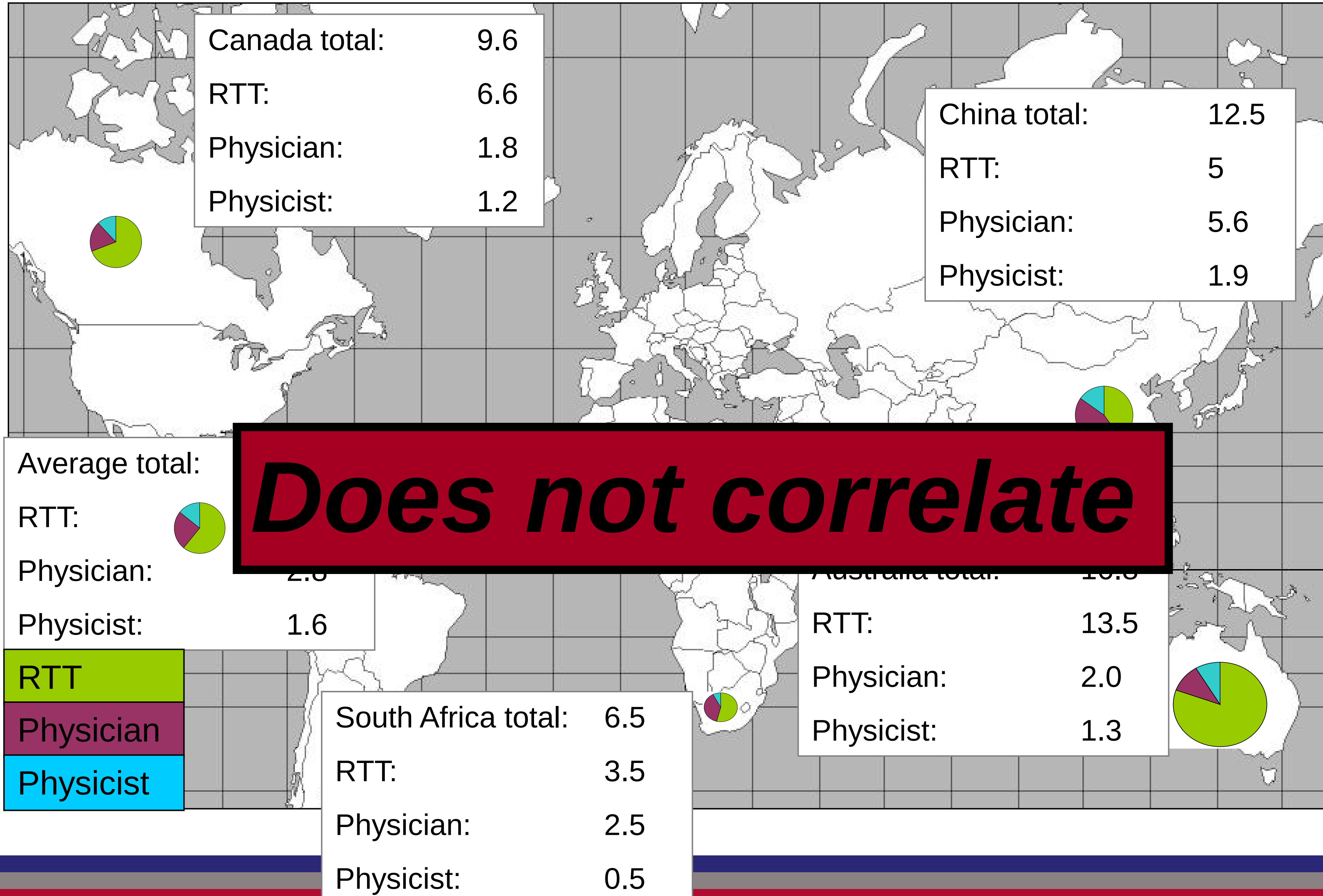
Resources per treatment machine
Department size



Average total:	11.1 (6.0 – 18.6)
RTT:	6.7 (3.5 – 15.0)
Physician:	2.8 (1.0 – 5.4)
Physicist:	1.6 (0.5 – 2.4)
Linacs/department	4.3 (1 – 12)
Patients/Linac/year	438 (200 – 700)


Sweden total: 12
RTT: 8.0
Physician: 2.4
Physicist: 1.7
Germany total: 7.8
RTT: 3.8
Physician: 2.5
Physicist: 1.6
Average total: 11.1
RTT: 6.7
Physician: 2.8
Physicist: 1.6
RTT
Physician
Physicist
Turkey total: 6
RTT: 3.5
Physician: 2.0
Physicist: 0.5


Canada total: 9.6
RTT: 6.6
Physician: 1.8
Physicist: 1.2
China total: 12.5
RTT: 5
Physician: 5.6
Physicist: 1.9
Average total: 11.1
RTT: 6.7
Physician: 2.8
Physicist: 1.6
RTT
Physician
Physicist
Australia total: 16.8
RTT: 13.5
Physician: 2.0
Physicist: 1.3
South Africa total: 6.5
RTT: 3.5
Physician: 2.5
Physicist: 0.5


Canada total: 9.6
RTT: 6.6
Physician: 1.8
Physicist: 1.2
China total: 12.5
RTT: 5
Physician: 5.6
Physicist: 1.9
Average total:
RTT:
Physician:
Physicist: 1.6
Does not correlate
RTT: 13.5
Physician: 2.0
Physicist: 1.3
RTT
Physician
Physicist
South Africa total: 6.5
RTT: 3.5
Physician: 2.5
Physicist: 0.5

IGRT

IGRT Modalities:

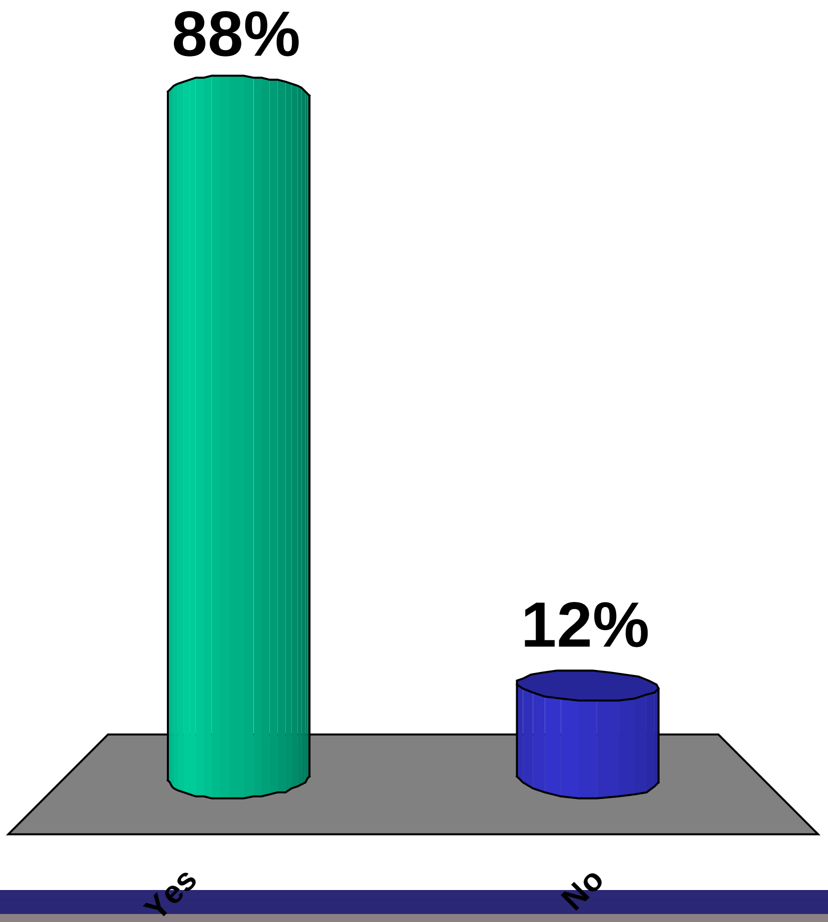
2D Portal Images	79%
2D kV Images	6%
kV Conebeam CT	66%
MV Conebeam CT	17%

IGRT protocols are:

– **Tumor site specific**	**100%**
– Patient specific	18%
– Physician specific	2%

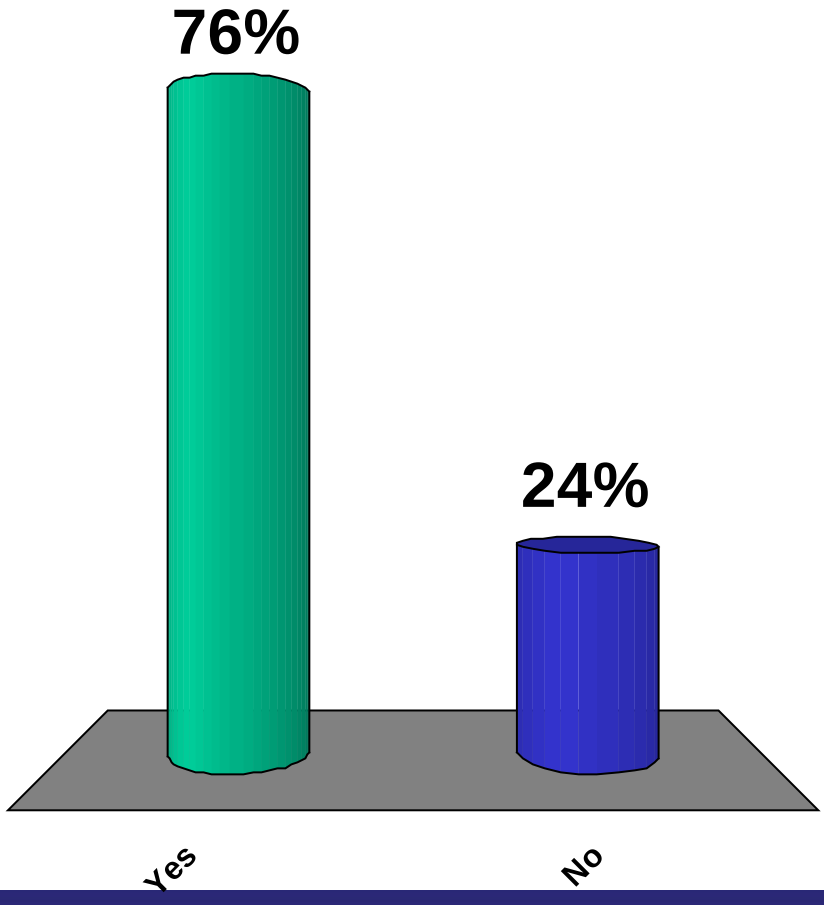
IGRT modalities: 2D MV

A. Yes
B. No



IGRT modalities: 2D kV

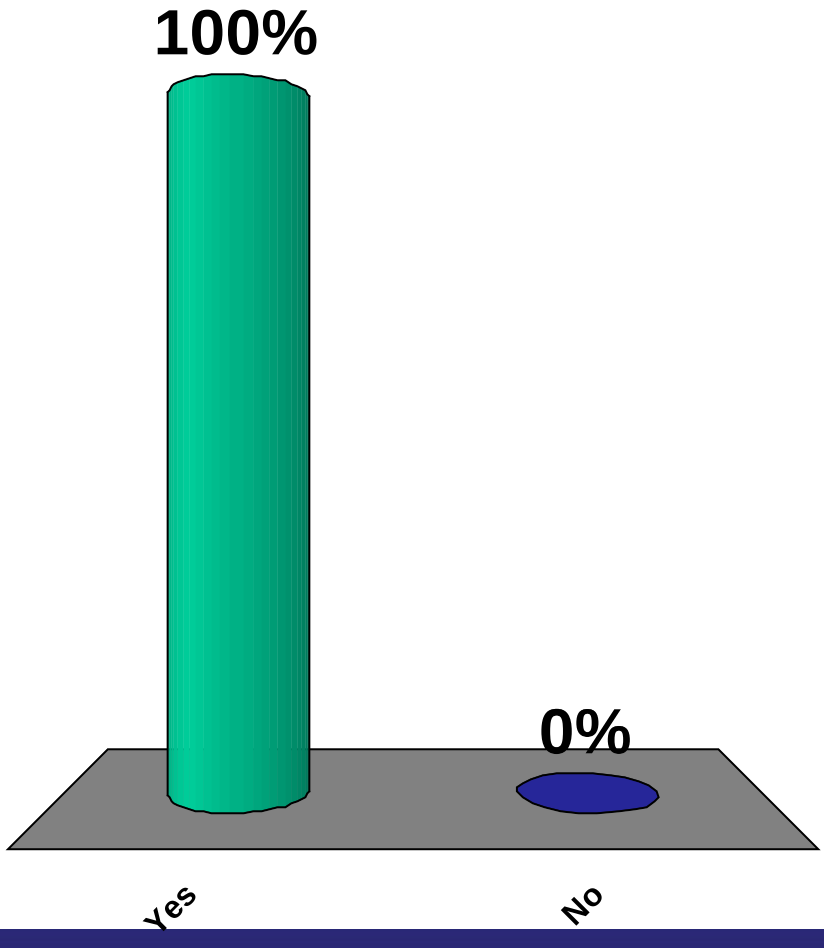
A. Yes
B. No



IGRT modalities: 3D kV

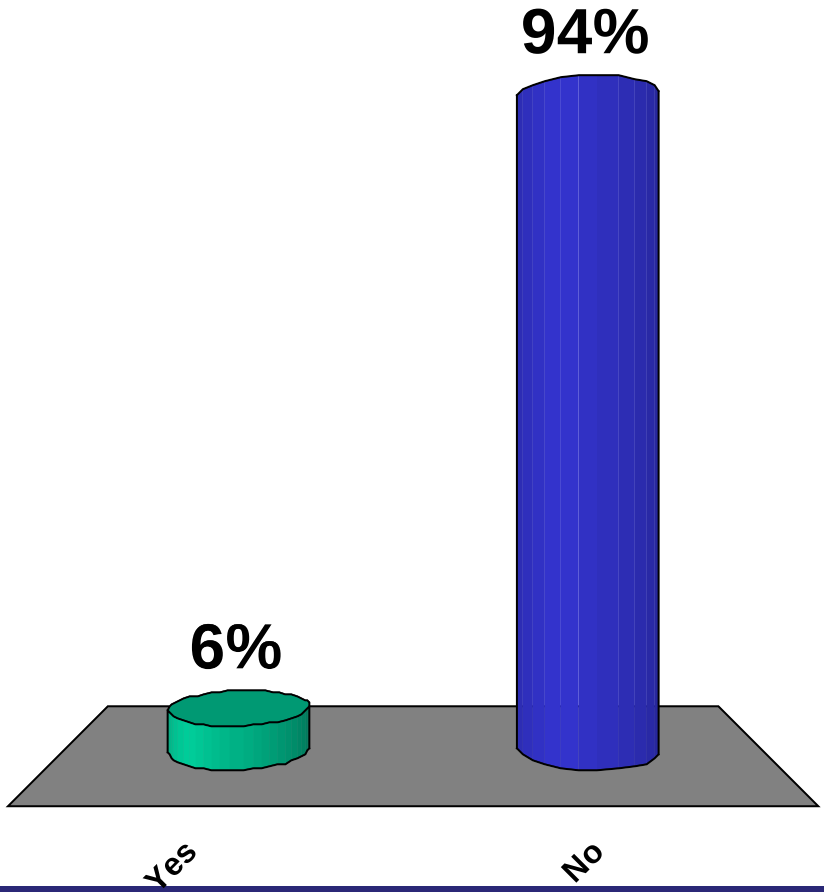
A. Yes

B. No



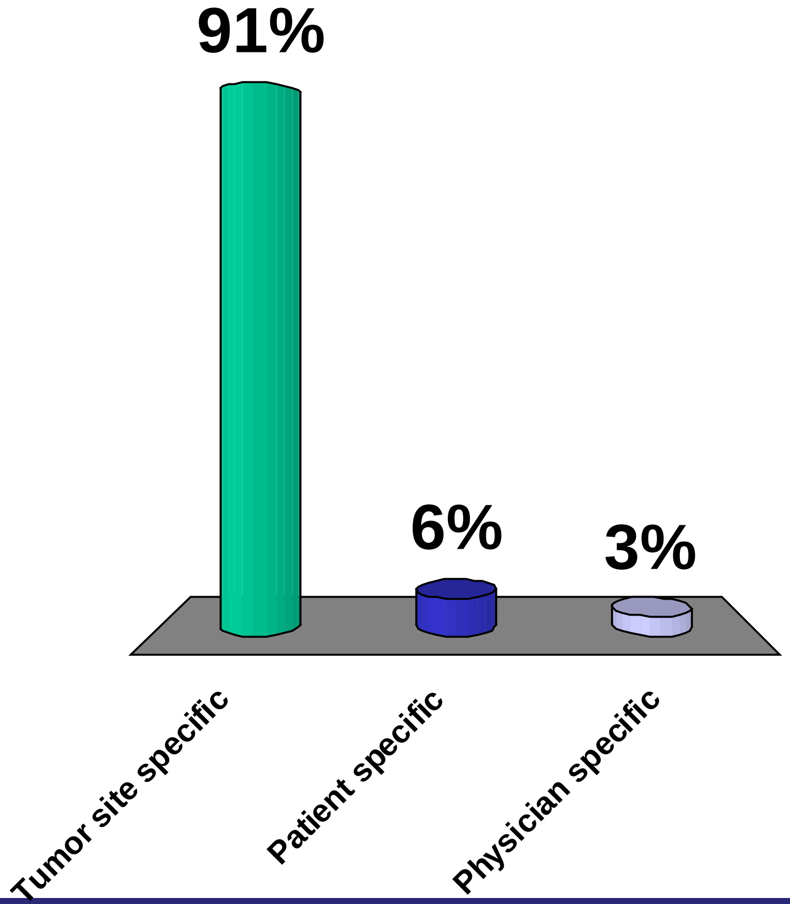
IGRT modalities: 3D MV

A. Yes
B. No



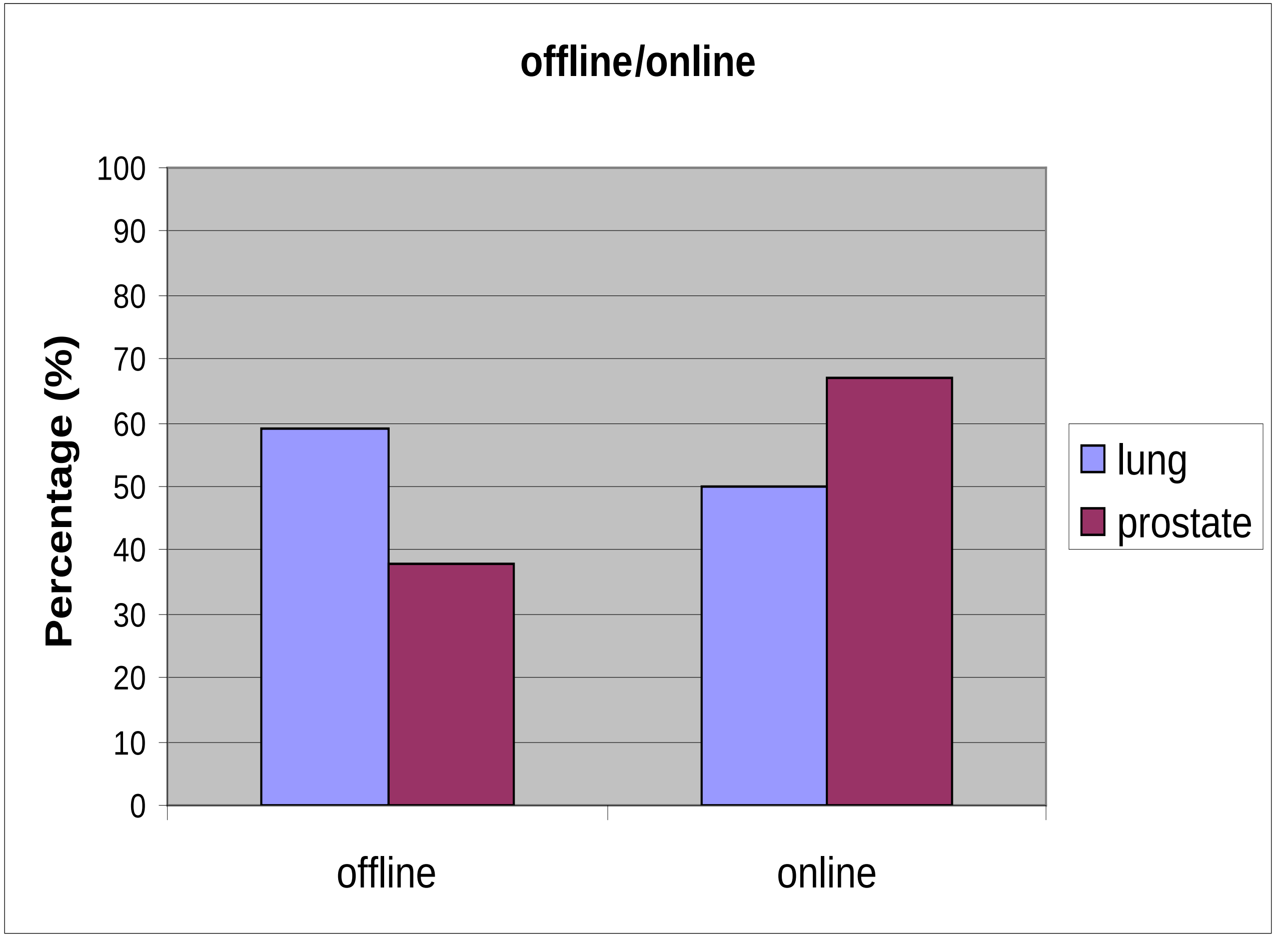
IGRT protocols are

A. Tumor site specific
B. Patient specific
C. Physician specific



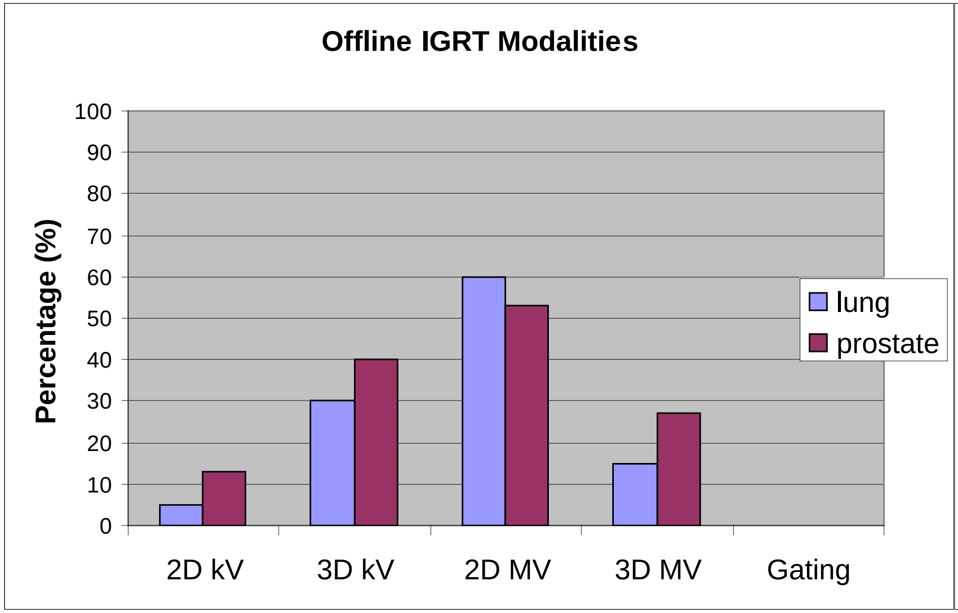
IGRT

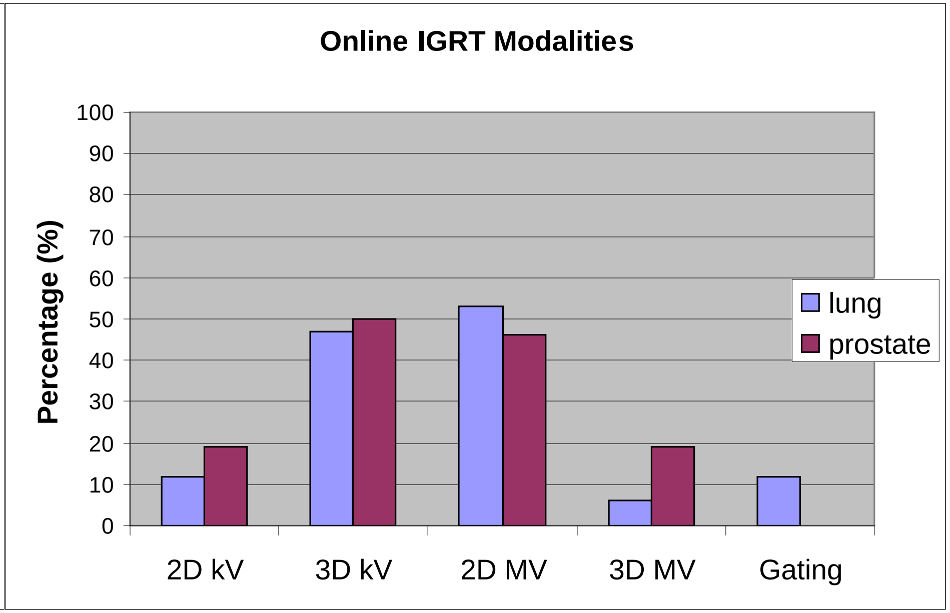
2D Portal Images	69%
kV Conebeam CT	67%
MV Conebeam CT	18%



IGRT

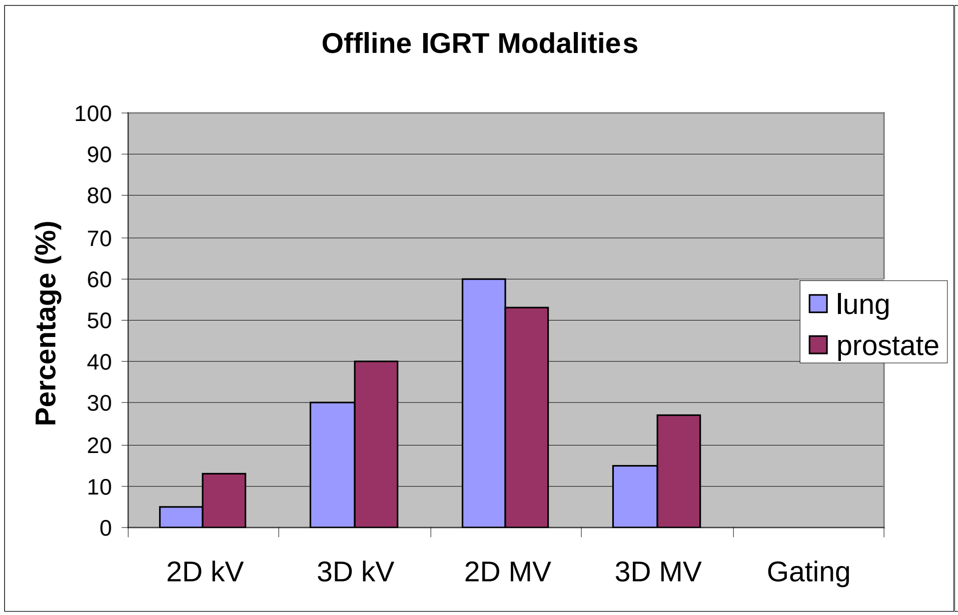
2D Portal Images	69%
kV Conebeam CT	67%
MV Conebeam CT	18%

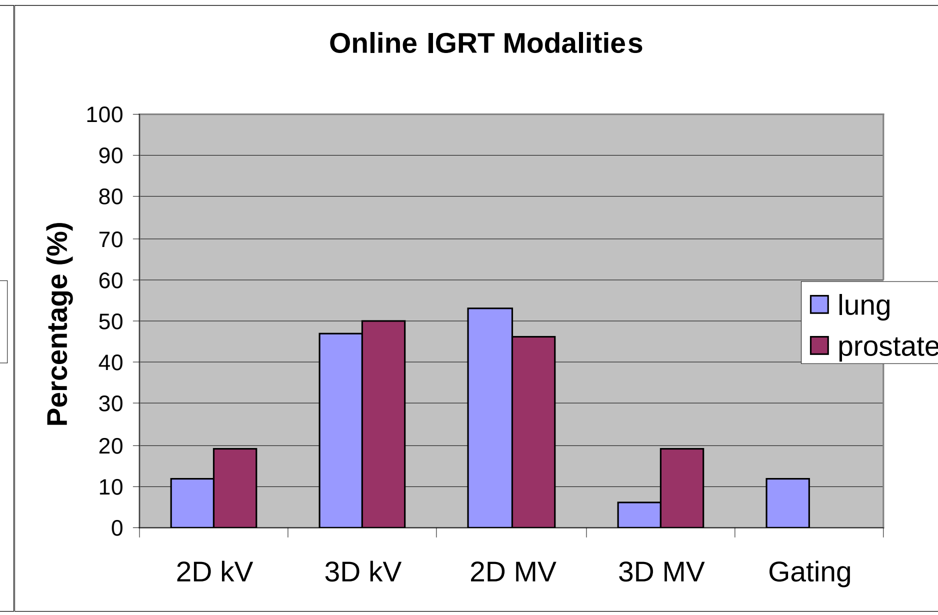




IGRT

2D Portal Images	69%
kV Conebeam CT	67%
MV Conebeam CT	18%

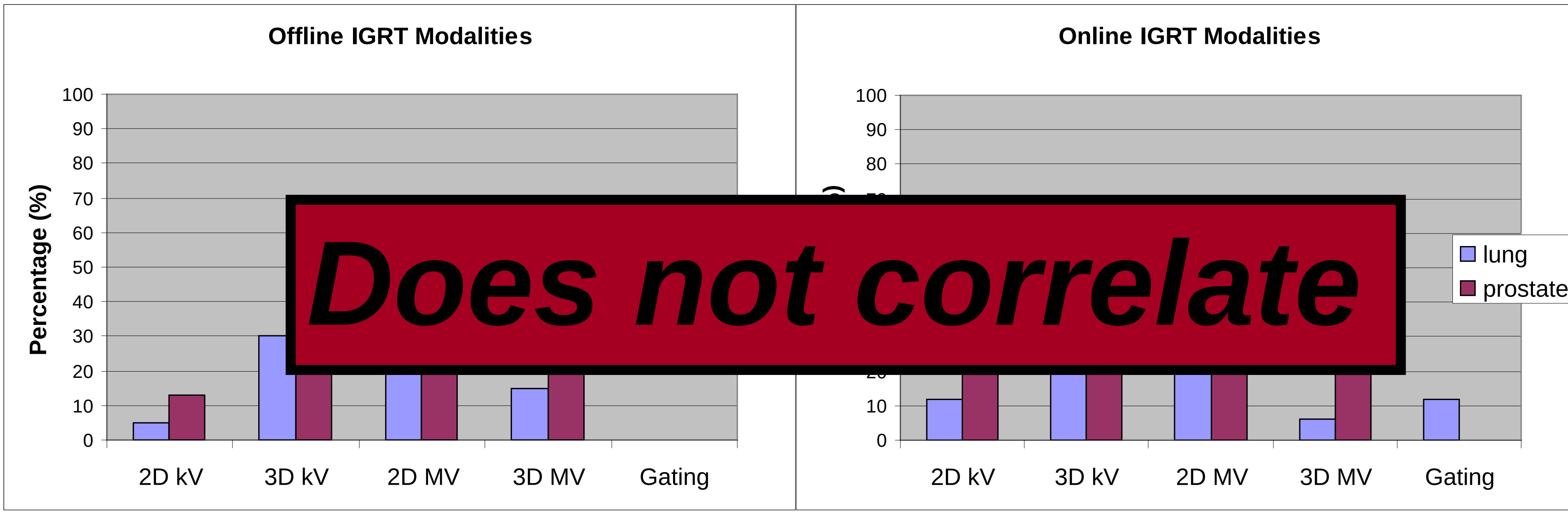




Adaptive Radiation Therapy… 0%

IGRT

2D Portal Images	69%
kV Conebeam CT	67%
MV Conebeam CT	18%

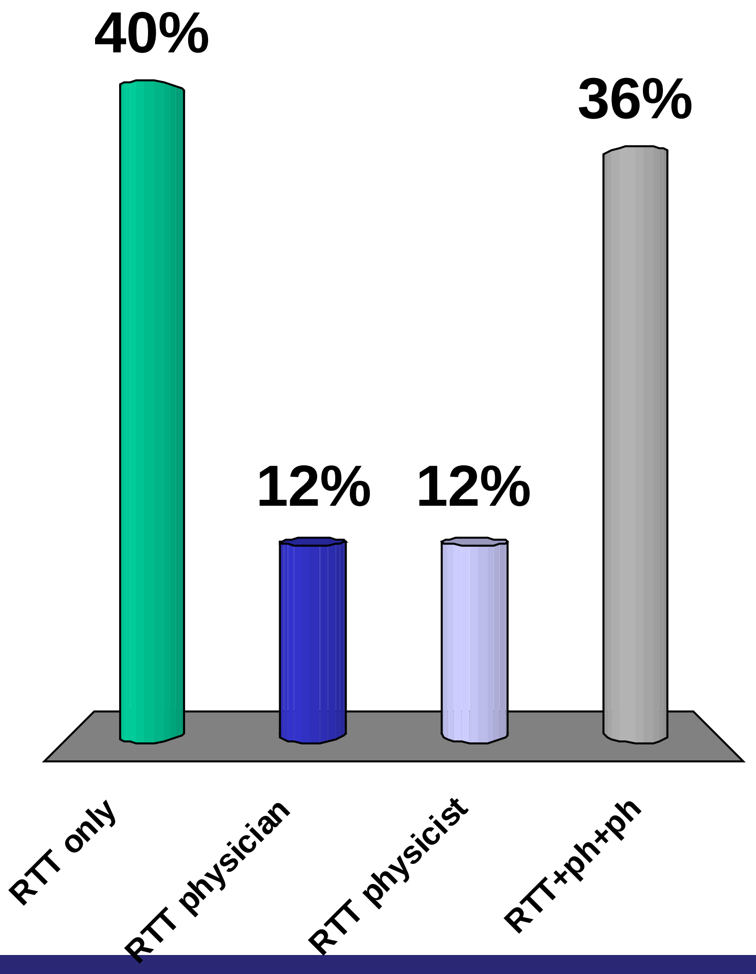


Does not correlate

→ Adaptive Radiation Therapy… 0%

MR-Linac?

A. RTT only
B. RTT physician
C. RTT physicist
D. RTT+ph+ph



Summary

Large variation between departments in:

- Amount of resources per linac
- Their distribution in different disciplines:
  - Treatment planning
  - IGRT evaluation

Some Variables

- RTT training and education
- Department size
- Resources per treatment machine
- IGRT Modalities
      - » Culture – History
      - » Money

Not decisive

Might consider different solutions?

Questions & Discussion

m.a.j.dejong@amc.uva.nl

NKI-AVL

The Netherlands Cancer Institute
Antoni van Leeuwenhoek Hospital

HFMEA – Martijn Kamphuis

Introduction

Ensuring Safety in Radiotherapy:

- Incident analysis
- Prevent is better then cure

Introducing new/altered techniques:

- Potential full of risks
- (H)FMEA
- VA National Center for Patient Safety (US)

Failure Modes and Effects Analysis (FMEA)

- Prospective risk assessment process
- Identify where and how it might fail (similar to aviation industry)

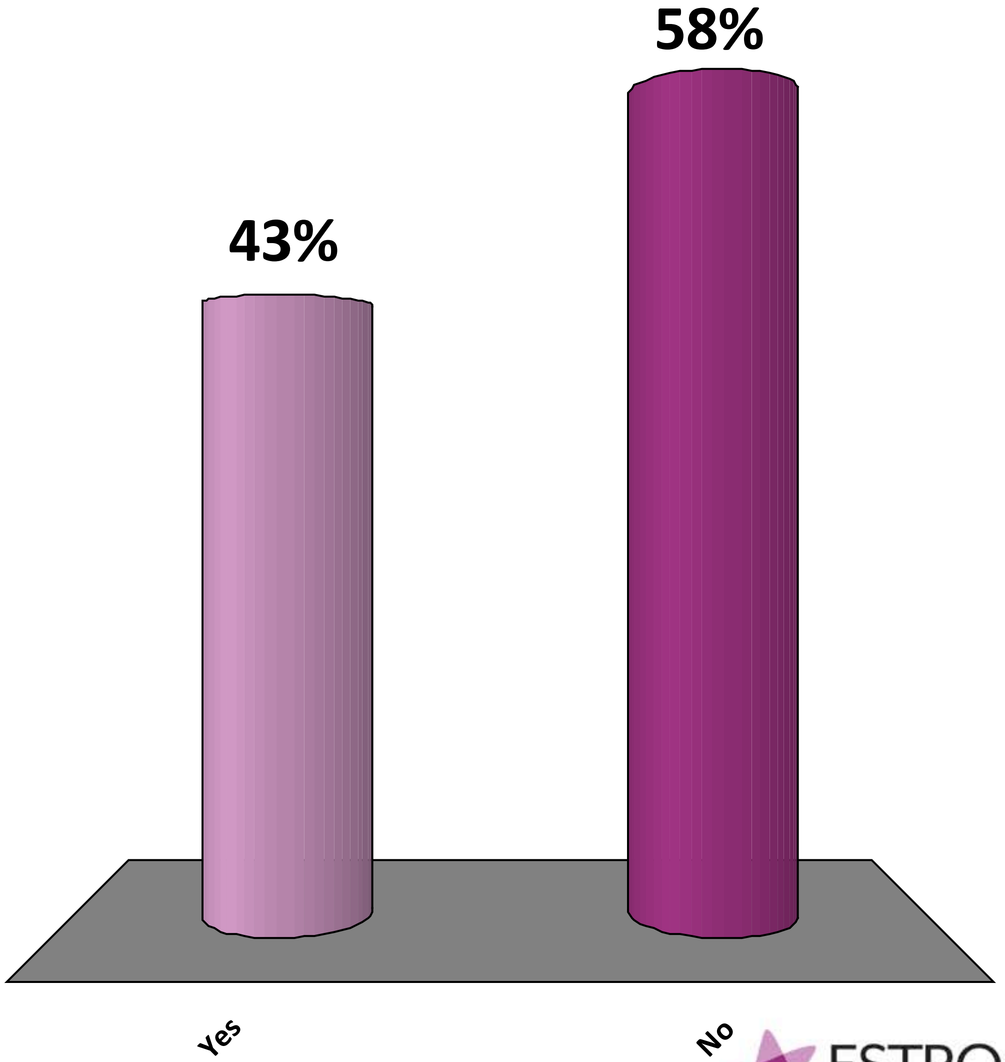
- Especially useful for new processes/changes to an existing process

- Dutch version, called SAFER: http://www.veiligezorgiederszorg.nl/speerpunt-vms/safer-boekje.pdf

Is anyone of you acquainted with FMEA or SAFER?

A. Yes

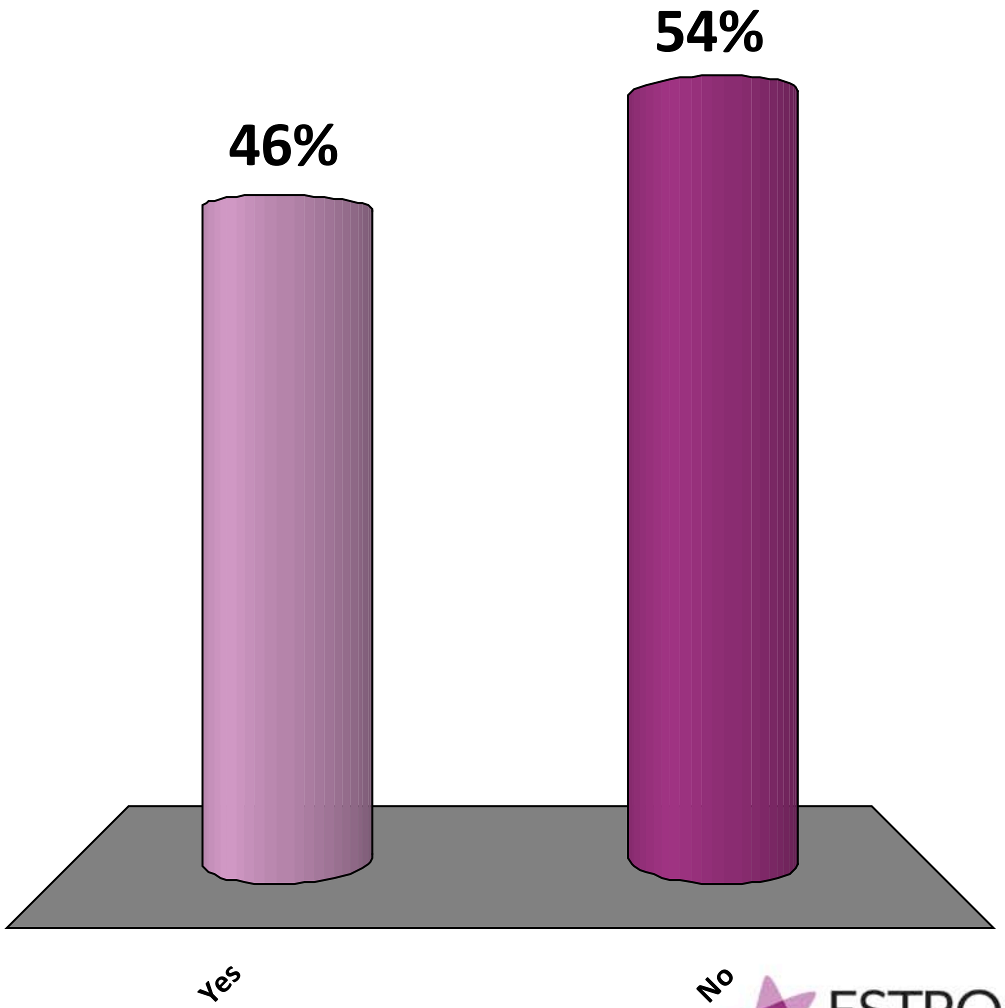
B. No



Is there anyone who was involved in a FMEA procedure?

A. Yes

B. No



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FMEA project

1. Process map/process tree
2. Recruit a multidisciplinary team
3. Organise a meeting of all of the relevant team members
4. List failure modes and causes
5. Assign RPN to each failure mode

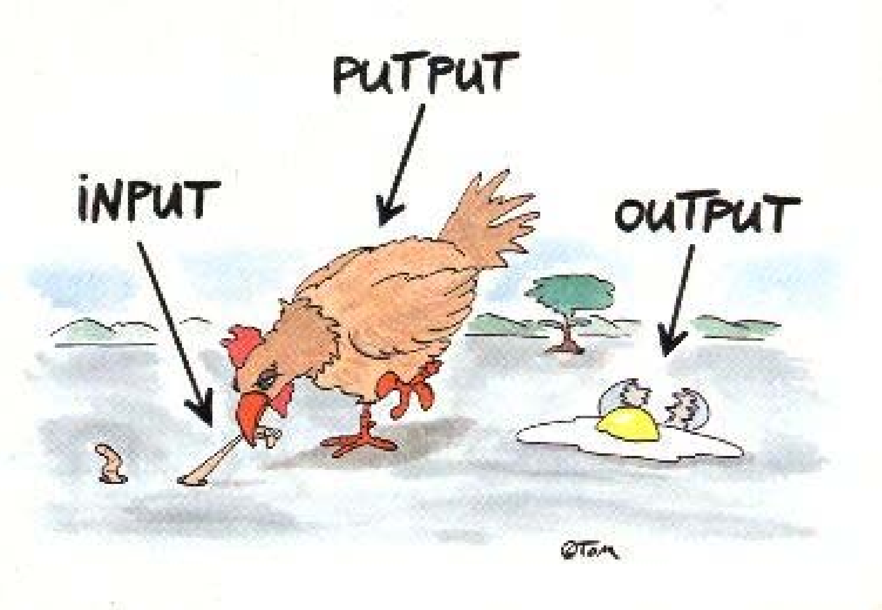
FMEA project

1. **Process map/process tree**
2. Recruit a multidisciplinary team
3. Organise a meeting of all of the relevant team members
4. List failure modes and causes
5. Assign RPN to each failure mode

Process Mapping

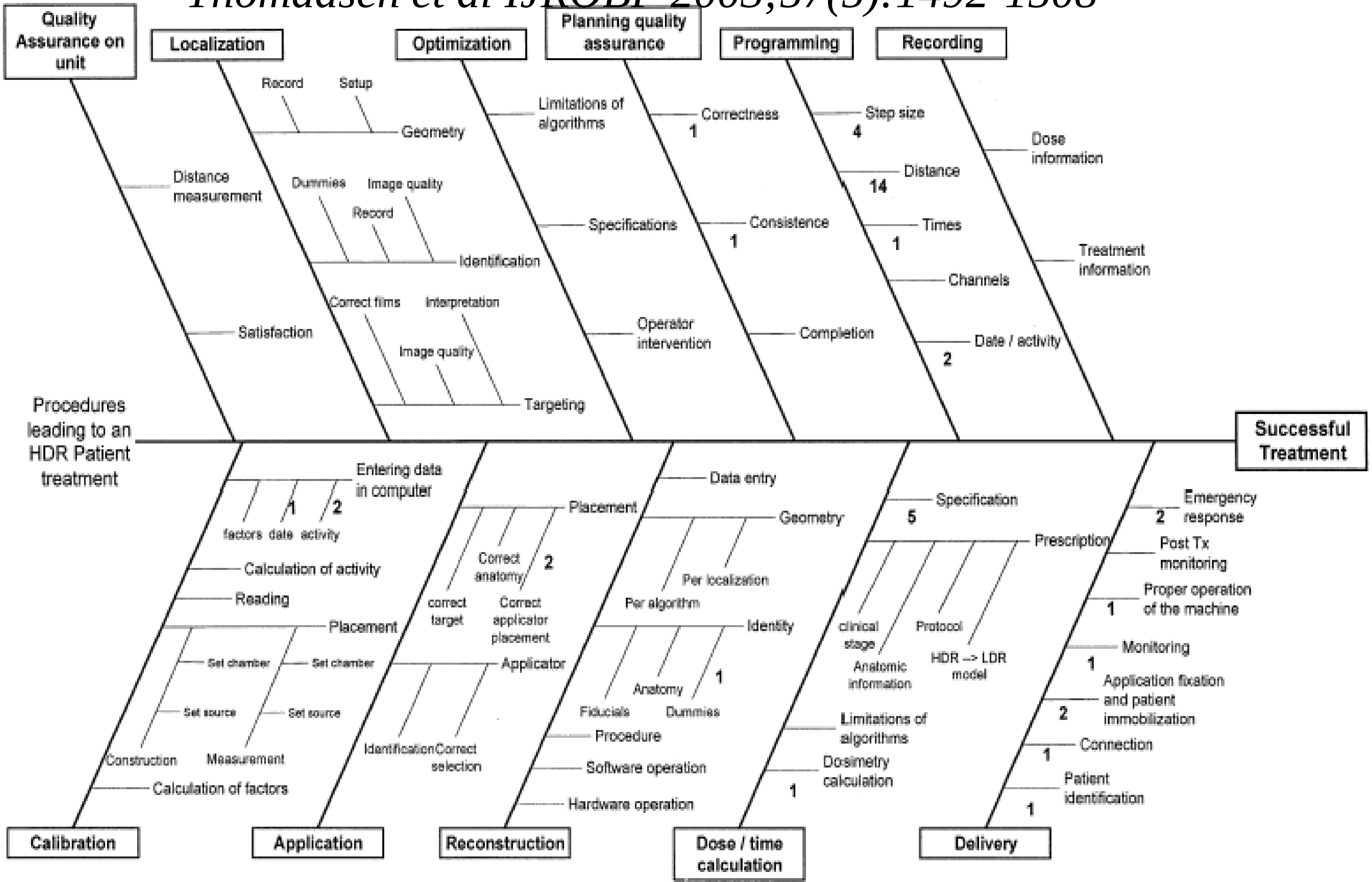
- Visual demonstration of work processes
- How inputs, outputs and tasks are linked together

- Input required from all stakeholders to ensure accuracy



Flow Chart - HDR Process Tree

Thomadsen et al IJROBP 2003;57(5):1492-1508



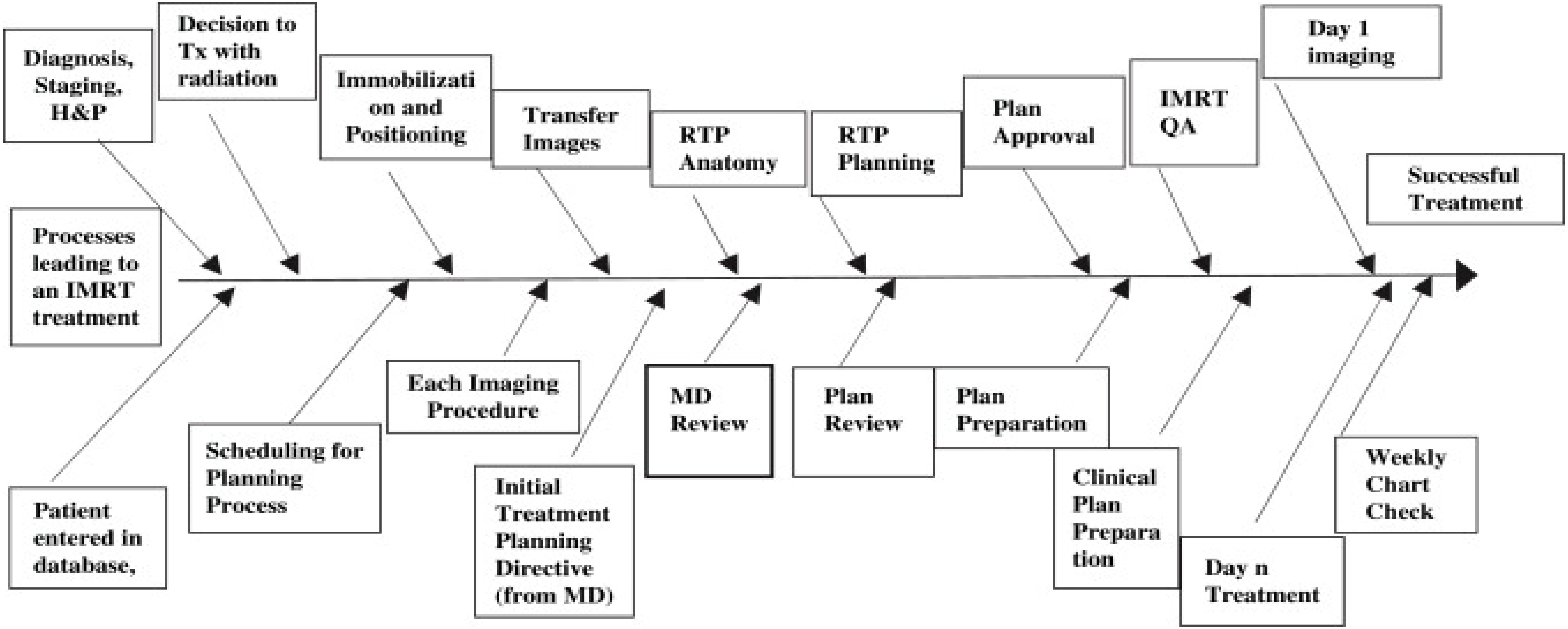


Fig. 1 An intensity-modulated radiation therapy (IMRT) process tree. MD = physician; QA = quality assurance; RTP = radiation therapy planning; Tx = treatment; H&P = history and physical.

