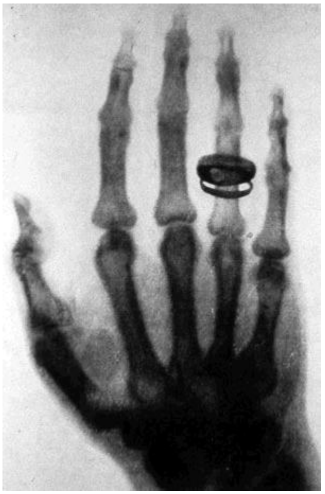
Image Guided Radiotherapy

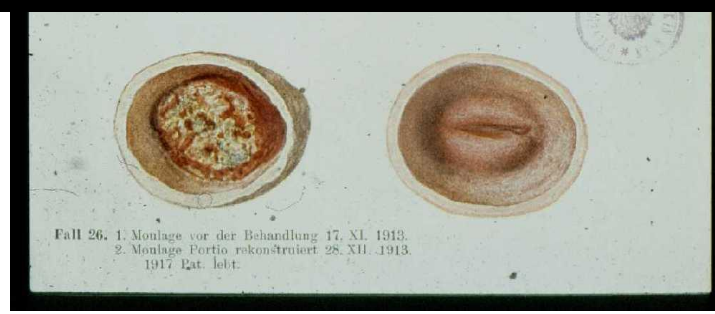
Richard Pötter, MD,
supported through Markus Stock PhD, Med Austron
Wolfgang Marik MD, Department of Radiology,
Maximilian P Schmid MD, Department of Radiotherapy
Dietmar Georg, PhD, Medical Physicis,
Peter Kuess, PhD, Medical Physics
Medical University of Vienna

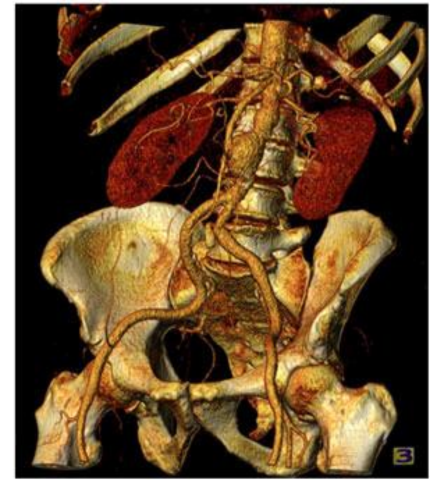
Image Guided RadioTherapy (IGRT):

a comprehensive view (7Ds)

What is medical imaging?

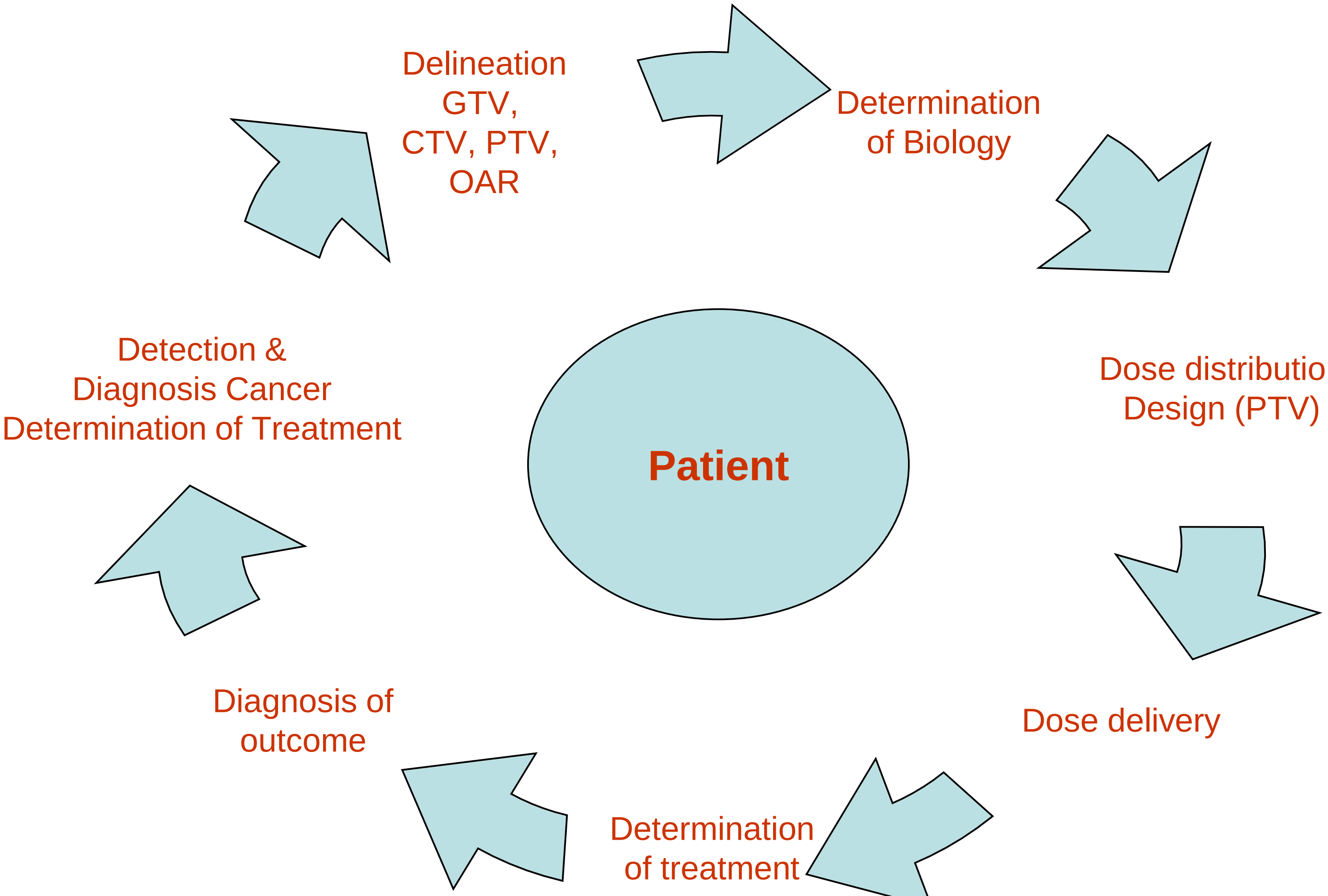






- Techniques and processes used to create images of the human body for clinical purposes
- Radiography, Fluroscopy, CT, Ultrasound, MRI, PET CT, Endoscopy, Cartoons…
- How is medical imaging used in Radiotherapy?

Imaging-Cycle



modified from Greco & Ling Acta Oncol 2008

(D1) Detection, Diagnosis, Determination of treatment

- improvements in (cancer-specific) survival -

- Screening programs (Mammography, endoscopy, tests)
- Diagnosis at earlier stage → more effective treatment options (cervix, breast, colorectal, prostate, stomach, oesophagus...)
- More appropriate stage (risk) assessment (CT/MRI)

    more appropriate treatment strategy allocation
- More appropriate spread assessment (e.g. PET CT)

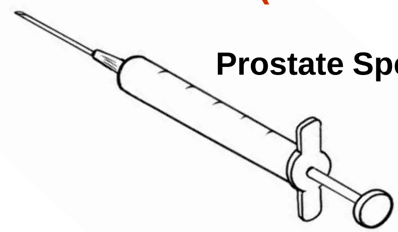
  Decision: local (where), regional, systemic approach (e.g. lung)