M. Saiful Huq , Benedick A. Fraass , Peter B. Dunscombe , John P. Gibbons Jr. , Geoffrey S. Ibbott , Paul M. Medin...

A Method for Evaluating Quality Assurance Needs in Radiation Therapy

International Journal of Radiation Oncology*Biology*Physics Volume 71, Issue 1, Supplement 2008 S170 - S173
http://dx.doi.org/10.1016/j.ijrobp.2007.06.081

FMEA project

1. Process map/process tree
2. **Recruit a multidisciplinary team**
3. **Organise a meeting of all of the relevant team members**
4. List failure modes and causes
5. Assign RPN to each failure mode

Team

Radiation oncologists

Radiation therapists

Medical physicists

Administrators

Nurses

Clinical research coordinators

Information technologists

Managers

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FMEA project

1. Process map/process tree
2. Recruit a multidisciplinary team
3. Organise a meeting of all of the relevant team members
4. **List failure modes and causes**
5. Assign RPN to each failure mode

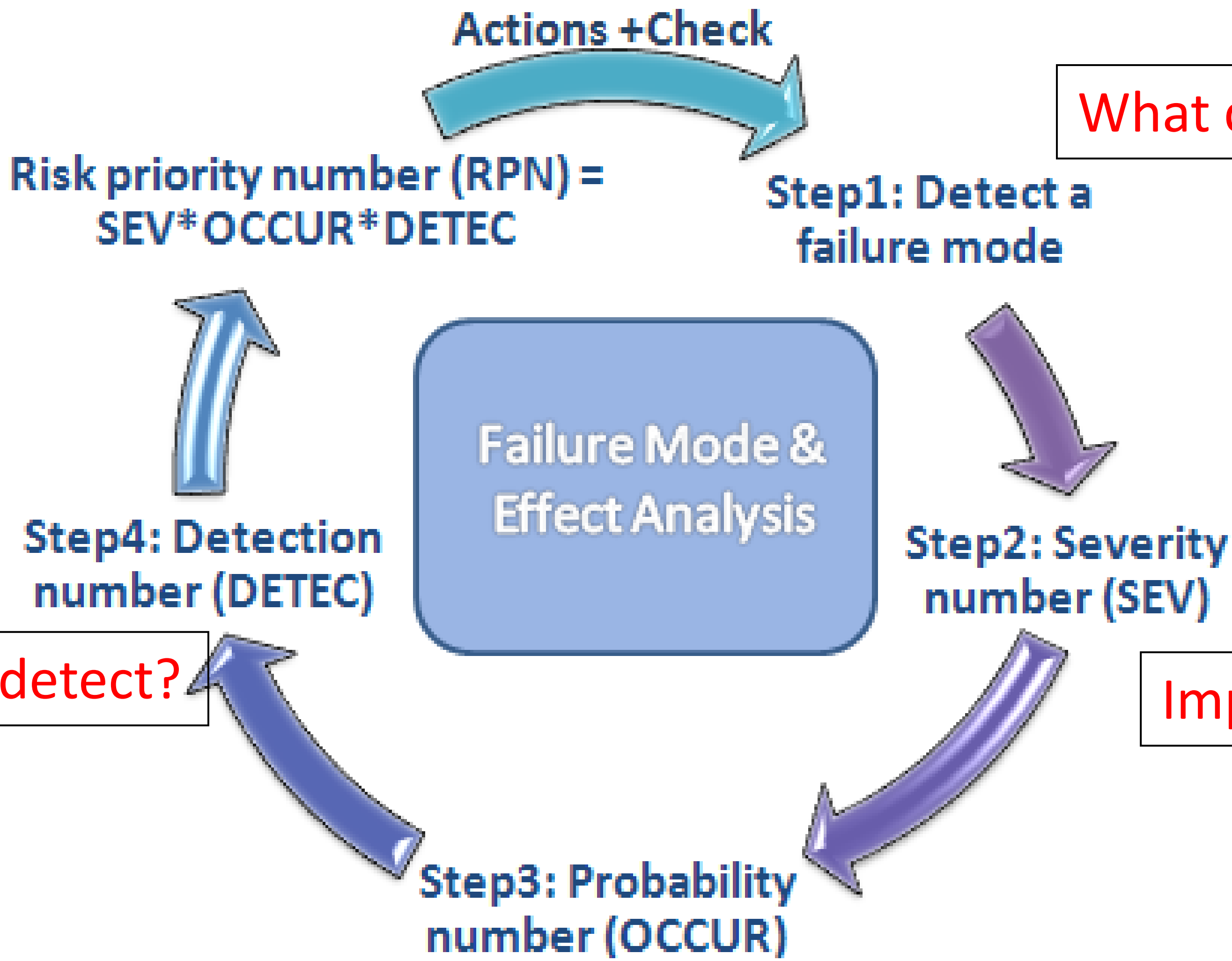
Steps in a FMEA Process

Reviews the entire process, broken down into individual steps

Determine per step:

- Failure modes – what can go wrong?
- Failure causes – why would the failure happen?
- Failure effects – what would the consequences be for each possible failure?

FMEA



What can go wrong?

Impact on patient

How likely is it that it will occur?

How easy is it to detect?

Source:www.meraevents.com

FMEA project

1. Process map/process tree
2. Recruit a multidisciplinary team
3. Organise a meeting of all of the relevant team members
4. List failure modes and causes
5. **Assign RPN to each failure mode**

Rank	Occurrence (O)		Severity (S)		Detectability (D)	
	Qualitative	Frequency	Qualitative	Categorization	Qualitative	Estimated Probability of going undetected (%)
1	Failure unlikely	1/10,000	No effect		Very easy to detect; QA checks already in place	0.01
2		2/10,000	Inconvenience	Inconvenience		0.2
3	Relatively few failures	5/10,000			Easy to detect, could be missed without double check, human error (e.g. transcription error)	0.5
4		1/1,000	Minor dosimetric error	Suboptimal plan or treatment		1.0
5		<0.2%	Limited toxicity or under-dose	Wrong dose, dose distribution, location or volume	Moderate, a “lucky catch”	2.0
6	Occasional failures	<0.5%			Very difficult to detect	5.0
7		<1%	Potentially serious toxicity or under-dose			10
8	Repeated failures	<2%				15
9		<5%	Possible very serious toxicity	Very wrong dose, dose distribution, location or volume	Almost impossible to detect; no QA in place	20
10	Failures inevitable	>5%	Catastrophic			>20

Example RT Process: Ford *et al*, 2009

Identified four sub processes in EBRT:

1. Patient consult
2. Simulation
3. Treatment Planning
4. Patient Treatment

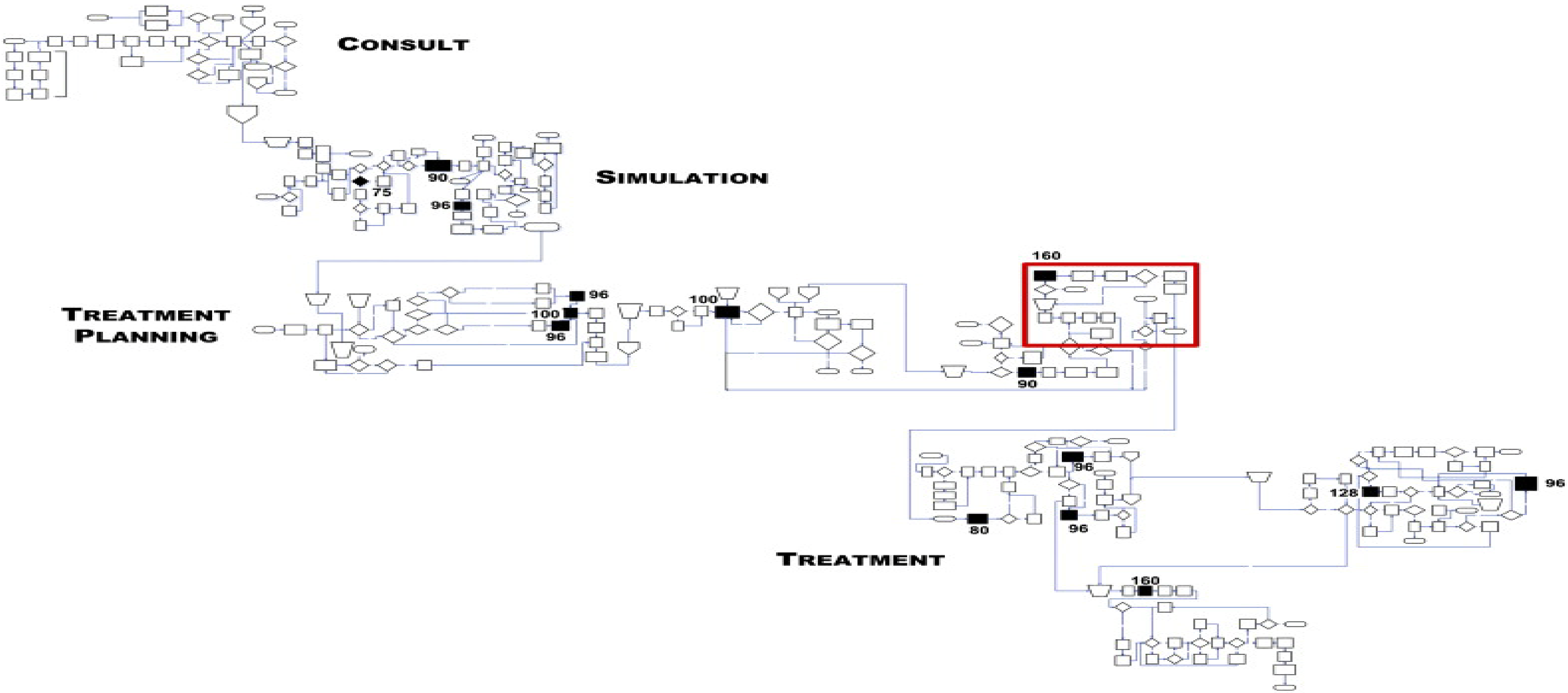


Fig. 1 External beam process map exhibiting 269 process nodes.

Eric C. Ford , Ray Gaudette , Lee Myers , Bruce Vanderver , Lilly Engineer , Richard Zellars , Danny Y. Song , Jo...

Evaluation of Safety in a Radiation Oncology Setting Using Failure Mode and Effects Analysis

International Journal of Radiation Oncology*Biology*Physics Volume 74, Issue 3 2009 852 - 858
http://dx.doi.org/10.1016/j.ijrobp.2008.10.038

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Example: Step _*x*_ in Process: *Field Placement*

Failure Mode	Failure Causes	Failure Effects
Incorrect Isocentre	Planning shift not specified in R&V set-up	Target under-dosed; Dose delivered to incorrect area; recurrent
	Shift specified incorrectly in set-up instructions	Target under-dosed; Dose delivered to incorrect area; recurrent
	Shift specified correctly but made incorrectly	Target under-dosed; Dose delivered to incorrect area; once-off
	Staff omitted to make shift	Target under-dosed; Dose delivered to incorrect area; once-off

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Example: Step _x_ in Process: *Field Placement*

Likelihood of Occurrence	Likelihood of Detection	Severity	RPN Risk Priority Number	Actions to reduce occurrence of failure
5	3	5	75	Training;
5	3	5	75	Training: 2nd checking systems/methods;
3	7	1	21	Verify table position
3	7	1	21	Verify table position

FMEA: putting it all together

1. Process map/process tree
2. Recruit a multidisciplinary team
3. Organise a meeting of all of the relevant team members
4. List failure modes and causes
5. Assign RPN to each failure mode

Is the procedure safe enough for clinical introduction or should it be altered?

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The Workshop (50 minutes)

Prospective Risk Analysis of a Online 3D portal imaging protocol

- Form groups of 4-6 people
- Form your group find a nice spot to discuss
- Discuss the topics suggested for your group
  - ➢ For every topic, think of 3 possible failure modes
  - ➢ For every failure mode, write down:
    - It’s cause
    - It’s effects
    - The likely hood of occurence
    - The likely of detection
    - Its severity
  - ➢ Calculate the RPN
  - ➢ If there time left, think of recommanded actions

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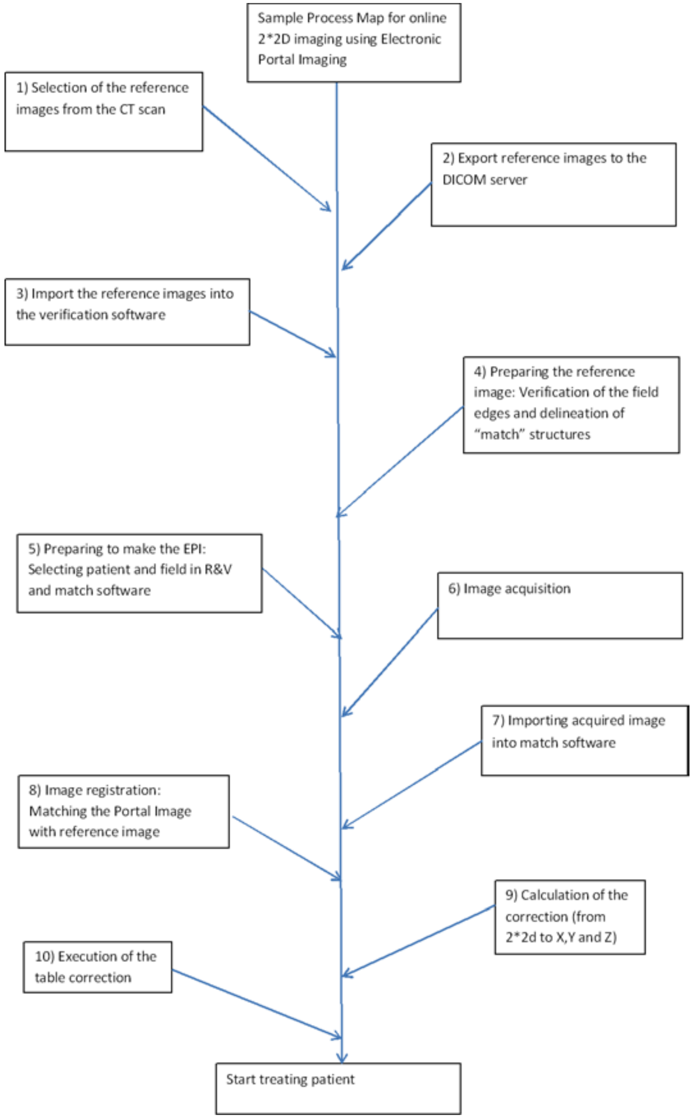
Process map: Online 3D portal imaging

e.g. 6) Image acquisition:

- Image field treated, PI software wasn't ready yet
- Additional dose of 3 cGy put into patient
- Likelyhood: 3-4
- Severity: 2-4
- Detectability: 3

- RPN=3-4*2-4*3=18-48
- Recommendations:
  - Education
  - Better software



Feedback session

Steps in the Process	Potential Failure Mode	Potential Failure Causes	Potential Failure Effects	Likelihood of Occurrence (1-10)	Likelihood of Detection (1-10)	Severity (1-10)	Risk Priority Number (RPN)	Recommended Actions
1	select wrong patient	No check	Treating with different iso	1	3	10	30	Compare ID Automatic check ID
2								
3								
4								
5	Image wrong patient	wrong patient selection	Imaging and treating wrong	4	3	5-9	60-120	Second check, interlock systematic
6								
7	imported under wrong fraction	Software fout	Register wrong image	1	4	3	12	One intergrated system
8	sagging	Pane off set	Not able to import	3-4	1	4	24-32	Automatic postion verification
9								
10								

Thank you for your attention!

See you in Sydney!

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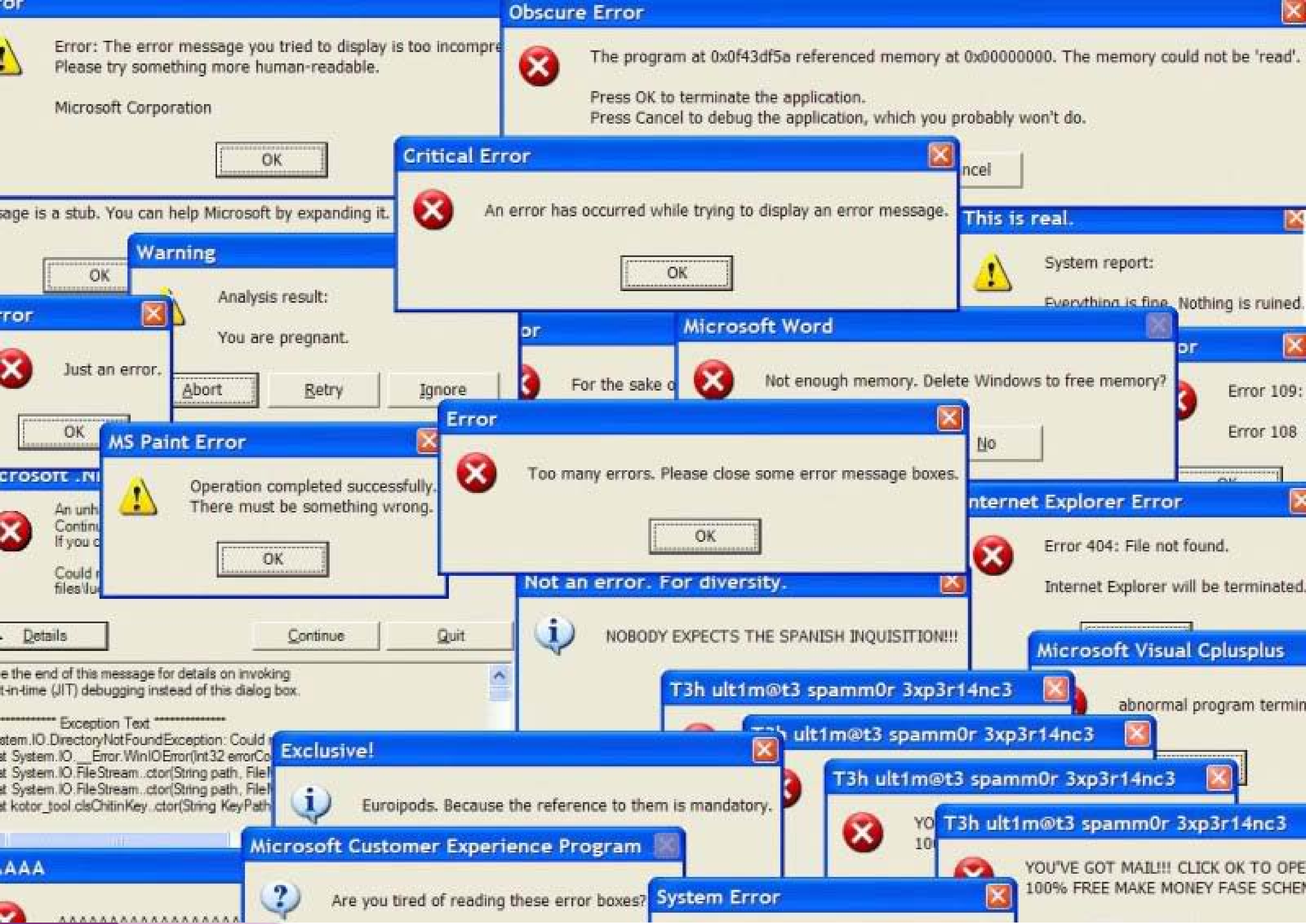
School

WWW.ESTRO.ORG/SCHOOL

Error management

Peter Remeijer
Department of Radiation Oncology
The Netherlands Cancer Institute


Error: The error message you tried to display is too incompre
Please try something more human-readable.
Microsoft Corporation
OK
Obscure Error
The program at 0x0f43df5a referenced memory at 0x00000000. The memory could not be 'read'.
Press OK to terminate the application.
Press Cancel to debug the application, which you probably won't do.
ncel
Critical Error
An error has occurred while trying to display an error message.
OK
sage is a stub. You can help Microsoft by expanding it.
OK
Warning
Analysis result:
You are pregnant.
Abort
Retry
Ignore
This is real.
System report:
Everything is fine. Nothing is ruined.
Just an error.
OK
For the sake o
Microsoft Word
Not enough memory. Delete Windows to free memory?
No
Error 109:
Error 108
Error
Too many errors. Please close some error message boxes.
OK
MS Paint Error
Operation completed successfully.
There must be something wrong.
OK
An unh
Continu
If you c
Could
files\lu
Details
Continue
Quit
nternet Explorer Error
Error 404: File not found.
Internet Explorer will be terminated.
Not an error. For diversity.
NOBODY EXPECTS THE SPANISH INQUISITION!!!
Microsoft Visual Cplusplus
abnormal program termin
e the end of this message for details on invoking
t-in-time (JIT) debugging instead of this dialog box.
************** Exception Text **************
stem.IO.DirectoryNotFoundException: Could
t System.IO.__Error.WinIOError(Int32 errorC
t System.IO.FileStream..ctor(String path, File
t System.IO.FileStream..ctor(String path, File
t kotor_tool.clsChitinKey..ctor(String KeyPath
T3h ult1m@t3 spamm0r 3xp3r14nc3
T3h ult1m@t3 spamm0r 3xp3r14nc3
T3h ult1m@t3 spamm0r 3xp3r14nc3
T3h ult1m@t3 spamm0r 3xp3r14nc3
Exclusive!
Euroipods. Because the reference to them is mandatory.
YOU'VE GOT MAIL!!! CLICK OK TO OPE
100% FREE MAKE MONEY FASE SCHEN
AAA
Microsoft Customer Experience Program
Are you tired of reading these error boxes?
System Error

More errors?

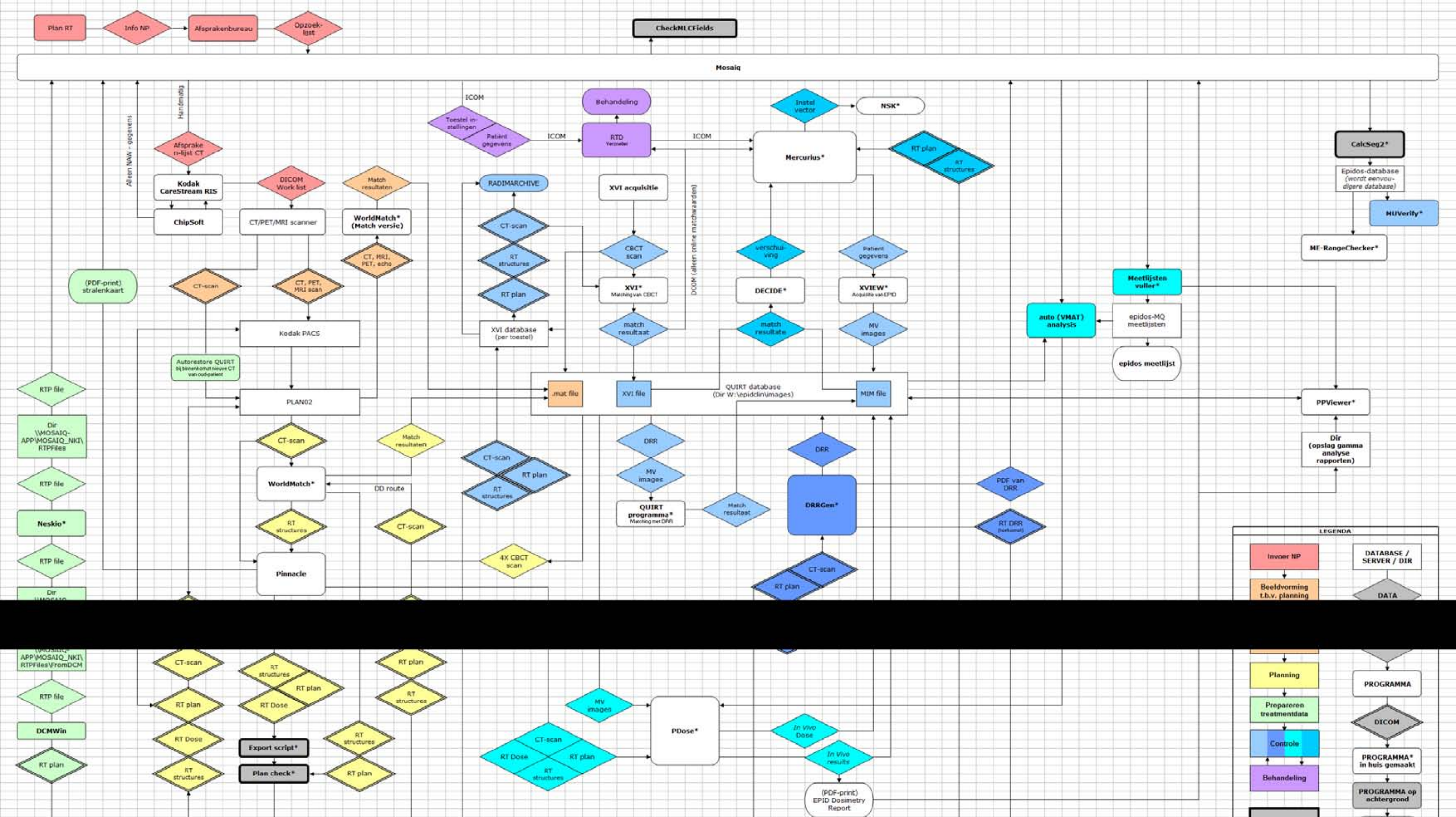
- Transfer errors (planning → linac)
- Linac errors (both dosimetric and geometric)
- Dosimetric errors in plan
- Input errors
- Patient setup (e.g. CT reference to isoc shifts)
- Select the right patient / treatment in all systems

More errors?

- Transfer errors (planning → linac)
- Linac errors (both dosimetric and geometric)
- Dosimetric errors in plan
- Patient setup (e.g. CT reference to isoc shifts)
- Input errors
- Select the right patient / treatment in all systems

Errors and the radiotherapy “chain”

The radiotherapy "chain"



“Chain test” a.k.a regression test with phantom

Regression testing

- Run a phantom through the whole treatment chain and check for problems / errors
  - May be necessary to do this for different situations, i.e. HFS, HFP, etc
  - New methods, e.g. ART, library of plans, new planning techniques (VMAT)
- This will check
  - Connectivity
  - Systematic equipment and software errors
  - Overall dosimetry
  - Overall geometry

More errors?

- Transfer errors (planning → linac)
- Linac errors (both dosimetric and geometric)
- Dosimetric errors in plan
- Patient setup (e.g. CT reference to isoc shifts)
- Input errors
- Select the right patient / treatment in all systems

Independent MU checks

- Recalculates the dose, based on the plan parameters from the planning system (or v.v.)
- This will check (in theory)
  - Amount of monitor units
  - Problems with plan normalization
  - Computation errors of planning system
- Third party software
  - Lots of software around (small companies)
  - Check what it really checks
  - Test with intentional errors

MU range checking

- In house NKI development

- Plans following a certain protocol, e.g. prostate
  - Amount of MU for a VMAT plan will be similar for each patient
  - Depends a little on patient size, etc

  → MU range check

  - If patient does not fall within the range, something may have gone wrong
  - Check by physics
  - About 5-10%
  - Usually anatomical reasons
  - Some errors found (wrong dose specification point)

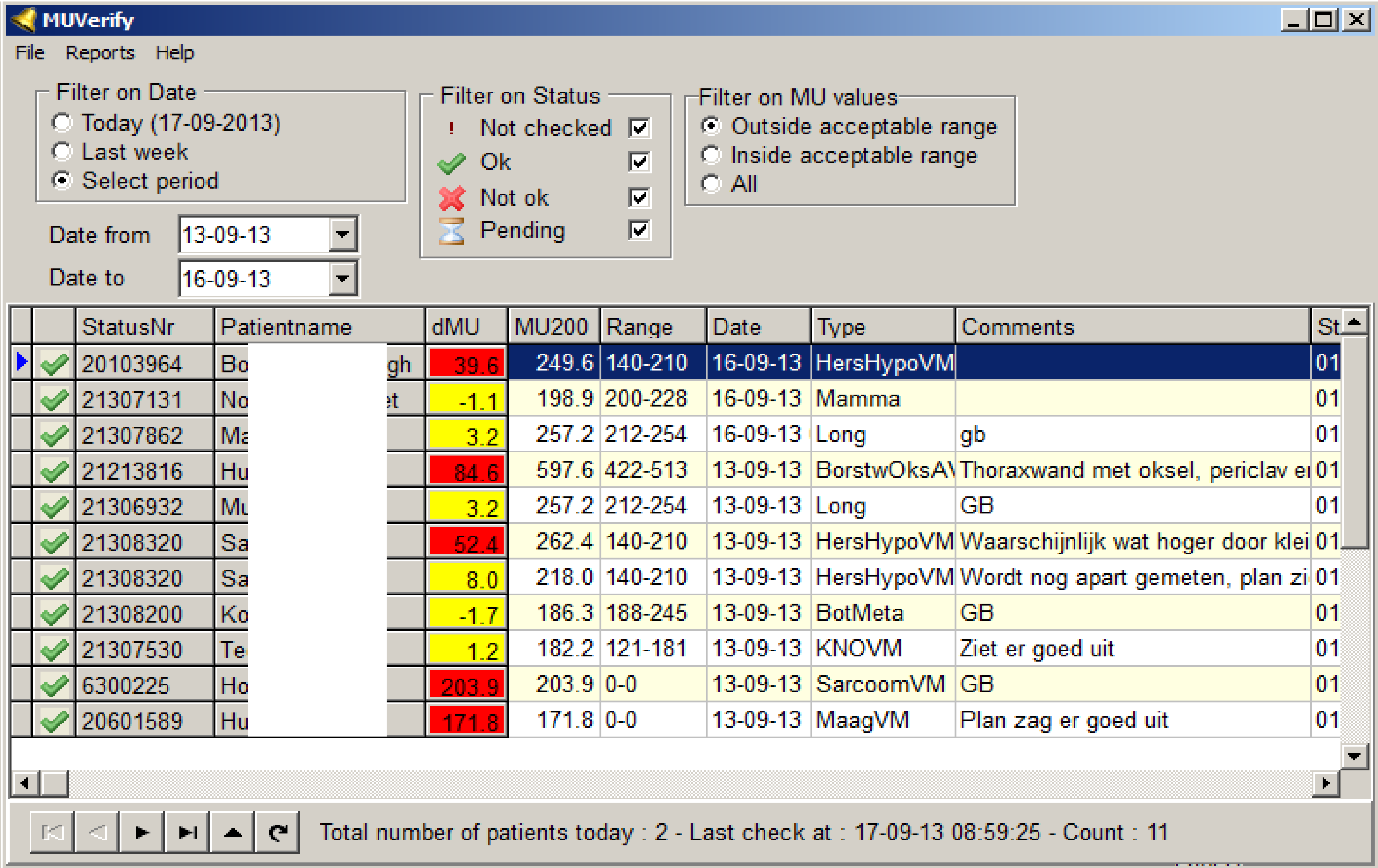
MU range checking

- Plan type depends on
  - Careplan name (brain, breast, prostate, etc)
  - RX-site name (plan name), e.g. Sacrum <231290>
  - Number of beams
  - Number of segments
  - Energy
  - Fraction dose

- Range for each type

CP	Nbeam		Nsegm		Energy		Fr.Dosis		Type	Min	Max
Anus	2	8	2	70	6	10	180	300	Anus	188	261
Blaas	1	2	70	180	6	10	180	400	BlaasVM	158	218
Cervix	2	10	2	60	6	10	180	800	Gyn	221	284

Automated message on desktop physicist



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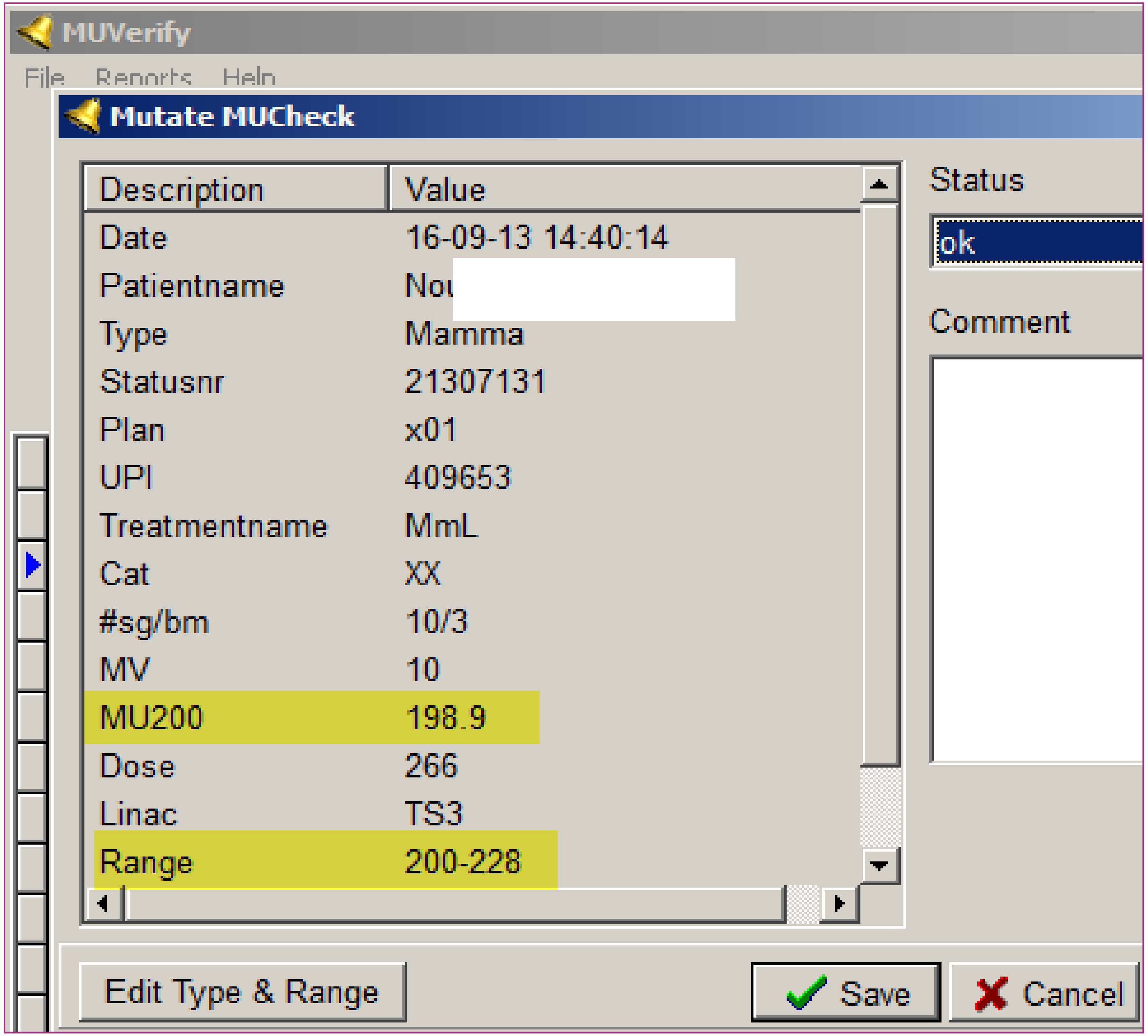
Automated message on desktop physicist



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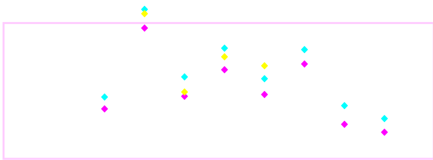
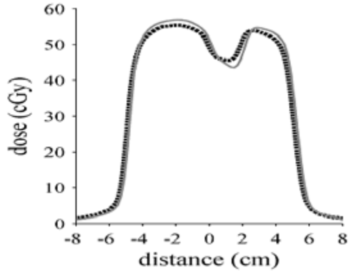
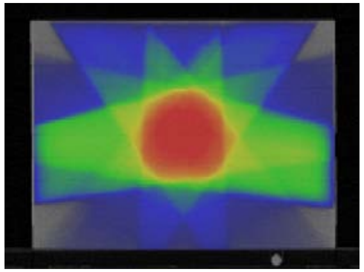
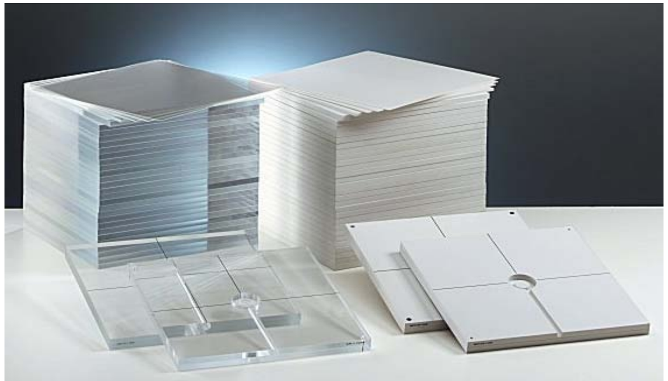
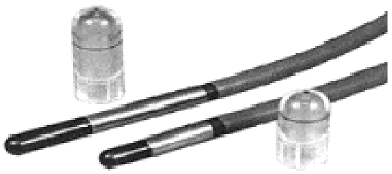
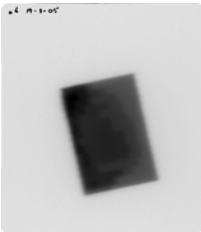
In-vivo portal dosimetry

in most centres today:

	0D	1D	2D
not 3D			
not *in vivo*			
not with an EPID			

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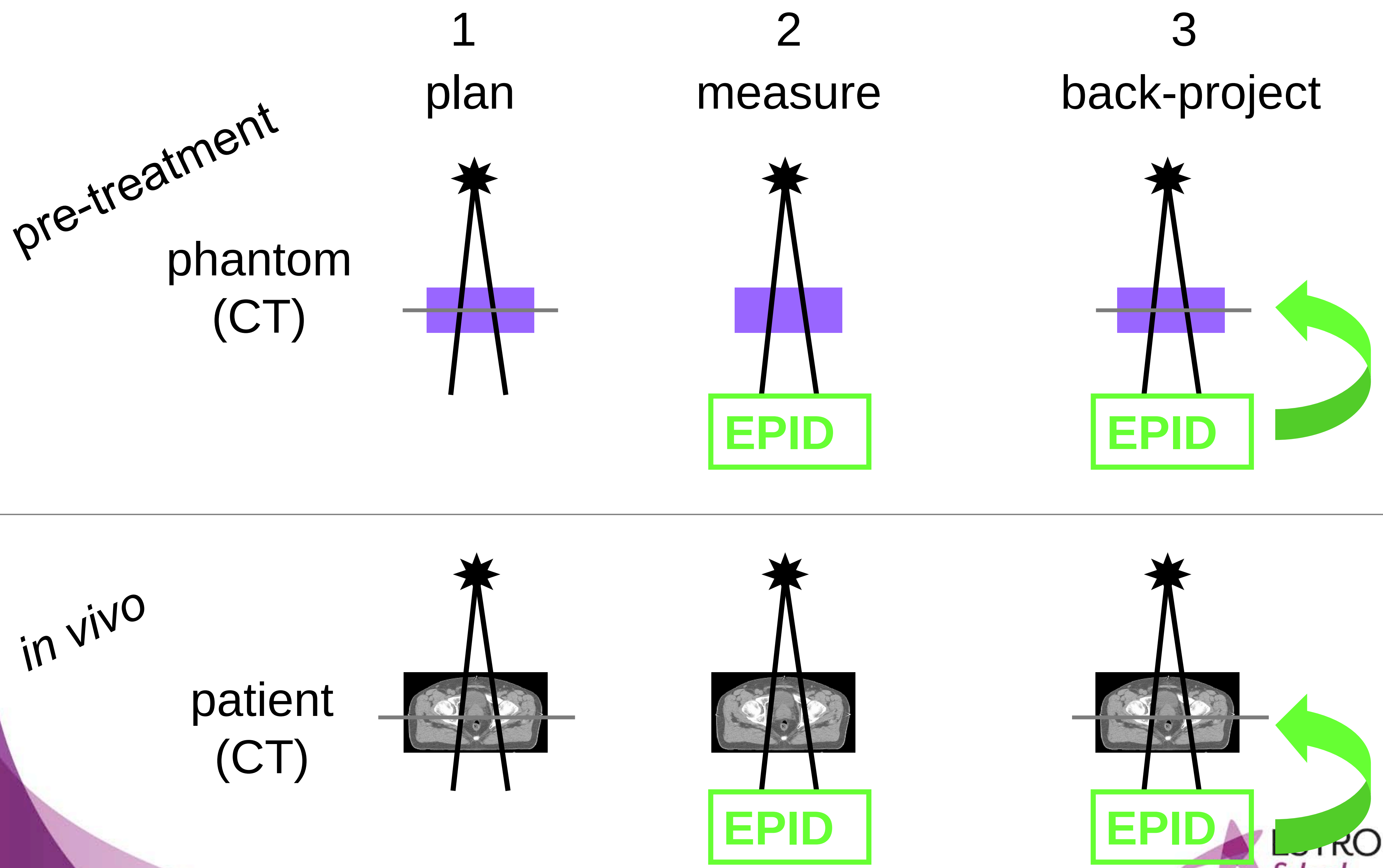
The NKI back-projection approach



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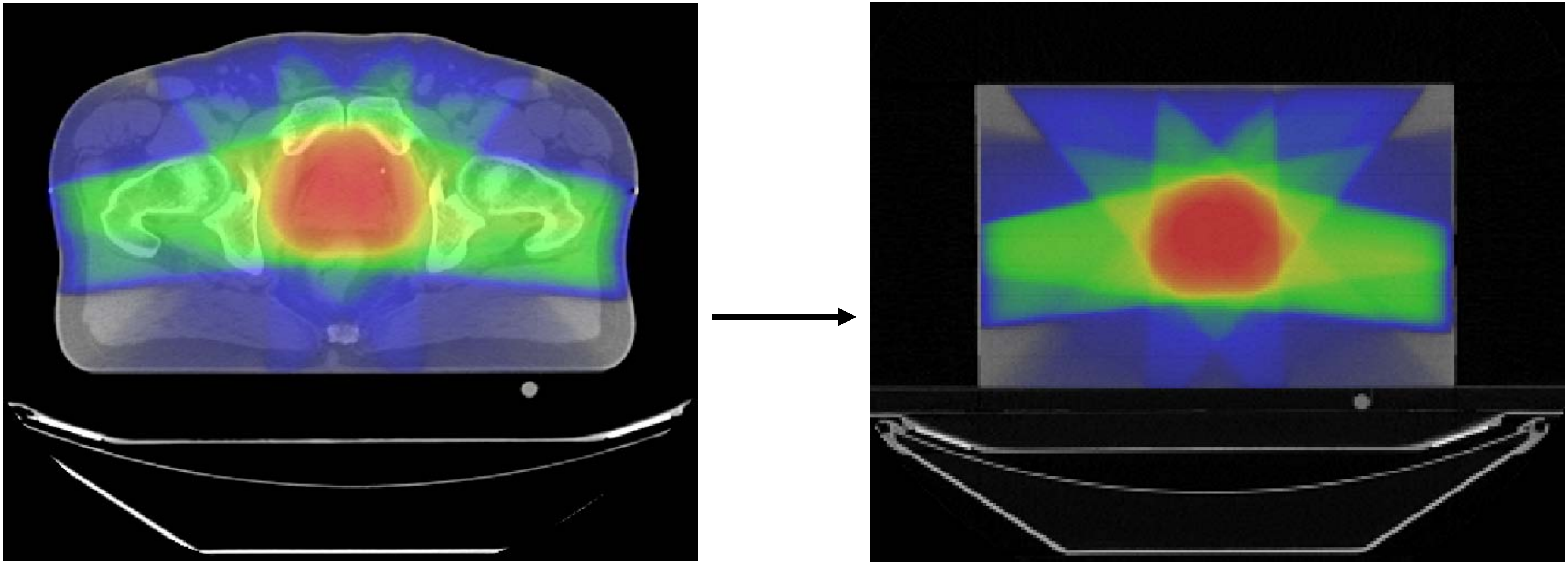
Pre-treatment : in a phantom

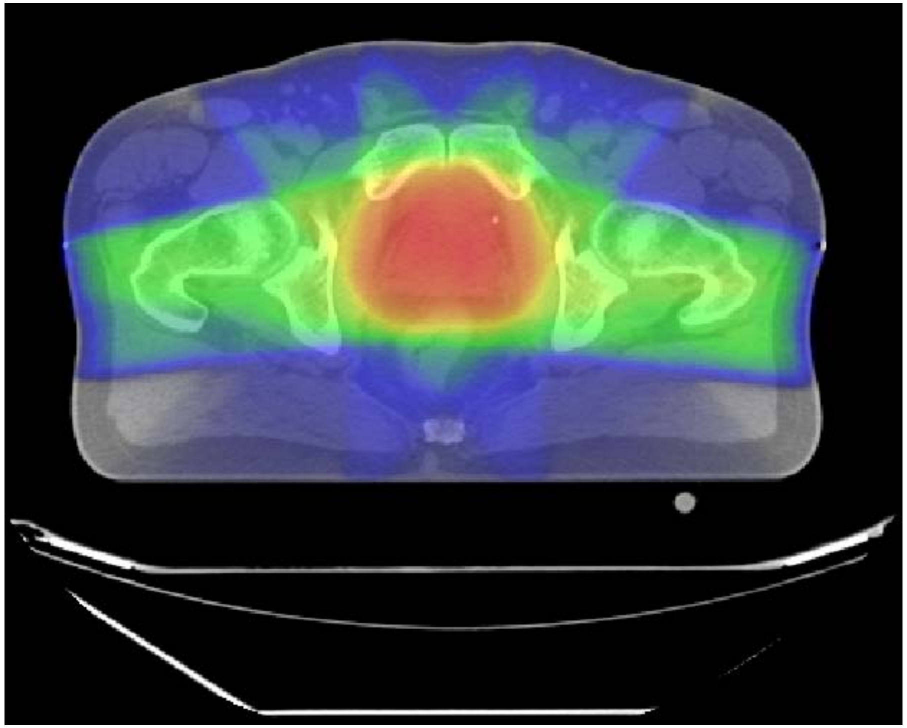


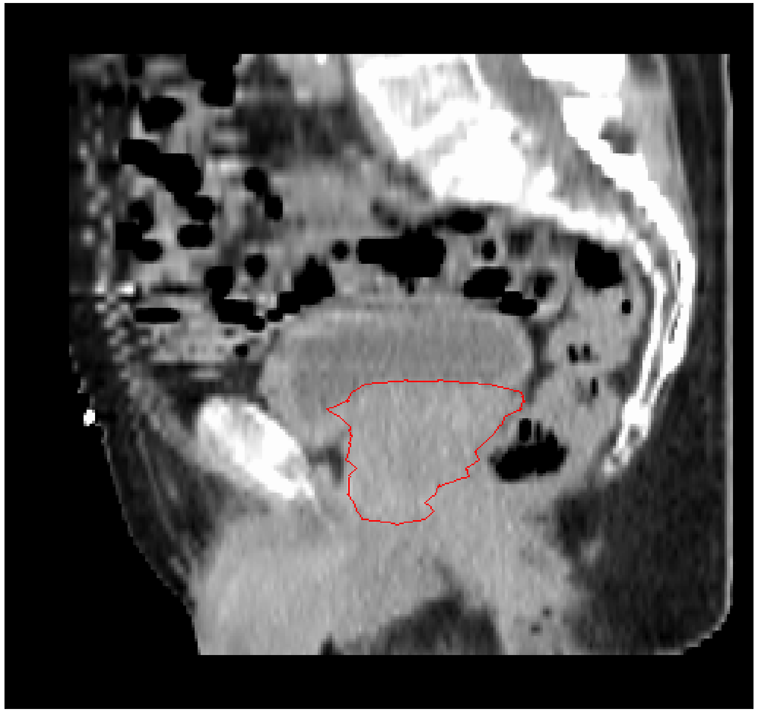
checks: plan deliverability

dose calculation

extra time : about 1 hour

In vivo : in the patient





checks: plan deliverability

dose calculation

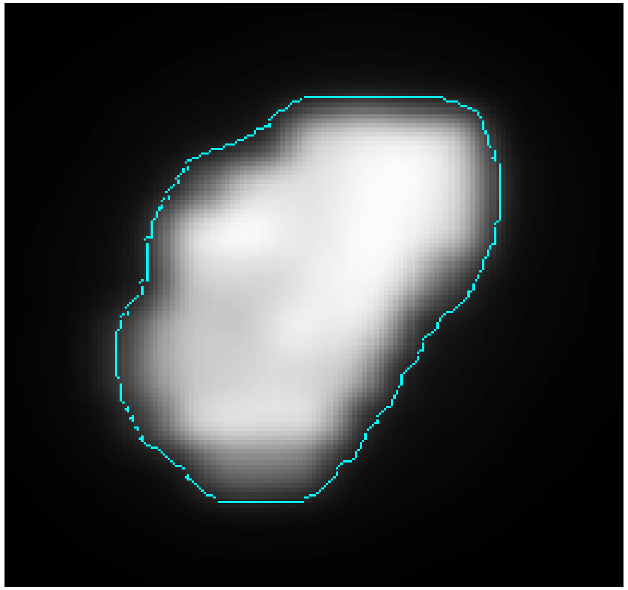
anatomy changes

random delivery errors

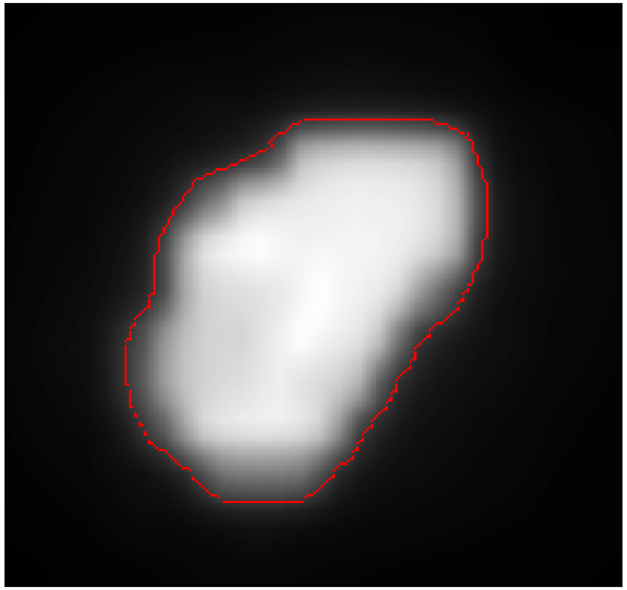
extra time : ~ 25 min in case of an error
+ 30s/day

Field-by field
reference vs calculated or measured dose

how do we compare them in 2D?

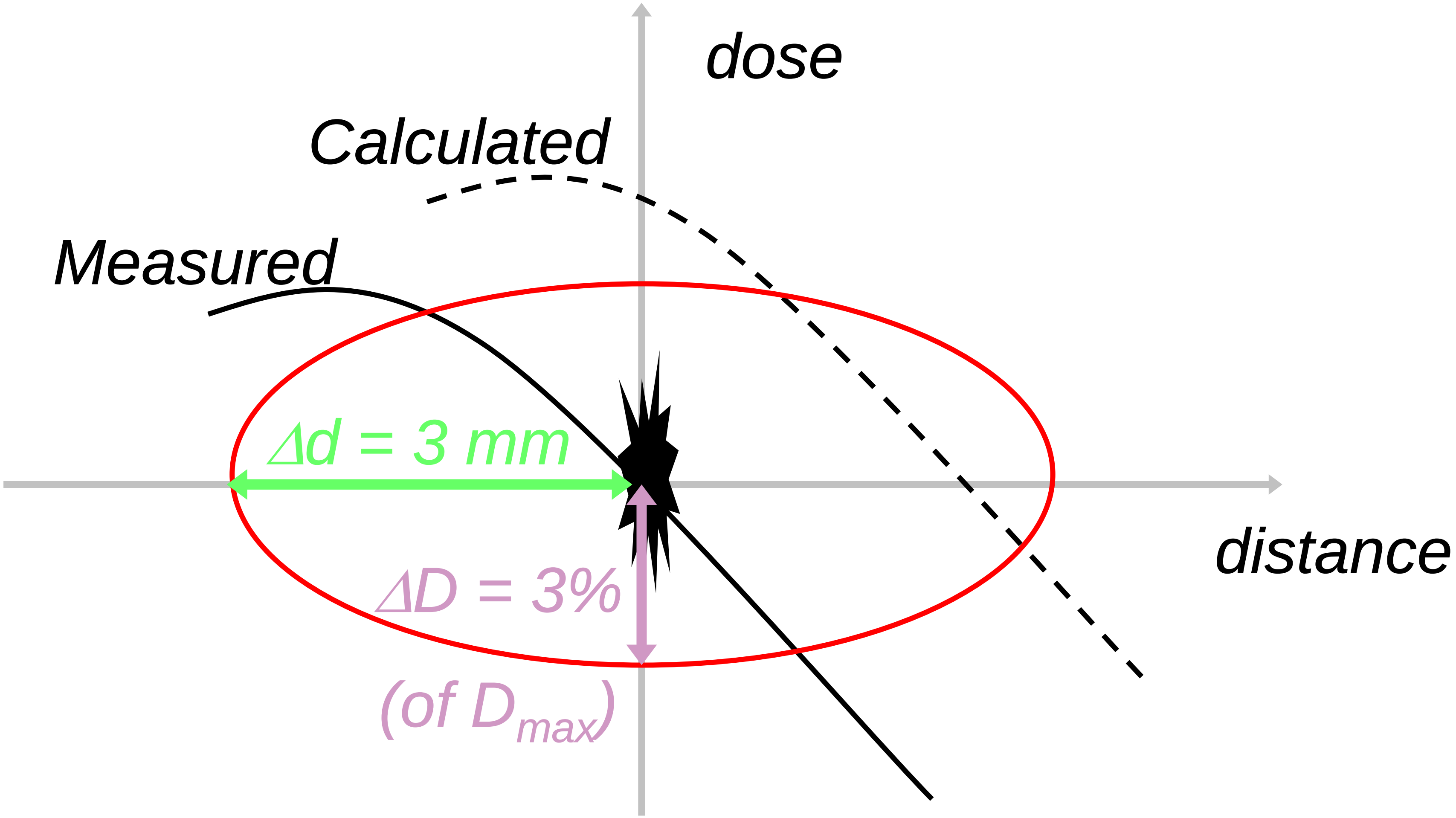


PLAN



EPID

γ-evaluation: calculation vs measurement



combines dose and distance criterion

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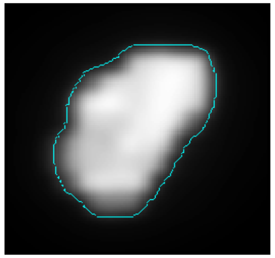
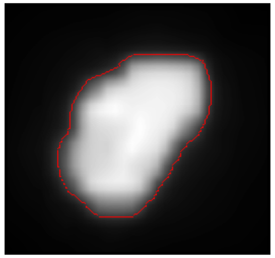
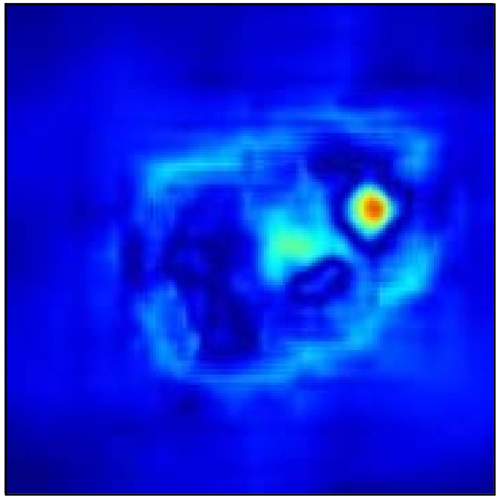
To compare the dose in 2D

plan



EPID



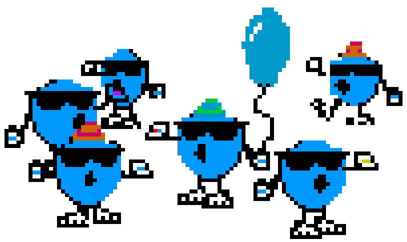


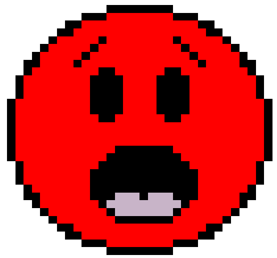
γ image

3% or 3mm

6% or 6mm

γ





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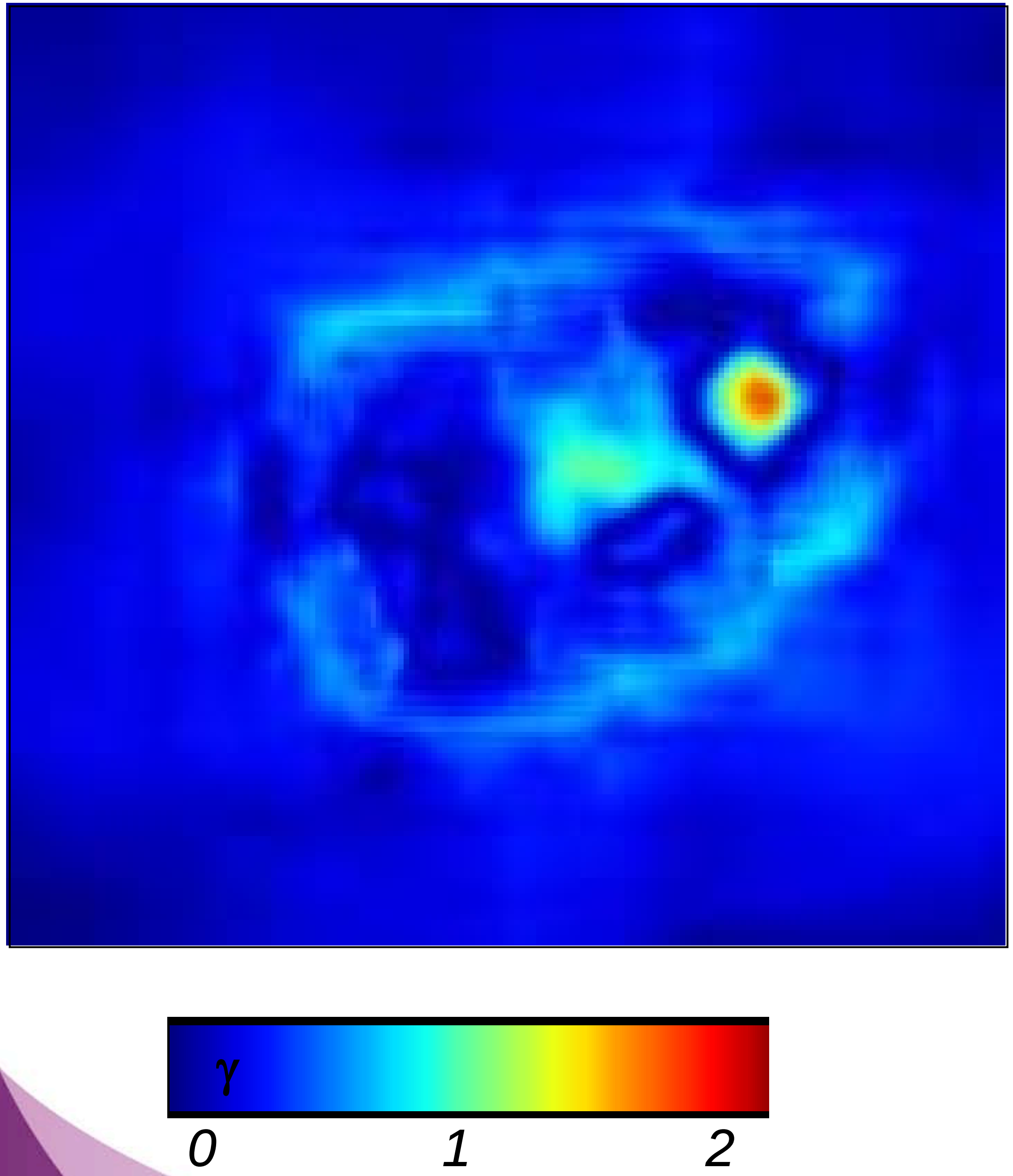
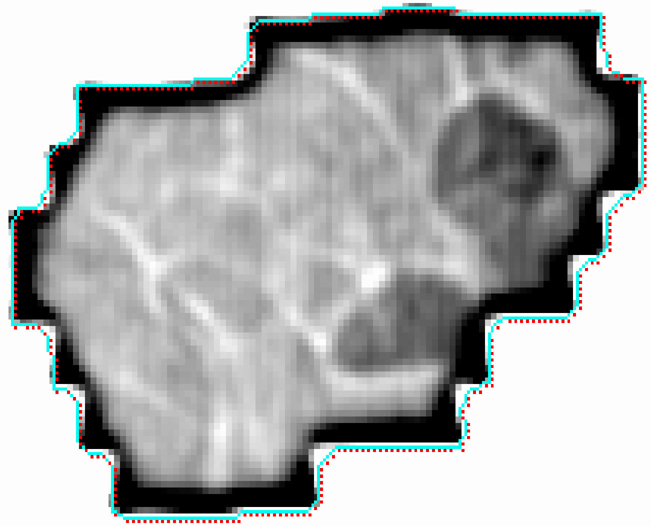
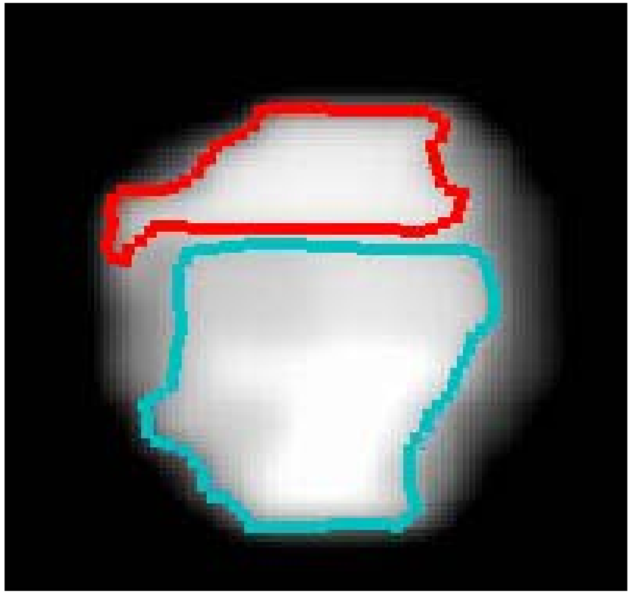
What can you detect?

Gas pockets

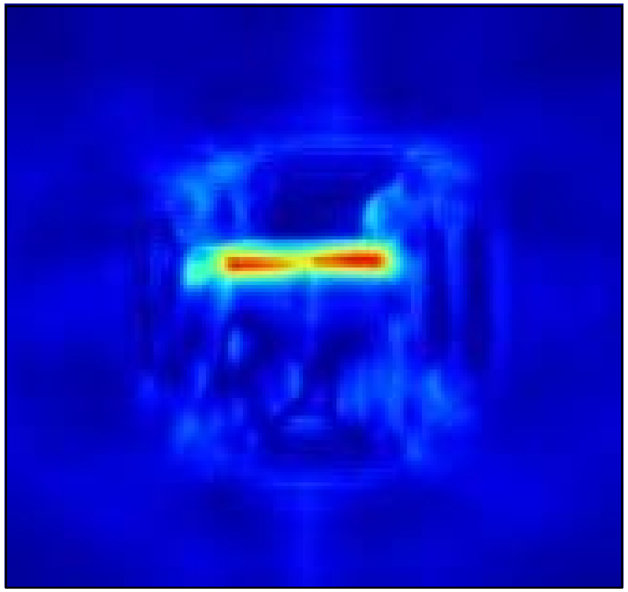




abutting leaves



isodose lines
segments 3 & 6



γ-evaluation
3% / 3mm
EPID vs plan

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More errors?

- Transfer errors (planning → linac)
- Linac errors (both dosimetric and geometric)
- Dosimetric errors in plan
- Patient setup (e.g. CT reference to isoc shifts)
- Input errors
- Select the right patient / treatment in all systems

Patient setup

- CT reference to isocenter shift
  - Potentially really large errors (e.g. 10cm!)
  - They DO occur

- Possible countermeasures
  - Online imaging for ALL patients
  - Table shift surveillance software

ZERO

LCS: B2 PATID:

Please align patient

to CT Ref

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Automatically retrieved from planning system

Includes shifts from offline protocols as well

Height:	La al:	Longitudinal
-10.0	2.4	-3.1

TABLE:

Height:	Lateral:	Longitudinal:
0.0	0.0	0.0

ZERO

Interlock released when numbers are the same

Height: -10.0

Lateral: 2.4

Longitudinal -3.1

TABLE:

Height: -10.0

Lateral: 2.4

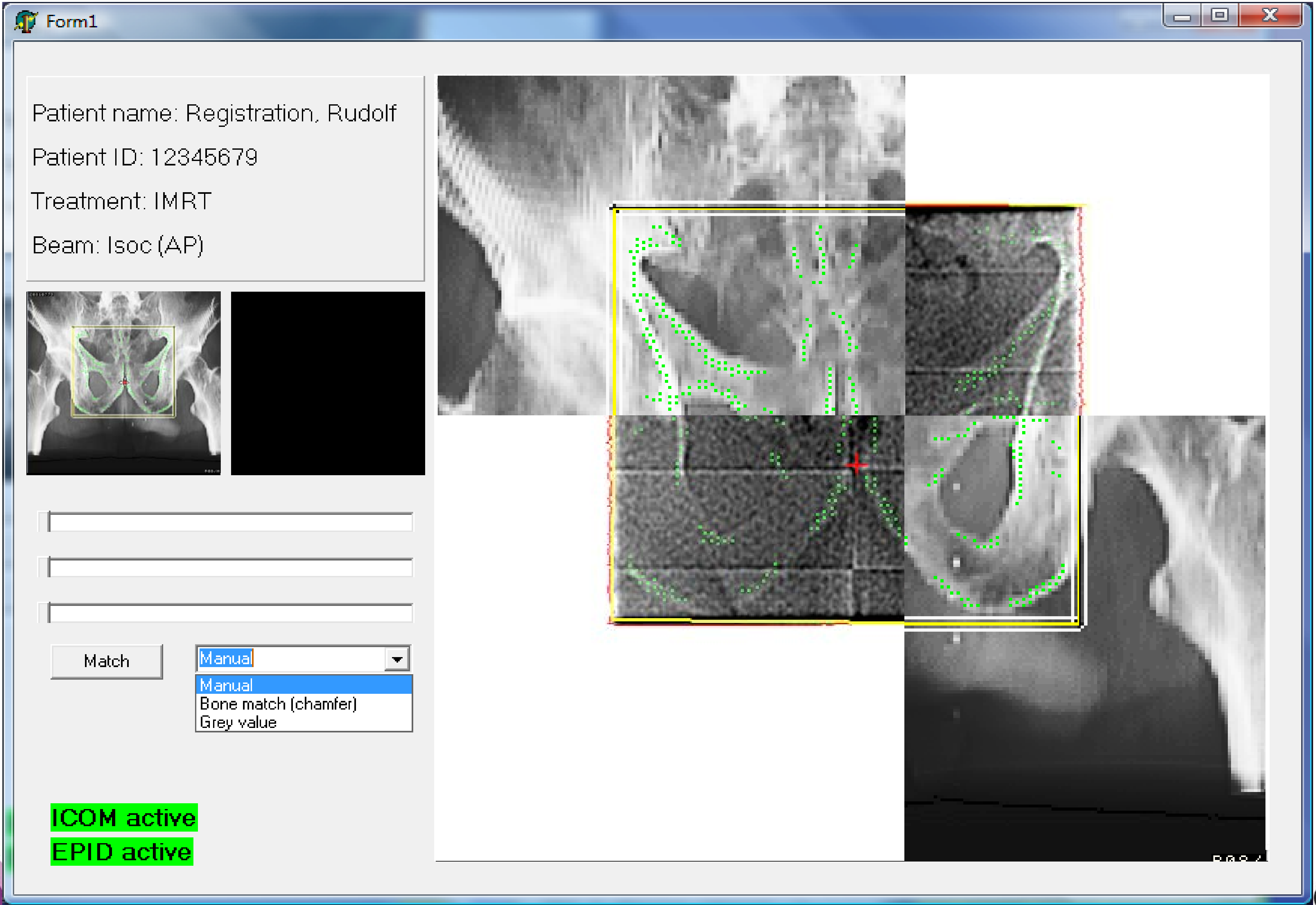
Longitudinal -3.1

Input errors / patient / treatment selection

- Automation. Make the number of user interaction as small as possible
- Intuitive user interfaces
- Double checks
- New technology, like RFIDs?

Automation: EPID acquisition

- Radiographer…
  - Deploys the imager
- Application…
  - Selects patient and beam
  - Saves data in database without any user intervention
- Different screens, depending on beam property, e.g.
  - Dosimetry screen
  - Online registration screen
  - Breathhold screen



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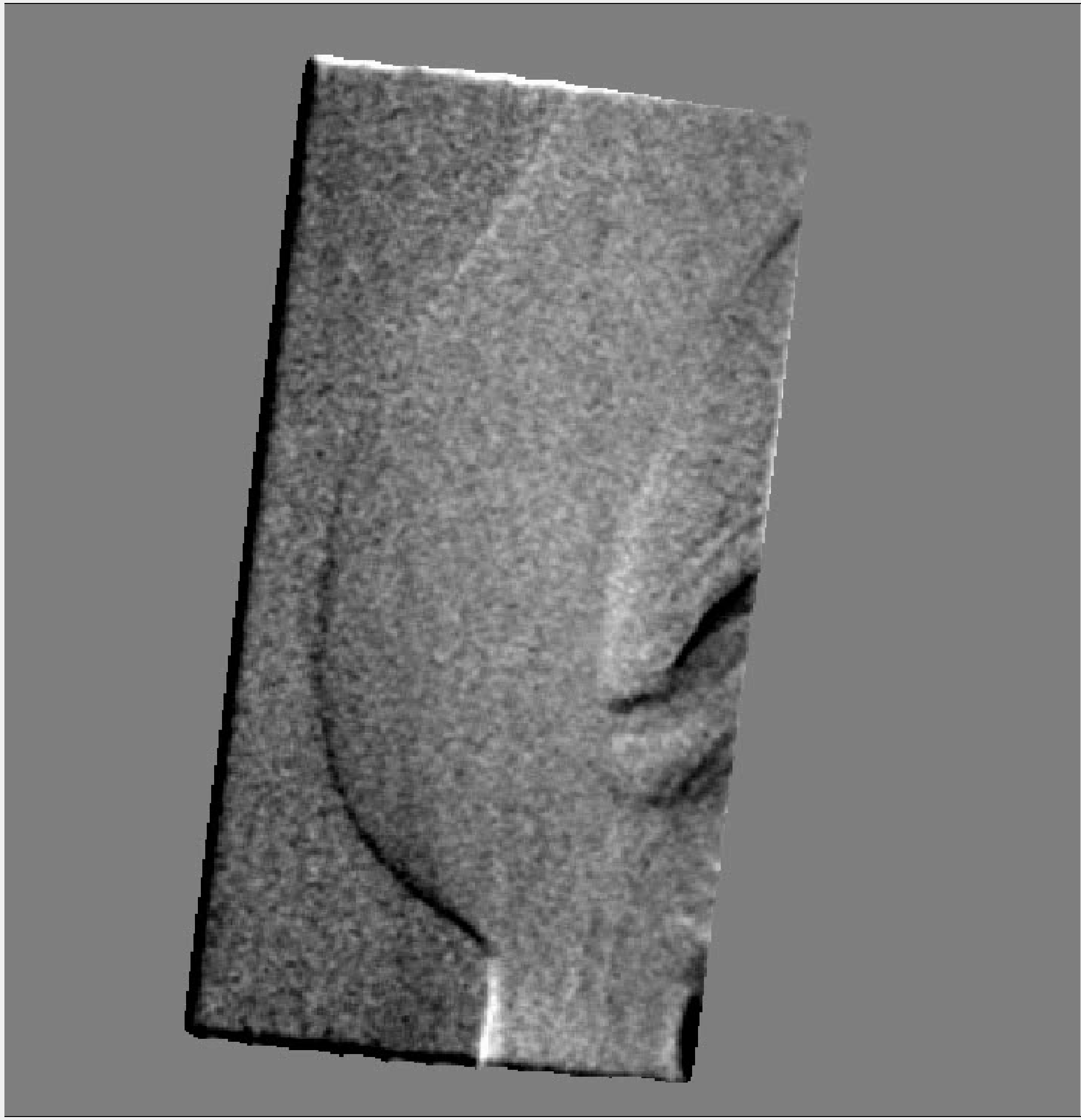
BREATHHOLD CHECK

Patient name: van Vliet

Patient ID: 12345678

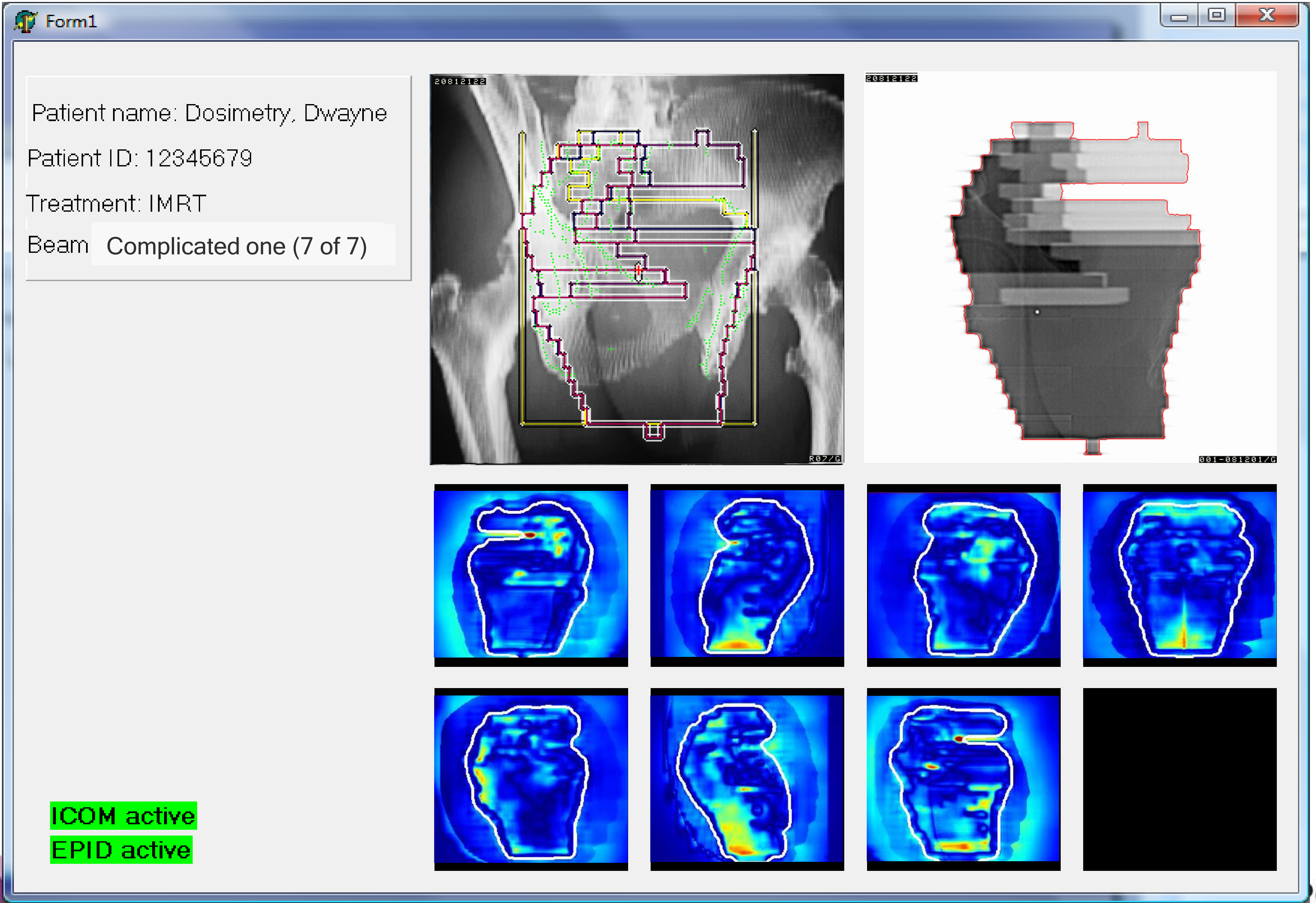
Treatment: Breast breathhold

Beam: Left lateral



Automation: Zero button EPID dosimetry

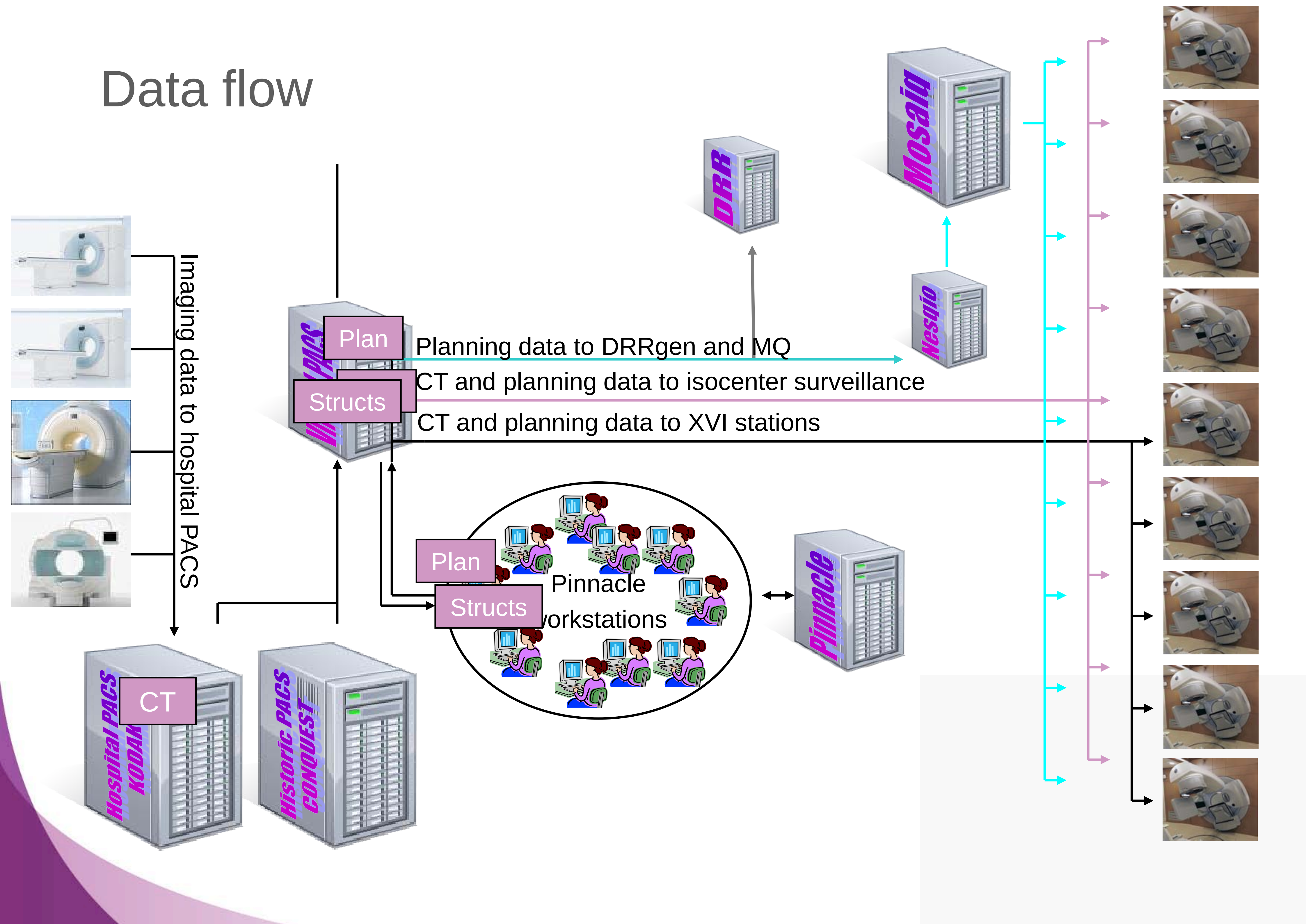
- Radiographer…
  - Deploys the imager and treats the patient
- Application…
  - ‘Triggers’ on new images from EPID acquisition application
  - Computes dose
  - Sends a report to physics
  - Notifies physics when something is wrong


Form1
Patient name: Dosimetry, Dwayne
Patient ID: 12345679
Treatment: IMRT
Beam Complicated one (7 of 7)
ICOM active
EPID active

Automated dataflow example

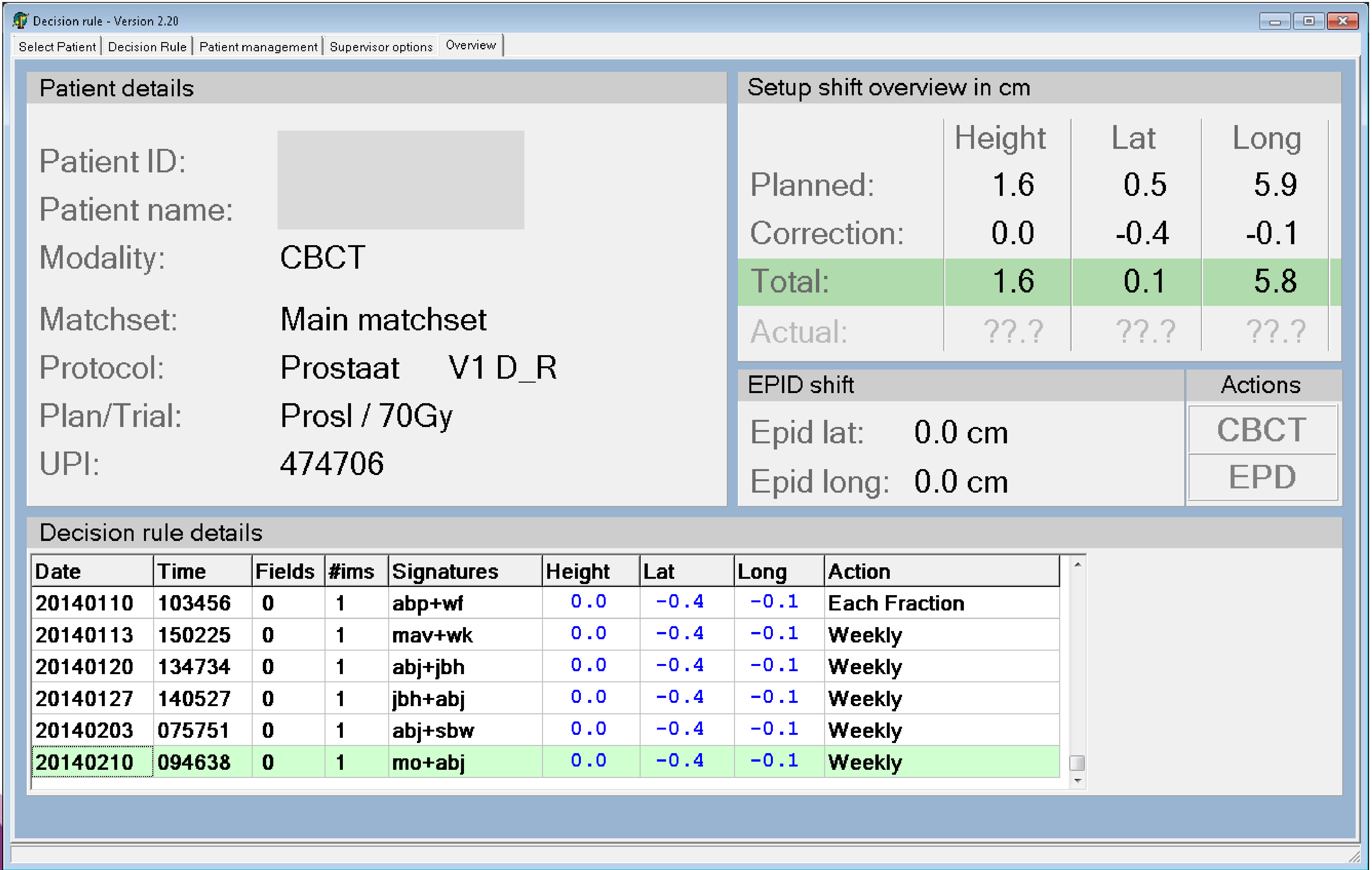
- Dosimetrist sends plan for B5 to central server
- Server finds corresponding CT scan and structure set
- All data is then automatically sent to XVI station on B5
- Plan is sent to Mosaiq
- Plan and structures are sent to hospital PACS
- DRRs are automatically generated
- Patient is automatically entered in imaging database

Data flow



Imaging data to hospital PACS
Hospital PACS
KODAK
CT
Historic PACS
CONQUEST
Plan
Structs
Planning data to DRRgen and MQ
CT and planning data to isocenter surveillance
CT and planning data to XVI stations
DRR
Mosaiq
Mosaiq
Plan
Structs
Pinnacle
workstations
Pinnacle

User interface



Take home messages

- IGRT is good but not enough
- Take countermeasures to catch gross errors
- Try to find the simplest workflow (user interface, protocols, forms)
- **Be especially aware when introducing new systems, protocols, or technologies**

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WWW.ESTRO.ORG/SCHOOL

Incident management

Mirjana Josipovic
Dept. of Radiation Oncology
Rigshospitalet
Copenhagen, Denmark

Advanced skills in modern radiotherapy
July 2015

Definitions

Incident

- Any unintended event, including operating errors, equipment failures, initiating events, accident precursors, near misses or other mishaps, or unauthorized act, malicious or non-malicious, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

(IAEA Safety Glossary, 2007)

Radiation incident

- The delivery of radiation during a course of RT is other than intended by prescription, and could have or did result in unnecessary harm to the patient.

(Towards safer radiotherapy, BJR 2008)

Incident

- An *unplanned, undesired* event that hinders completion of a task and may cause injury, illness, or property damage or some combination of all three in varying degrees from minor to catastrophic. Unplanned and undesired do not mean *unable to prevent.*

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Unintended does not mean *unable to prevent!*

Incidents

Actual incident = accident:

- The unforeseen event, that has affected the treatment of the patient

Potential incident:

- “Near miss”
- The unforeseen event, that was discovered and halted before it affected the treatment of the patient

From IAEA database of radiation incidents

Independent calculation checks 1998-2003 on 27830 charts/plans

An unintended "potential incident" was found:

- in ~3 % of all plans, during primary check
- in ~½ % of all plans, during secondary check

Actual incidents:

- in ~¼ % of cases

For each actual incident, ~14 potential incidents were found through checking.

From IAEA database of radiation incidents

Summary

- An incident frequency of 3% could be seen in a "typical clinic".

- Most of these potential incidents were stopped before they became actual incidents, through a good safety system.

Incidents

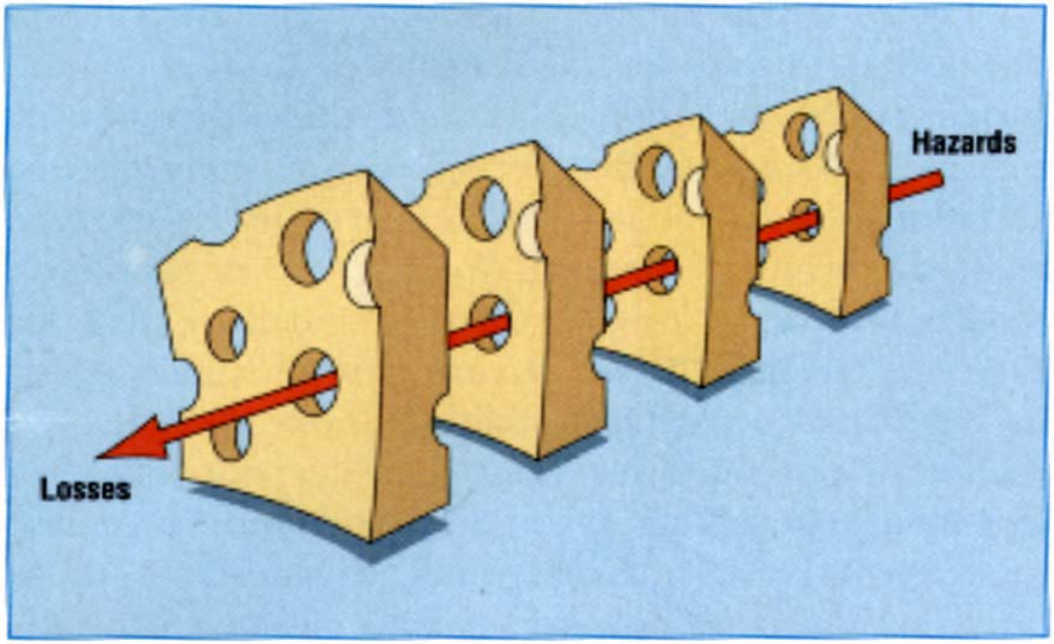
Incidents are more numerous than accidents:

- there are more opportunities to learn and improve the safety, than by only looking at major accidents.