Common screening programms

Breast Cancer

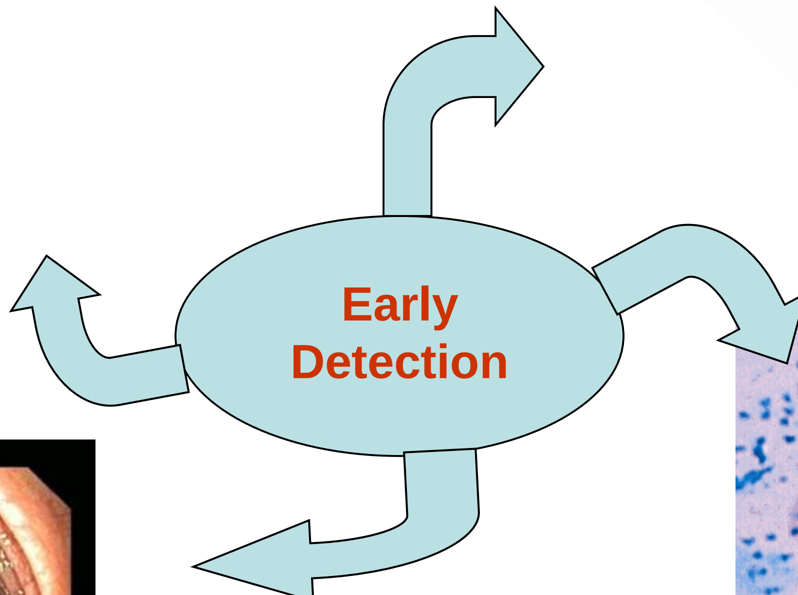
mammography

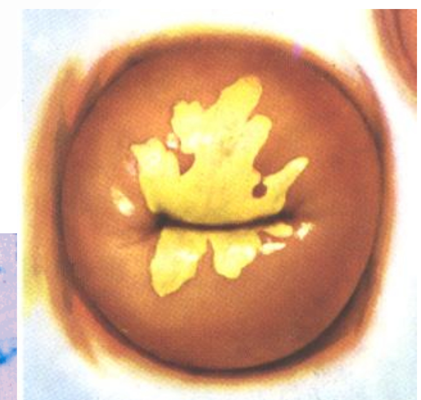
Tests (blood,…)

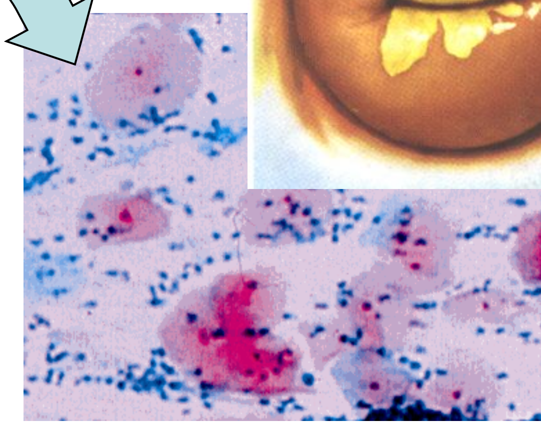


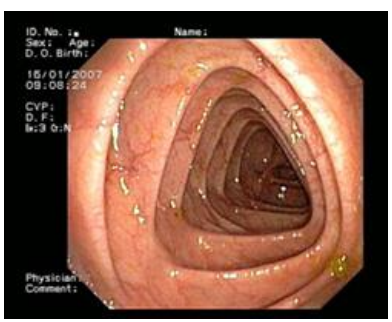
Prostate Specific Antigen (PSA)