Many incidents have a variable magnitude

- same type of incident can have different impact on different patients / treatment sites
- next time the same incident happens, it may become an accident

Swiss cheese model of accident causation



There is never a single cause for an incident to happen

Holes in cheese slices

- represent flaws of individual safeguard levels
- change constantly in a dynamic complex environment

J Reason BMJ 2000

Incident prevention to improve patient safety

Proactive

- Patient safety rounds
  Leadership tool

Reactive

- Reporting and analysing incidents

Role of incident reporting system

- To **identify** system design flaws and critical steps in the radiotherapy pathway
- To highlight **critical problems and patterns** of causes of these problems
- To **spread knowledge** on new risks or involving new technology
- To **promote safety culture** and awareness through involvement of and feedback to staff and managers

Incident reporting

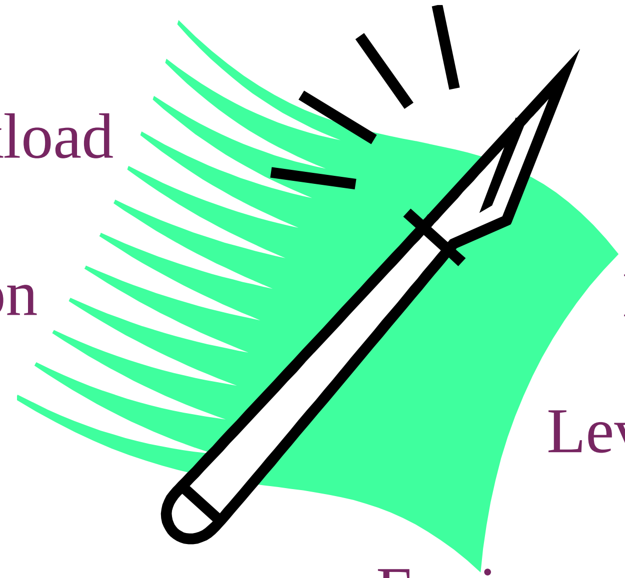
- Blaming individuals is emotionally more satisfying than targeting institutions

- We cannot change the human condition, but we can change the conditions under which the humans work

Human Error: models and management - J Reason, BMJ 2000

Incident reporting

- Incident reporting must not result in disciplinary investigation as a consequence of reporting



Incident reporting

Mandatory incident reporting

- Required reporting
  - to regulatory authorities

Voluntary incident reporting

- Encouraged reporting
  - to professional or international organisation

Internal incident reporting

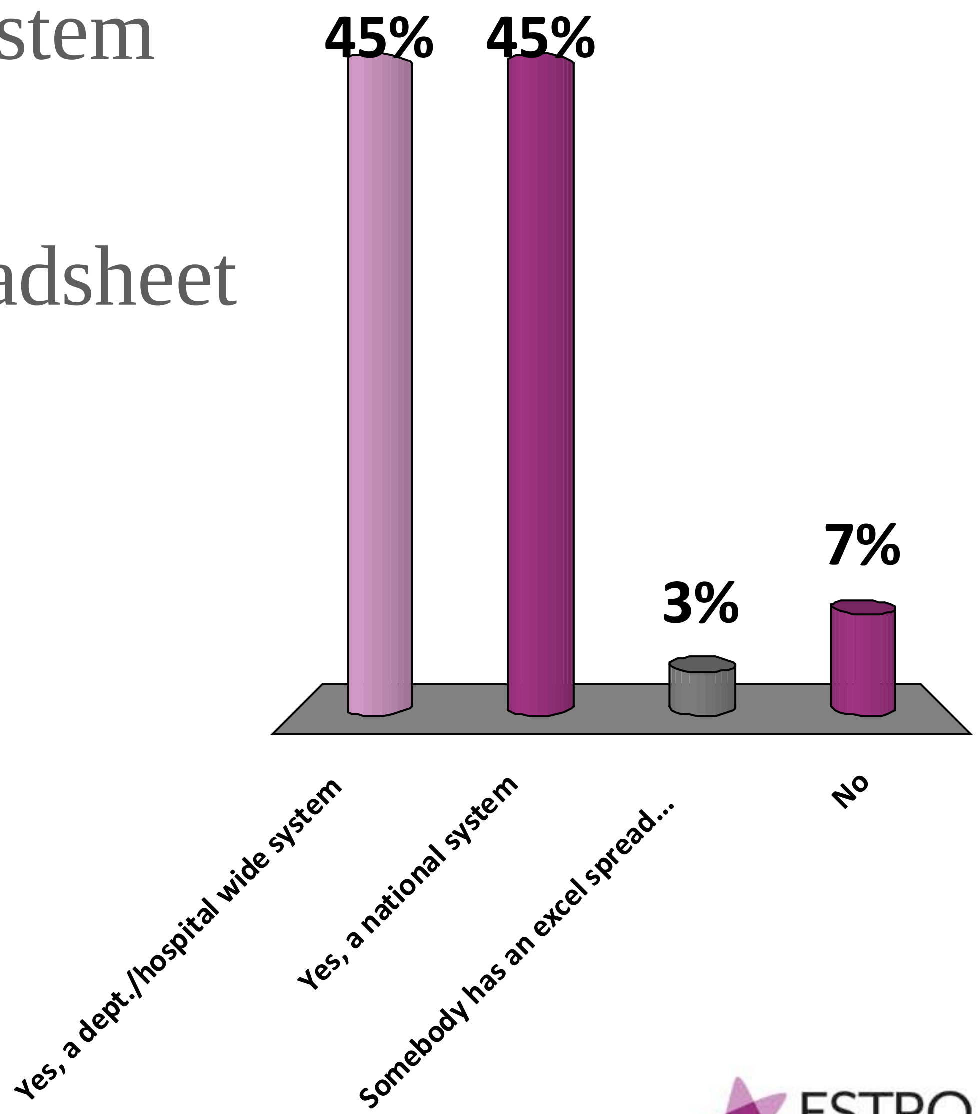
- Reporting locally, inside the organisation

External incident reporting

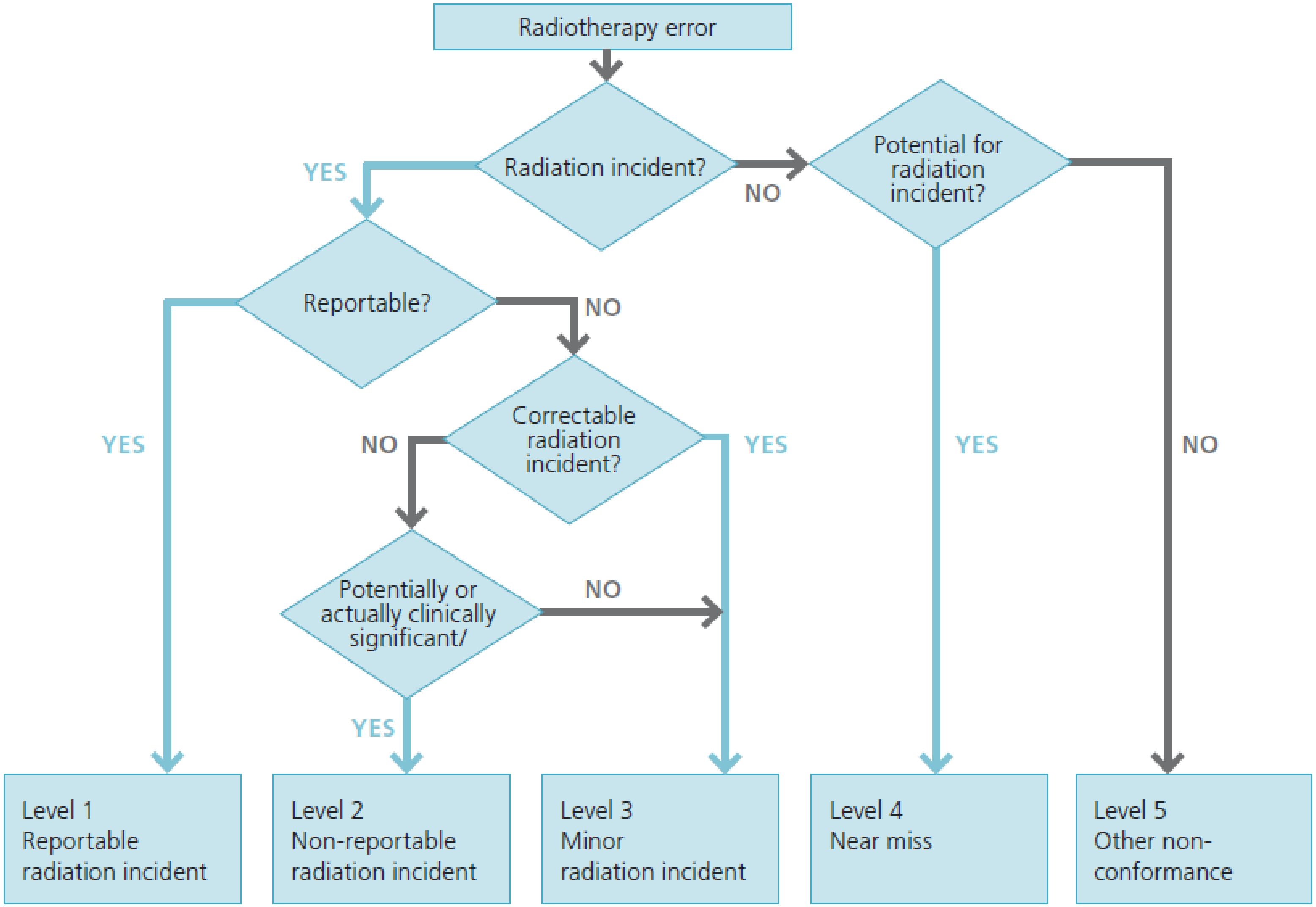
- Reporting outside the organisation
  - Sharing with peers

Do you have an incident reporting system?

A. Yes, a dept./hospital wide system
B. Yes, a national system
C. Somebody has an excel spreadsheet
D. No



What to report



from *Towards safer radiotherapy*

What to report

All incidents affecting patient safety or potentially affecting patient safety

- An incident involving a clear error, even if it did not result in treatment correction / change of treatment
- An incident as above, but with a potential of resulting in an accident
- An incident requiring treatment correction
- An incident resulting in irradiation of radiotherapy professionals
- An incident, where treatment corrections can not be facilitated, but where negative consequences for the patient are unlikely
- An incident, where treatment corrections can not be facilitated, but where negative consequences for the patient are likely to occur

What to report

- All unintended incidents:
  - Observed by you, during involvement in the incident
  - Observed by observing others
  - Made to attention at a later point in time

Case example

Incident description:

During weekly off-line check of the patient's CBCT the physicist noticed that the patient (H&N) lost weight / experienced tumour shrinkage in the treatment area. There is 8-10 mm air under the immobilisation net, on both right and left side. By analysing older CBCTs, it was discovered, that the loss of tissue already occurred 1-2 weeks earlier, but without reactions.

Incident consequences:

Uncertain setup, uncertainty in the delivered dose distribution

Assumed cause of incident:

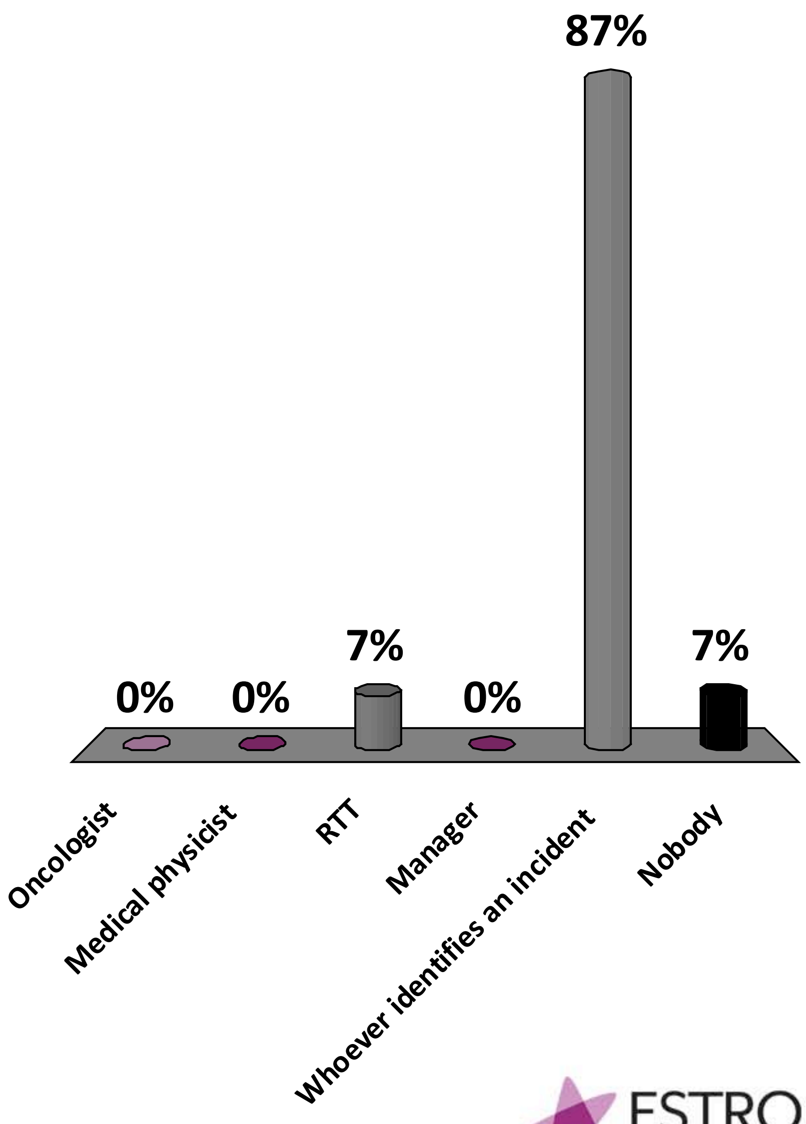
Image guidance was not performed satisfactorily

Suggestion to avoid repeating the incident:

Better/more detailed information to the RTT's to observe the images for potential weight loss resulting in air under the immobilisation mask. Better/more detailed information to the physicists to evaluate the images (during off-line controls) as a whole and not only focusing on the matching structures. Quicker actions required when observing anatomical changes.

Who reports an incident at your clinic?

A. Oncologist
B. Medical physicist
C. RTT
D. Manager
E. Whoever identifies an incident
F. Nobody



External incident reporting

- Bigger “pool of events” facilitate better identification of safety critical steps in the process of radiotherapy
- Incidents from another hospital can lead to early identification of hazard in your own hospital, before a potential incident occurrence
- Providing general culture of safety awareness

Radiation Oncology Safety Information System

- Established in 2001, under auspices of ESTRO
- International voluntary incident and near incident reporting system
- > 100 RT departments reporting

ROSIS
Radiation Oncology Safety Information System

www.rosis.info

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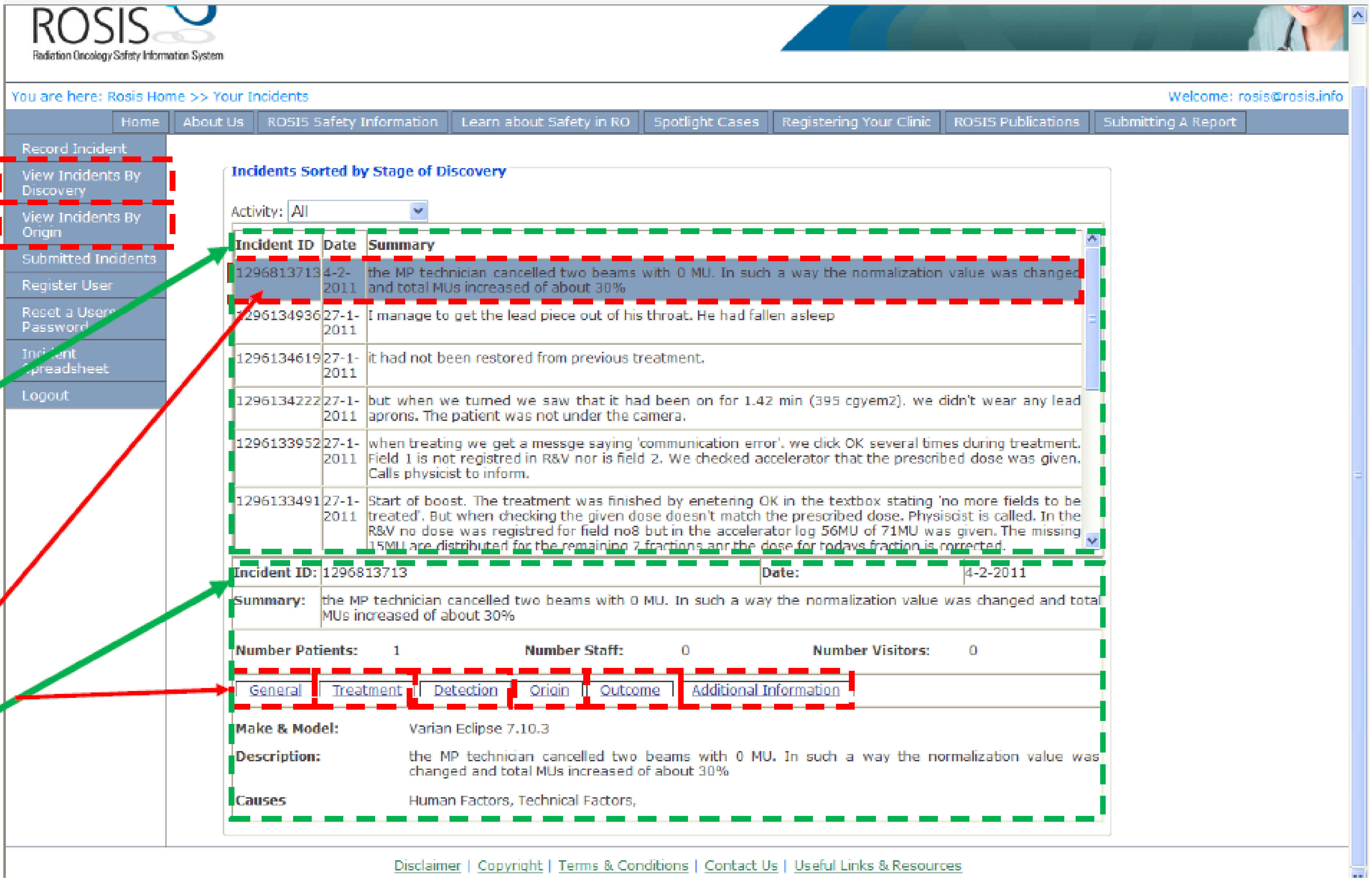
How to view reported incidents on ROSIS

If logged-in, click here to also see recent incident reports.

View short information on every incident here (use scroll bar on right to scroll down).

Select an incident (highlighted in blue); the full report is shown in the viewer underneath, use the tabs to view all the details.



For explanation of the reporting system and the classification used, please see the "ROSIS guide to reporting", once logged-in

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Role of incident reporting system

Incident reporting system has to be a part of a longer chain:

- Incident Identification
- Reporting
- Investigation
- Analysis
- Management
- Learning

Analysis methods

- Root cause analysis
- Journalaudit
- Mortality analysis
- Global Trigger Tool

Root cause analysis

A systematic method to identify

- WHAT happened
  ...the actual chain of events leading to the incident

- WHY could it happen
  ...identification of what caused the incident

- HOW to prevent the incident to happen again
  ...action plan & follow up

•...NEVER, who caused the incident

Quality Assurance in Radiation Therapy QART

- To record and report incidents
- To examine what has gone wrong
- To examine why sthg has gone wrong
- To effect action for correcting the immediate situation
- To prevent recurrence

Purpose of QART

- To **support patient safety** by reporting, recording, analysing and providing knowledge on unintended incidents in order to facilitate systematic learning process

- To **prevent** repeated incidents

- QART has to support the constant quality development in a health care environment

- QART has to enable the radiotherapy professionals to handle the incidents and learn form them

.

Take home message

- Incidents are more numerous and varying than major accidental exposures

- By learning from the incidents happening in your clinic you can avoid a potential future accident

- Incident report is an essential tool for safer radiotherapy

Further reading

- Towards safer radiotherapy

  https://www.rcr.ac.uk/docs/oncology/pdf/Towards_saferRT_final.pdf

- Lessons learned from accidental exposures in radiotherapy; IAEA safety reports series no.17

- ROSIS - A reporting and learning system for radiation oncology; J Cunningham 2011

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Erasmus MC
University Medical Center Rotterdam

Daniel den Hoed
Cancer Center

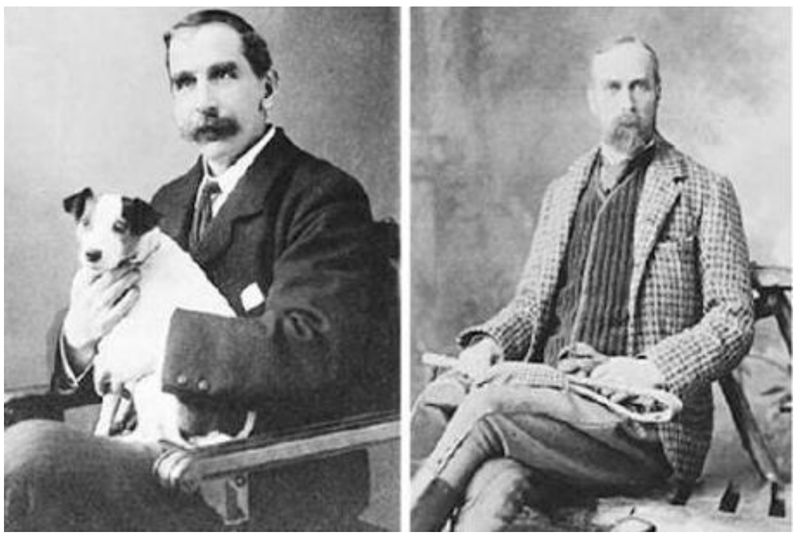
CyberKnife

Mischa Hoogeman

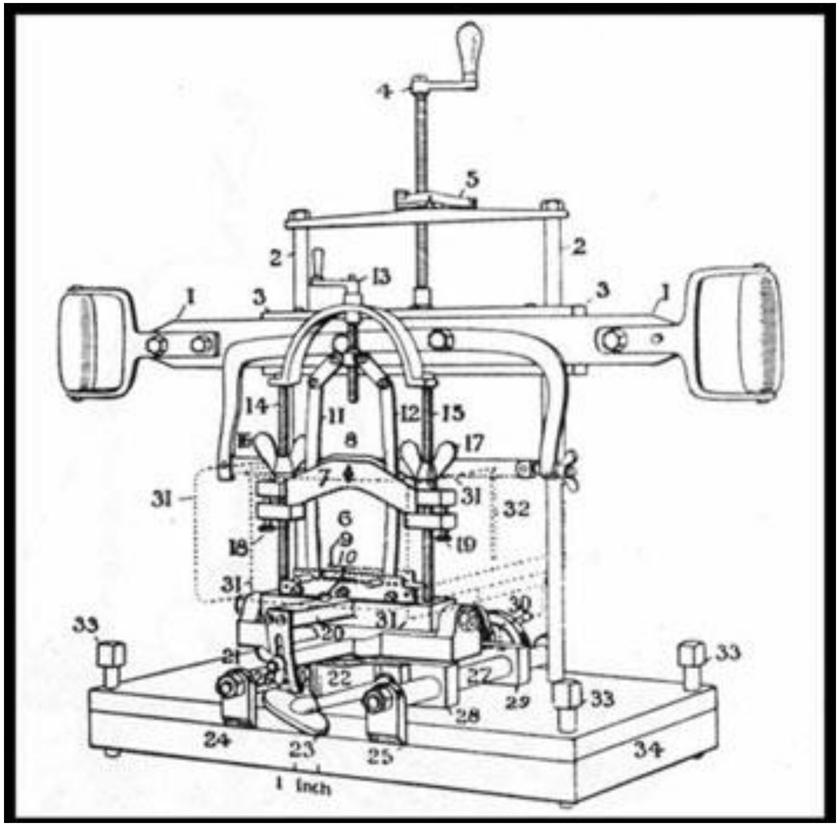
HISTORY

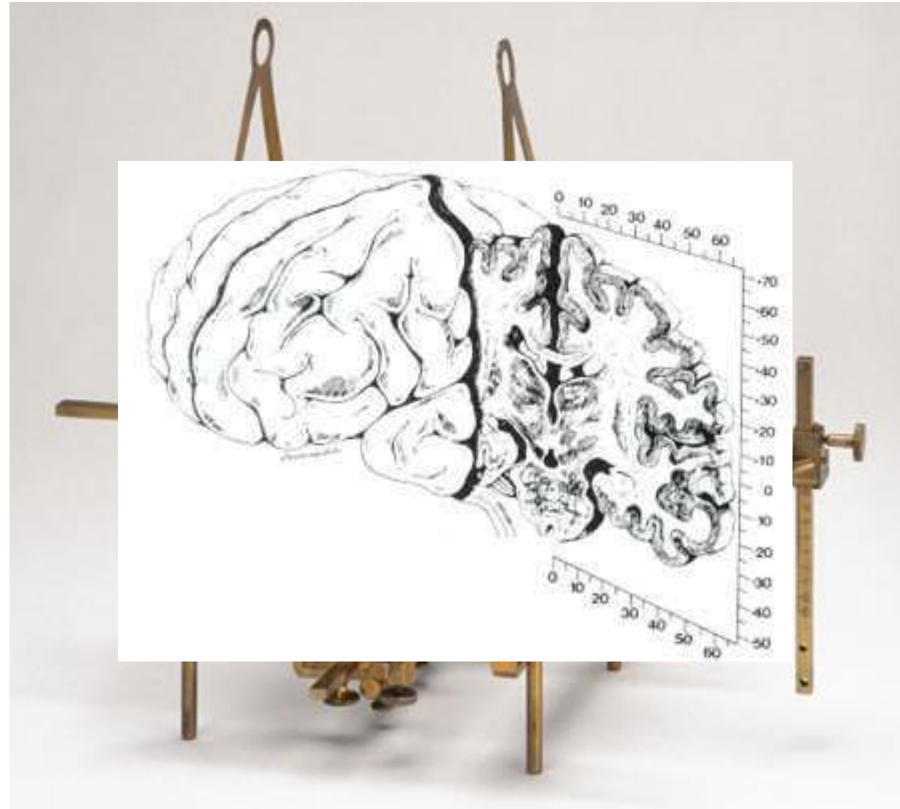
Founders of Stereotactic Surgery

- Stereotactic Surgery (1908)
    - Sir Victor Horsley and Robert H. Clark



Horsley-Clarke Apparatus





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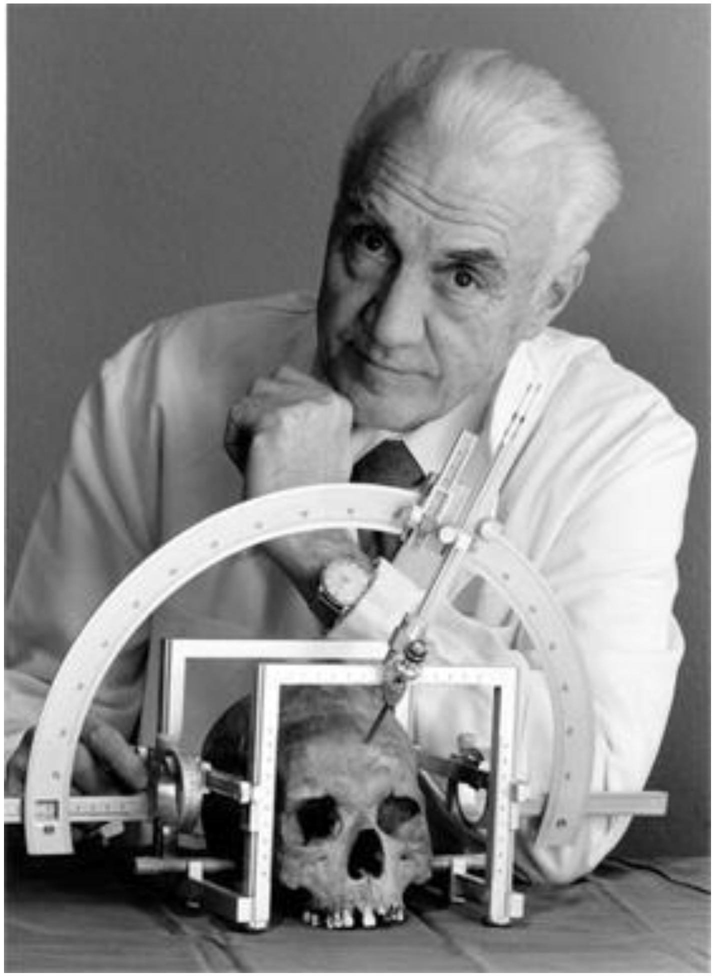
Dr. Lars Leksell (Neurosurgeon)



- Fixed to skull
- Pin fixed to arc

First Radiosurgery Devices (Lars Leksell 1954)

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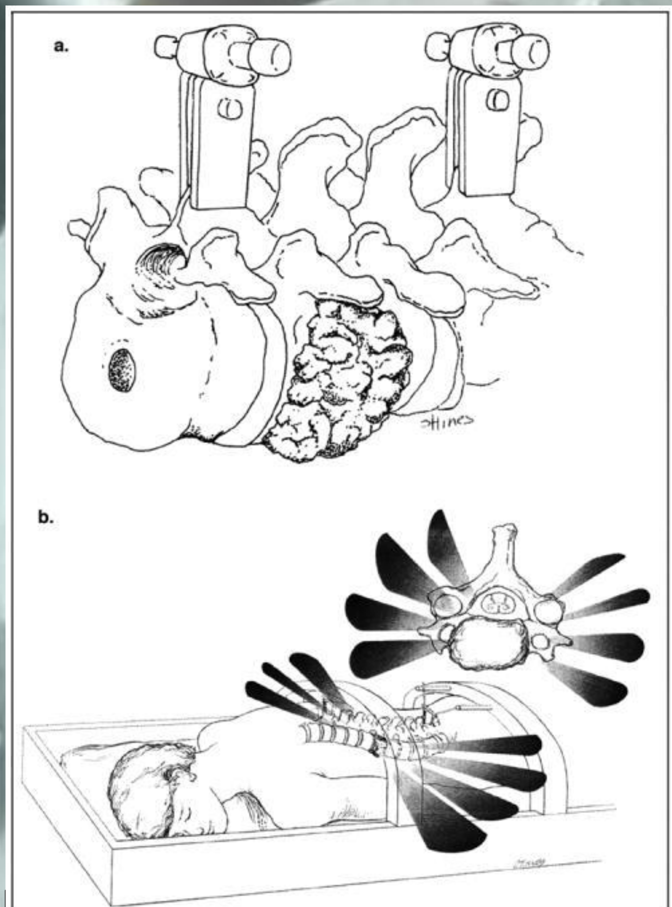
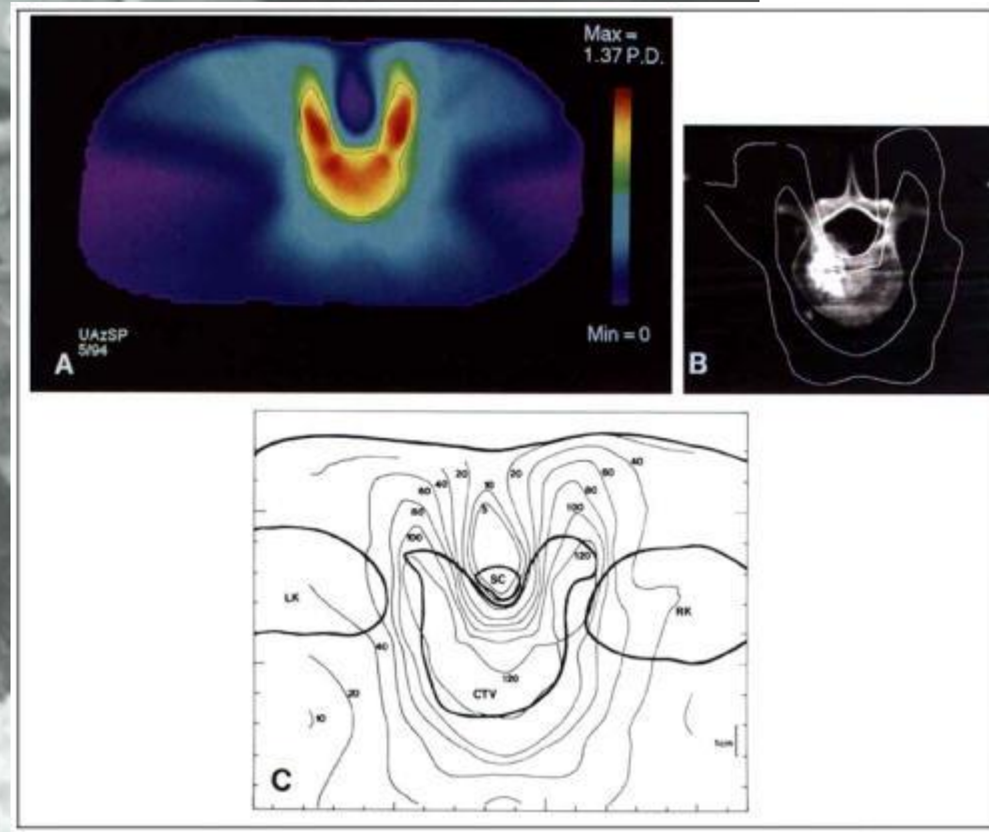
Stereotactic Body Radiotherapy





tor-based Spinal Stereotactic Radiosurgery
Hamilton, Allan J. M.D.; Lulu, Bruce A. Ph.D.; Fosmire, Helen M.D.; Stea, Baldassarre M.D., Ph.D.; Cassady, J. Robert M.D. Volume 36(2), February 1995, p 311–319.

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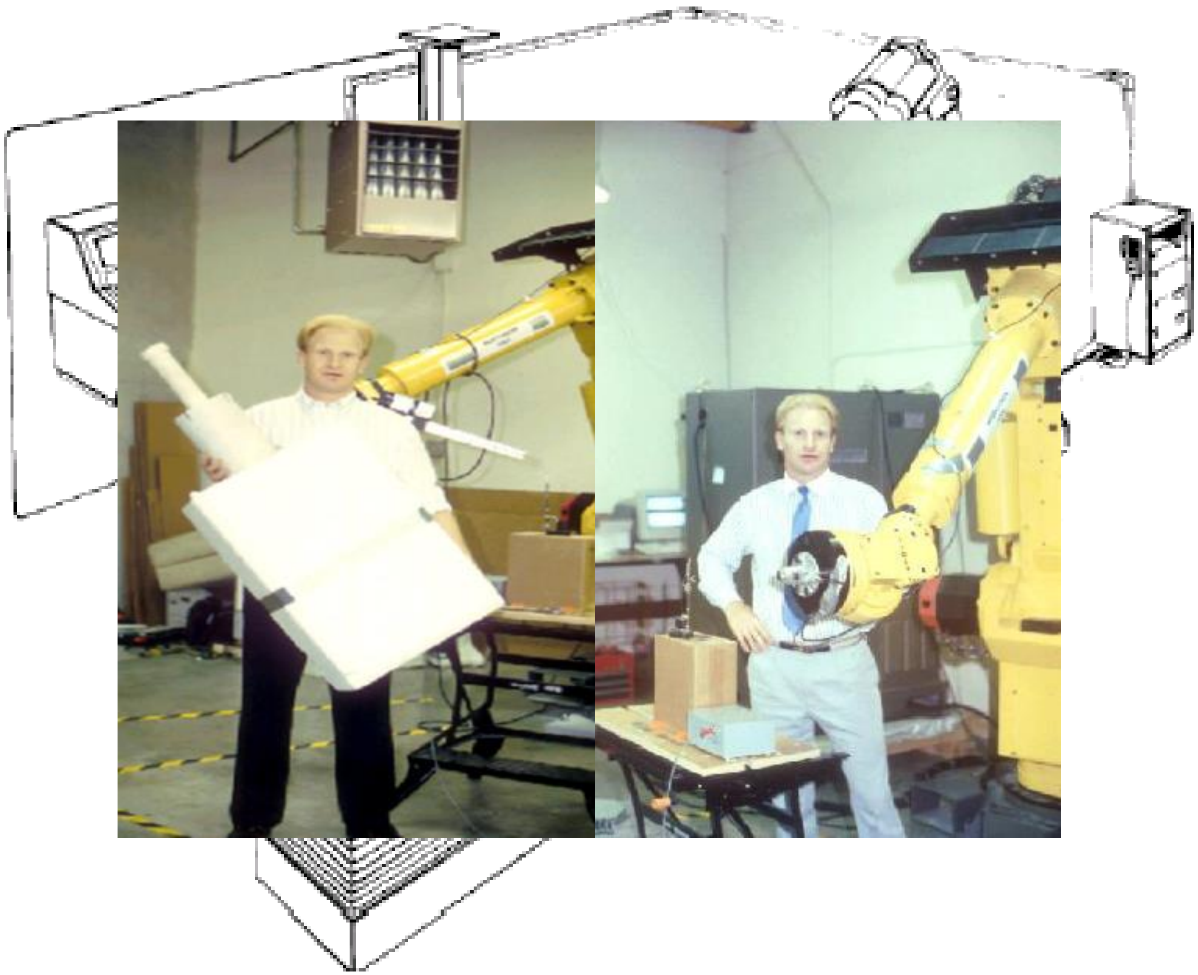
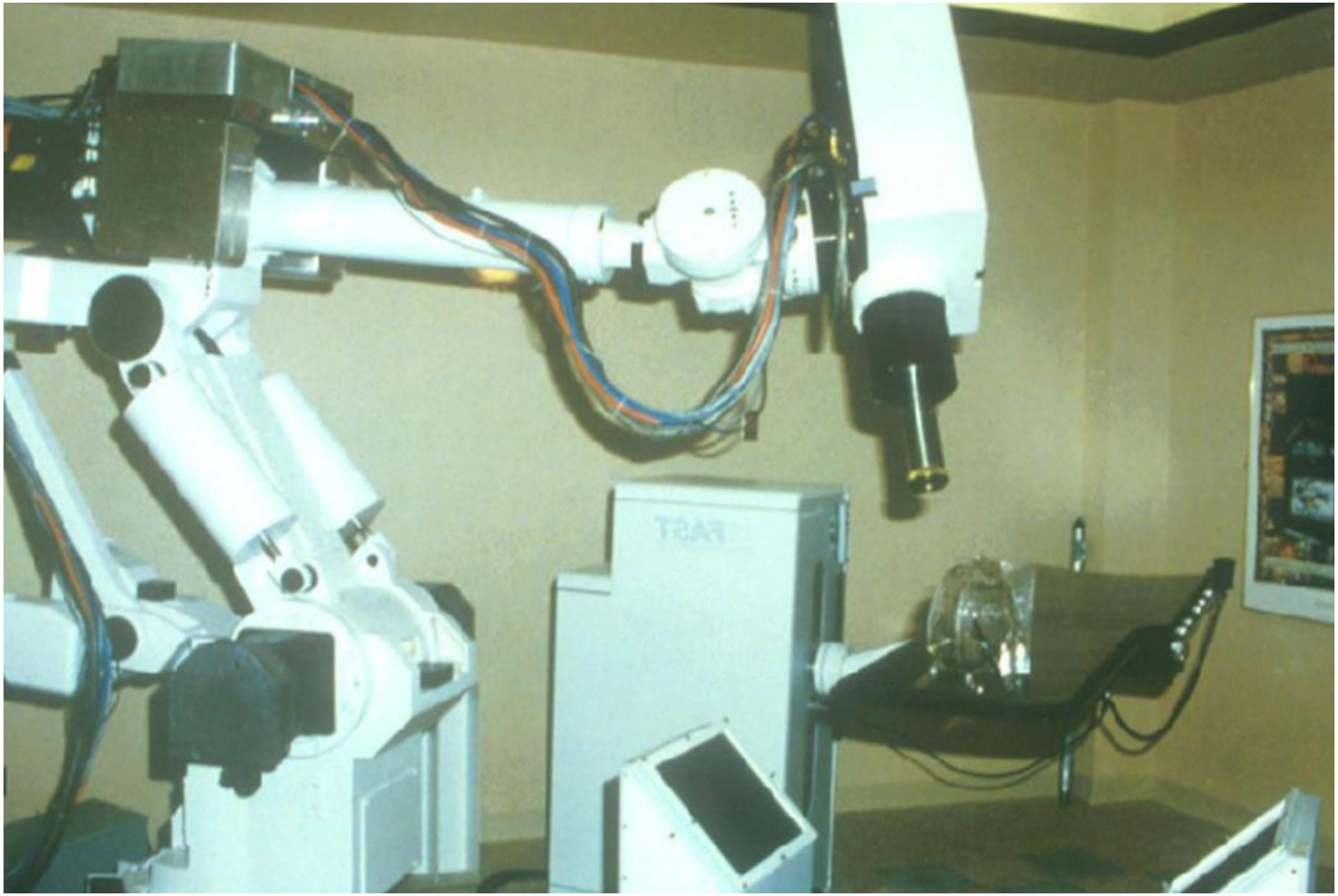
Development of CyberKnife Device

- John Adler (neurosurgeon) around 1987



CyberKnife in Stanford 1994



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Erasmus MC – operational since March 2005 (G3)

Erasmus MC

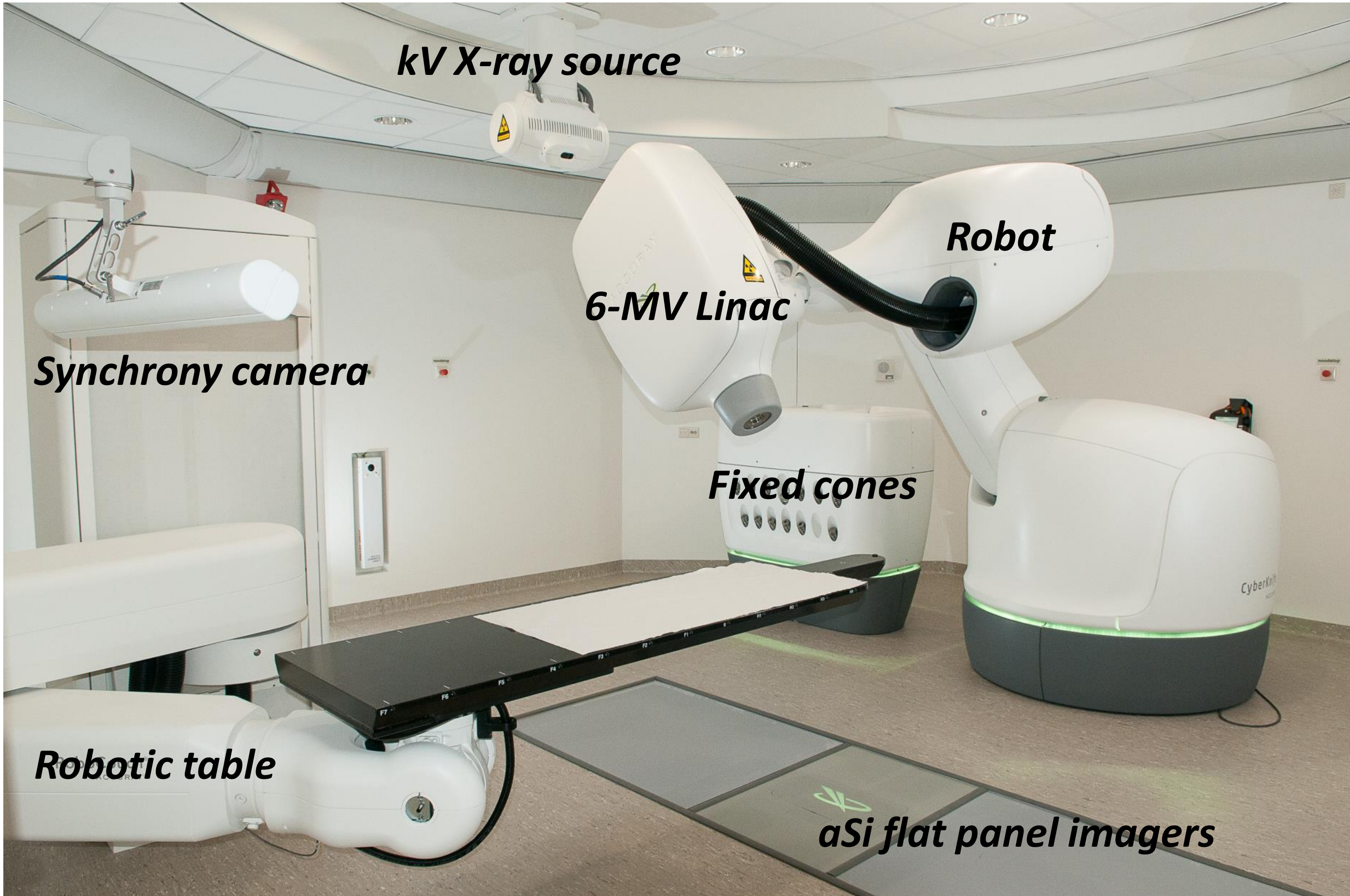
CyberKnife VSI - G4+

Erasmus MC

CyberKnife M6

SYSTEM OVERVIEW

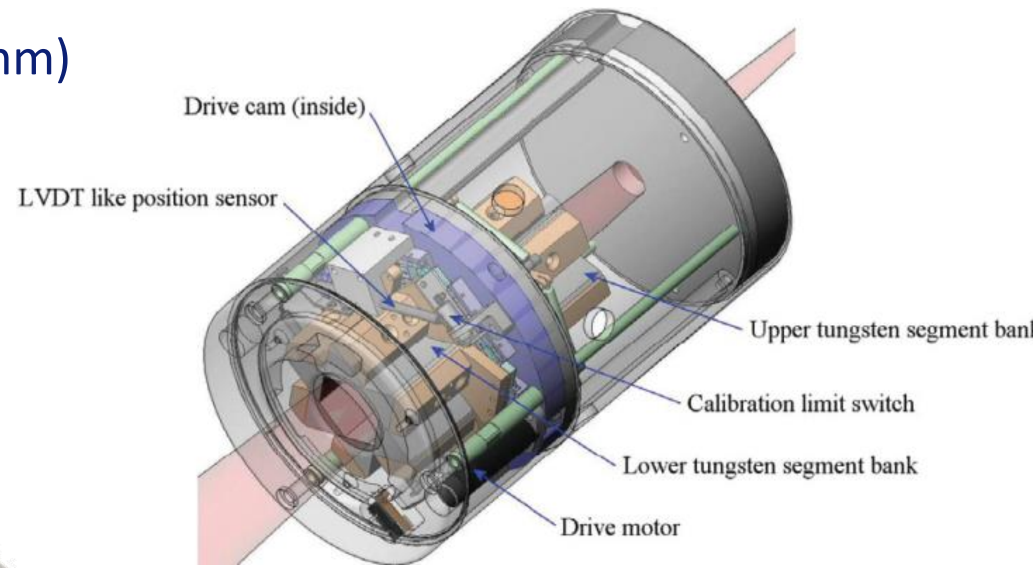
System Components



MC

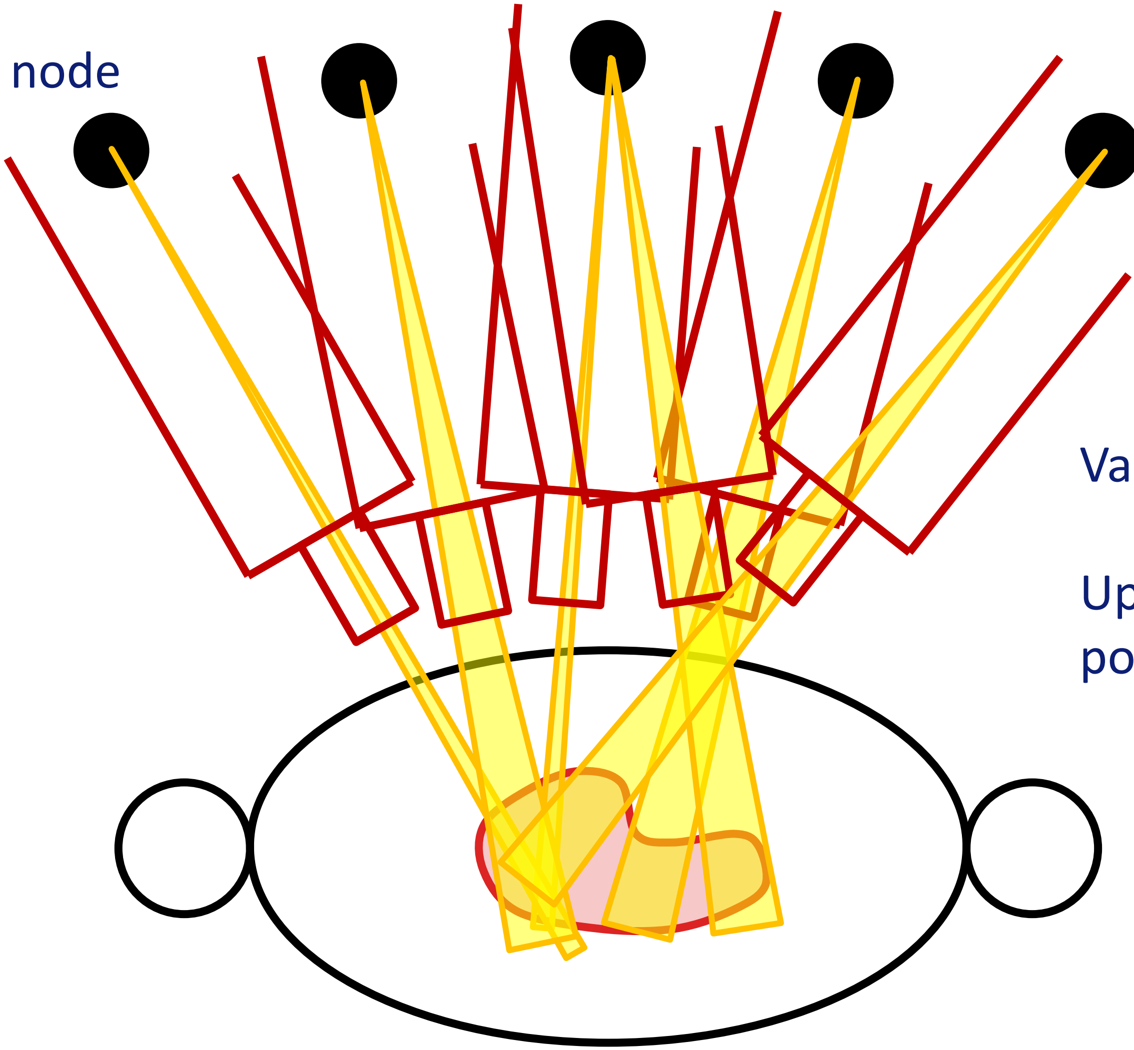
Field Collimation

- 12 “fixed” collimation (5 – 60 mm)
- Variable aperture collimator



Echner et al. 2009

CyberKnife



Various node sets

Up to 180 node positions

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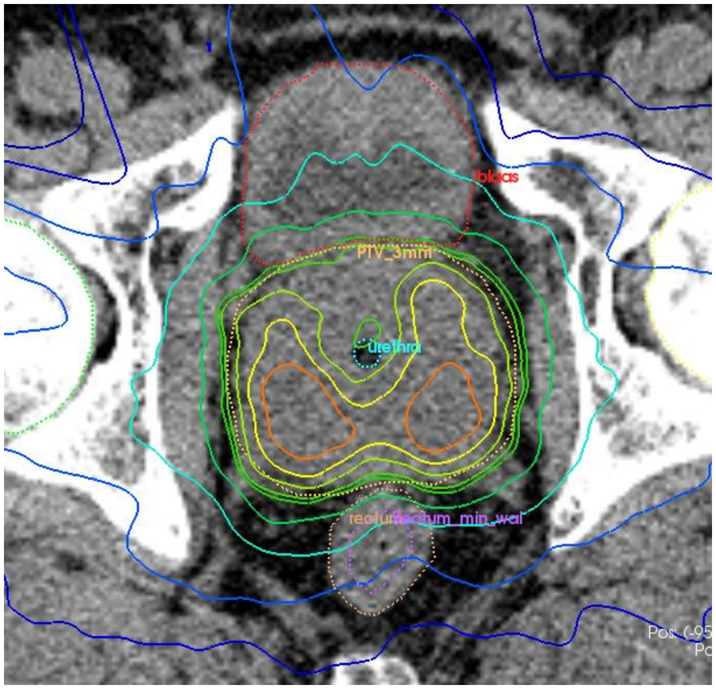
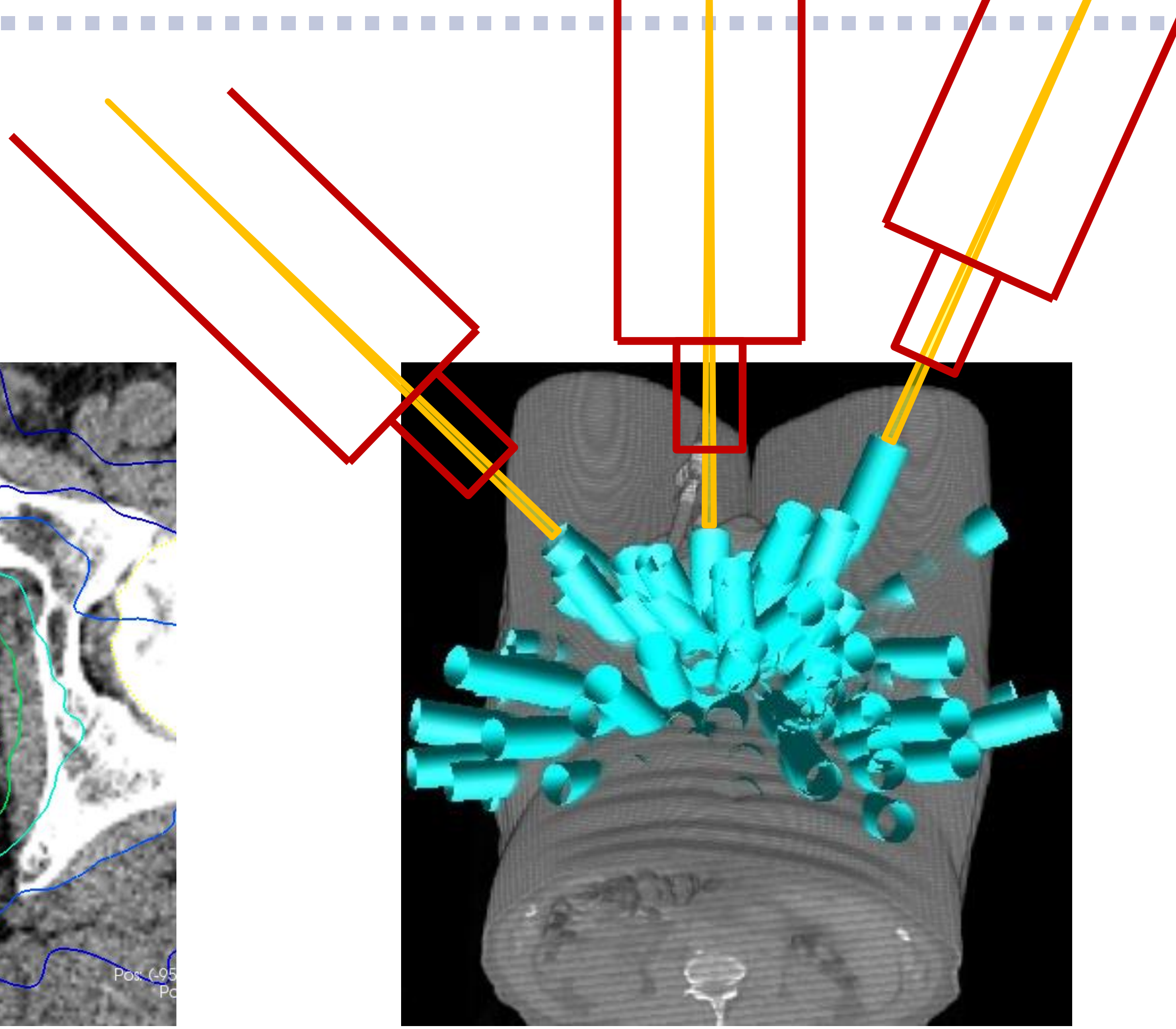
CyberKnife prostate