Prostate Cancer









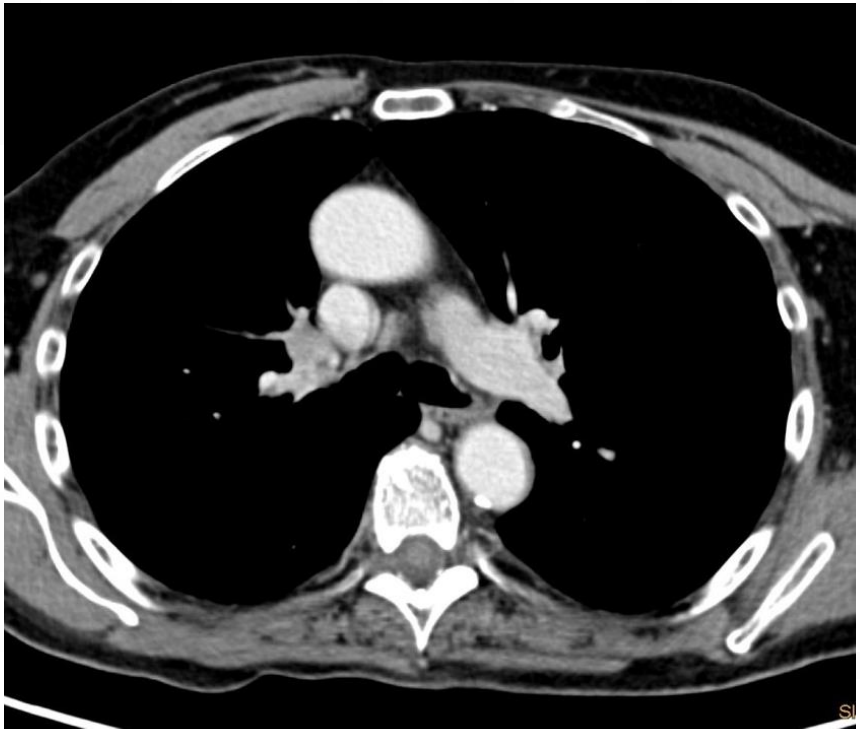
Colonoscopy

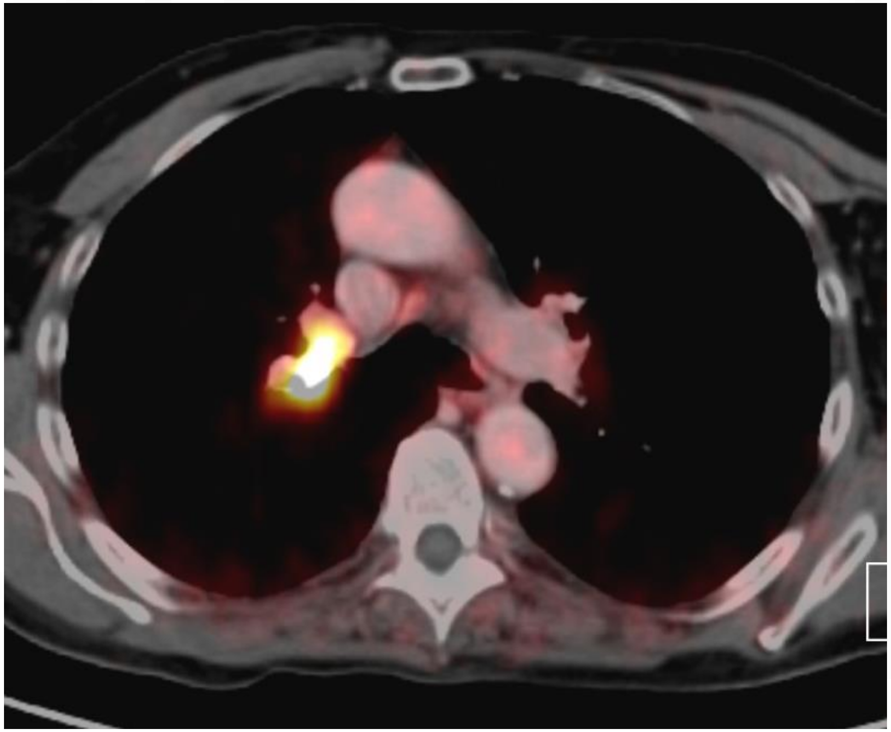
Cytology

Colorectal Cancer

Cervix Cancer

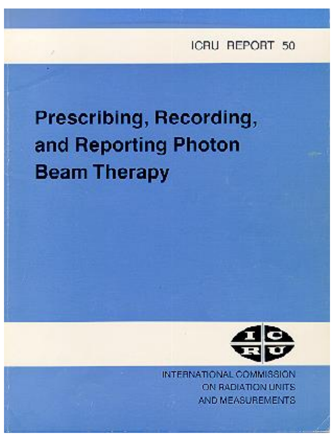
Lung Tumor
CT, PET CT

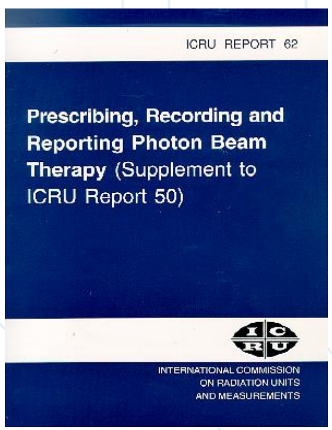


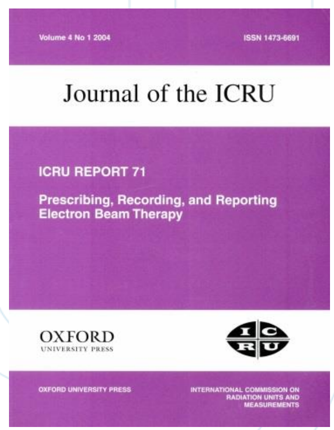


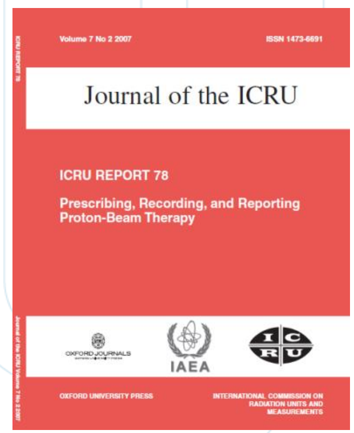
Tumor/Target volume and dose volume concepts in Radiation Oncology

- The **International Commission on Radiation Units and Measurements (ICRU (since 1927))** has as its principal objective the development of internationally acceptable recommendations
  - Quantities and units of radiation and radioactivity
  - **Procedures** suitable for the measurement and application of these quantities in clinical radiation oncology and radiobiology



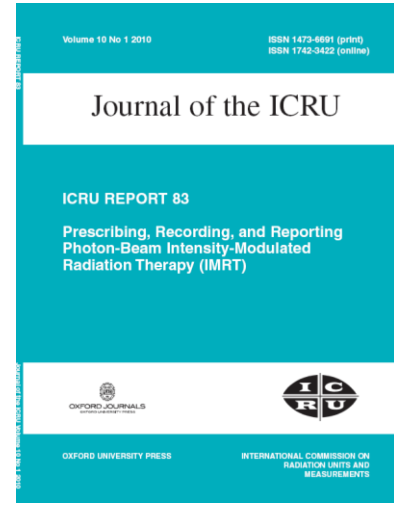


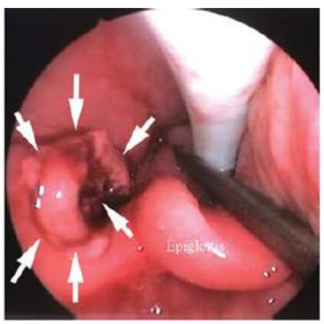




ICRU defines a common language for clinical practice and for medical and scientific communication in Radiation Oncololgy

Gross Tumor Volume (GTV)

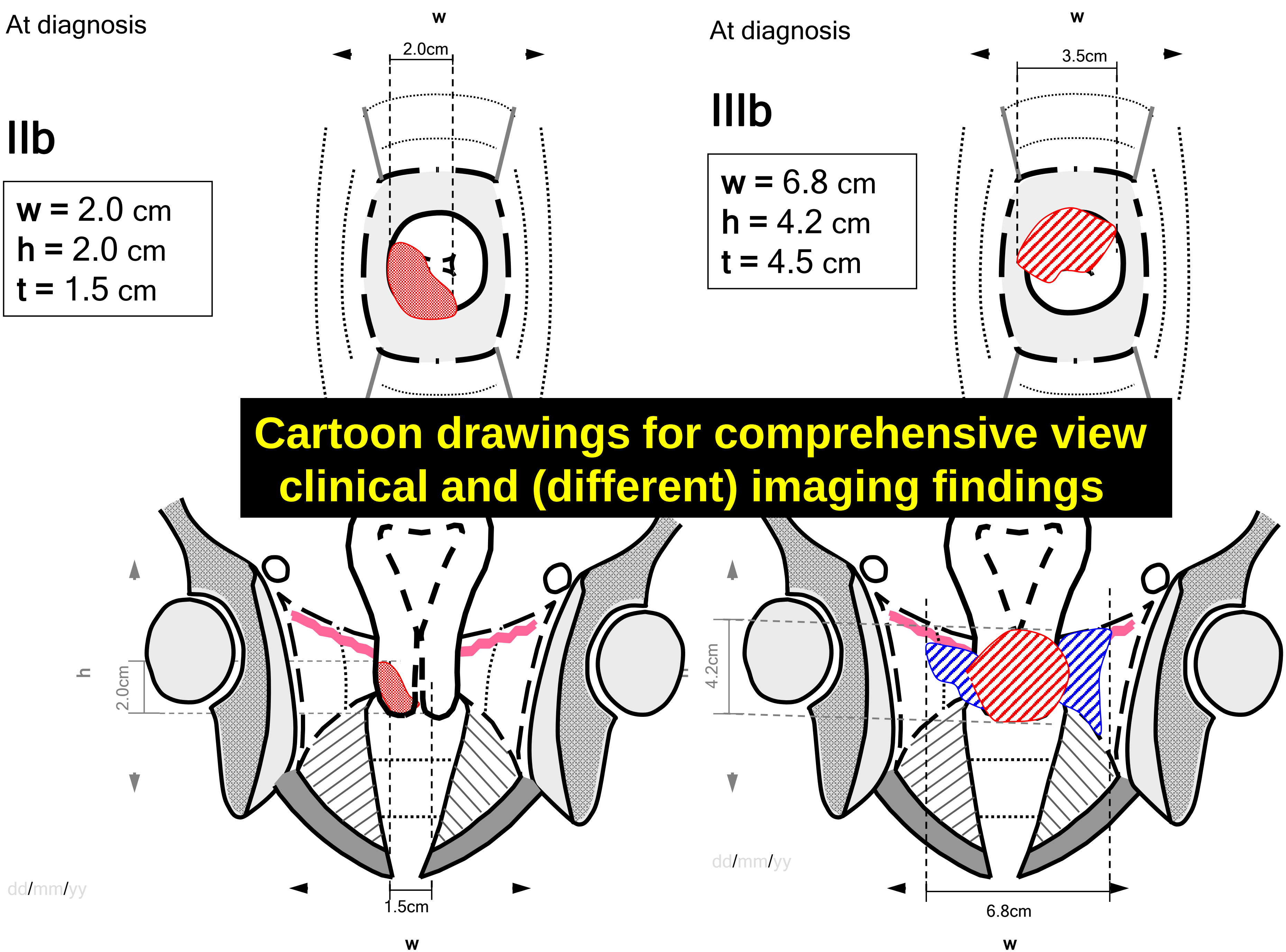




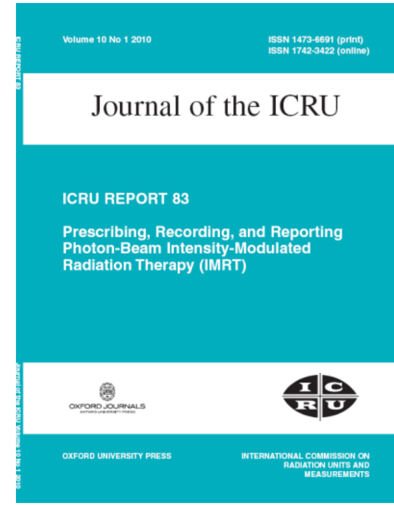
Laryngeal cancer view from a laryngoscope

- the gross palpable or visible / demonstrable extent and location of malignant growth.
- based on information from a combination of diagnostic modalities
  - clinical examination, endoscopy (light imaging)
  - X-Ray, CT, MRI, ultrasound, PET CT, etc.,
  - Histology after biopsy

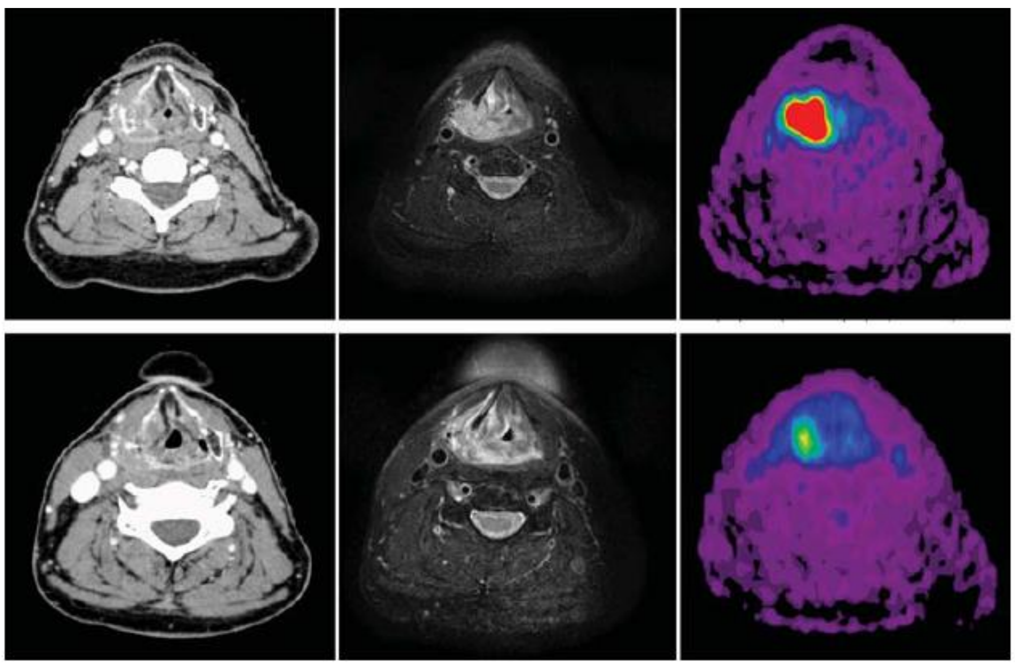
- TIME AND IMAGING MODALITY ARE IMPORTANT!!!


Cartoon drawings for comprehensive view clinical and (different) imaging findings
At diagnosis
IIb
w = 2.0 cm
h = 2.0 cm
t = 1.5 cm
w
2.0cm
h
2.0cm
1.5cm
w
dd/mm/yy
At diagnosis
IIIb
w = 6.8 cm
h = 4.2 cm
t = 4.5 cm
w
3.5cm
4.2cm
6.8cm
w
dd/mm/yy

Gross Tumor Volume (GTV)



- Comparison among various modalities for the definition of the primary head-and-neck tumor GTV.
- Upper panel: GTV imaged prior to any treatment
  - contrast-enhanced CT: GTV-T: volume of 25.8 ml.
  - fat-saturated T2-weighted MRI: GTV-T: volume of 28.5 ml.
  - FDG-PET: GTV-T: volume of 22.2 ml.



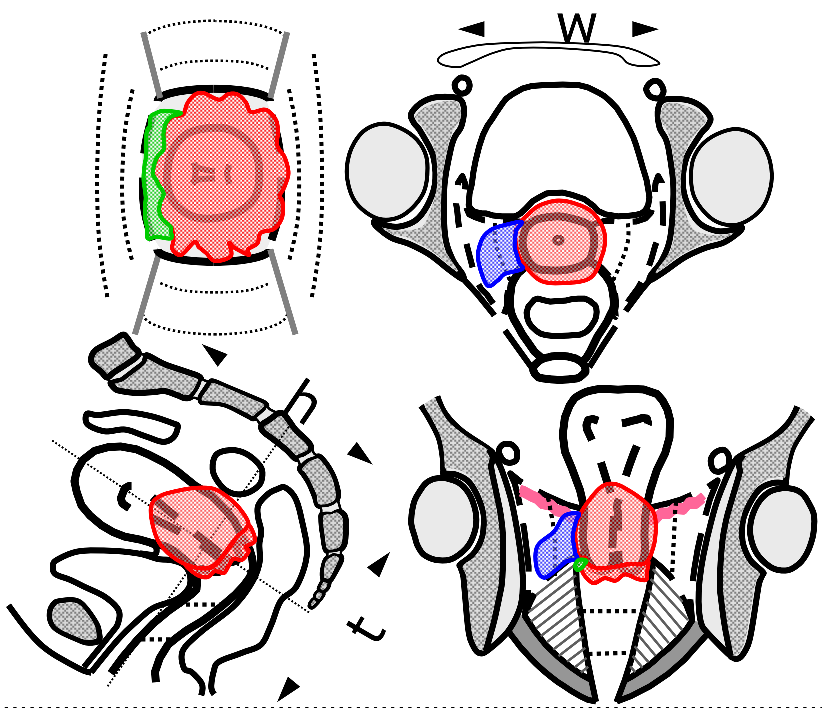
GTV during treatment

Lower panel: GTV imaged after an absorbed dose of 20 Gy.

- GTV-T (CT, 20 Gy): volume of 16.3 ml.
- GTV-T (MRI T2, fat sat, 20 Gy): volume of 19.8 ml.
- GTV-T (FDG-PET, 20 Gy): volume of 12.5 ml.

Fig.5.1: **GTV_{init} and GTV_{res} in cervix cancer**

Findings at time of diagnosis



Dimensions (cm):

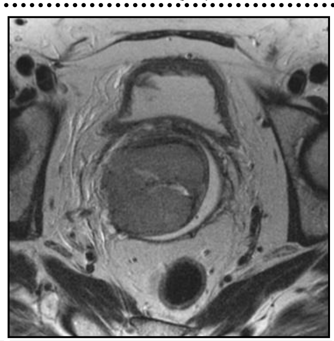
Width: 7

Thickness:>5

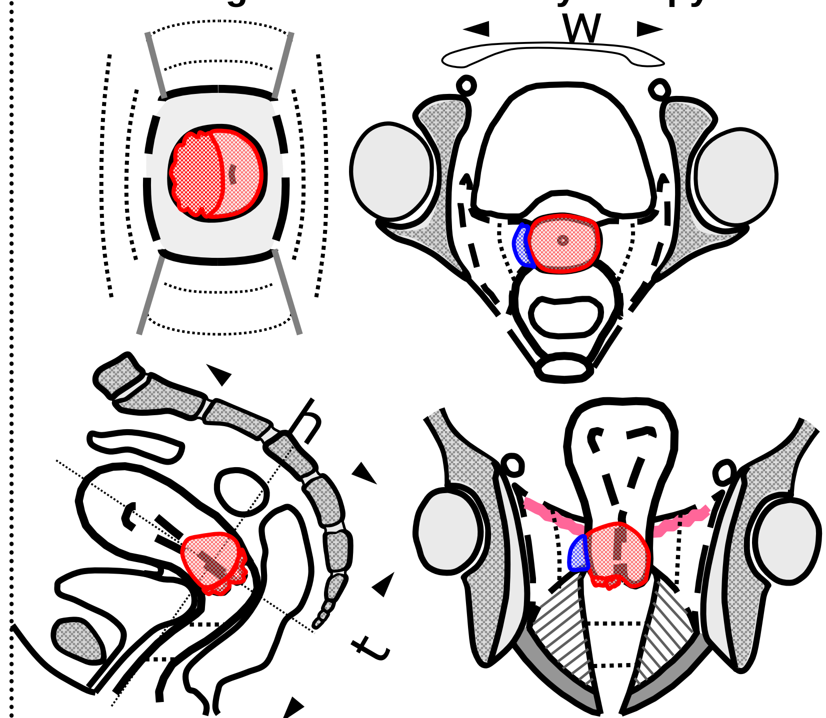
Height: >5

Vaginal inv.: 0.5

(right fornix)