4 x 9.5 Gy @ 60%

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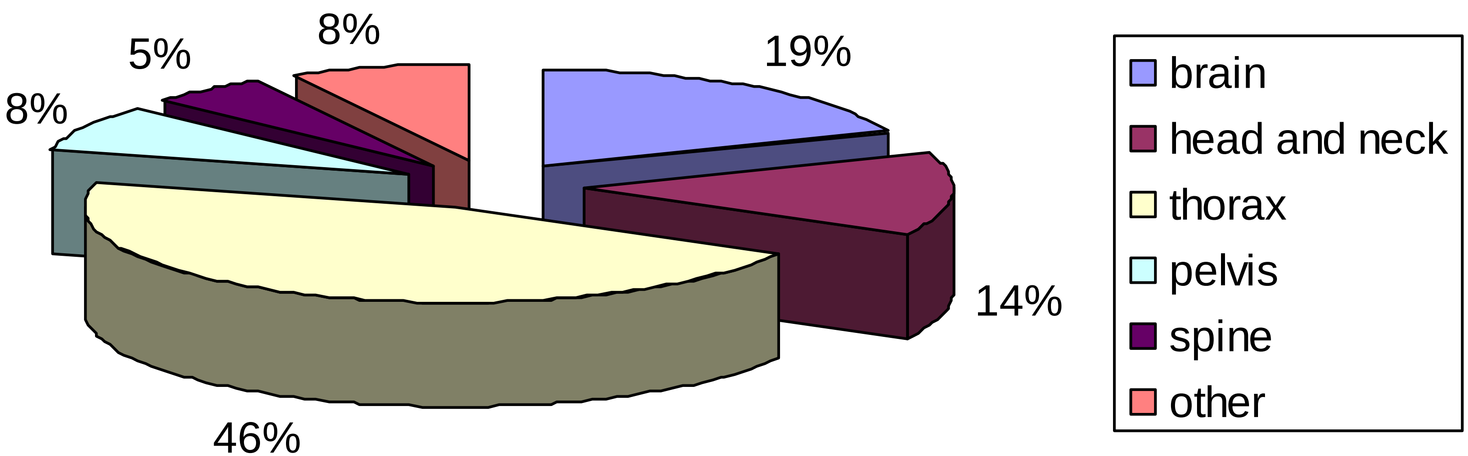
Treatment Sites Break Down

- The CyberKnife is used in our department to treat tumors in the



- The CyberKnife is used for mono therapy as well as for boost therapy
- The CyberKnife is used for palliative treatments as well as curative treatments
- Hypofractionation: mean number of fractions is 3

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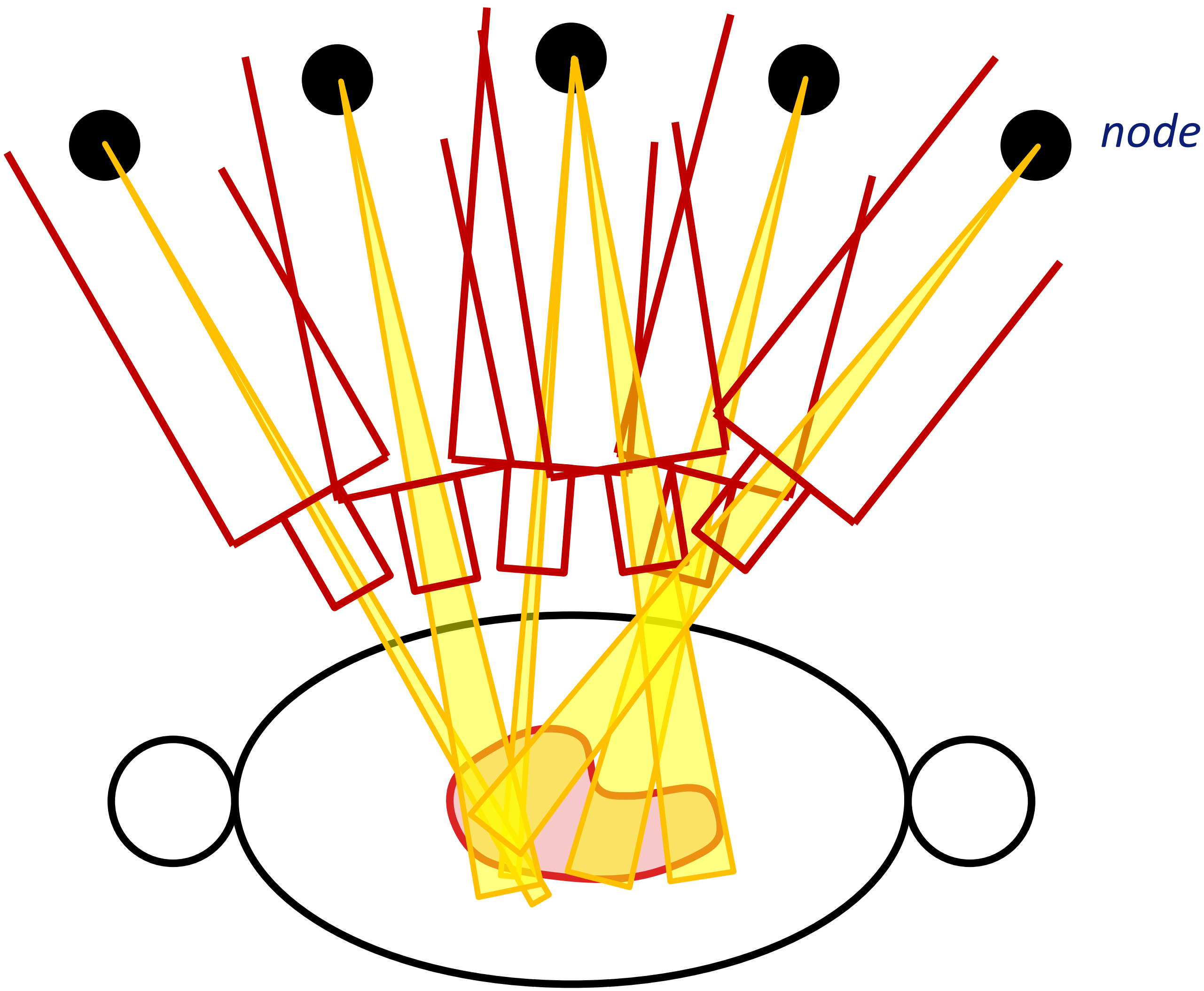
Fast and Slow Delivery



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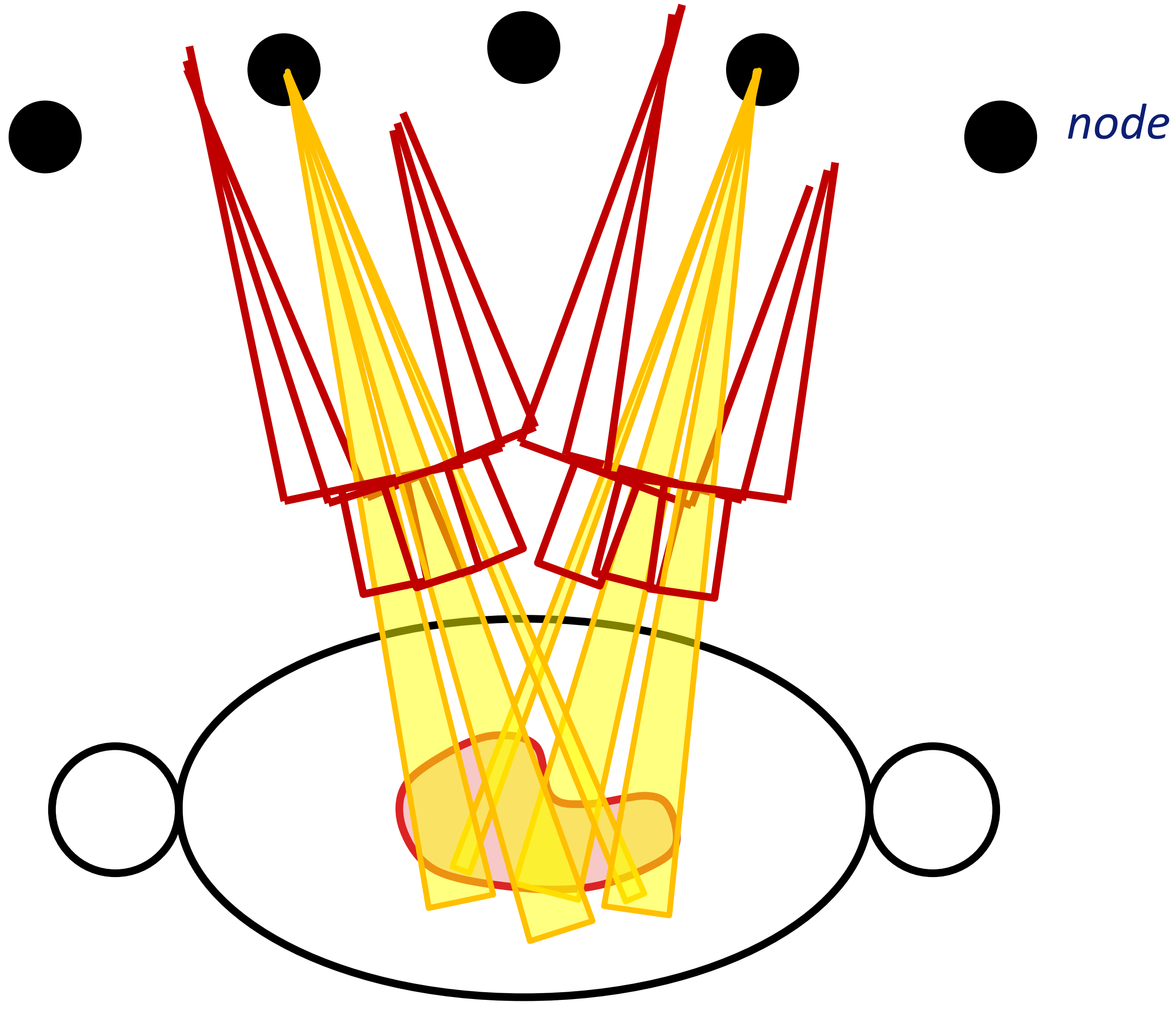
Optimize for Fast Delivery



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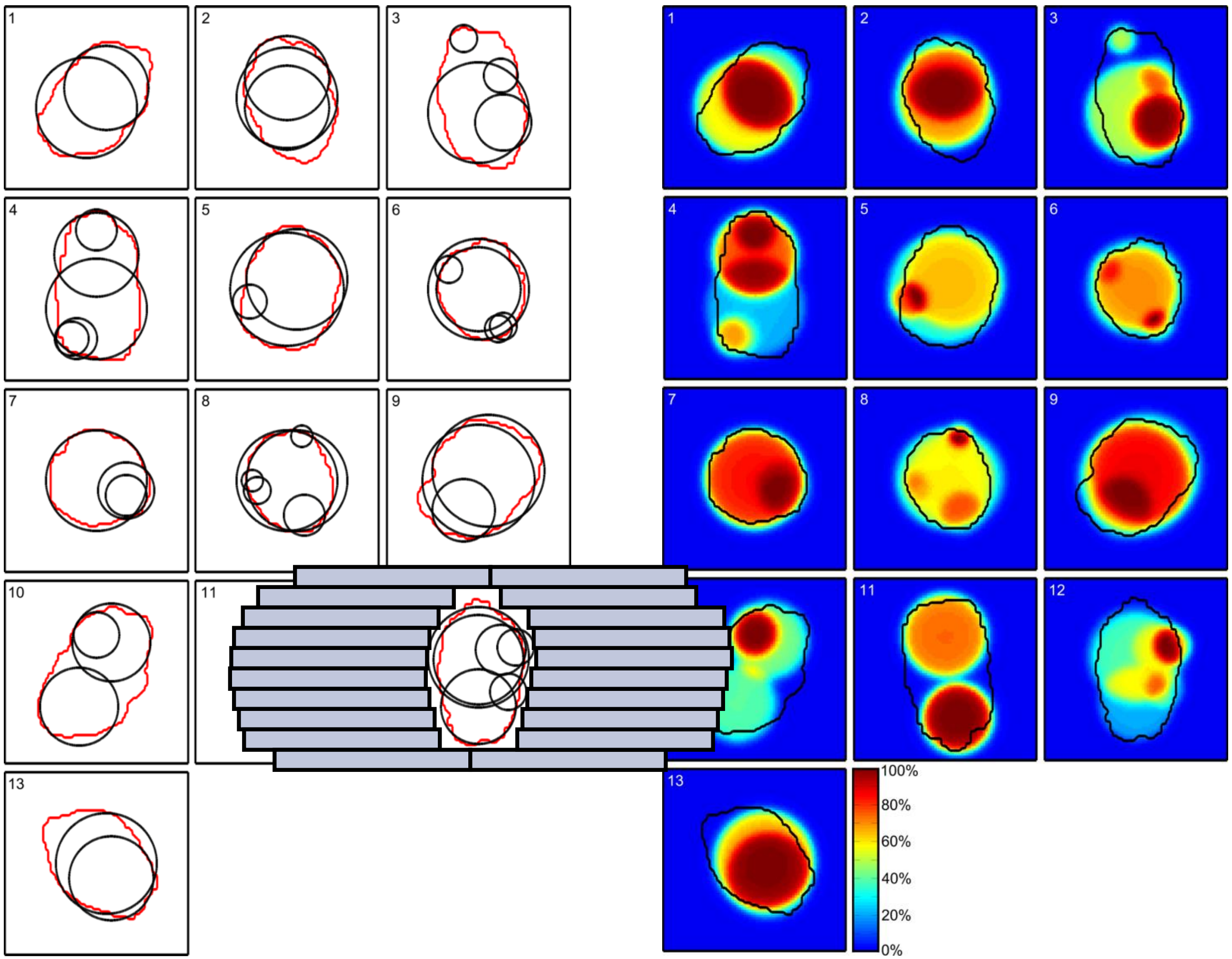
Beam Targeting



mMLC on CyberKnife

From IRIS to mMLC

IMAGE-GUIDANCE AND TRACKING

Image Guidance and Tracking System

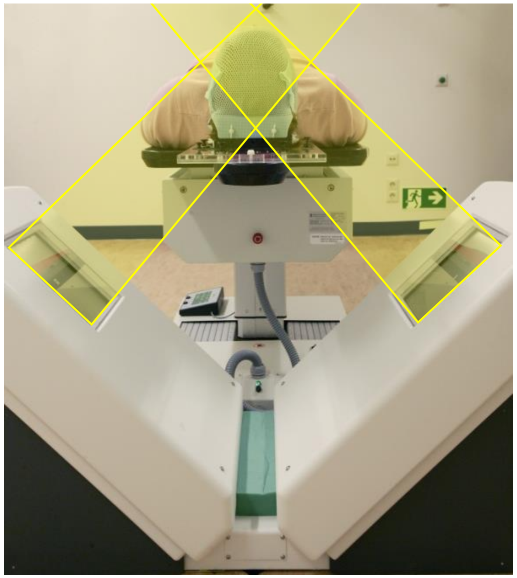
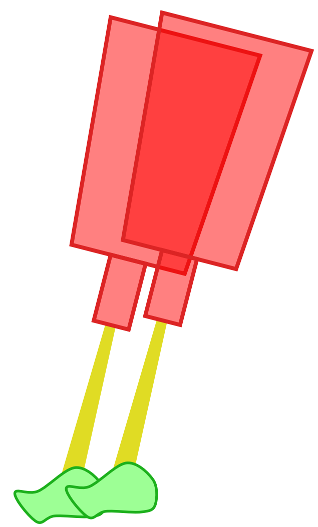
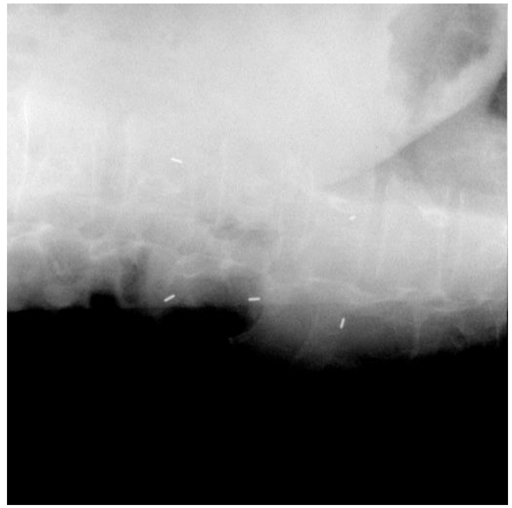


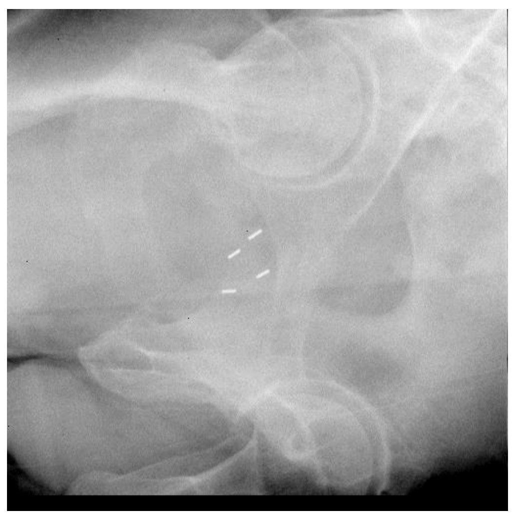
Image guidance

- Stereoscopic X-ray images are compared with **CT scan** or **fiducial marker** locations
- Robot corrects for patient and tumor movement during treatment



Intrafraction Motion





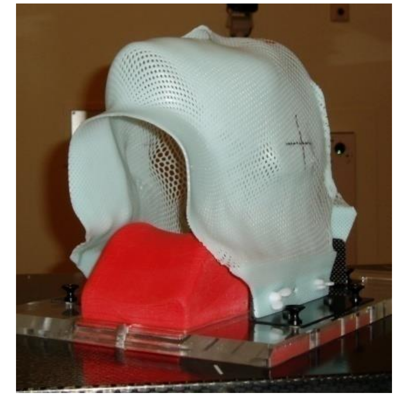


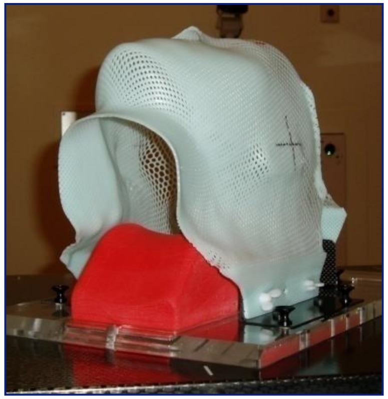
Image Guidance Modes

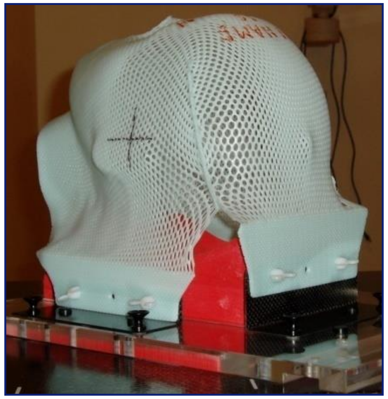
1. **Skull tracking**
   - For intracranial treatment (e.g.: Brain metastasis)
   - Stereoscopic images compared with DRR library
2. **Spine tracking**
   - For extracranial treatment with a fixed tumor to spine (e.g.: Spinal metastasis)
   - Stereoscopic images compared with DRRs (including deformable registration)
3. **Fiducial marker tracking**
   - For extracranial treatment (e.g. Prostate)
   - Fiducial position extracted from stereoscopic images
4. **Synchrony**
   - For tumors that move with respiration (e.g.: Lung ca)
   - Correspondence model between external markers and internal fiducials or tumor in X-ray images

Example:

movie of X-ray images

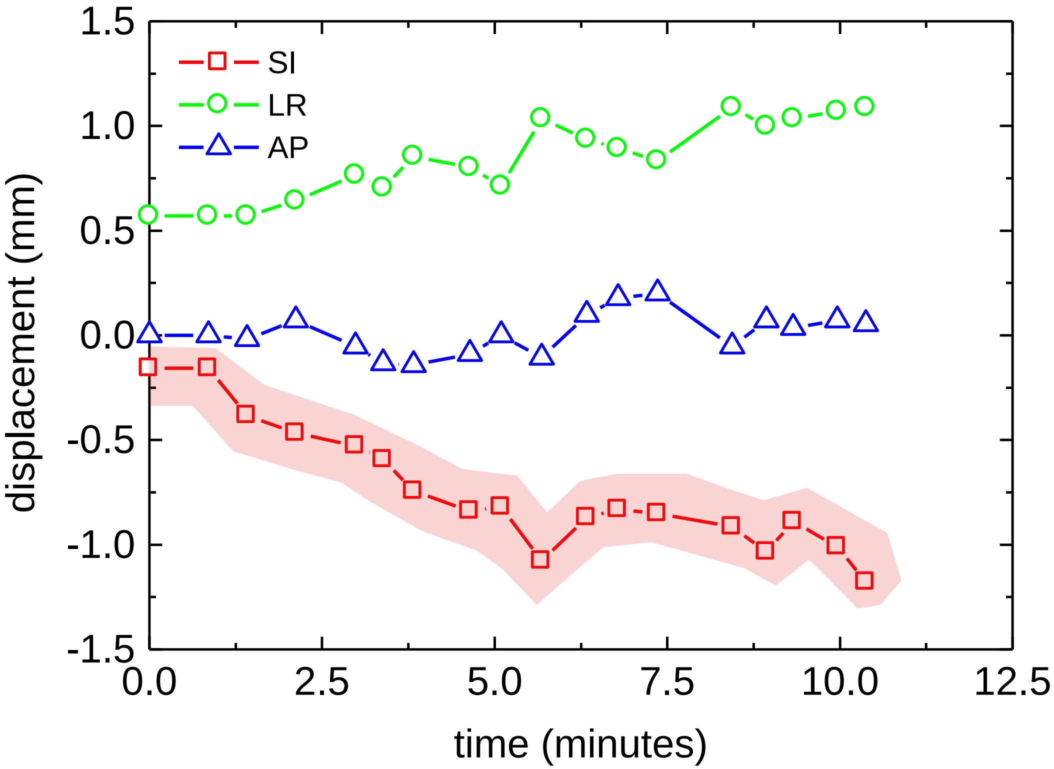
(12.5 minutes)

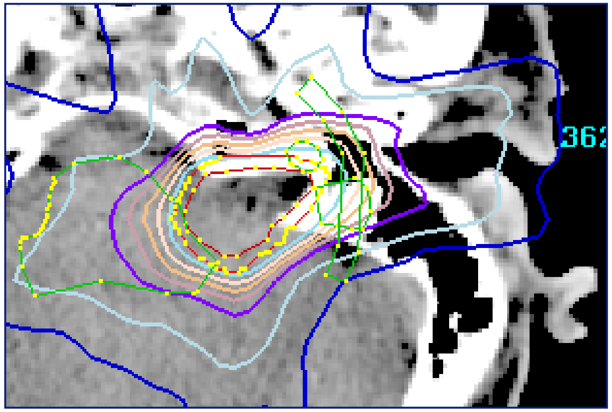




Example: vestibular schwannoma (skull tracking)

- Translations during first 12.5 minutes





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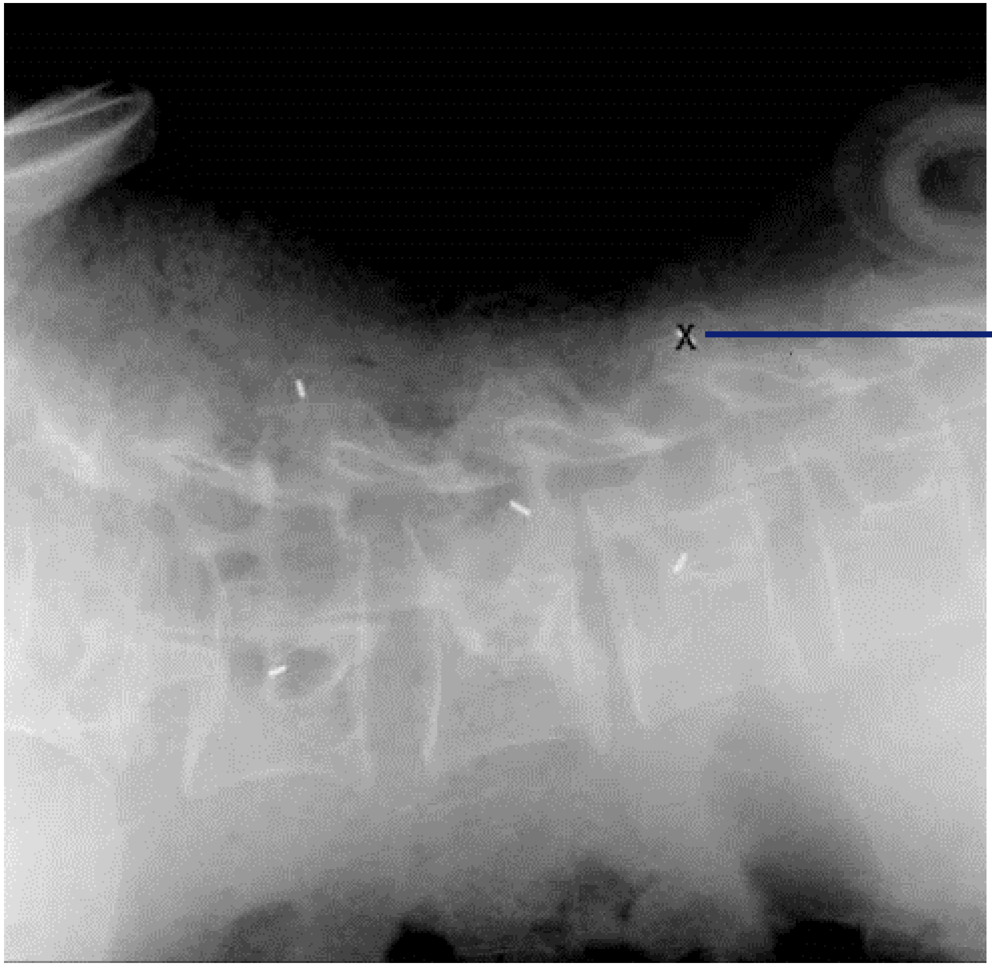
SPINE TRACKING

During Treatment: Spine Case



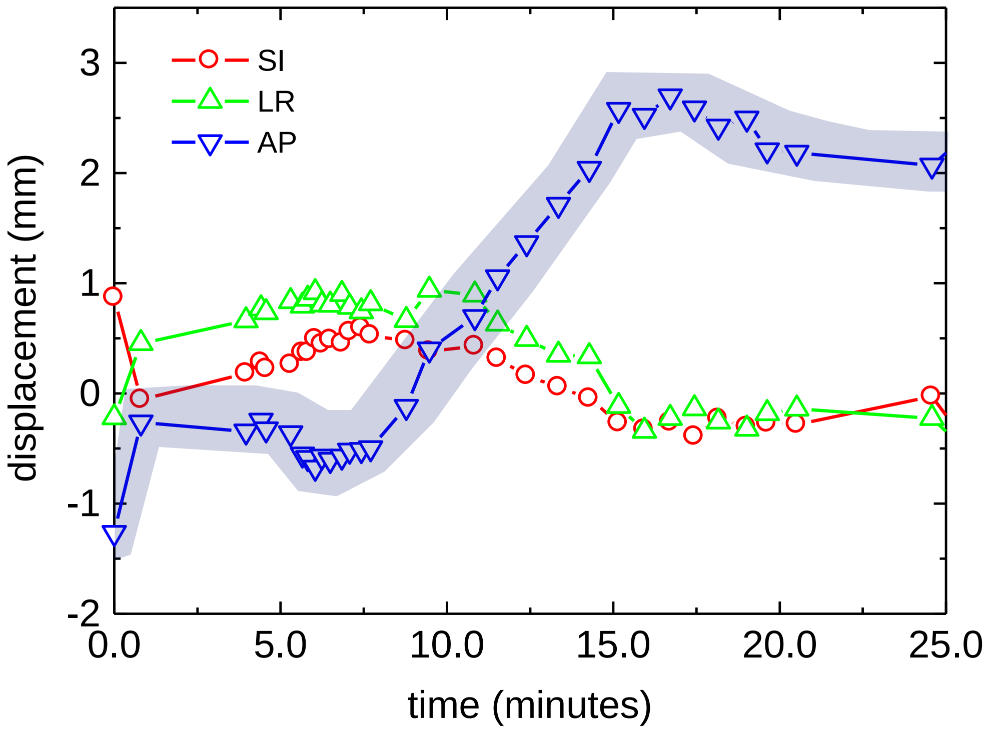
Time period: 25 minutes

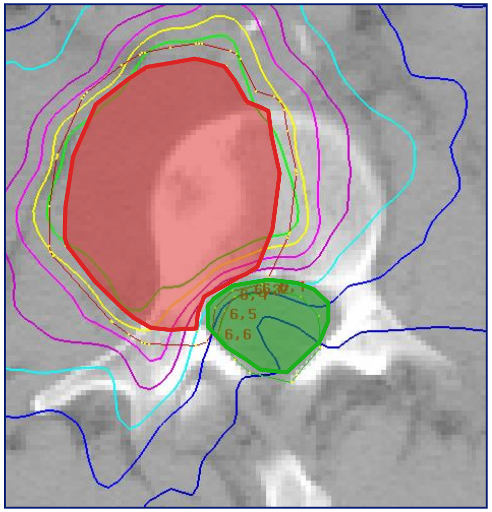
Initial position

Vacuum bag for immobilization and comfort

During treatment: spine case (fiducial tracking)

- Translations during first 25 minutes





Each symbol is an image acquisition

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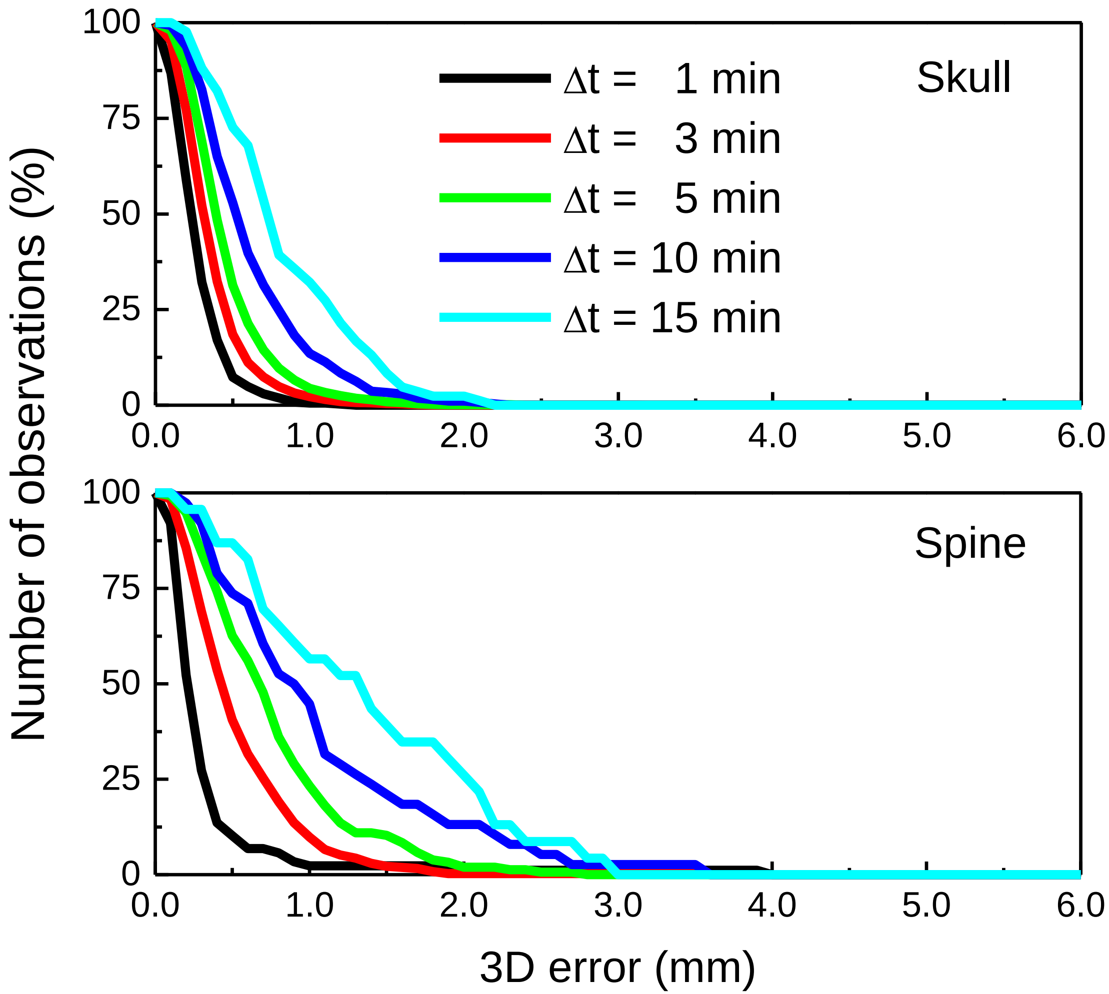
3D targeting error for different time intervals



Maximum translation: 3.8 mm after 3 min

Maximum translation: 4.3 mm after 2 min

Hoogeman et al. IJROBP 2008

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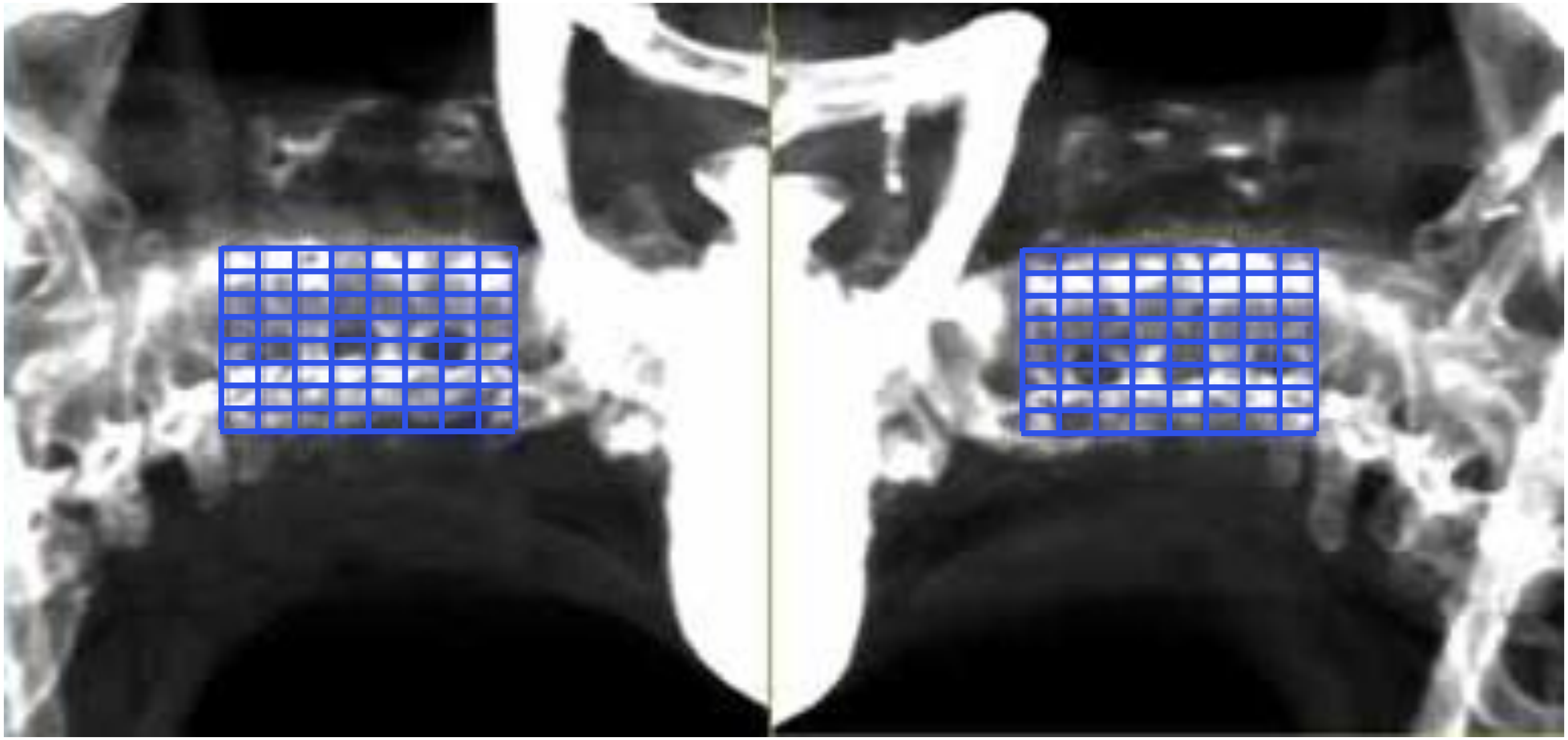
Optimize Location



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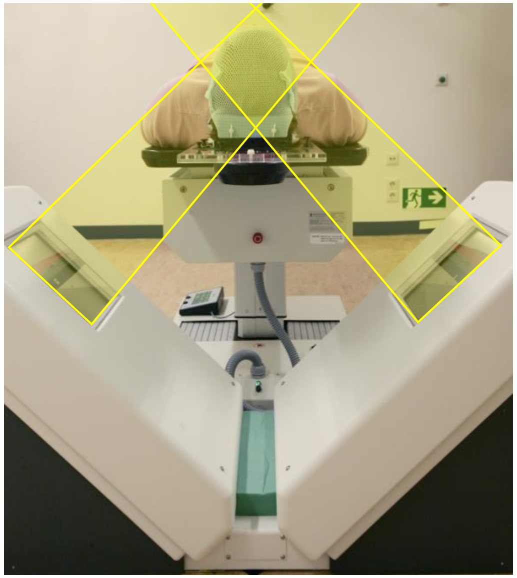
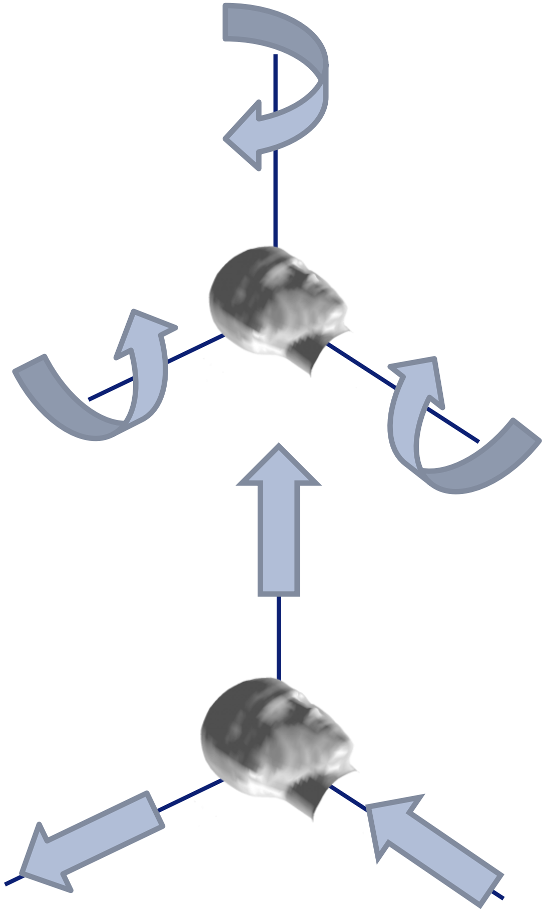
Six Degrees of Freedom





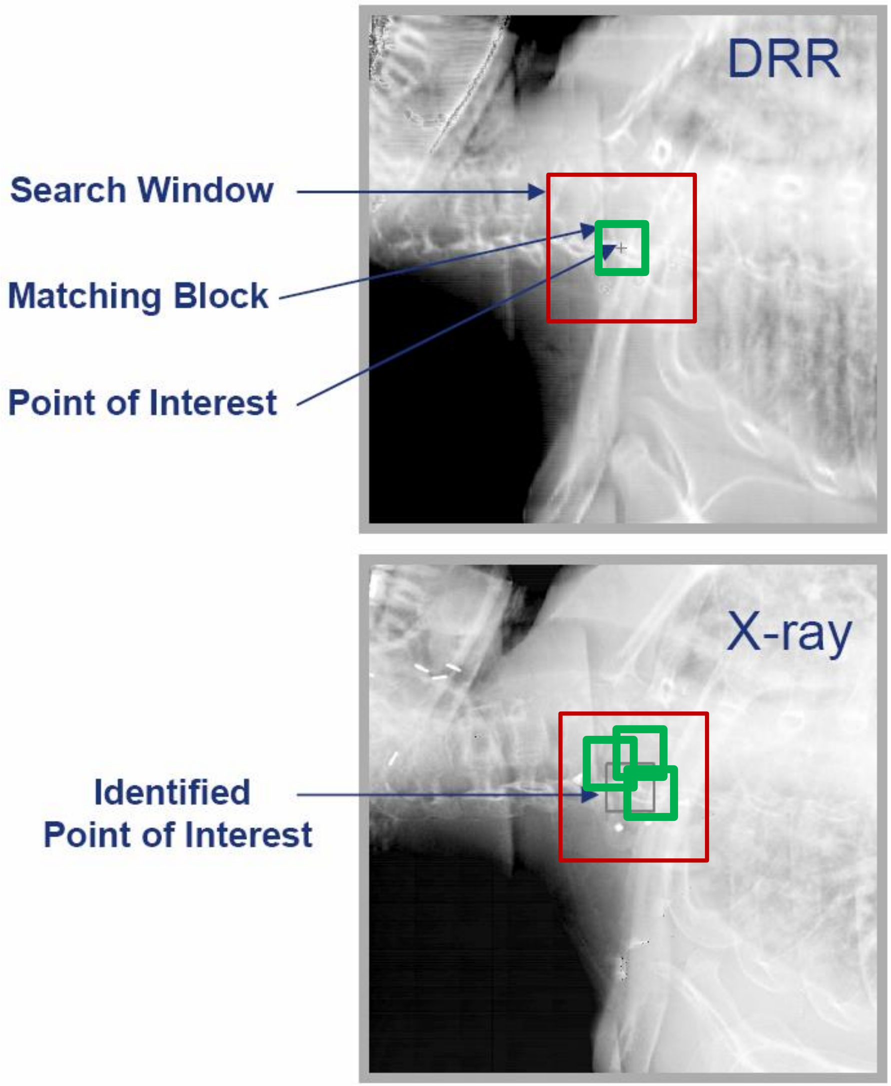
DRR Library for Out-of-Plane Rotations

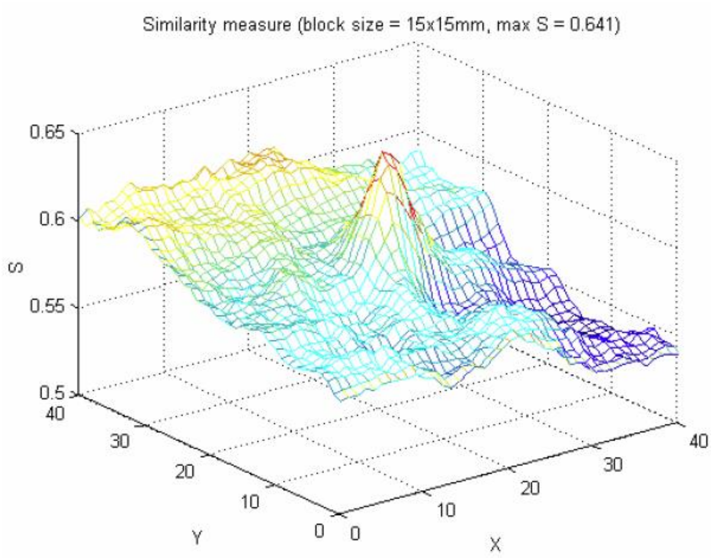
- Pitch and Yaw rotations yield in-plan rotations in the 2D X-ray images
  - Pitch and Yaw rotations can be approximated by 2D-2D matching

- Roll rotation correspond to an out-of-plane rotation that causes subtle changes in the X-ray images
  1. A set of reference DRR images (17 pairs) is generated corresponding to various out-of-plane rotations (roll)
  2. Image registration compares all of the DRRs with the X-ray image
     - Best match gives the roll rotation angle

- Similar as for 6D skull tracking

Placing Tracking Grid by Matching Block Algorithm





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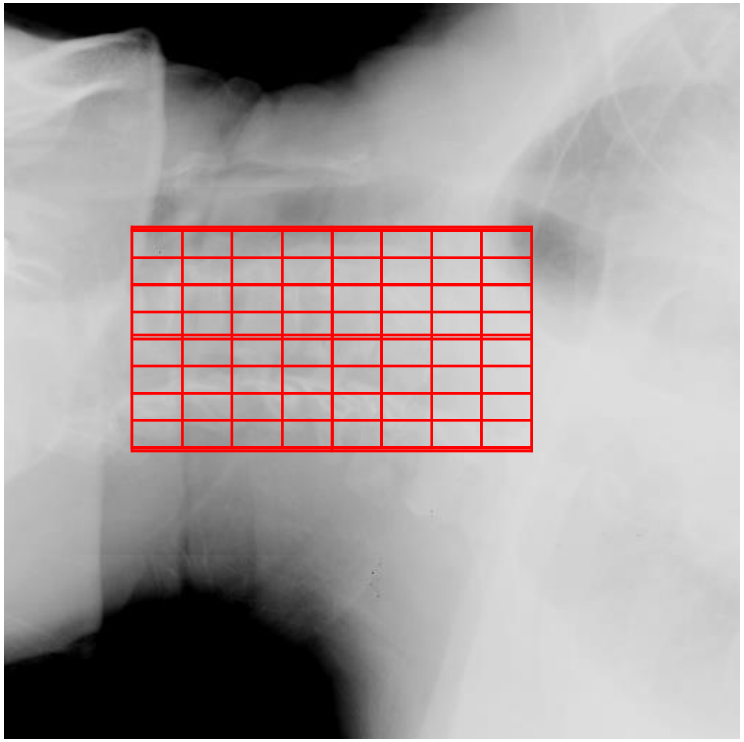
Matching the Mesh

- Hierarchical Mesh Tracking
  - Identifies unique bony structures
  - Enables registration of non-rigid skeletal anatomy
  - Estimates local displacements in bony features

Step 1



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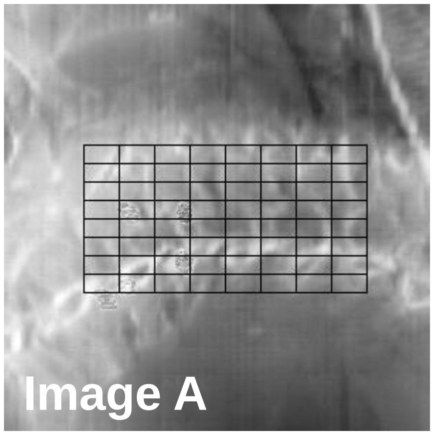
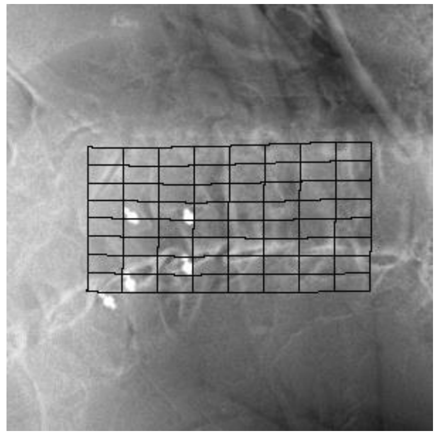
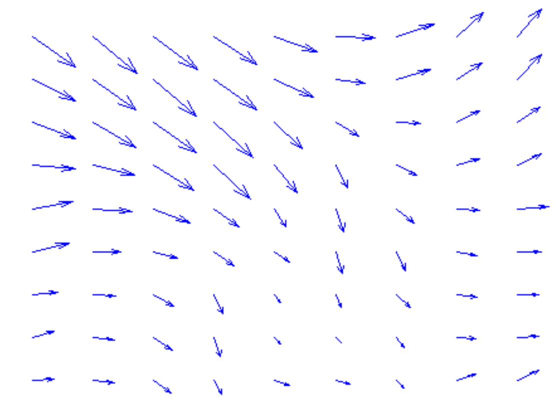
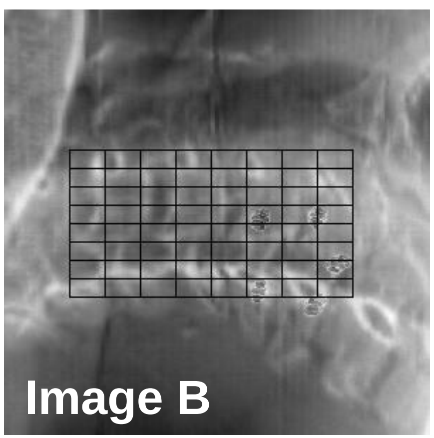
Non-Rigid Match Result

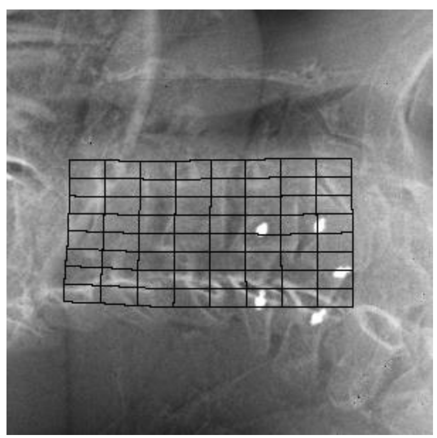
DRR (from CT) | Live X-ray image | Displacement Field

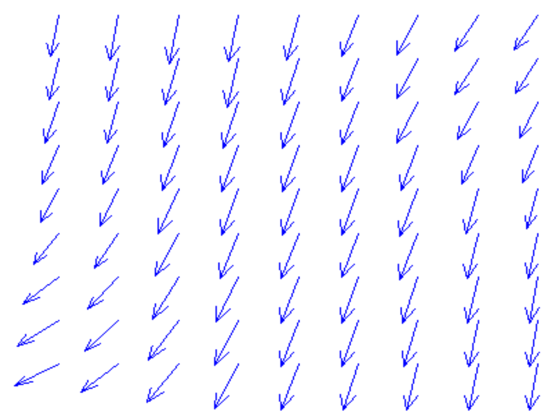












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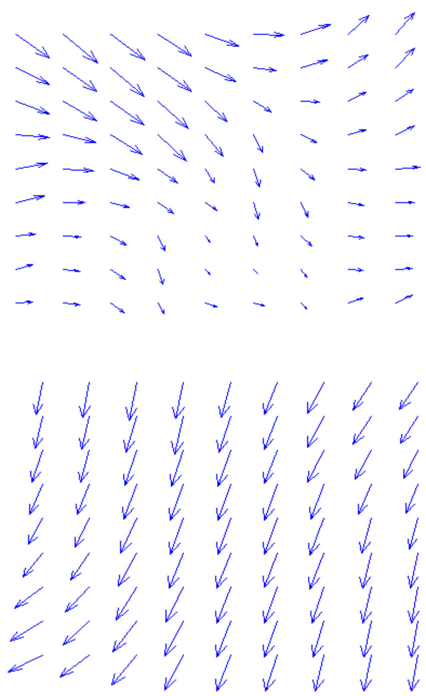
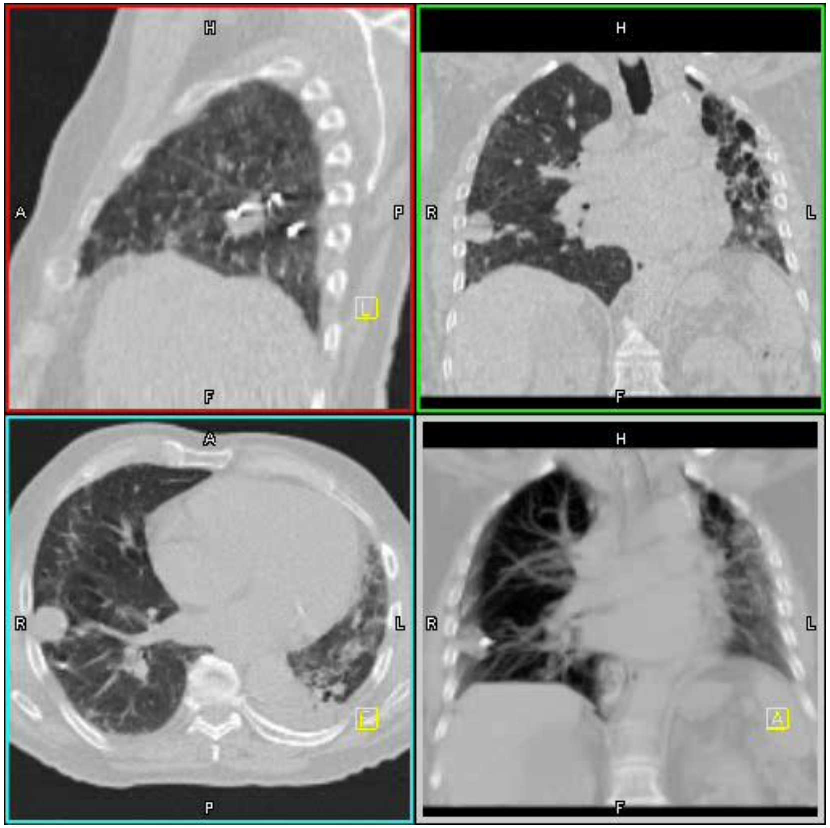
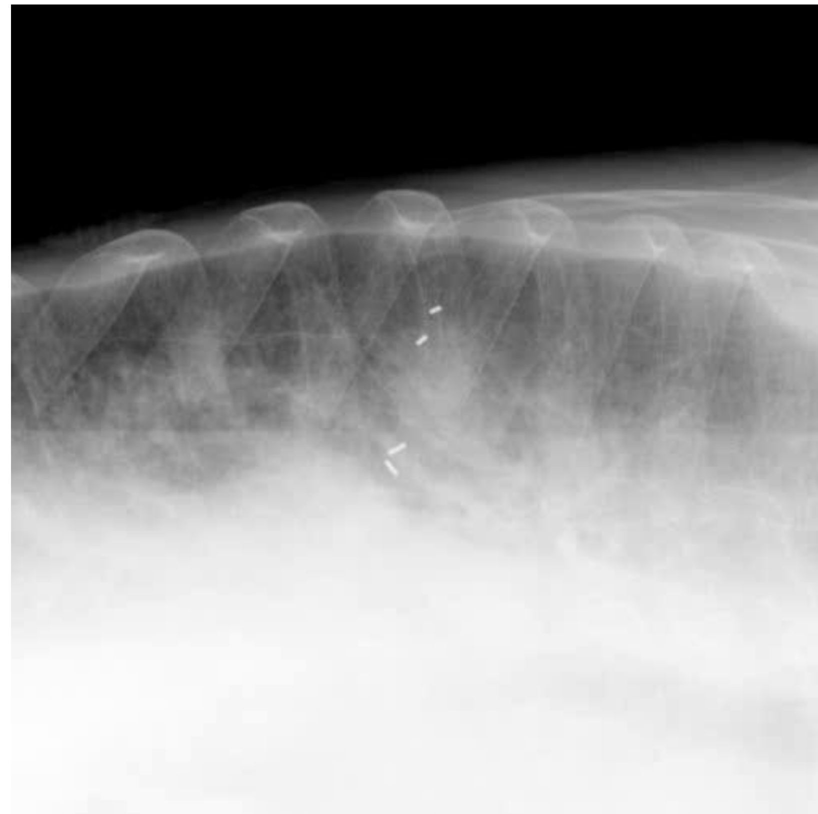
Calculation of the 6D Correction Vector

- Roll angle is based on the DRR selection
- Pitch, Yaw, and translation are derived from displacement pattern



SYNCHRONY: LUNG TRACKING





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Real-Time Respiratory Motion Tracking (Synchrony)

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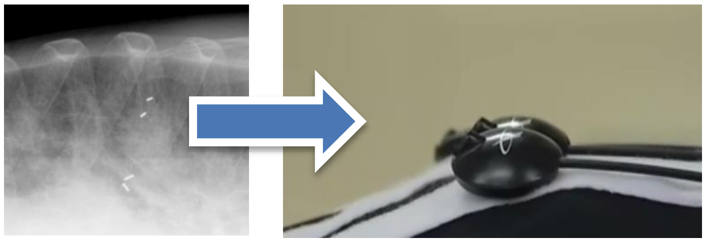
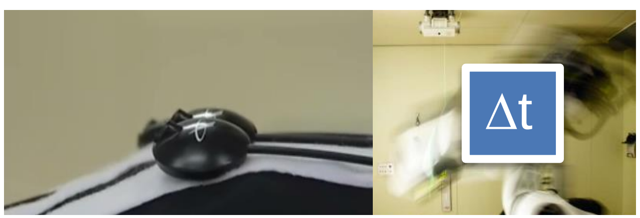
Breakdown of Components

1. **Correlation model relating tumor and chest motion**



2. **Prediction model forecasting motion to compensate system lag**



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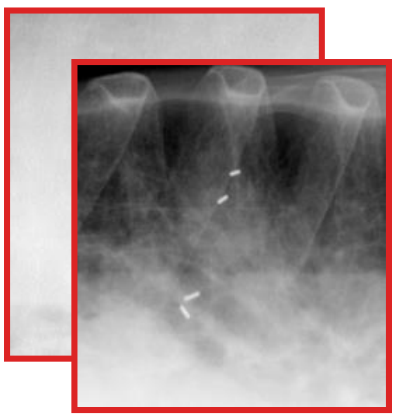
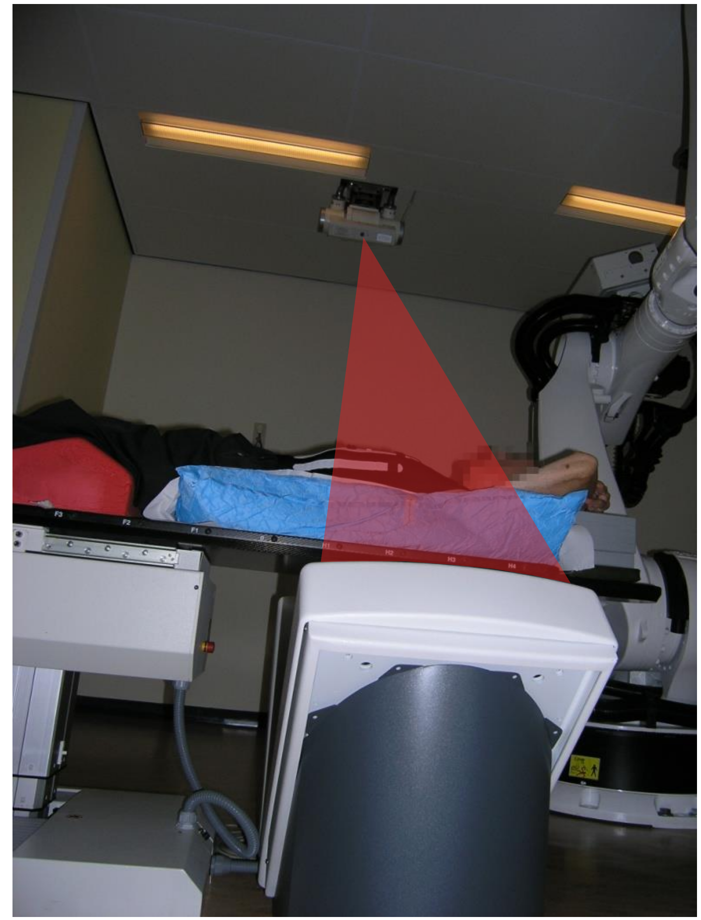
Correlation model: internal motion

- **Motion of markers or tumor**
  - X-rays at start of treatment

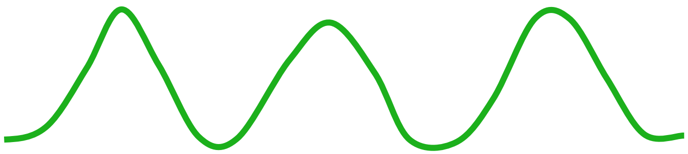




- Internal tracking can be based on
  - Implanted markers
  - Marker-free image-intensity matching

Correlation model: external motion

- **Respiratory motion of chest or abdomen**
  - LEDs and camera system



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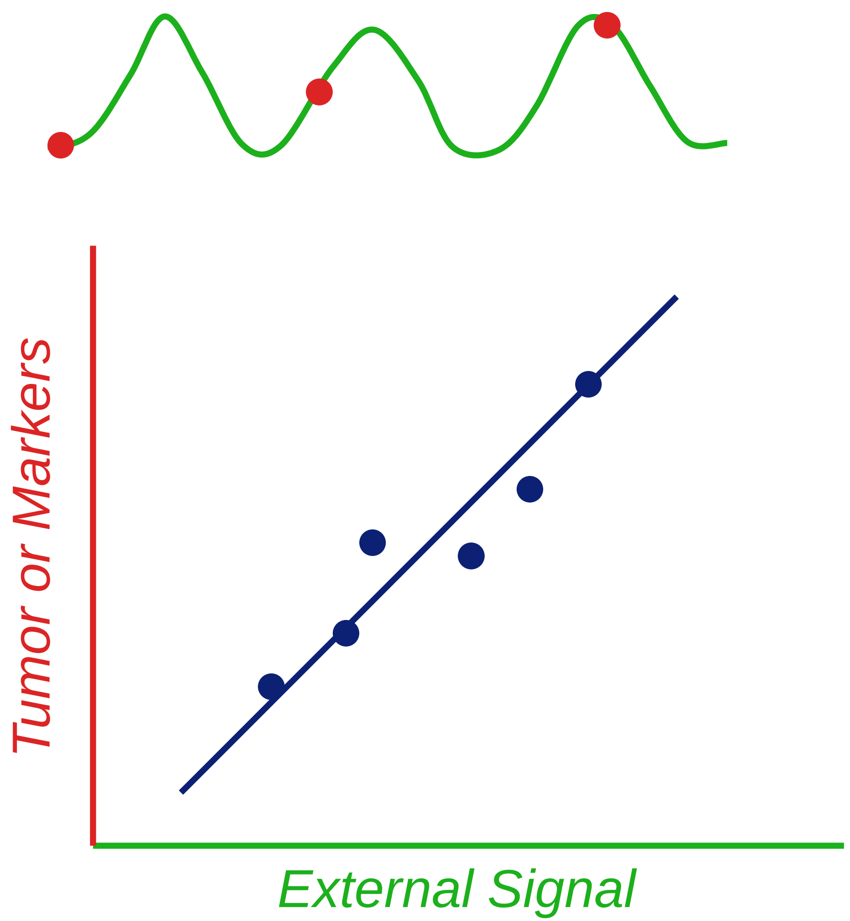
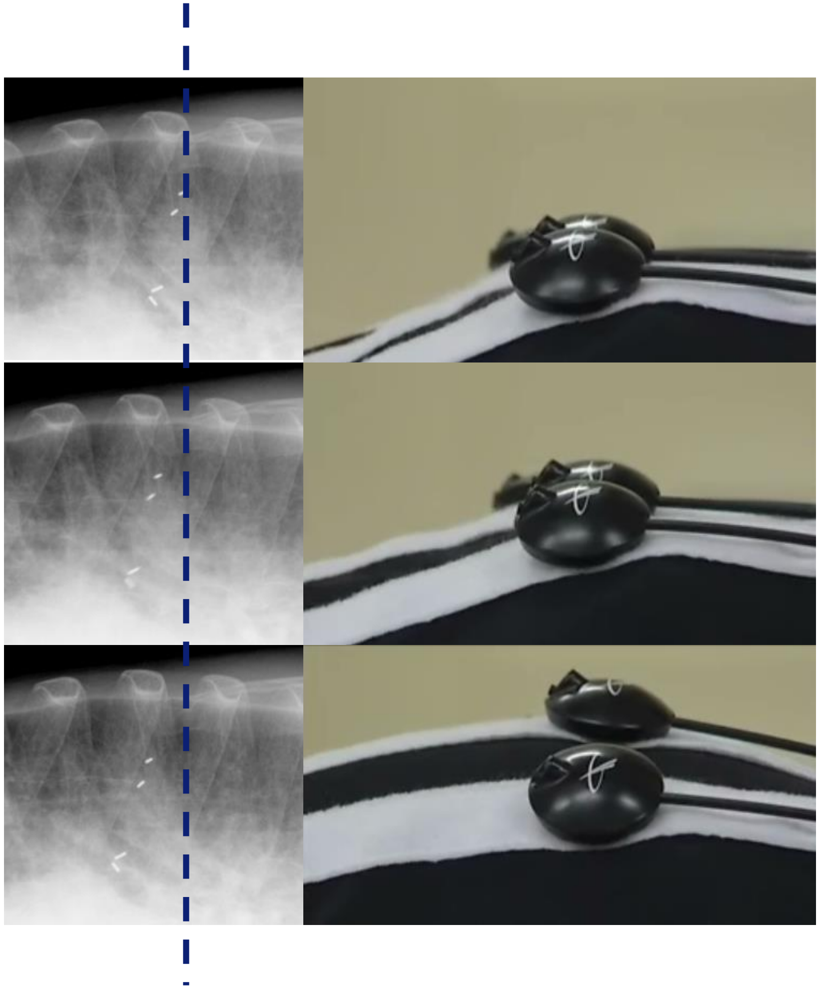
Building of a Correlation Model





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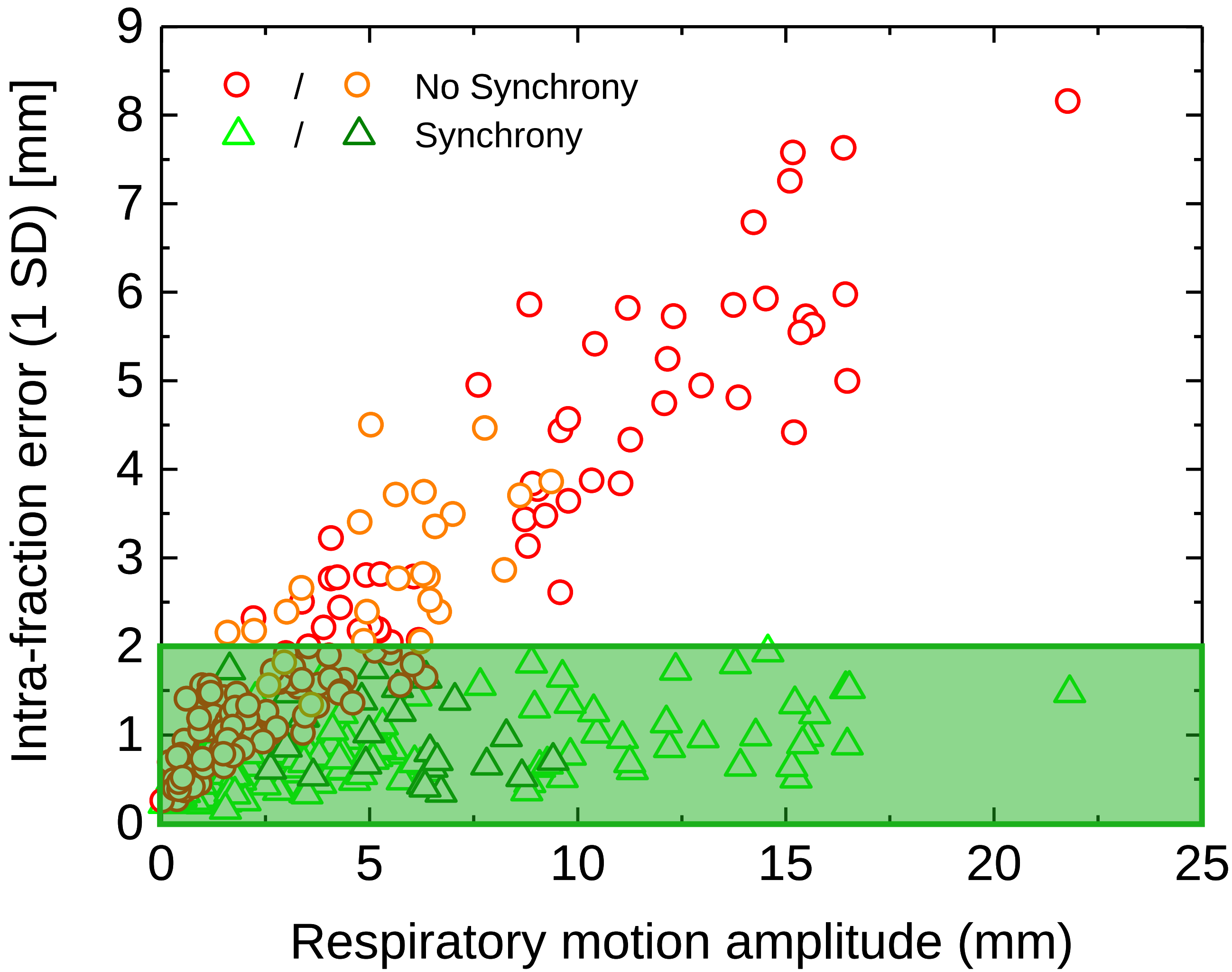
Correlation Model

- **Model built at start of treatment fraction**
  - Model is based on 15 data points
  - Automatic data-point acquisition for evenly distributed points across the breathing cycle

- **Various model types**
  - 1 linear type model (no hysteresis)
  - 5 polynomial type models (to account for hysteresis)

- **Model updated throughout the treatment fraction**
  - Data points are replaced on a first in first out basis
  - Automatic image acquisition ensures an even spread across breathing cycle

Intra-Fraction Error (167 treatment fractions)



Hoogeman M, Prévost JB, Nuyttens J, Pöll J, Levendag P, Heijmen B, Clinical accuracy of the respiratory tumor tracking system of the cyberknife: assessment by analysis of log files. Int J Radiat Oncol Biol Phys. 2009 May 1;74(1):297-303.

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XSIGHT LUNG TRACKING

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Xsight Lung Tracking

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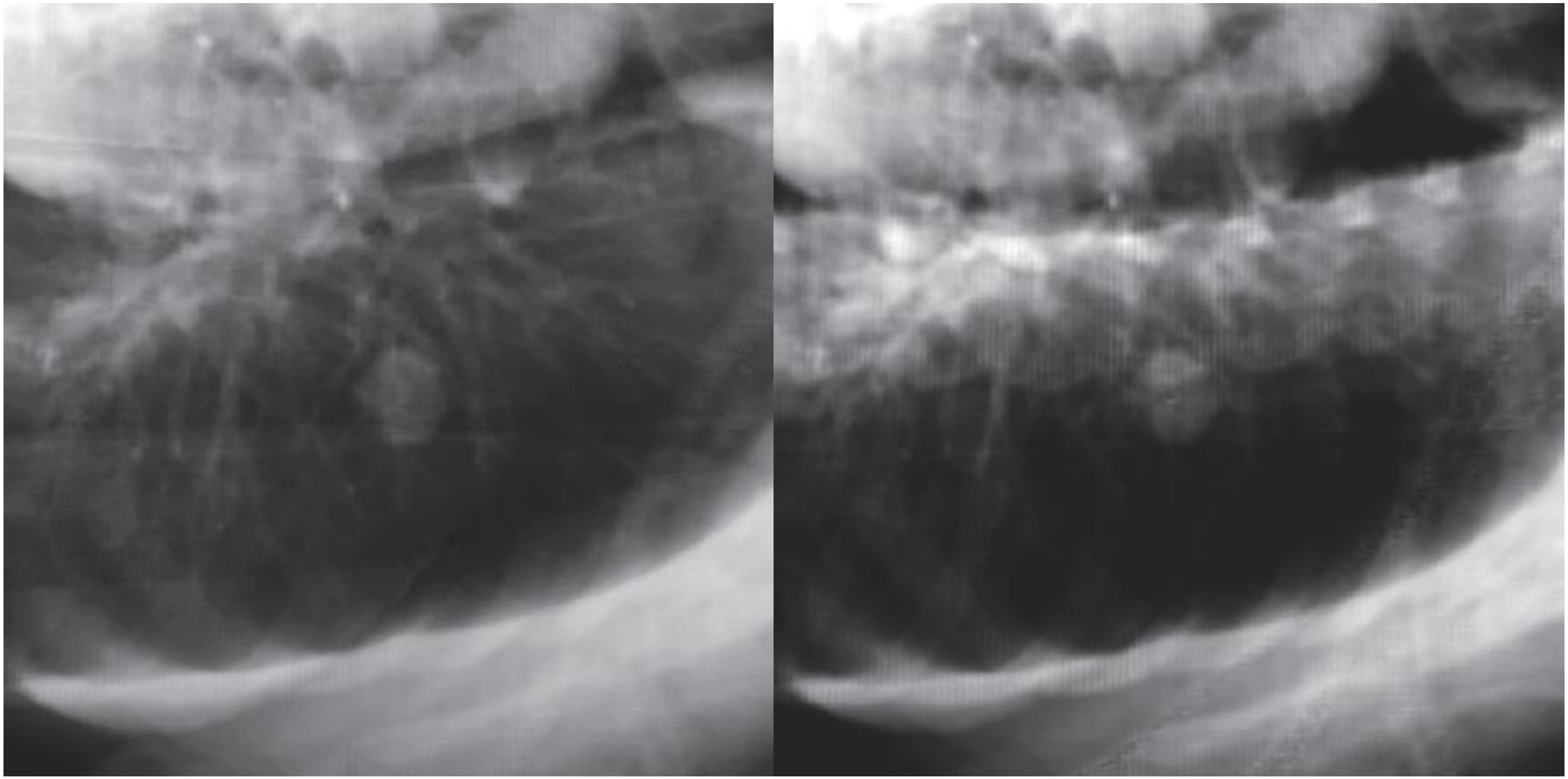
Spine Removal



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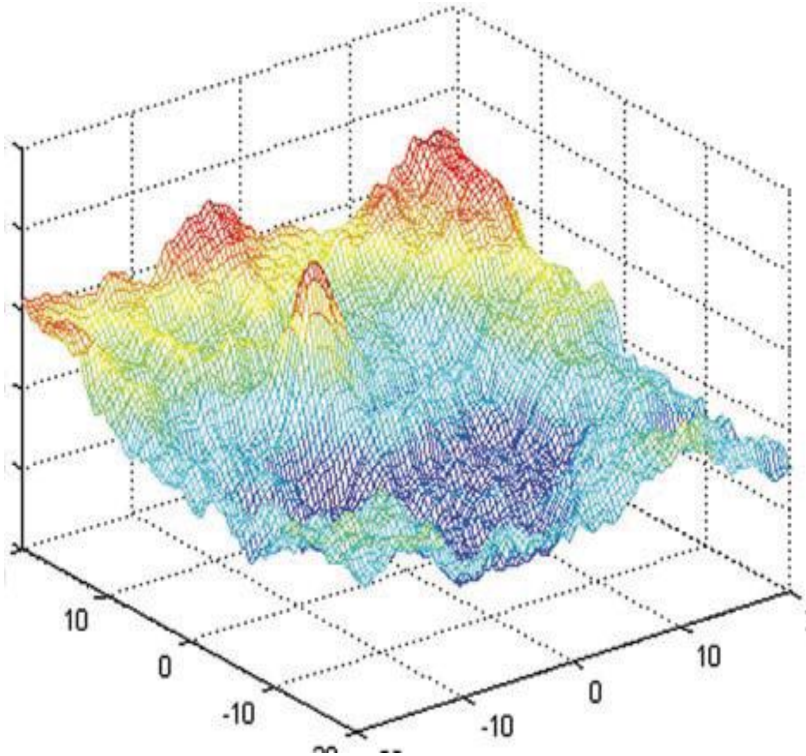
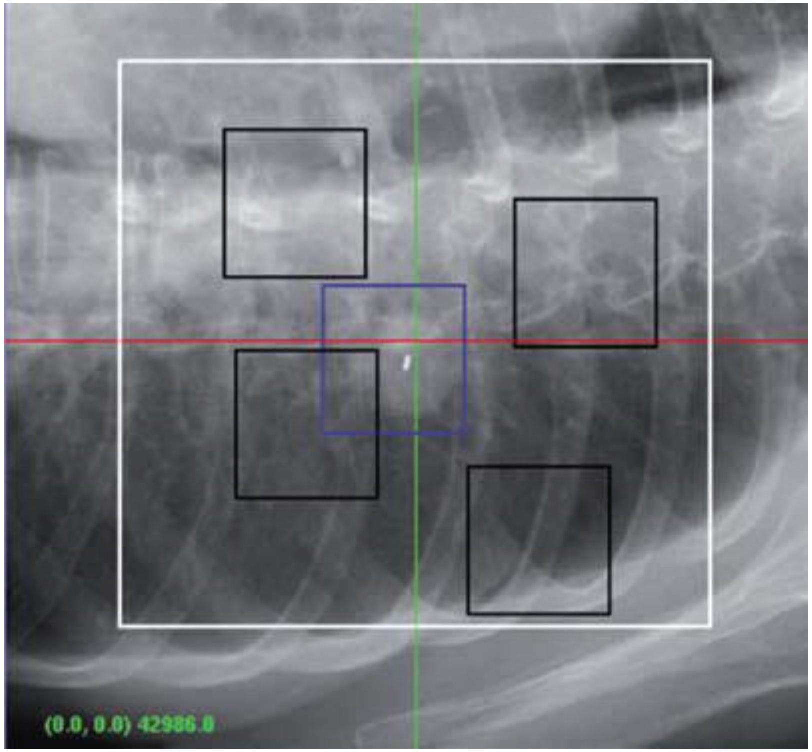
Block Matching





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Treatment Console

DURING TREATMENT DELIVERY

During Treatment Delivery

- **Treatments with tight safety margins**
  - No lock on the target => no treatment
    - Tumor cannot be localized (Xsight Lung Tracking)
    - Marker distances changed (Marker Tracking)

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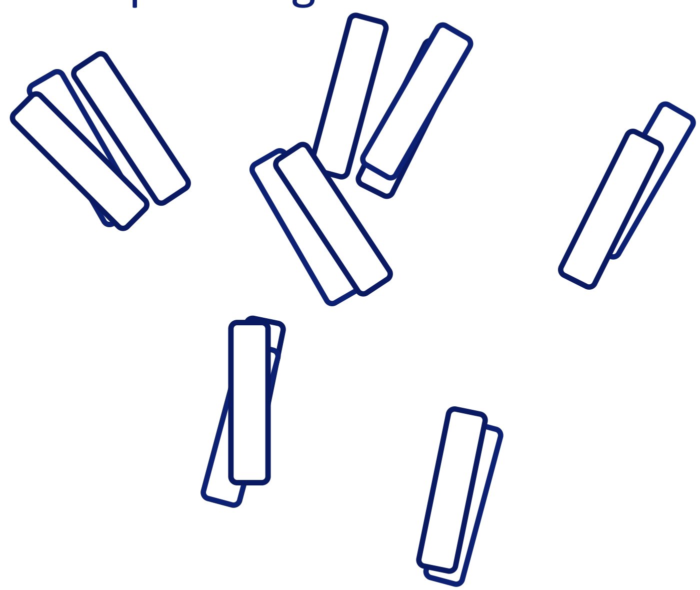
Deformation in Marker Configuration

- Rigid-body threshold exceeded => increase rigid-body threshold

planning



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Recommendations

- **Well-trained staff is required**
  - Recognize failures in localizing the tumor or markers
    - Understands metrics displayed by the system
    - Understands consequences of adjusting an imaging parameter
    - Visual verification (independent)
  - Recognize failures in the correlation model

- **Attendance of medical physicist and radiation oncologist**
  - Medical physicist present during first patient treatments
  - Radiation oncologist on site
  - Clear protocol and/or decision tree

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Workshop on Library of Plans

Rianne de Jong *RTT*,
Academic Medical Centre, Amsterdam
Copenhagen 2015

m.a.j.dejong@amc.uva.nl
ESTRO School

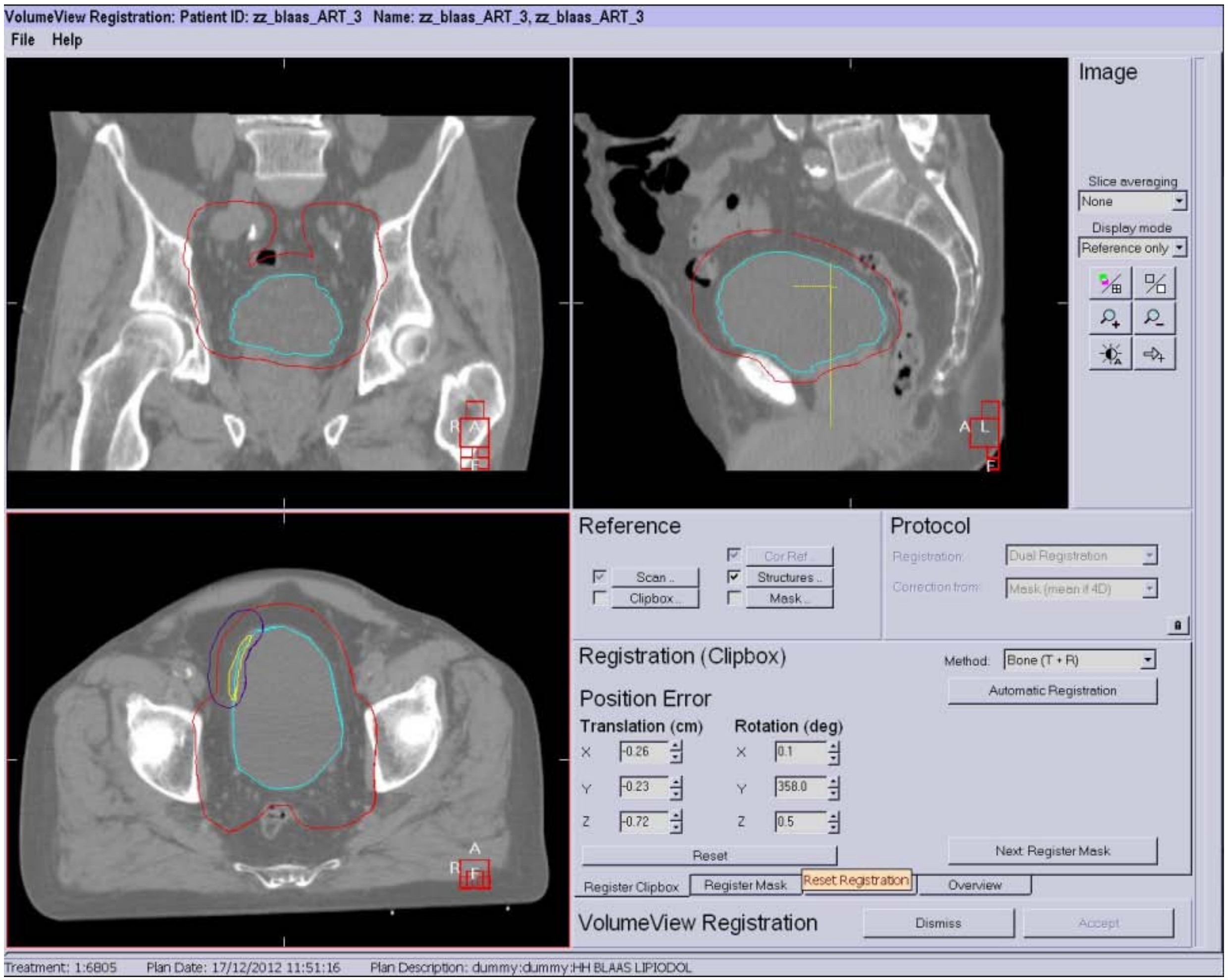
Contents workshop

Bladder:

- Registration protocol for bladder
- Live Observer Study

Cervix:

- Registration protocol for cervix
- Live Observer Study



Bladder plan selection @AMC

Targetvolume:

- Whole bladder low dose
- Boost part bladder high dose
- Nodal area up to L5

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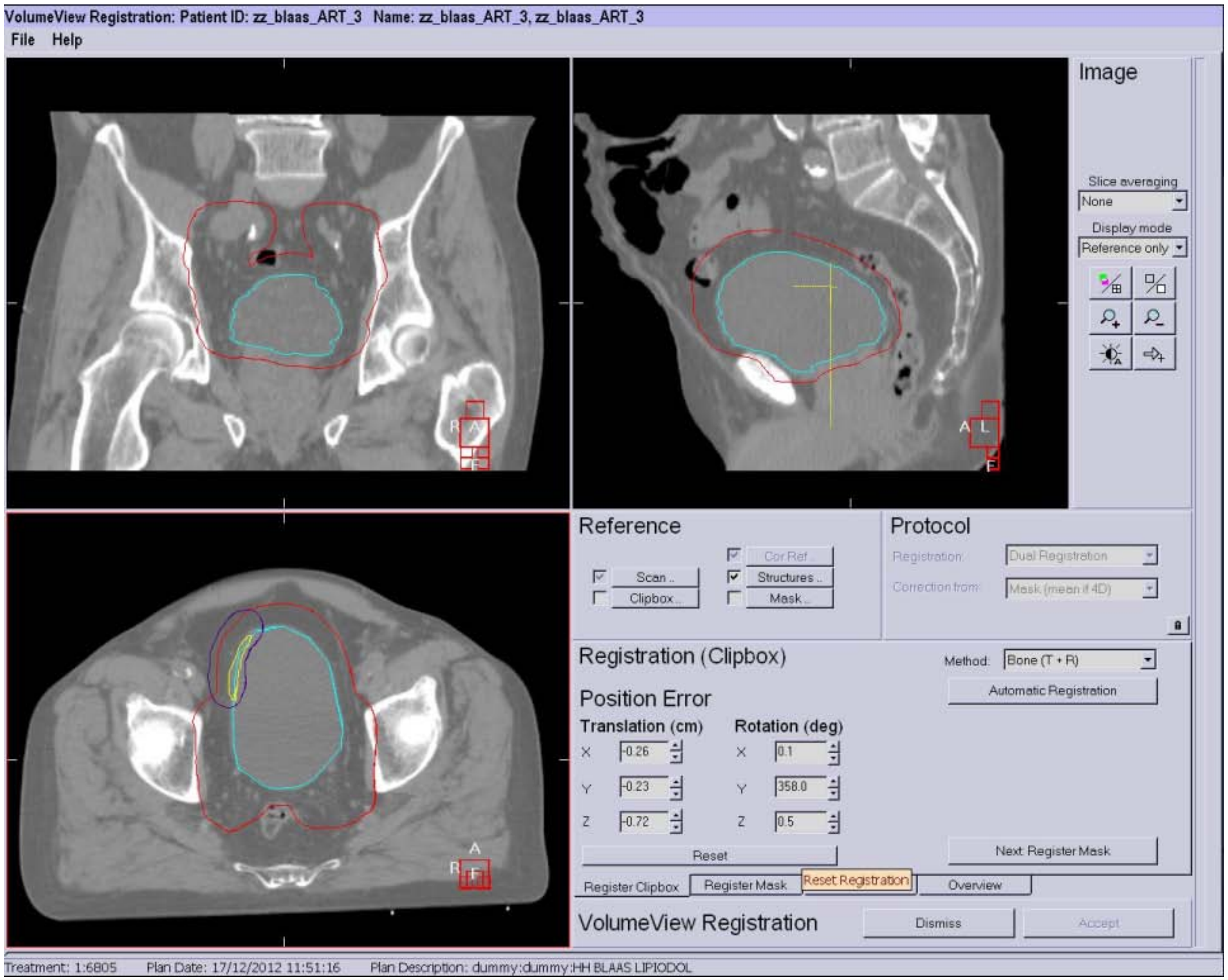
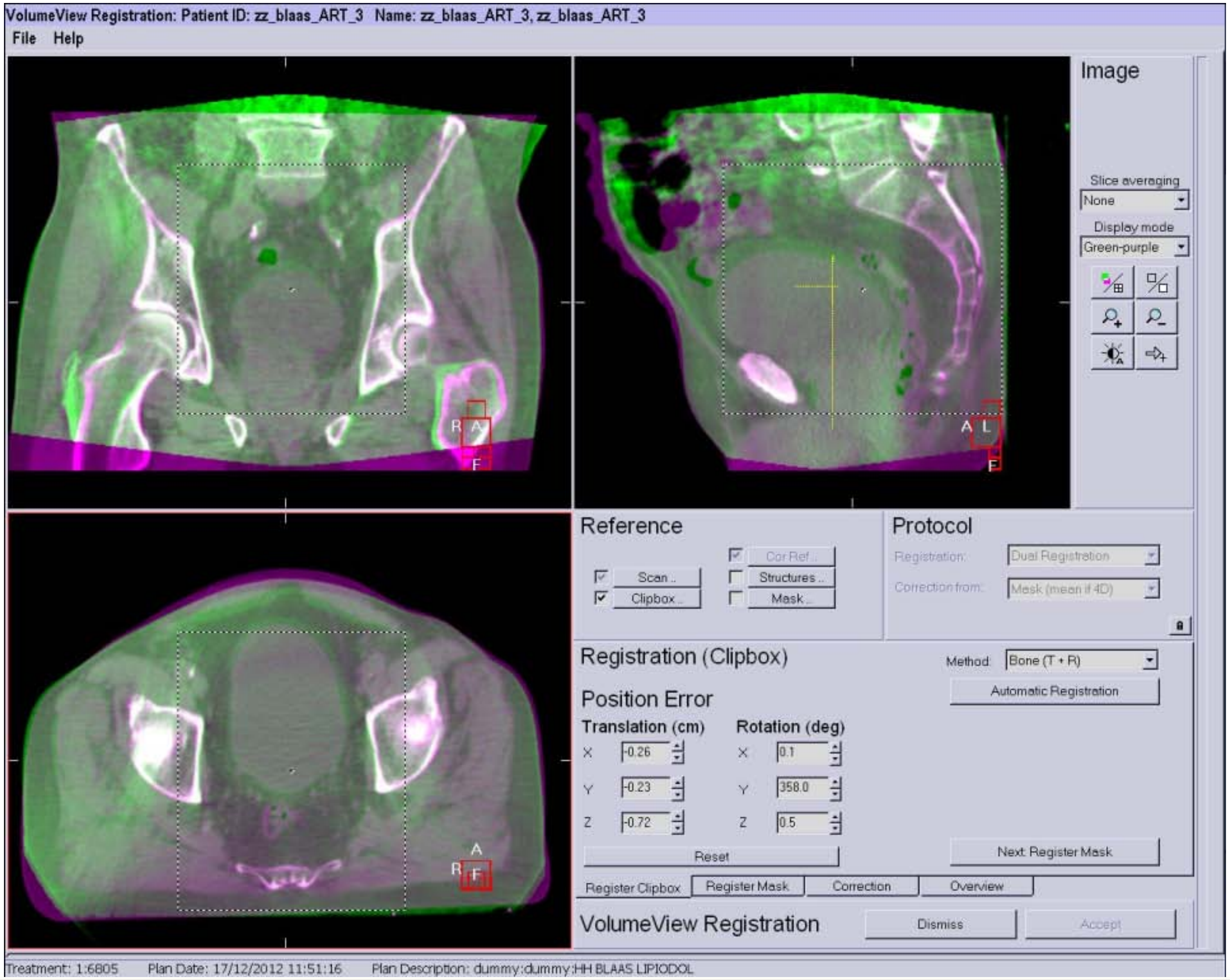