Findings at time of brachytherapy



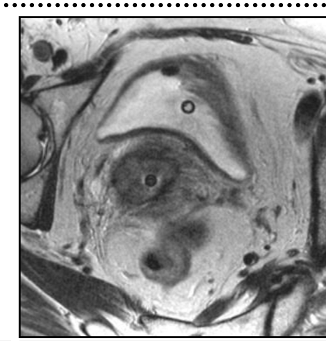
Dimensions (cm):

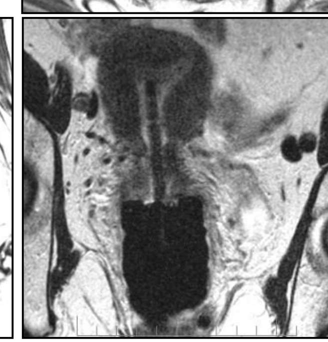
Width: 3.5

Thickness: 2

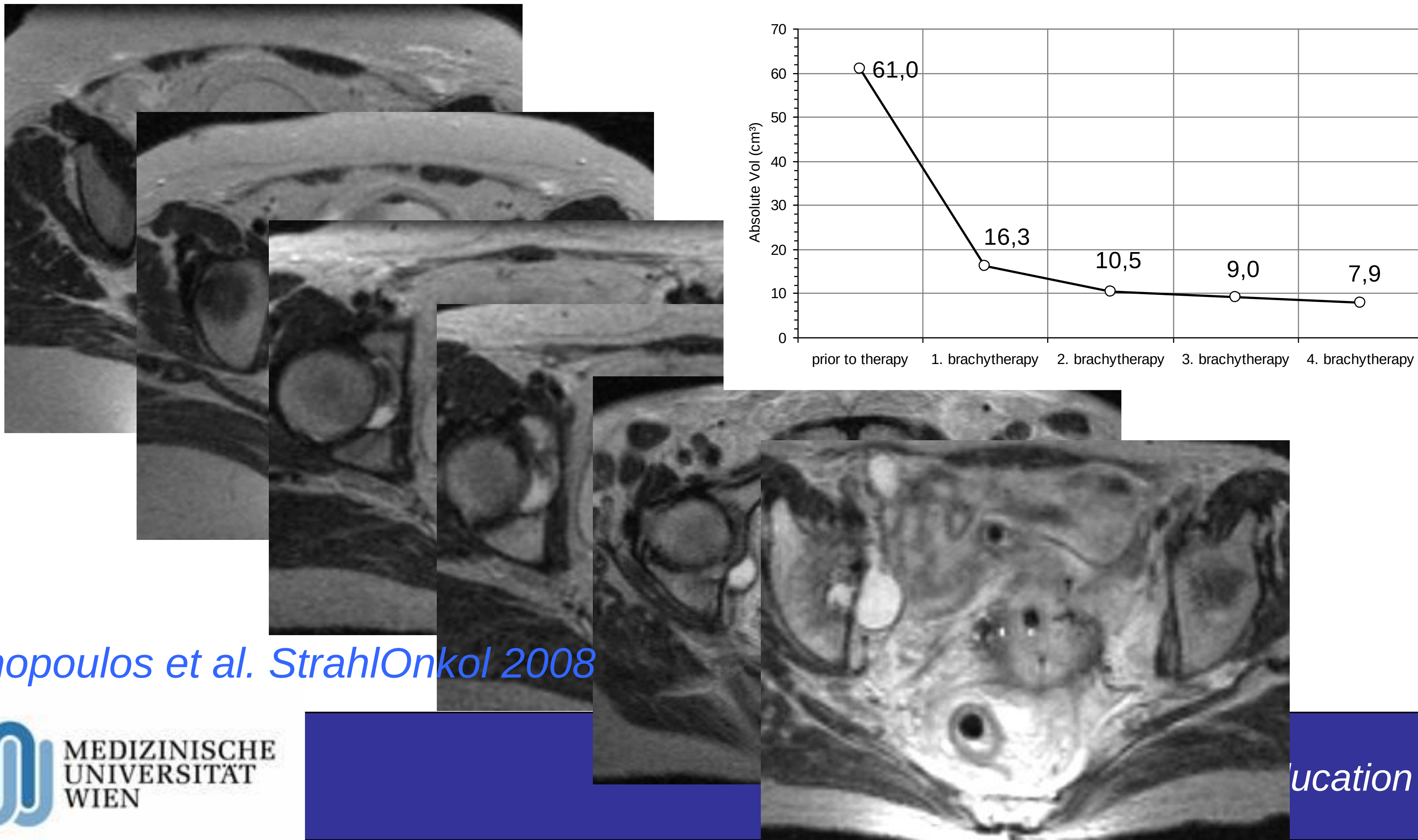
Height: 2

Vaginal inv.: 0





MRI: Initial tumour extension (3D RT) pattern of response (4D RT) for adaptive MRI based planning



Dimopoulos et al. StrahlOnkol 2008

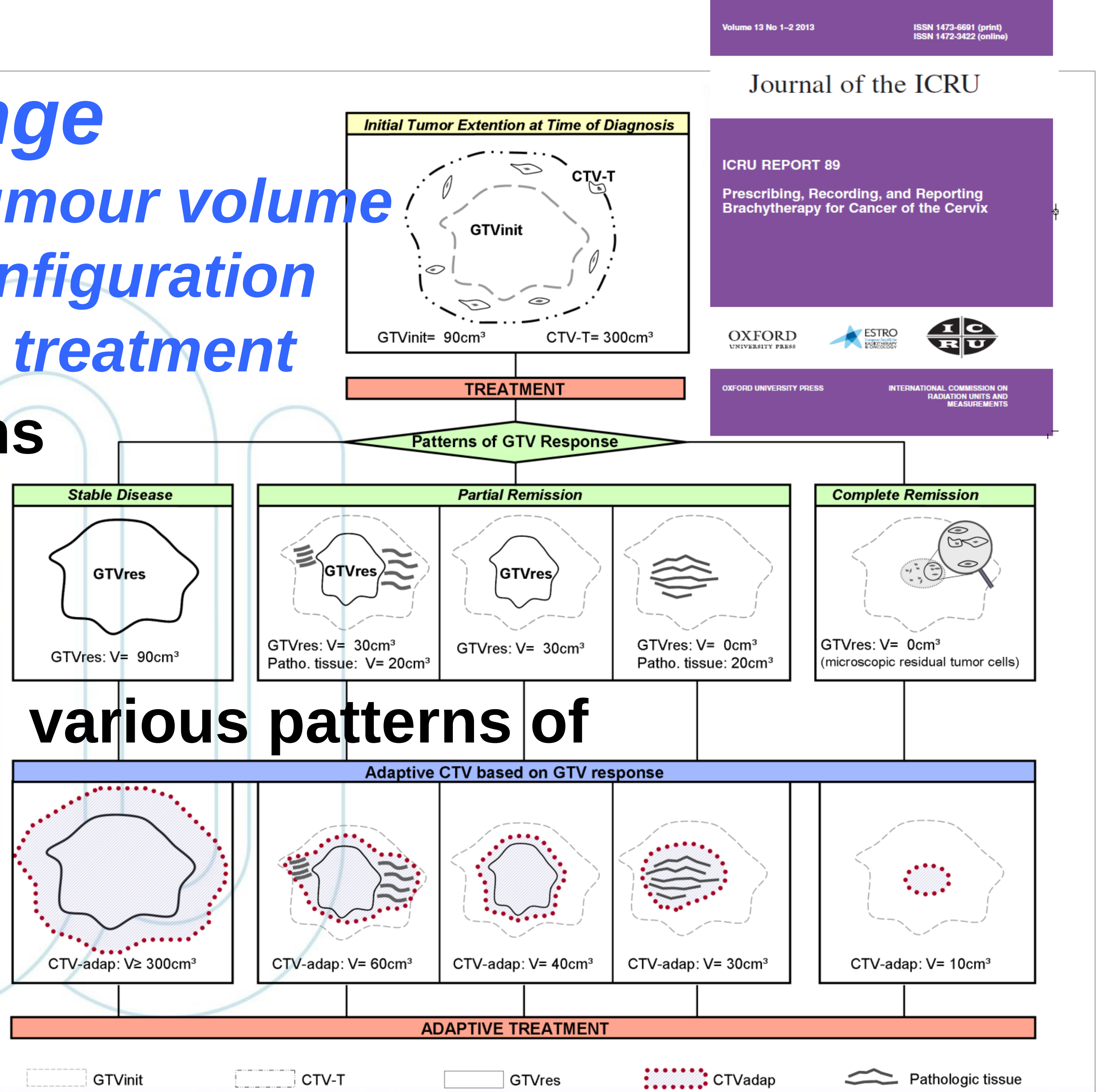
The challenge

of change in tumour volume and tumour configuration during treatment

Various patterns GTV response

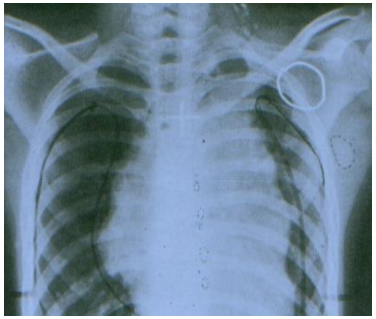
Corresponding various patterns of adaptive CTVs

ICRU/GEC ESTRO Report 89 Fig 5.3

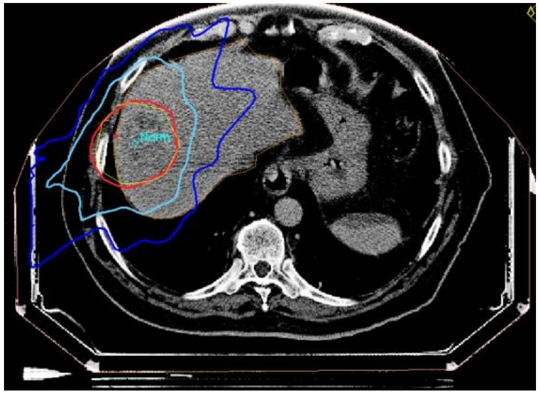


(D2) Delineation of GTV, CTV, PTV + organs at risk

- from planar imaging („2D“)
  - skin cancer (basalcellepitheliom)
  - X-ray Sim, individual blocks
  - Hodgkin´s Disease (2D-4D)
  - Boost Head and neck (clinical)(2D-4D)



- to volumetric imaging („3D“)
  - CT (MRI, US) based
  - GTV, CTV, PTV
  - ICRU 50&62 73&78&83&89 definitions



ICRU 62

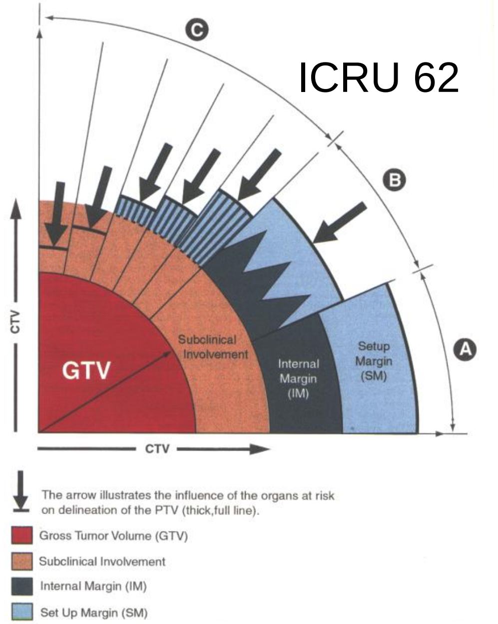
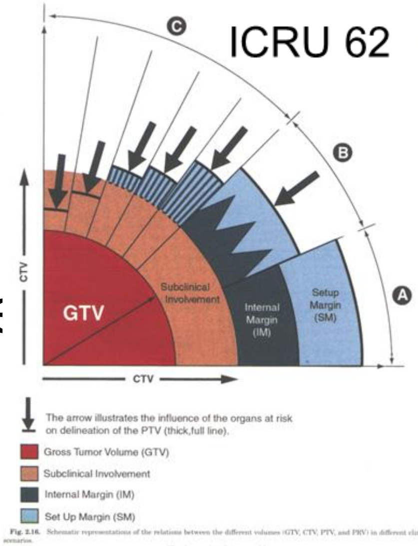


Fig. 2.16. Schematic representations of the relations between the different volumes (GTV, CTV, PTV, and PRV) in different clinica scenarios.

Volume definition (ICRU language)

- The process of determining the volume for the treatment of a malignant disease consists of **several distinct steps**.
- **Different volumes** may be defined, e.g. due to:
  - varying (assumed) concentrations of maligna
  - probable changes in the spatial relationship

    between volume and beam during the
  - movement of patient
  - possible inaccuracies in the treatment setup.



- **ICRU Reports define and describe several volumes:**

GTVs, targets and normal structures

to aid in the treatment planning process

to provide a basis for treatment comparisons

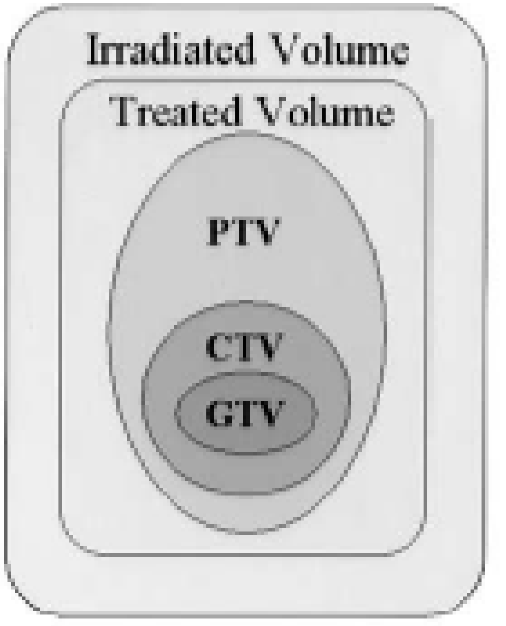
ICRU Report 50

- 1993 - 3D-CRT

  GTV *visible tumor*

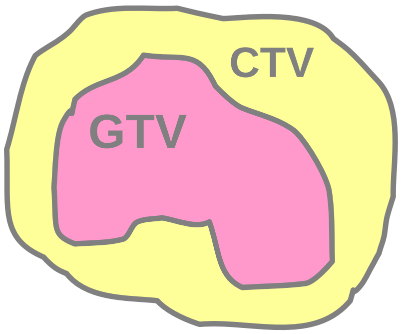
  CTV *= GTV + microscopic spread (lymph node, perivascular, perineural)*

  PTV *= CTV + geometric uncertainties (organ motion, tumor & patient movement, inaccuracies of beam &patient setup)*



- Appearance of new imaging modalities (MR, PET), technological progress (virtual simulation, MLC, IMRT), more information about target/organ movement lead to
  - Report 62 (Supplement to Report 50)

Clinical Target Volume (CTV)