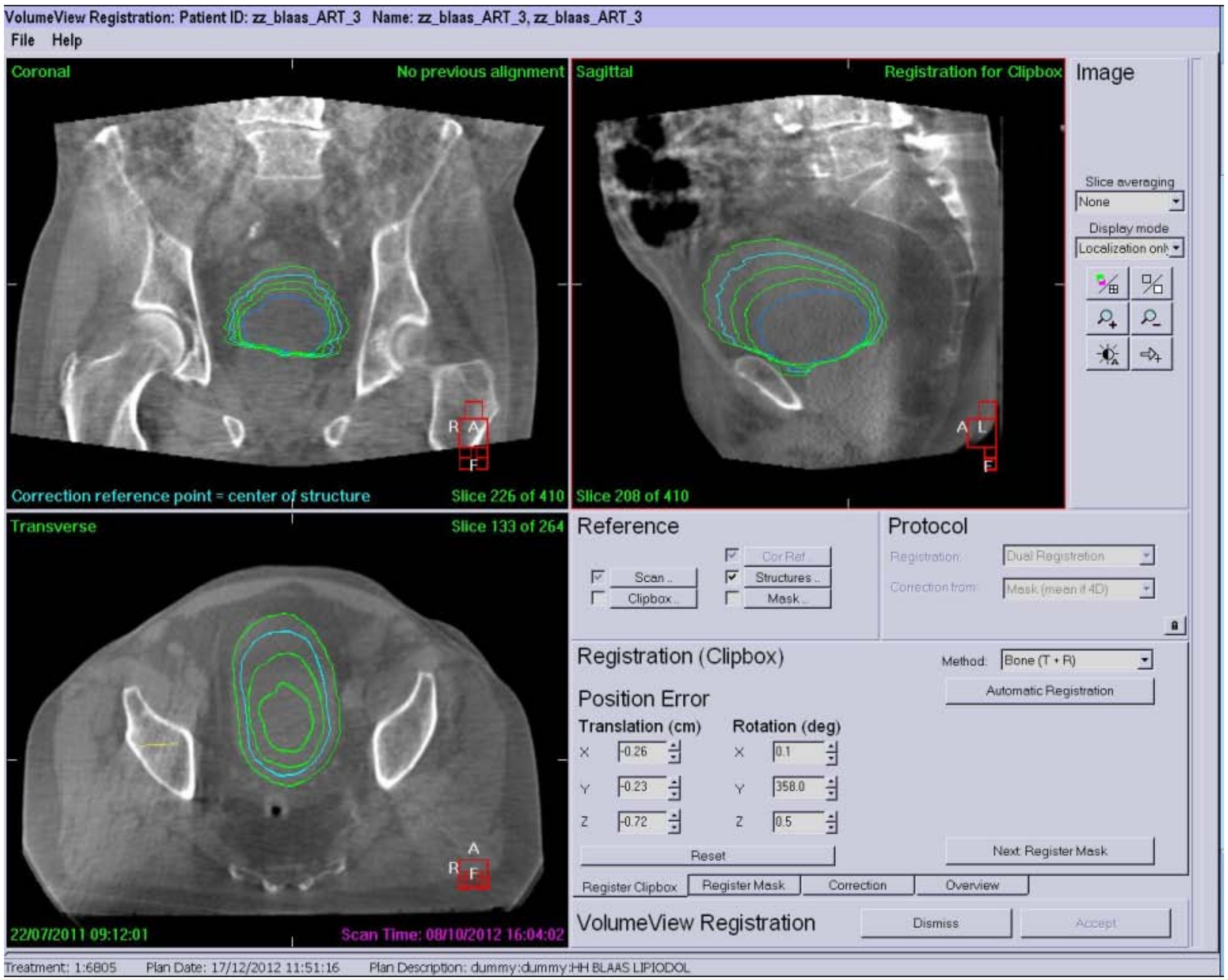
Bladder plan selection @AMC

1. Full bladder protocol
2. Bony anatomy registration for nodes
3. Selection of plan for whole bladder
4. *Optional: tweak for the high dose region*



1

- Bony anatomy registration in green-purple with bone algorithme



2

- Overlay of structures on the CBCT
- Do not use CT scan anymore at this point!
- Pick the plans that fits best based on bladder structure, by means of deduction

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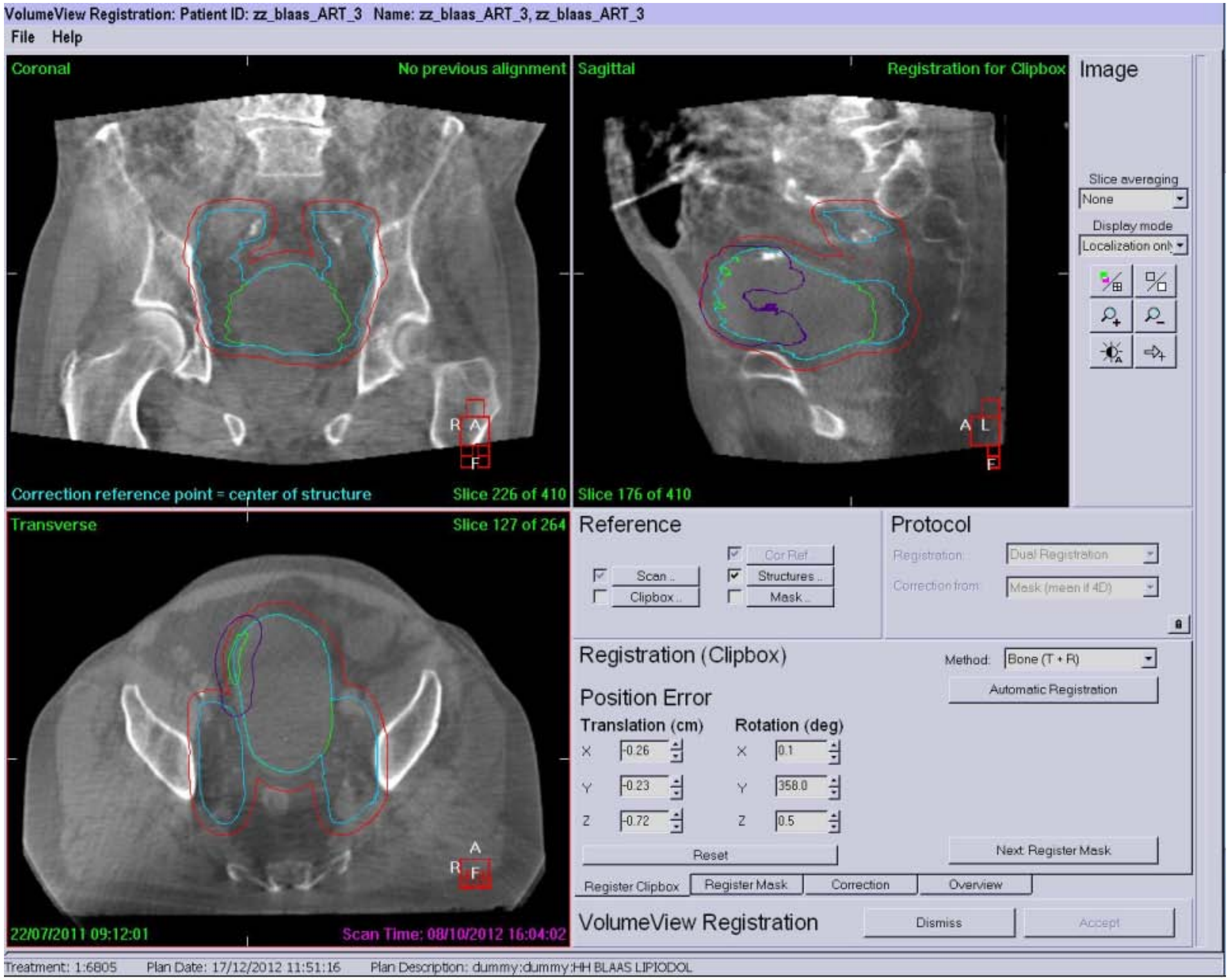
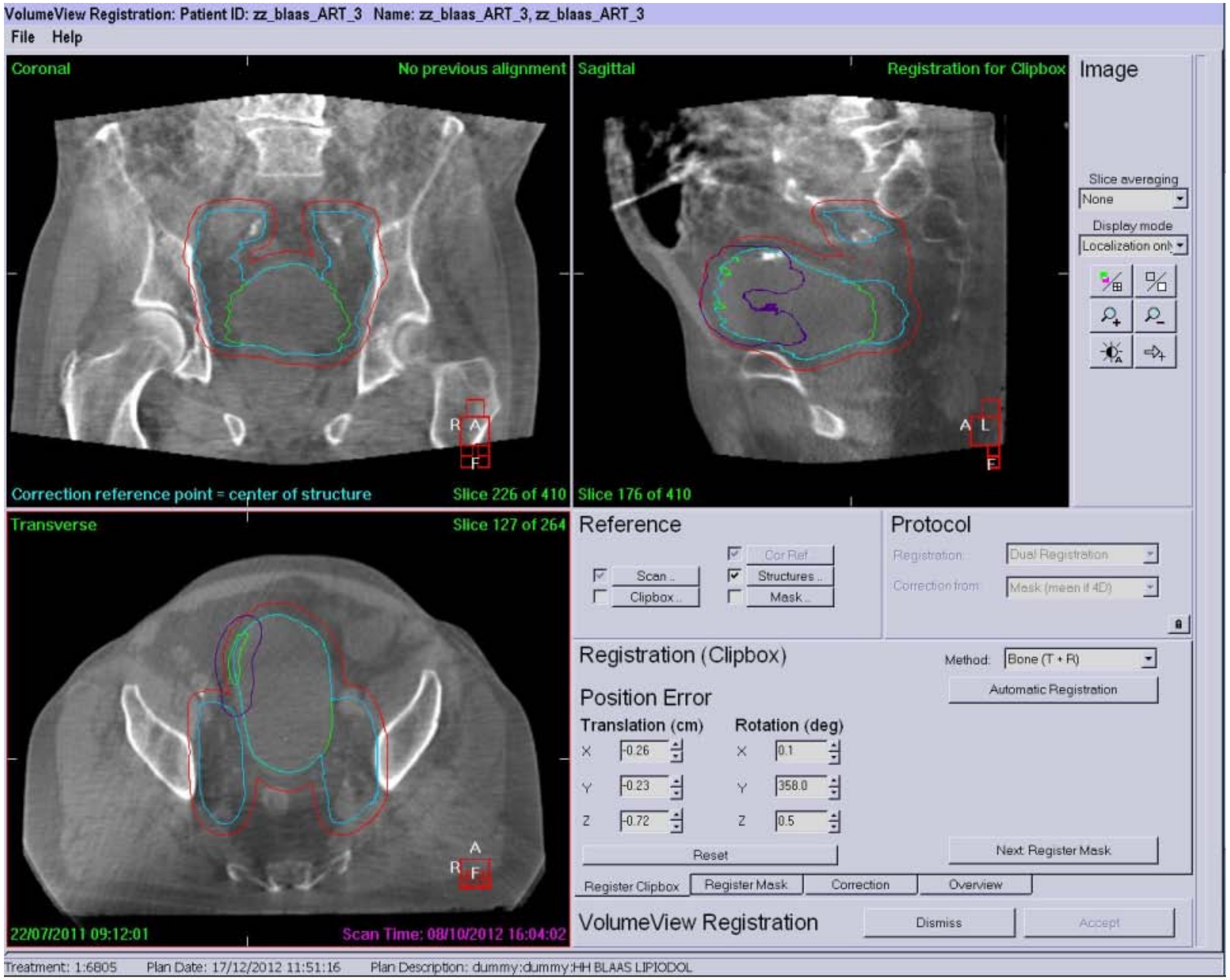


3

- Display accompanying structures
- Check target coverage in PTV, both before and after correction for rotations



4

Optional tweak: manual adjustement for the high dose region

?

Do not overstep on the tweak. Take the marginsize of the nodes into account

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Live Observer Study

4 bladder patients x 5 CBCT's

1. Individual selection by turning point
2. Group discussion
3. Selection by turning point

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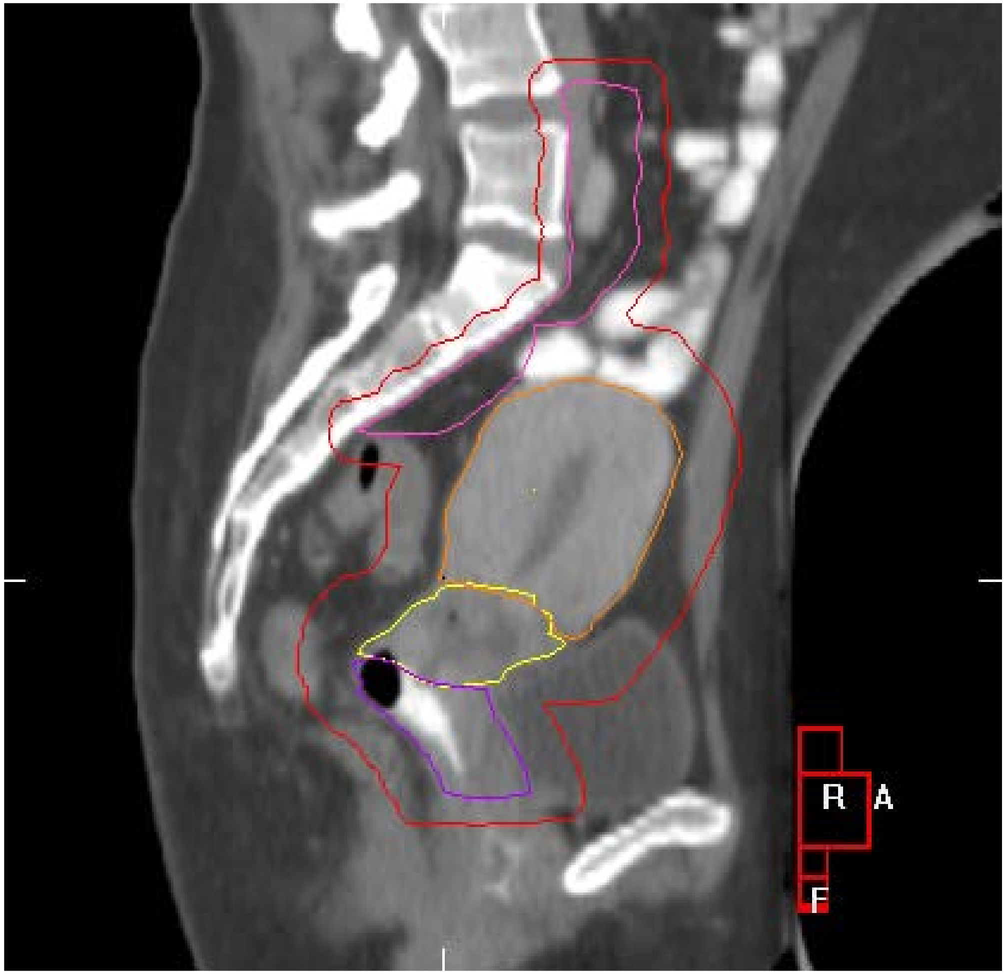
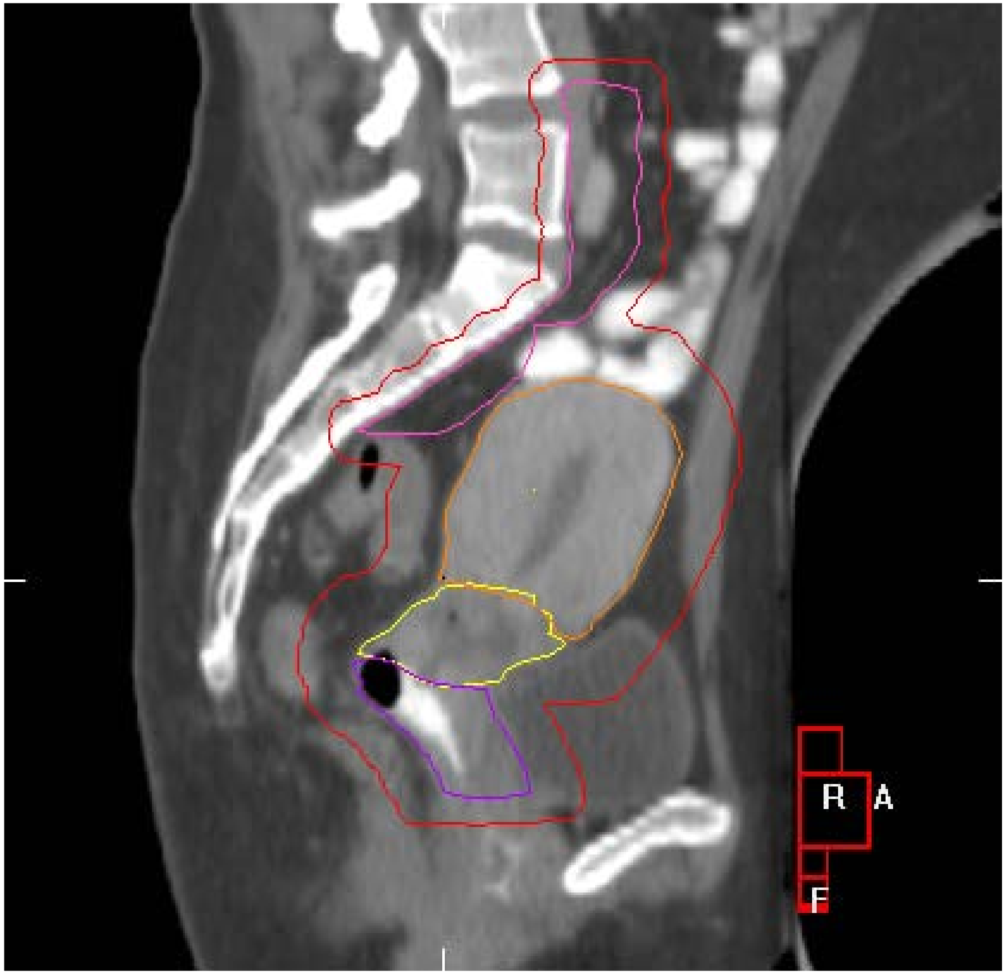


Cervix plan selection @AMC

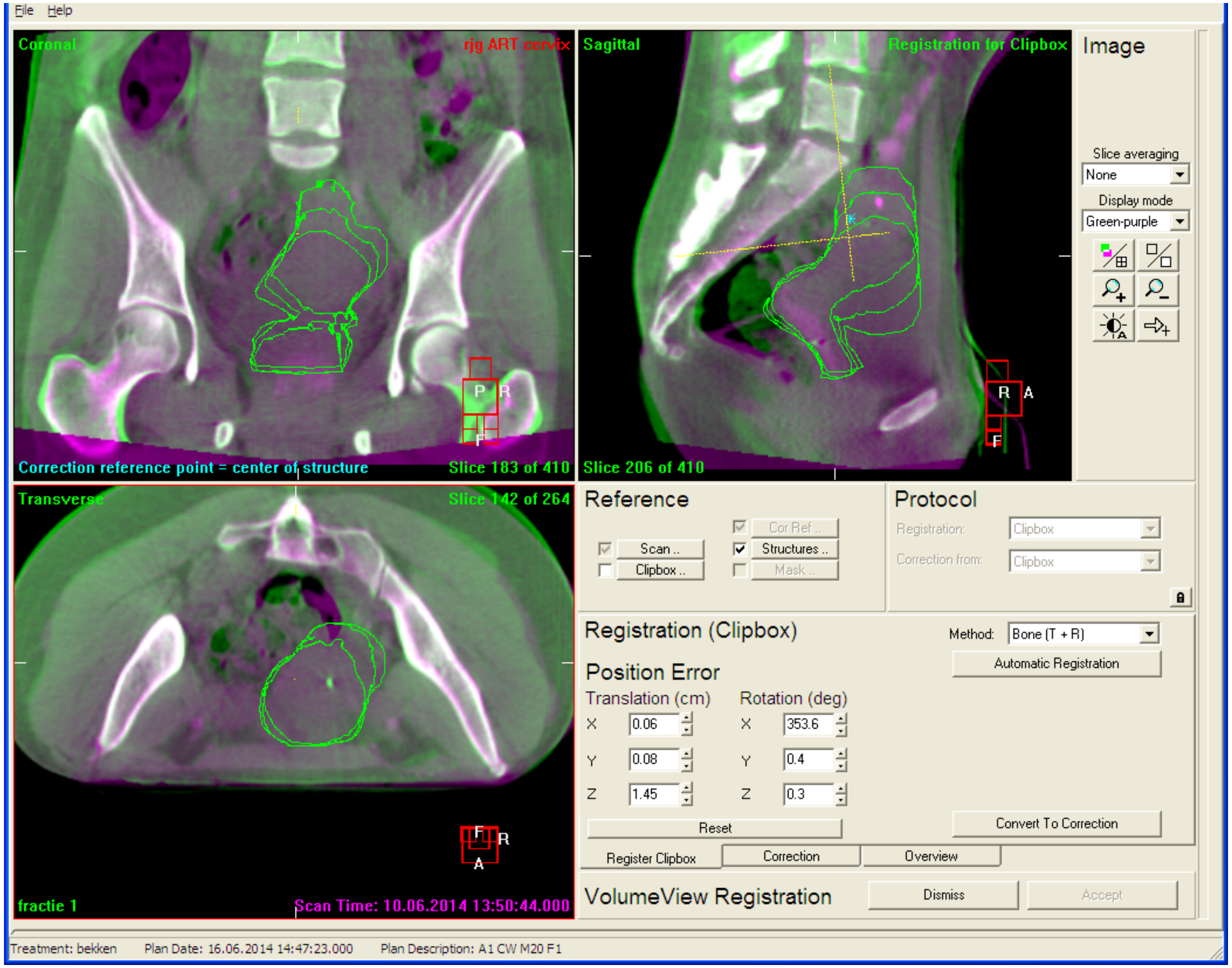
Target volume:

- Cervix
- Uterus
- Nodal region up to L2



Cervix plan selection @AMC

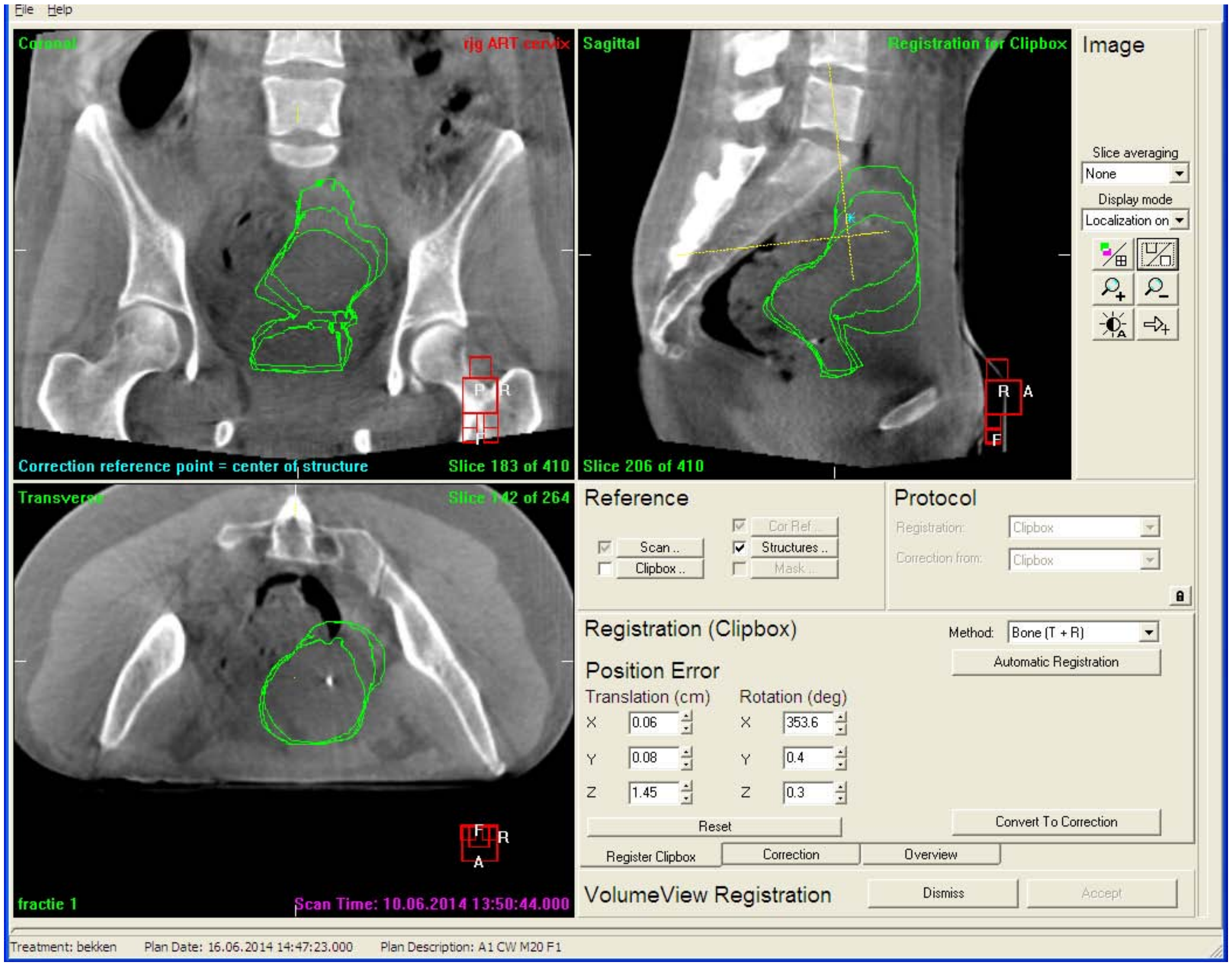
1. Full bladder protocol
2. Bony anatomy registration for nodes
3. Selection of plan for cervix&uterus
4. Marker check
5. **NO tweak**



1

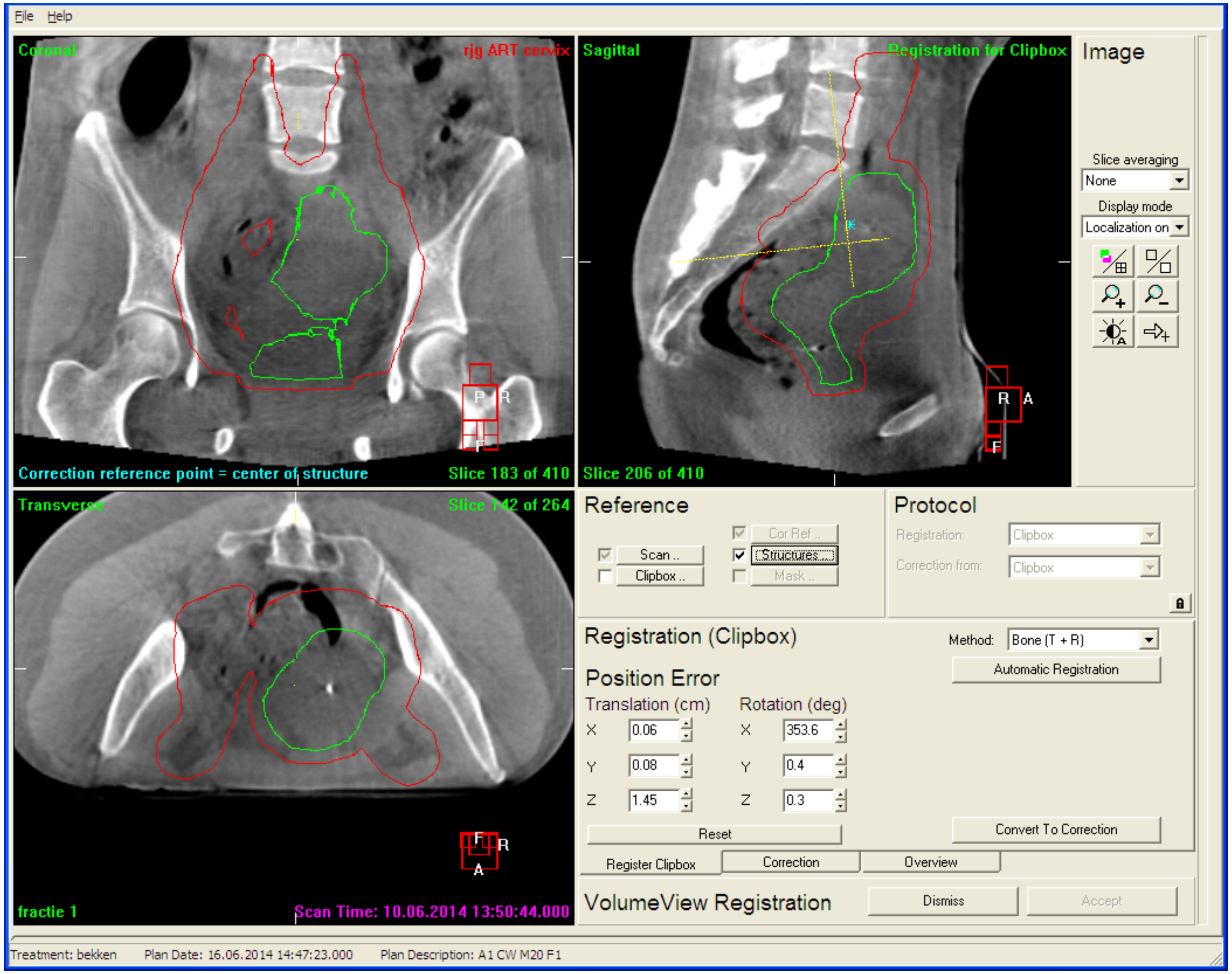
Bony anatomy registration in green purple overlay with bone algorithm

ESTRO School



2

- Overlay of (ITV) structures on the CBCT
- Do not use CT scan anymore at this point!
- Pick the plans that fits best based on ITV structure, by means of deduction



3

- Display accompanying structures
- Check target coverage in PTV, both before and after correction for rotations
- Check markers

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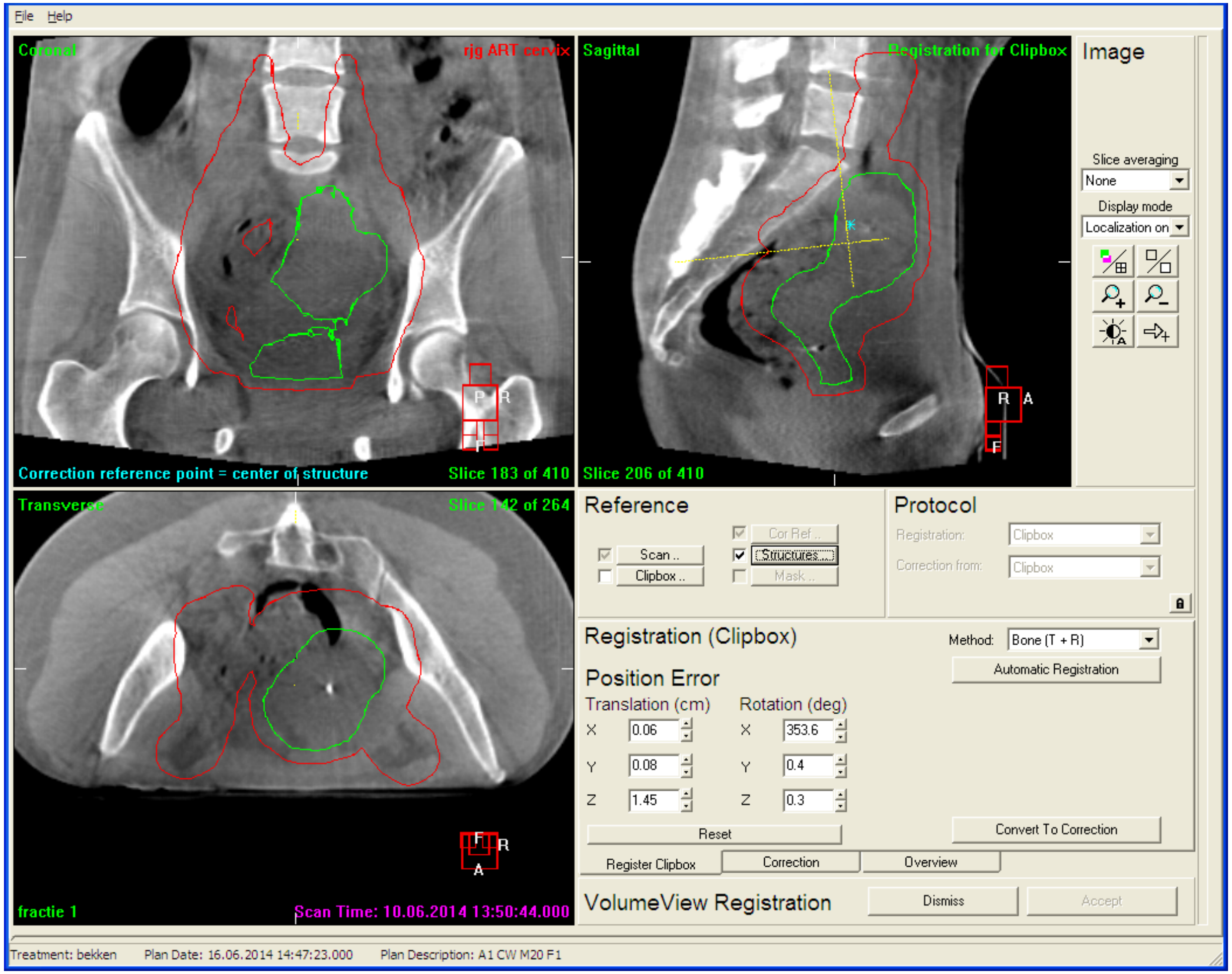


4

No Tweak!!

ESTRO School

Live Observer Study

5 cervix patients x 5 CBCT's

1. Individual selection by turning point
2. Group discussion
3. Selection by turning point

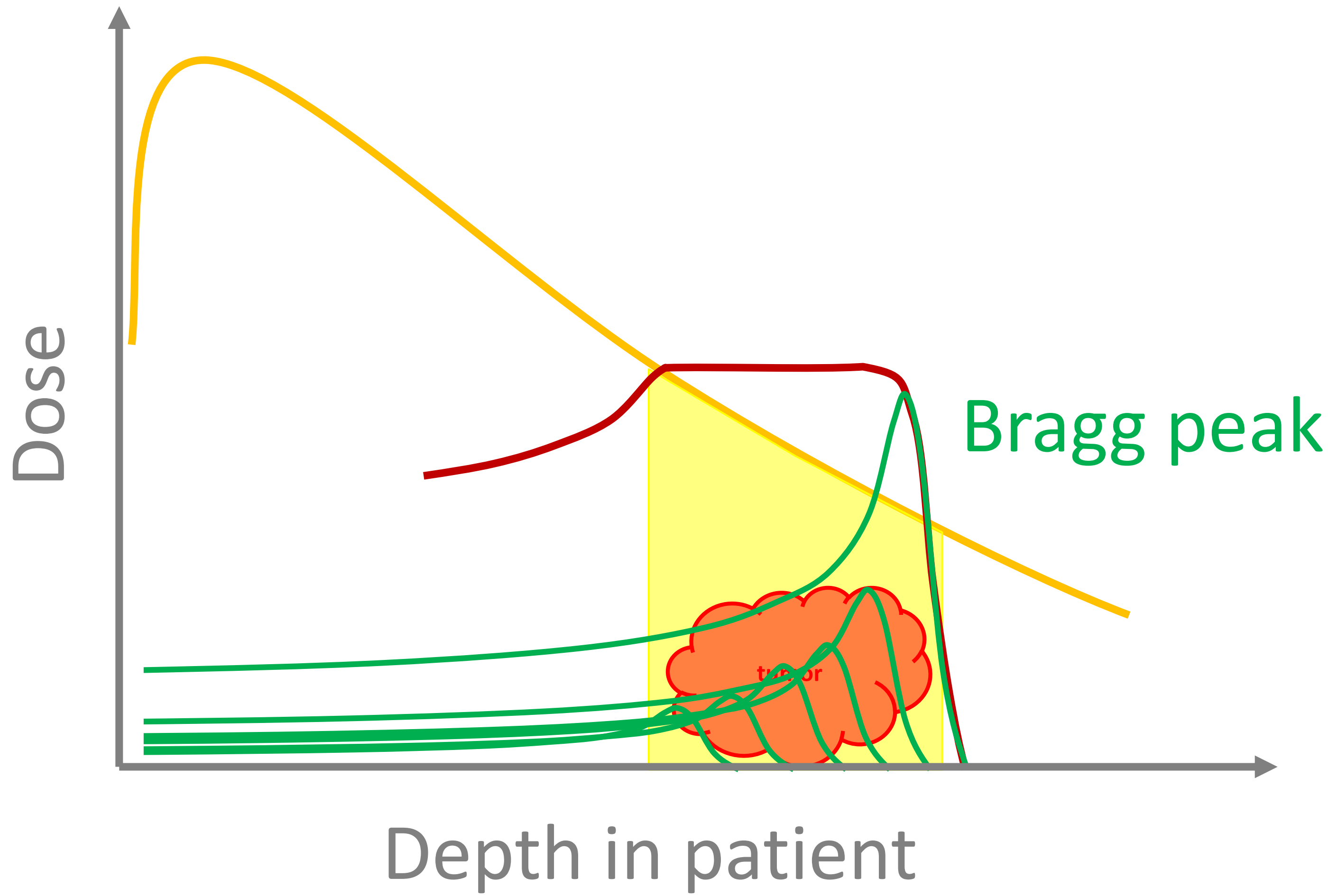
Proton Therapy

Mischa Hoogeman

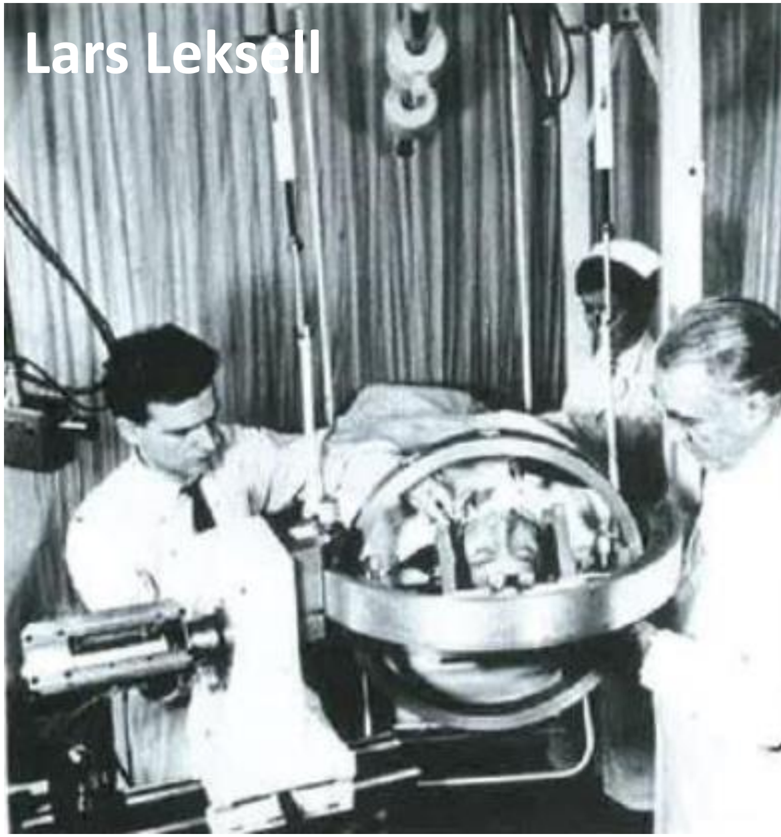
Contents

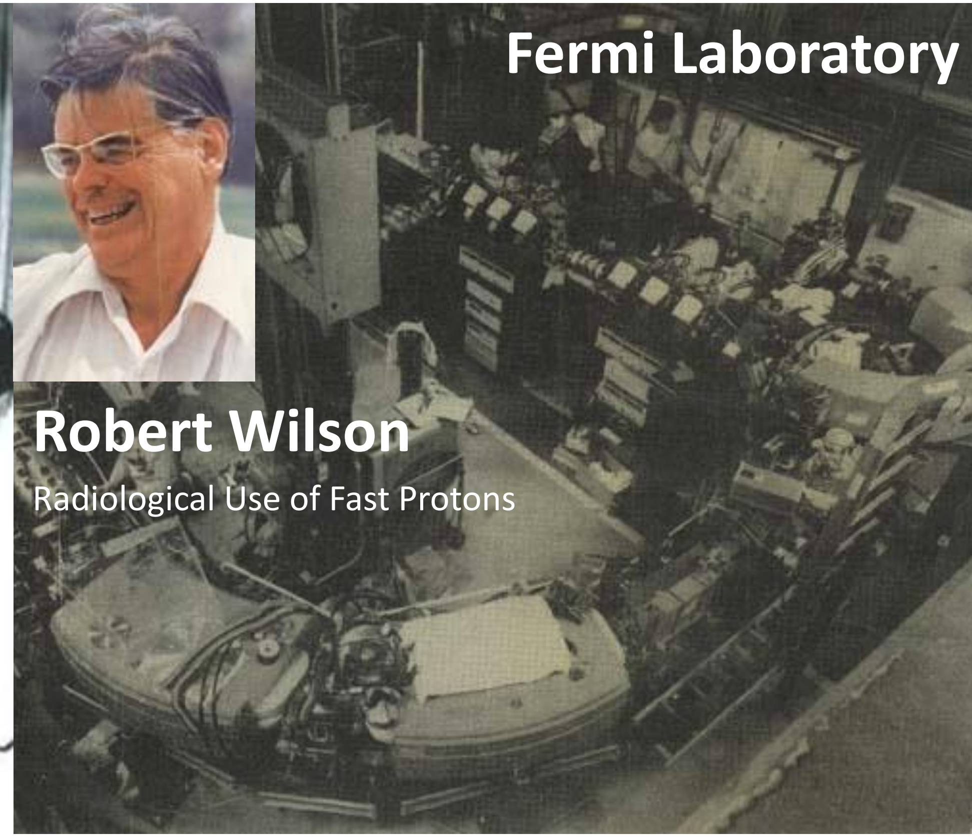
- History of proton therapy
- Introduction to pencil beam scanning technique
- Patient selection
- Challenges of proton therapy and ways to address those challenges

X-rays vs. Protons



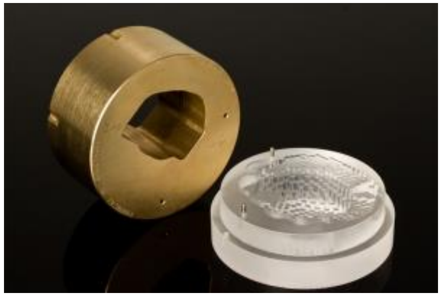
History


Lars Leksell


Fermi Laboratory
Robert Wilson
Radiological Use of Fast Protons

Proton Therapy: No Widespread Use

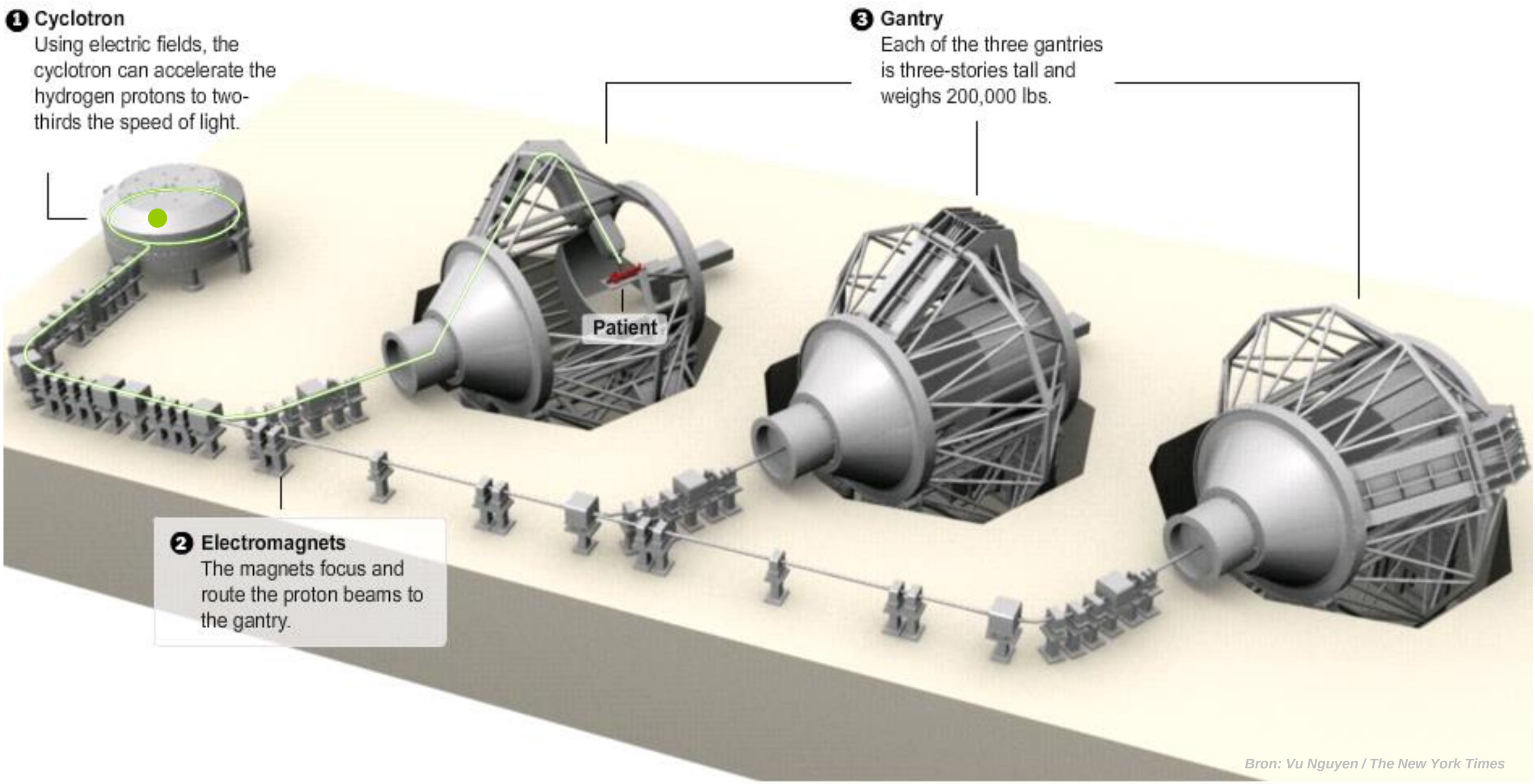
- Mostly in physics laboratories
- Large machines (one of a kind)
- Lack of image-guidance
- Passive Scattering Technique (broad beam approach)
  - Only conformal at the lateral and distal sides of tumor
  - Many patient-specific and beam-specific accessories required => not cost-effective



Promises of Proton Therapy

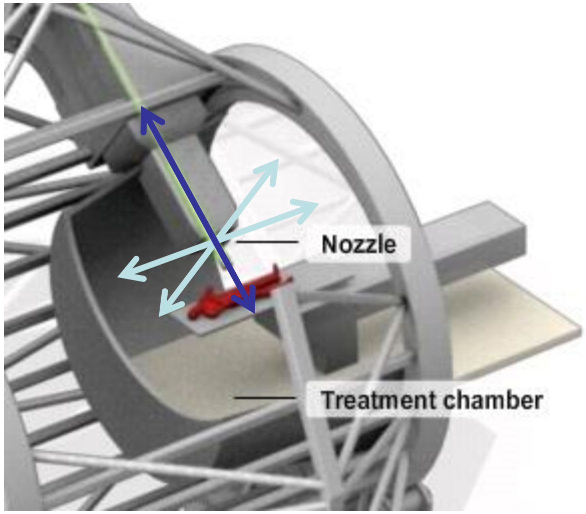
- Only in physics laboratories
  - **Technique has matured**
  - **Various vendors offer proton therapy equipment**
- Large machines
  - **Still large, although some more compact machines are available now**
- Lack of image-guidance
  - **Proton therapy is catching up**
- Passive Scattering being replaced by **Pencil Beam Scanning**

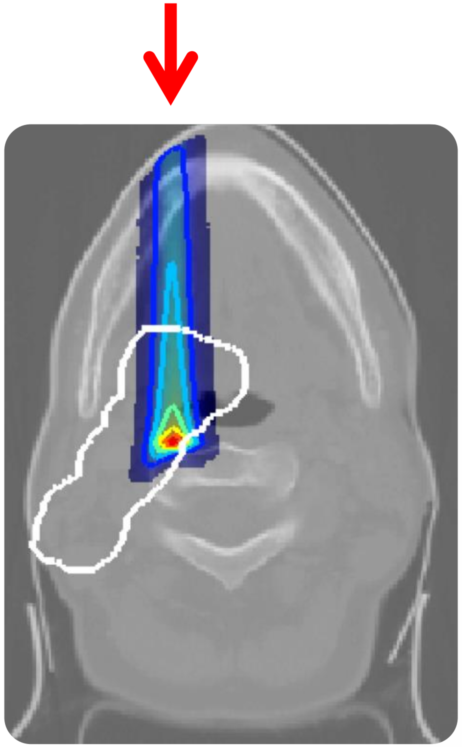
Proton Therapy Center

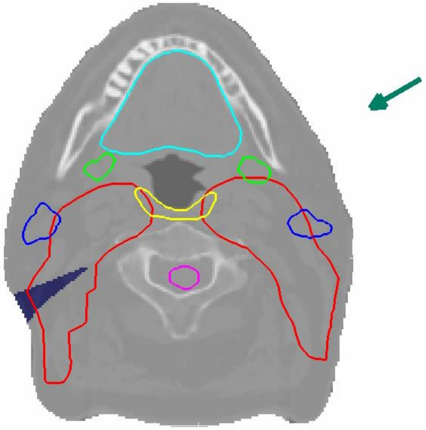


Rotating Gantry

Pencil beam scanning







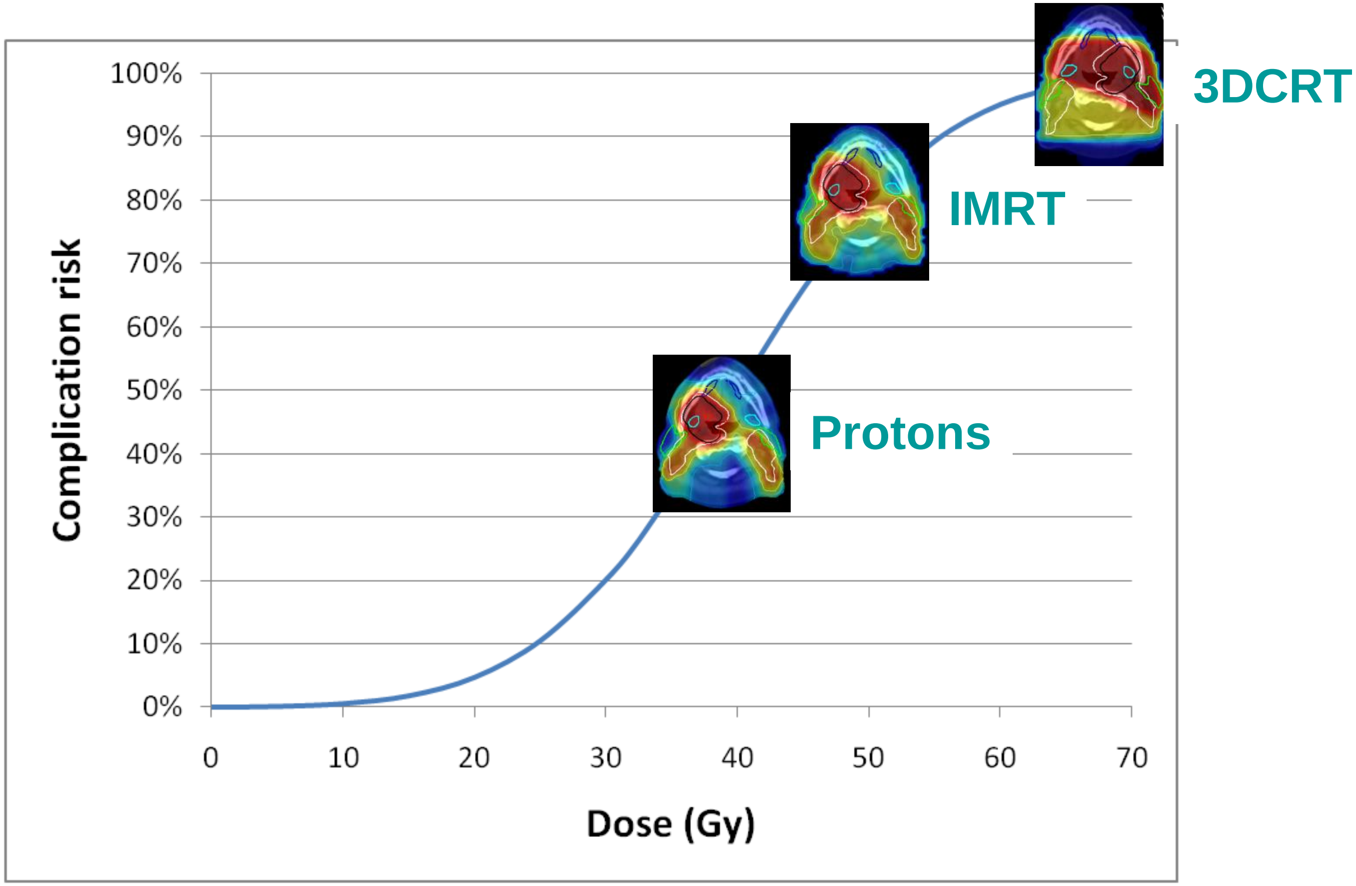
What is the Clinical Benefit?