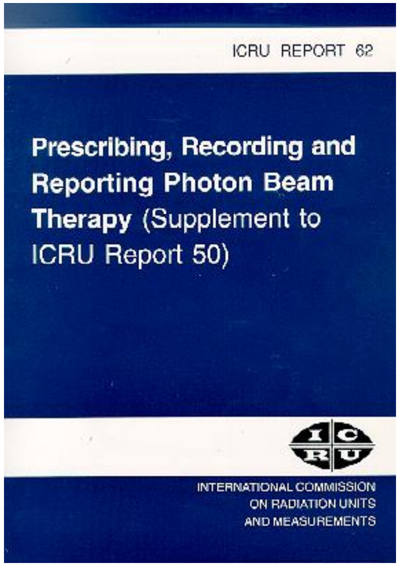
- the tissue volume that contains a demonstrable GTV and/or sub-clinical microscopic malignant disease, which has to be eliminated.
- often includes an area directly surroun-ding the GTV that may contain micros-copic disease and other areas considered to be at risk and require treatment.
- is an anatomical-clinical volume:

  CTV-T (Tumor),

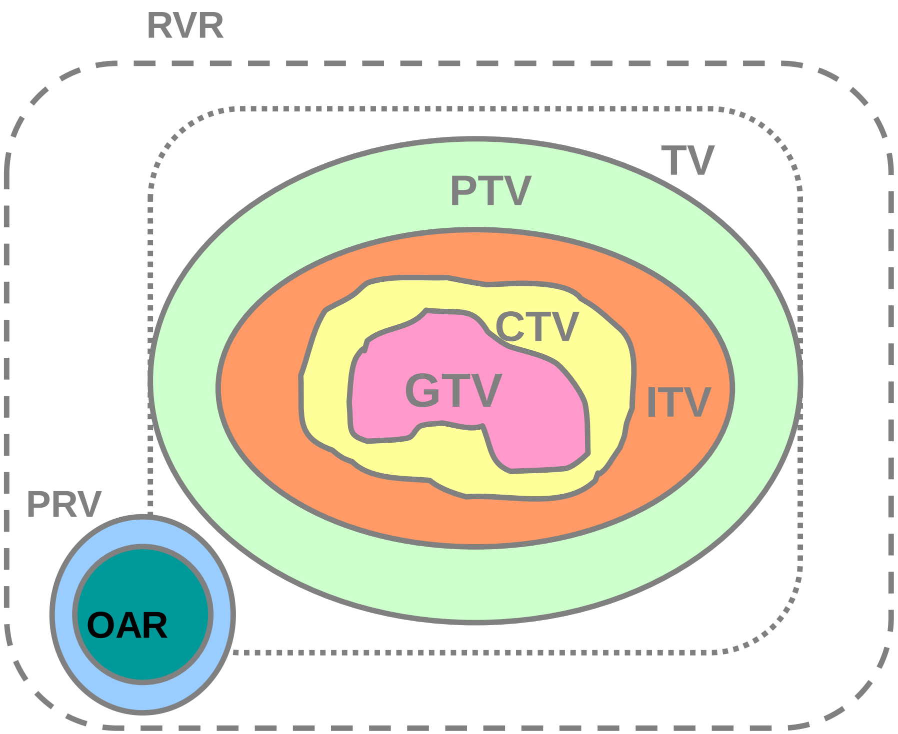
  CTV-N (involved lymph Node)

  CTV-M (Metastasis)

ICRU Report 62



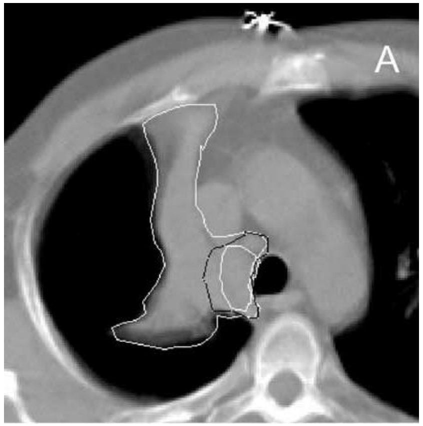
- Gross tumor volume: GTV
- Clinical target volume: CTV
- Organ at risk: OAR
- Planning target volume: PTV
- Internal target volume: ITV
- Treated volume or TV
  - Volume enclosed by specific isodose (D98%)
- Planning organ-at-risk volume:
- Remaining volume at risk: RVR
  - Remaining volume at risk
  - (Patient –(CTV+OARs))



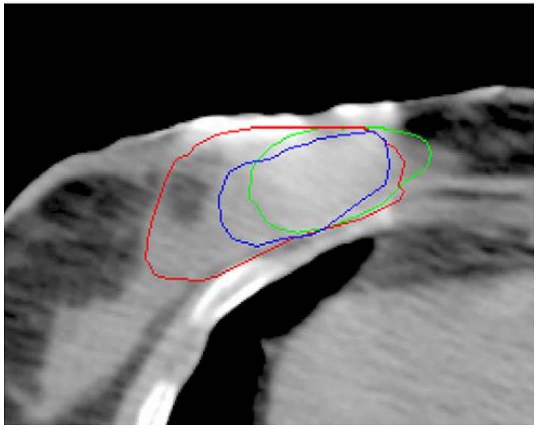
Volume definition

Target Volume definition

InTerobserver variability in delineation…

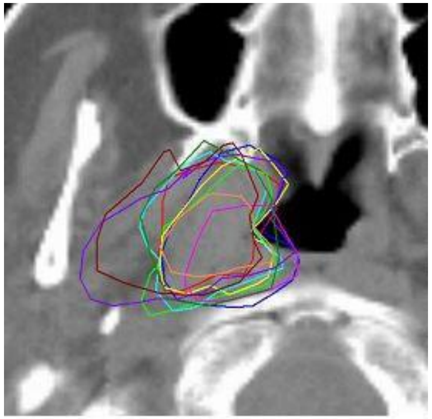


J. Van de Steene et al. / Radiotherapy and Oncology 62 (2002) 37–49

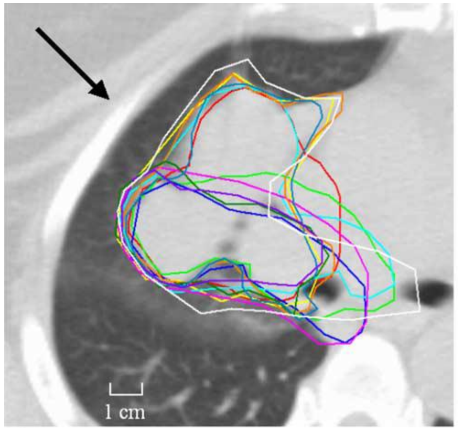


R. P. PETERSEN et al.

I. J. Radiation Oncology ● Biology ● Physics Volume 69, Number 1, 2007



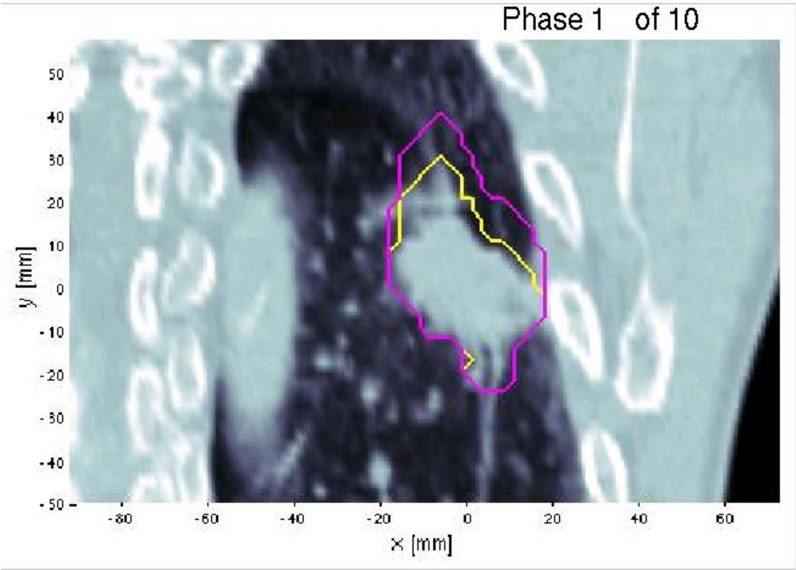
Rasch *et al.* *Radiation Oncology* 2010, **5**:21