- Protons
  - Tumor will be killed as effectively as with photons
  - Improved sparing of healthy tissues
  - Enables dose escalation for radio-resistent tumors
- Pediatric indications
  - Less long term side effects

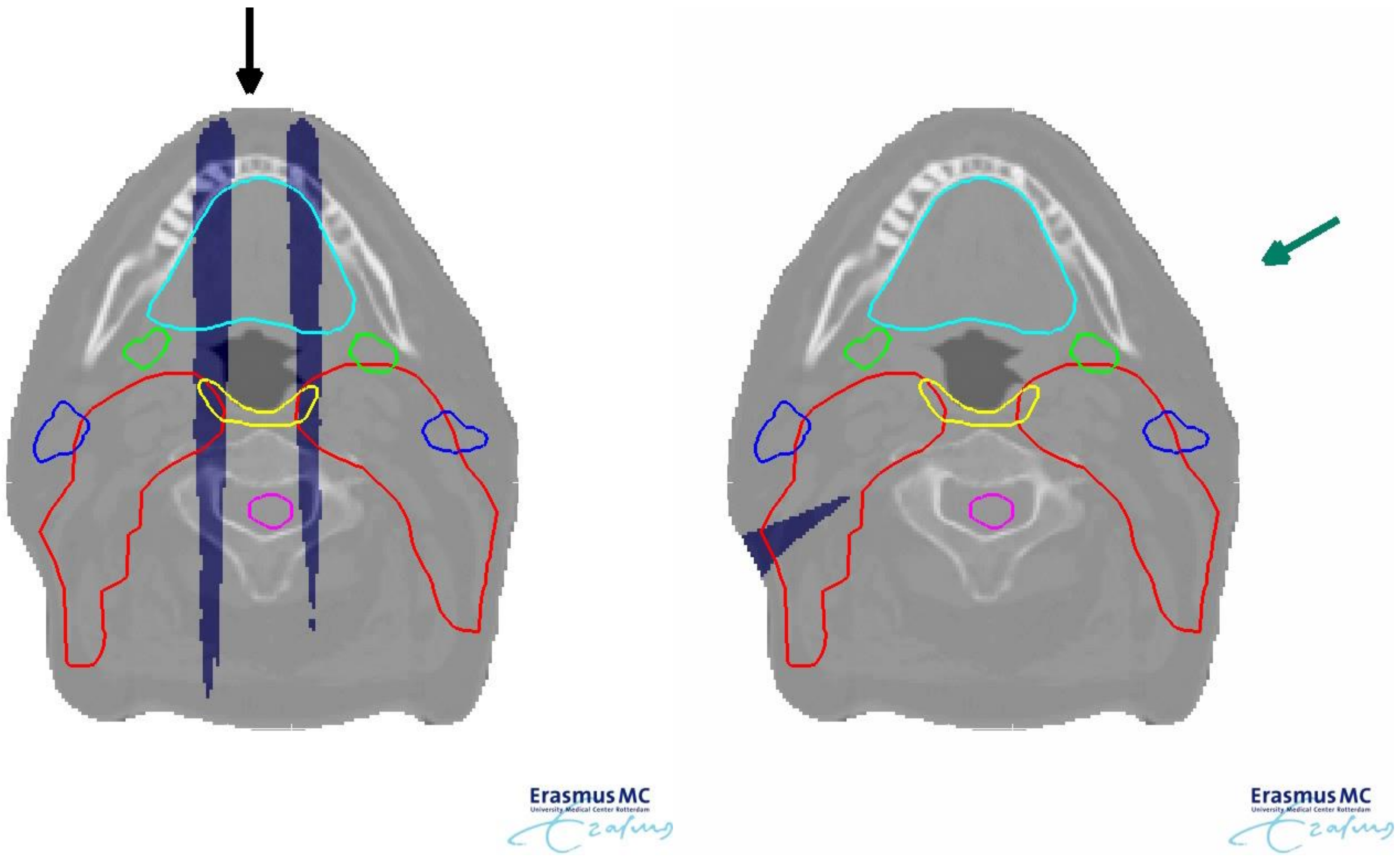
Evidence

- Randomized Controlled Trials
  - Golden standard to determine benefit for competitive therapies
  - But, if the new technique is meant to reduce side effects and secondary tumors (long term) the equipoise is missing.

From Dose to Risk



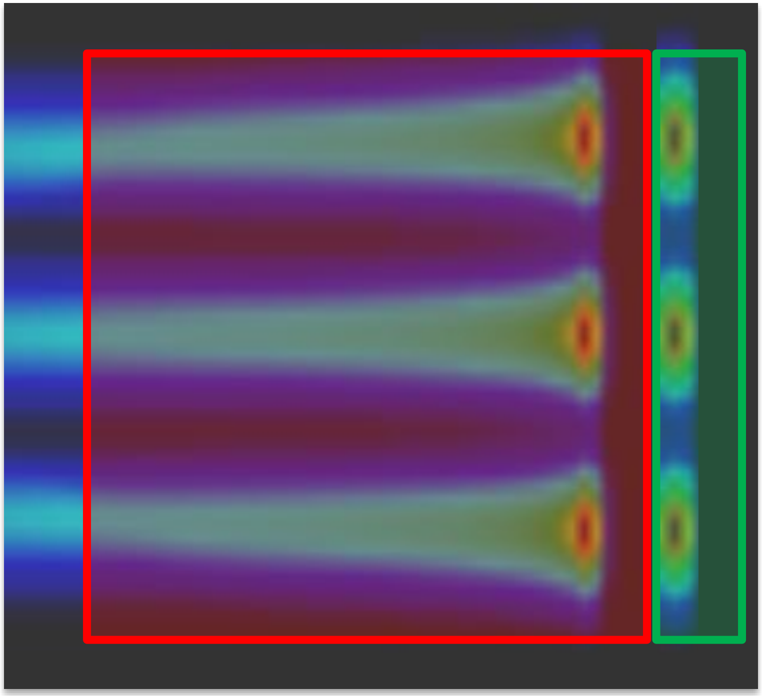
Comparison: VMAT vs. IMPT



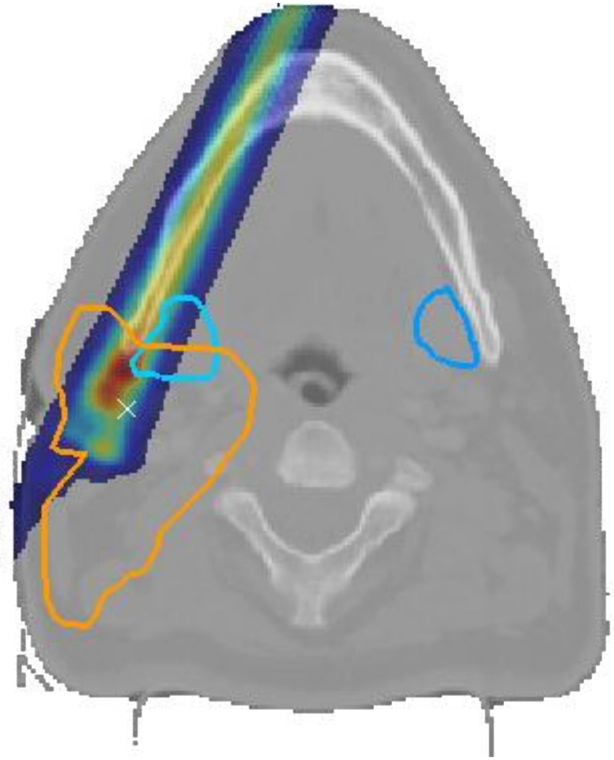
Comparing IMRT/VMAT and IMPT …
Is it fair?

Protons Stop, But Where?

- Dose calculation uncertainties (stopping power)
- Patient setup variation and internal organ motion that also induce range errors
  - Interfraction
  - Intrafraction (interplay)
- Anatomical changes

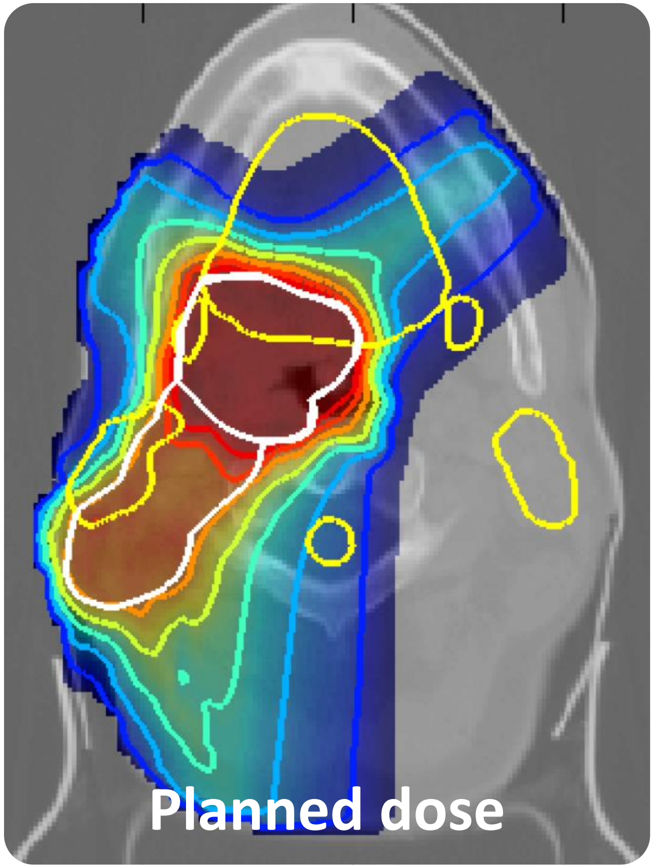


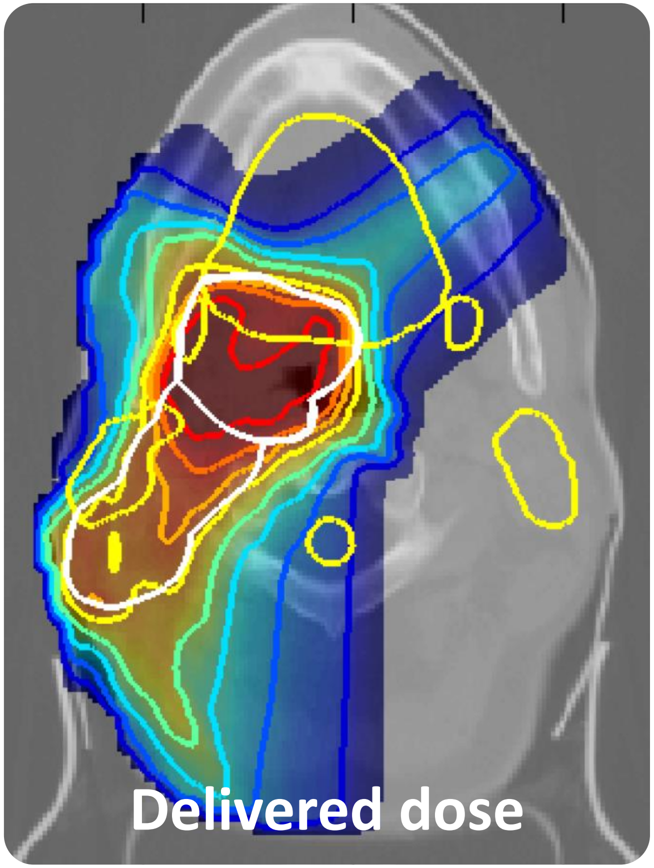
Patient Setup And Dose



A Kraan, S van de Water et al.

Patient Setup Error of 4 mm





IMRT/VMAT vs. IMPT

IMRT/VMAT

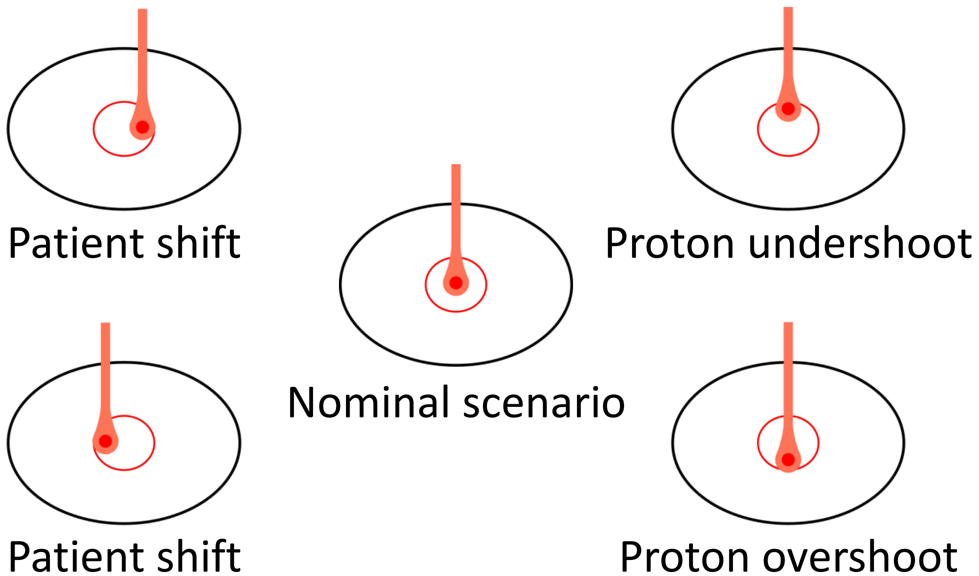
- **Image-guidance!**
- Patient setup: in PTV
- Organ motion: in PTV
- Dose calculation: -
- Intra-fraction interplay: double arcs
- Anatomic changes: re-planning

IMPT

- **Image-guidance!**
- Patient setup: ?
- Organ motion: IM
- Dose calculation: ?
- Intra-fraction interplay: repainting
- Anatomic changes: re-planning

Robust treatment planning

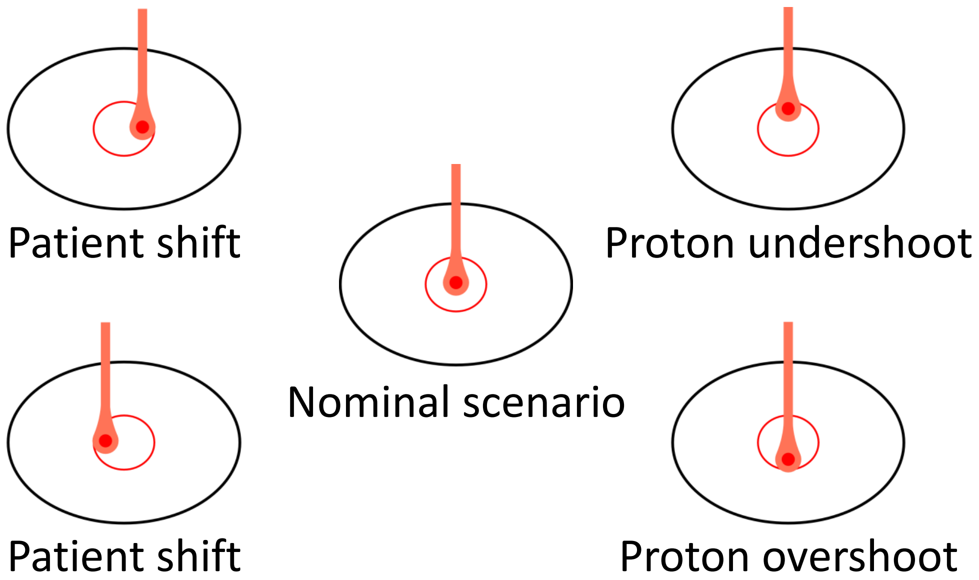
- Robust treatment planning should be used for protons:



- Optimize all ‘error scenarios’ simultaneously

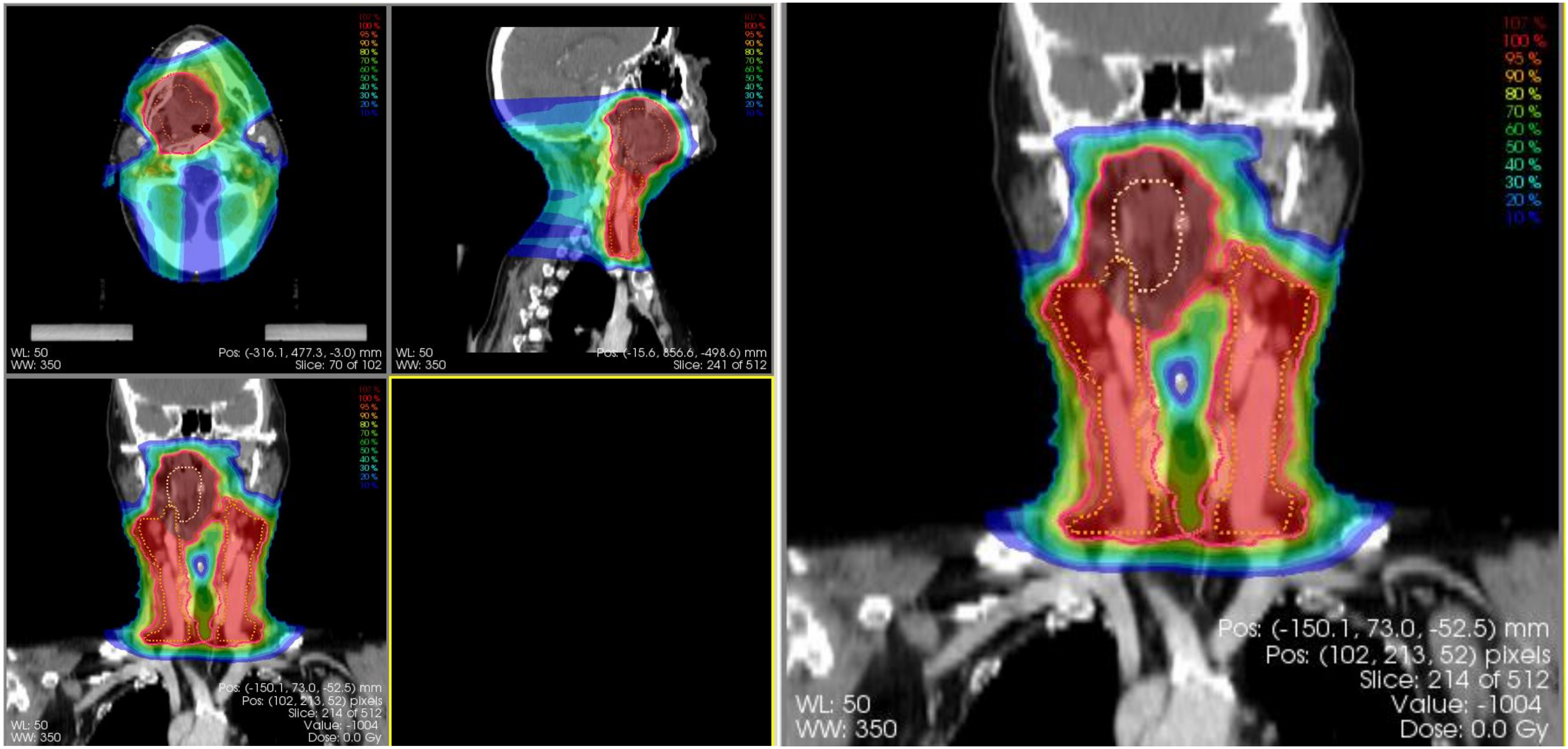
Robust treatment planning

- Robust treatment planning should be used for protons:

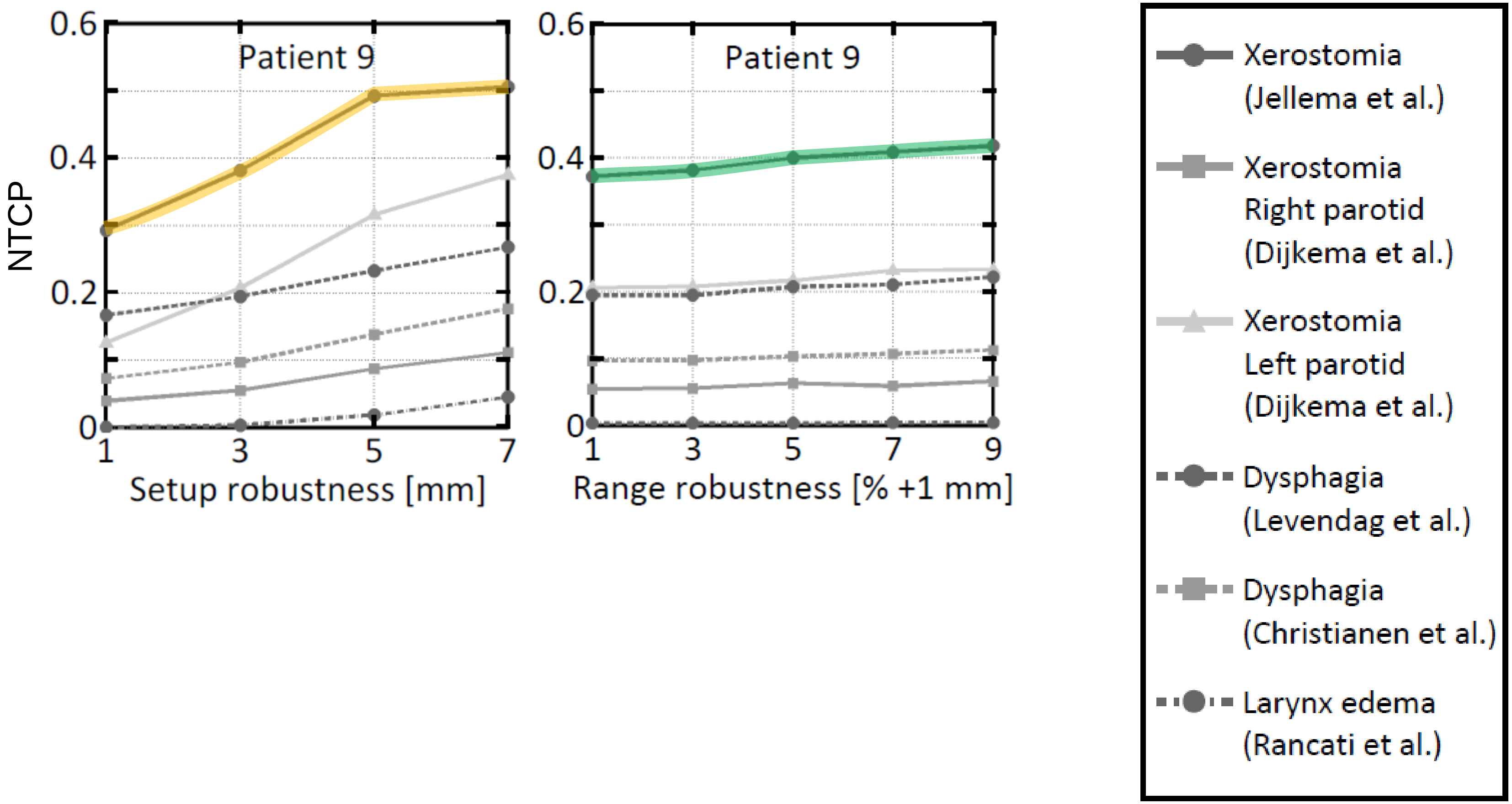


- Optimize all ‘error scenarios’ simultaneously
- Optimize worst-case dose values

Increasingly More Robust

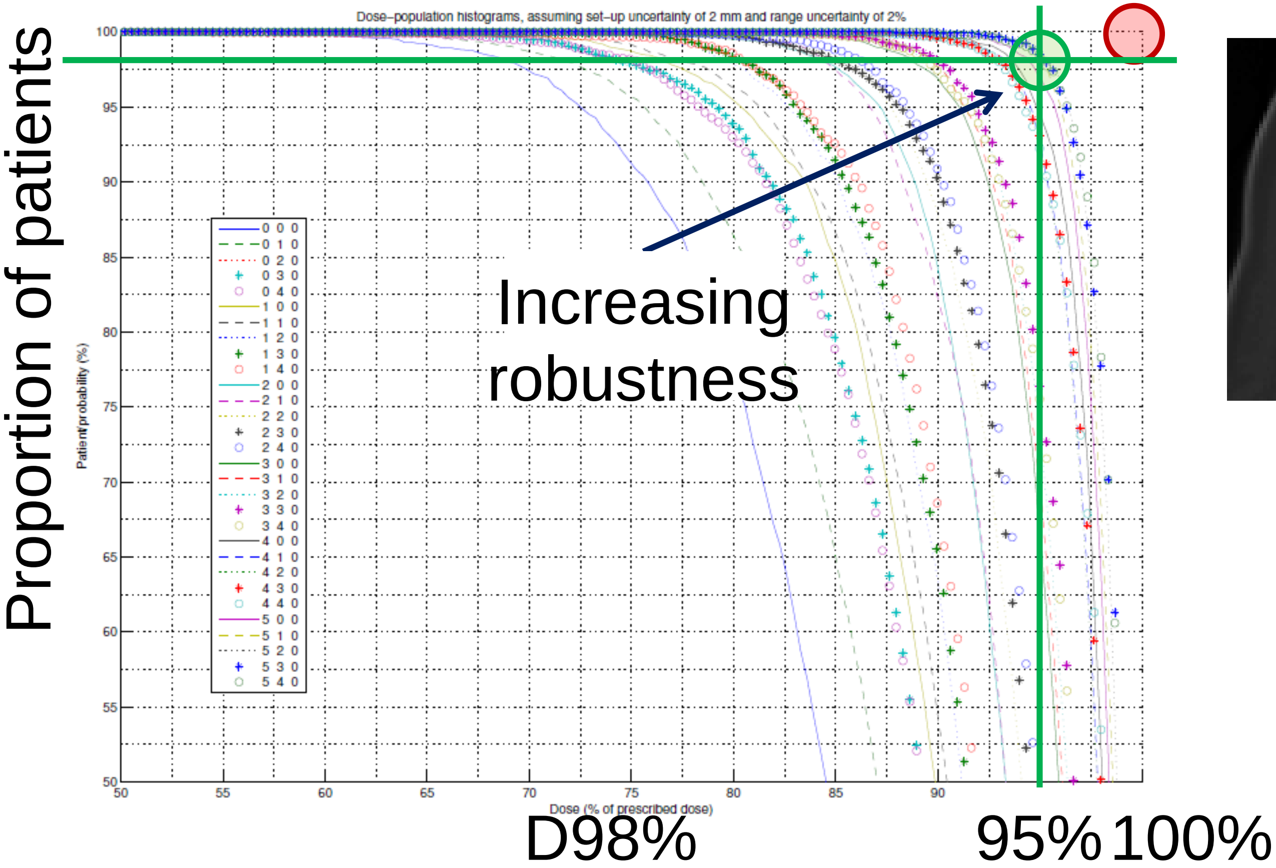


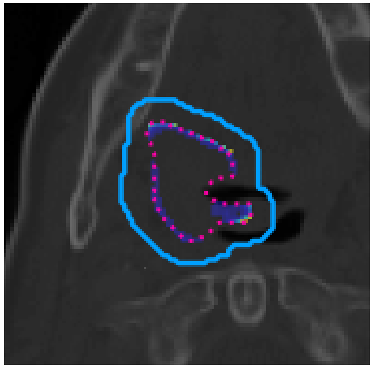
Price of Robustness



Iris van Dam et al. submitted to Radiotherapy and Oncology

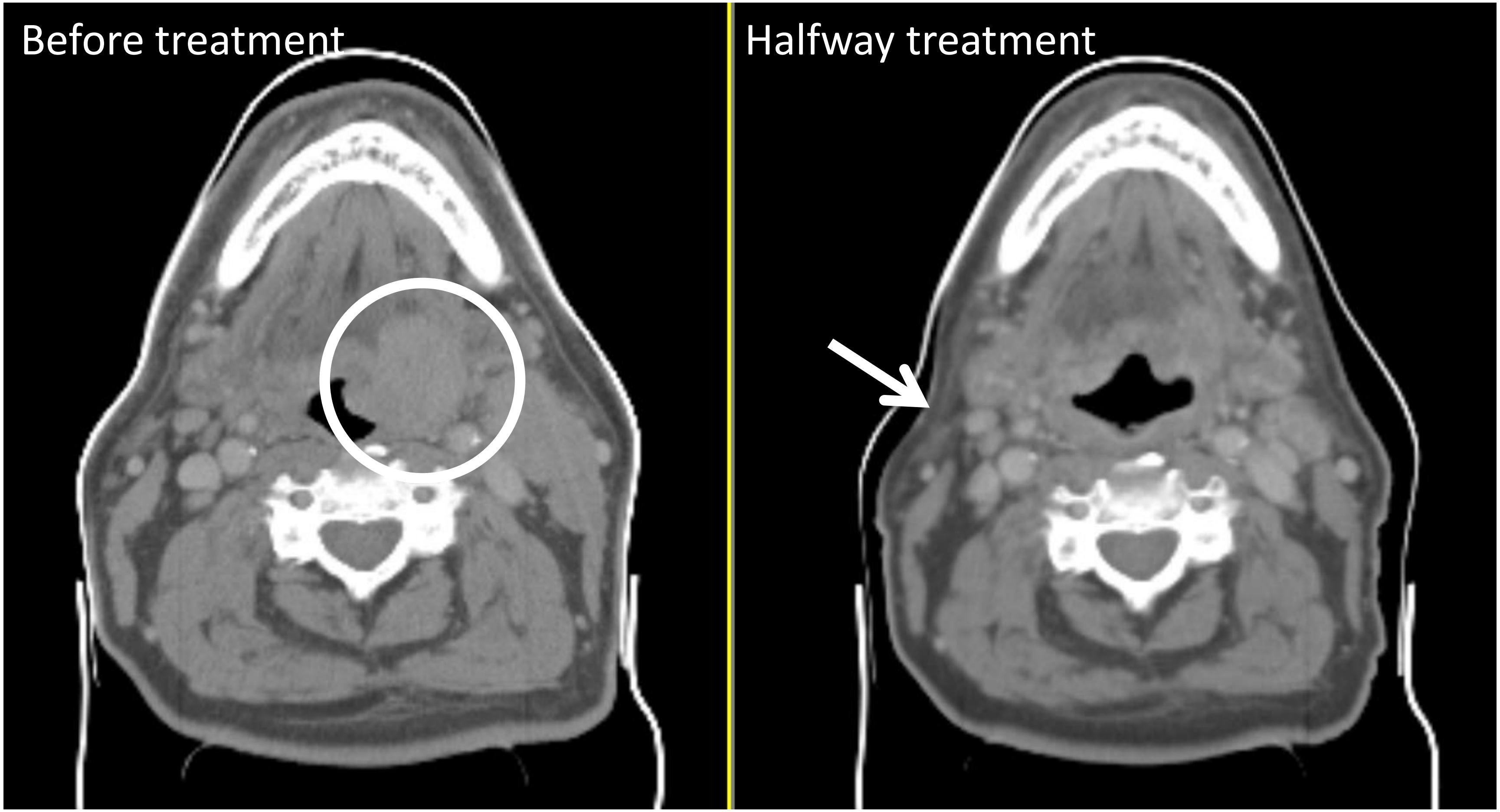
Dose Population Histogram





S. van der Voort et al.

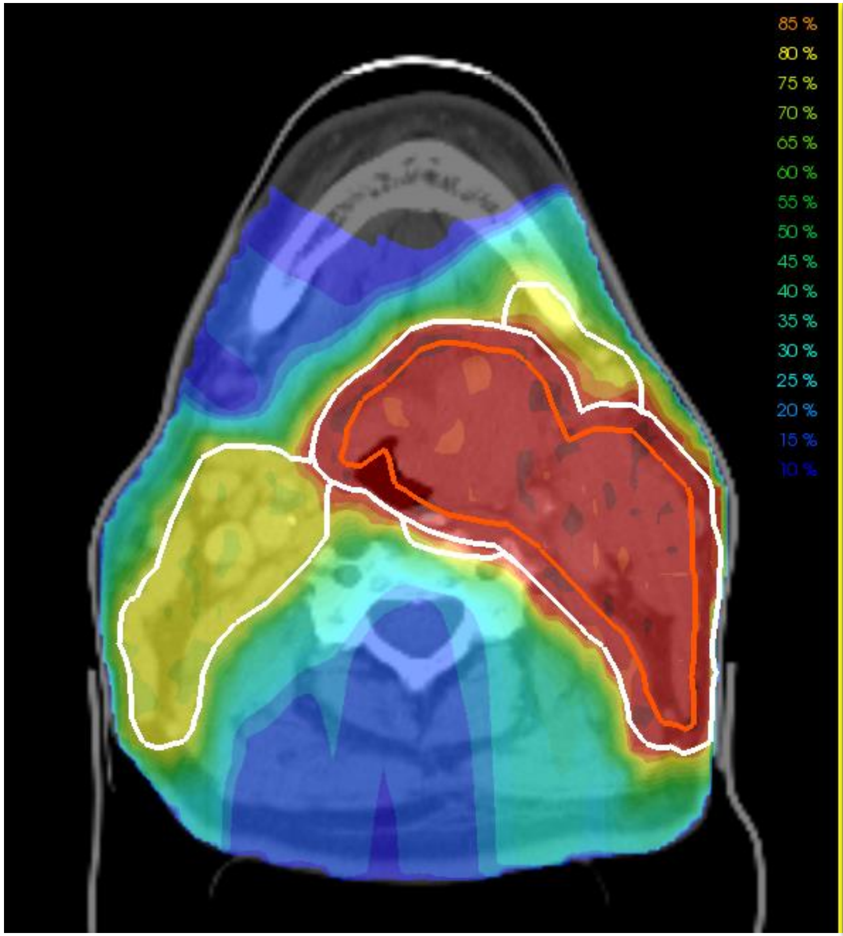
Anatomic Changes



Vasquez Osorio EMV, Hoogeman MS, Al-Mamgani A, Teguh DN, Levendag PC, Heijmen BJM. International Journal of Radiation Oncology Biology Physics 2008;70:875-82.

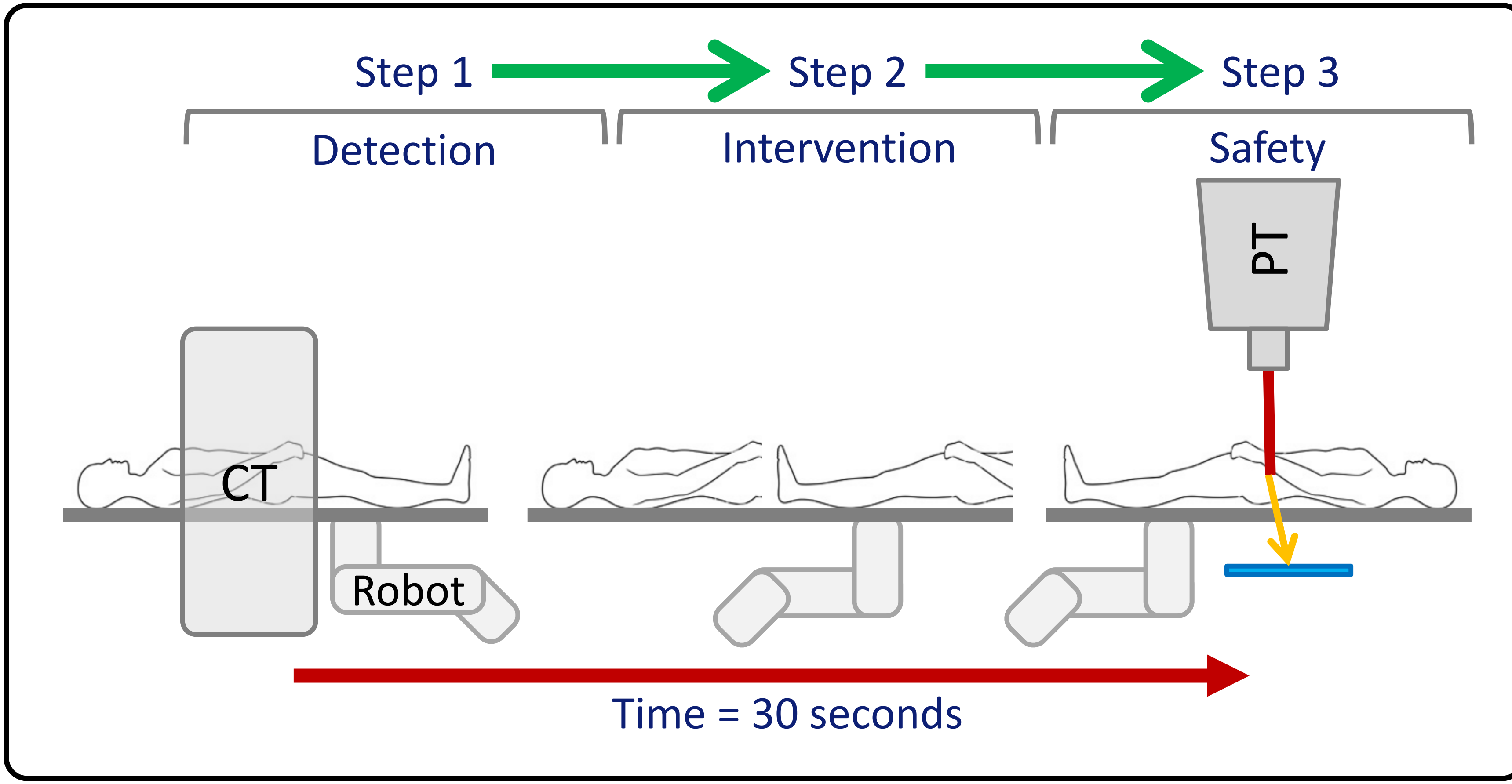
Erasmus MC Cancer Institute

Dosimetric Consequences of Anatomical Changes



Kraan AC, van de Water S, Teguh DN, Al-Mamgani A, Madden T, Kooy HM, Heijmen BJM, Hoogeman MS. International Journal of Radiation Oncology Biology Physics 2013;87:888-96.

ADAPTNOW



ADAPTNOW project, Medical Delta collaboration funded by ZonMw

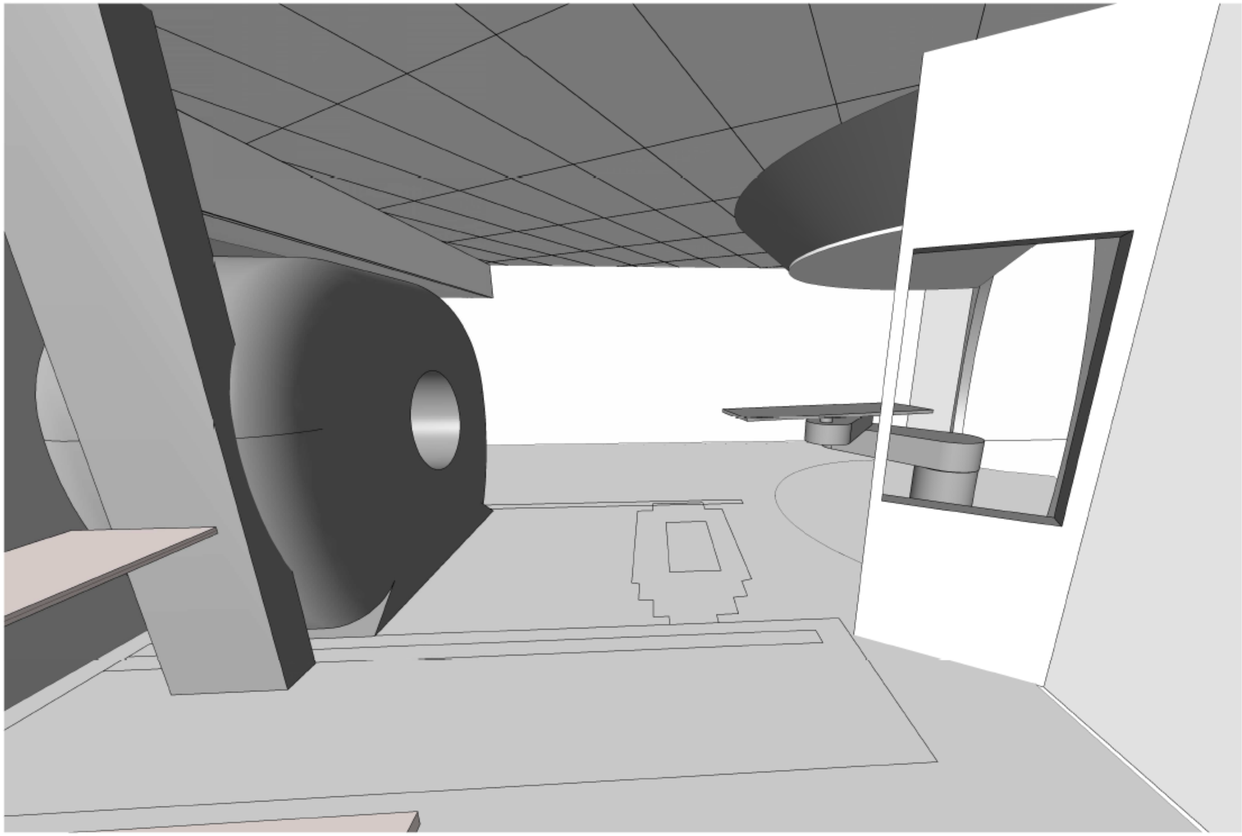
medical delta

Erasmus MC Universitair Medisch Centrum Rotterdam

LUMC Leids Universitair Medisch Centrum

TU Delft

In-room CT Scanner



Conclusions

- Intensity Modulated Proton Therapy is a promising treatment modality
- The main goal is to reduce side effects
- Patients will be selected following a treatment plan comparison
  - This should be a fair comparison