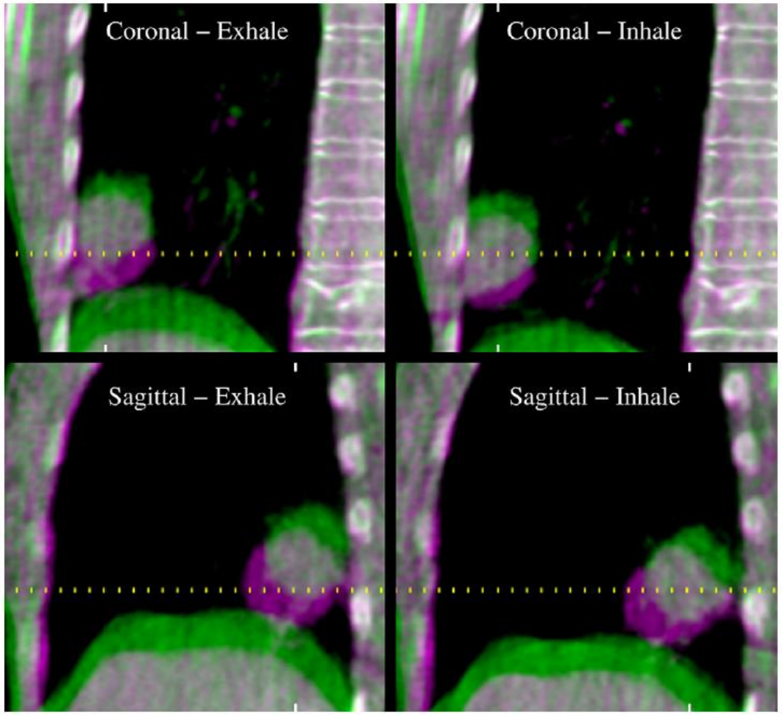


R.J.H.M. Steenbakkers et al. / Radiotherapy and Oncology 77 (2005) 182-190

4D – Intrafraction motion (lung)

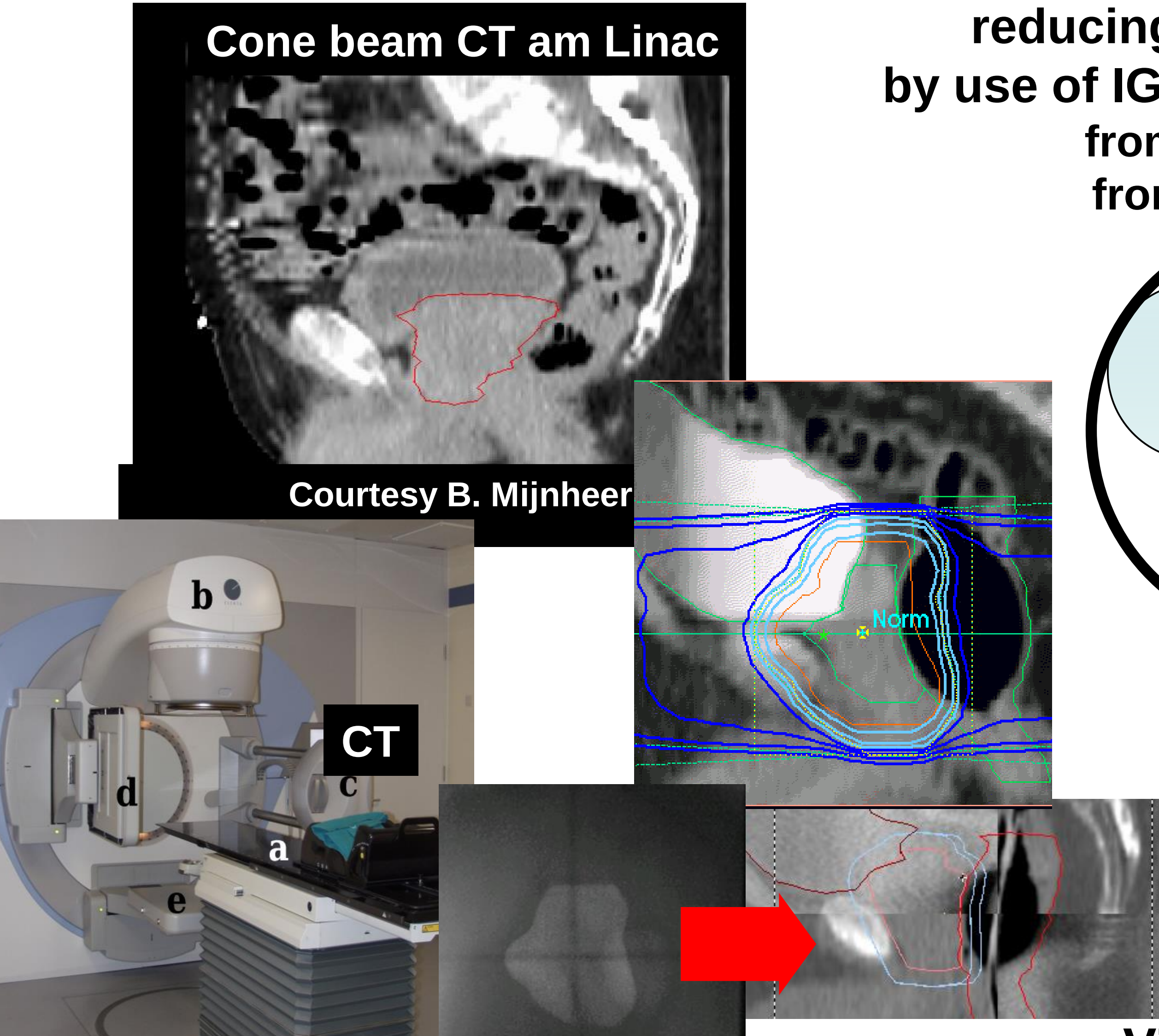
- 4D CT
  - feasibility of 4D CT
  - 4D also at treatmet machine (4D CBCT)





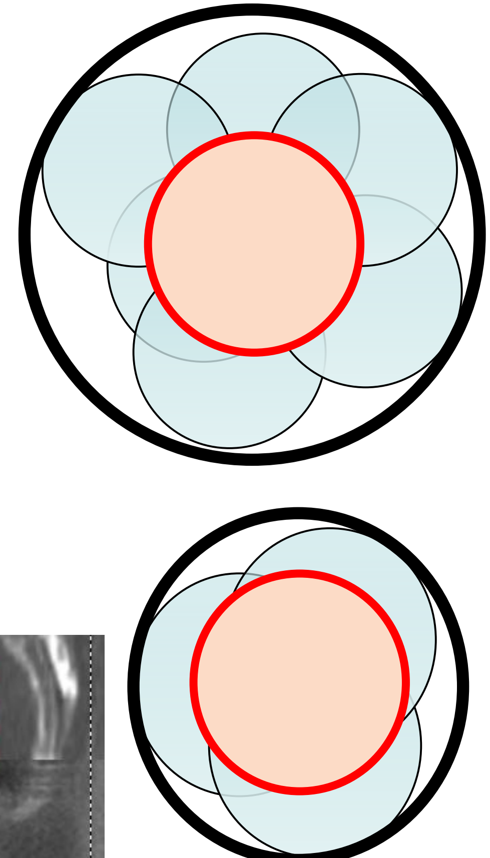
Sonke et al (Red 2008)

„dancing PROSTATE“
„Amsterdam prostate waltz“



Intrafraction motion

reducing safety-margins
by use of IGRT (CTV-PTV/IORV)
from 5 to 2-3 mm
from 10 to 7 mm

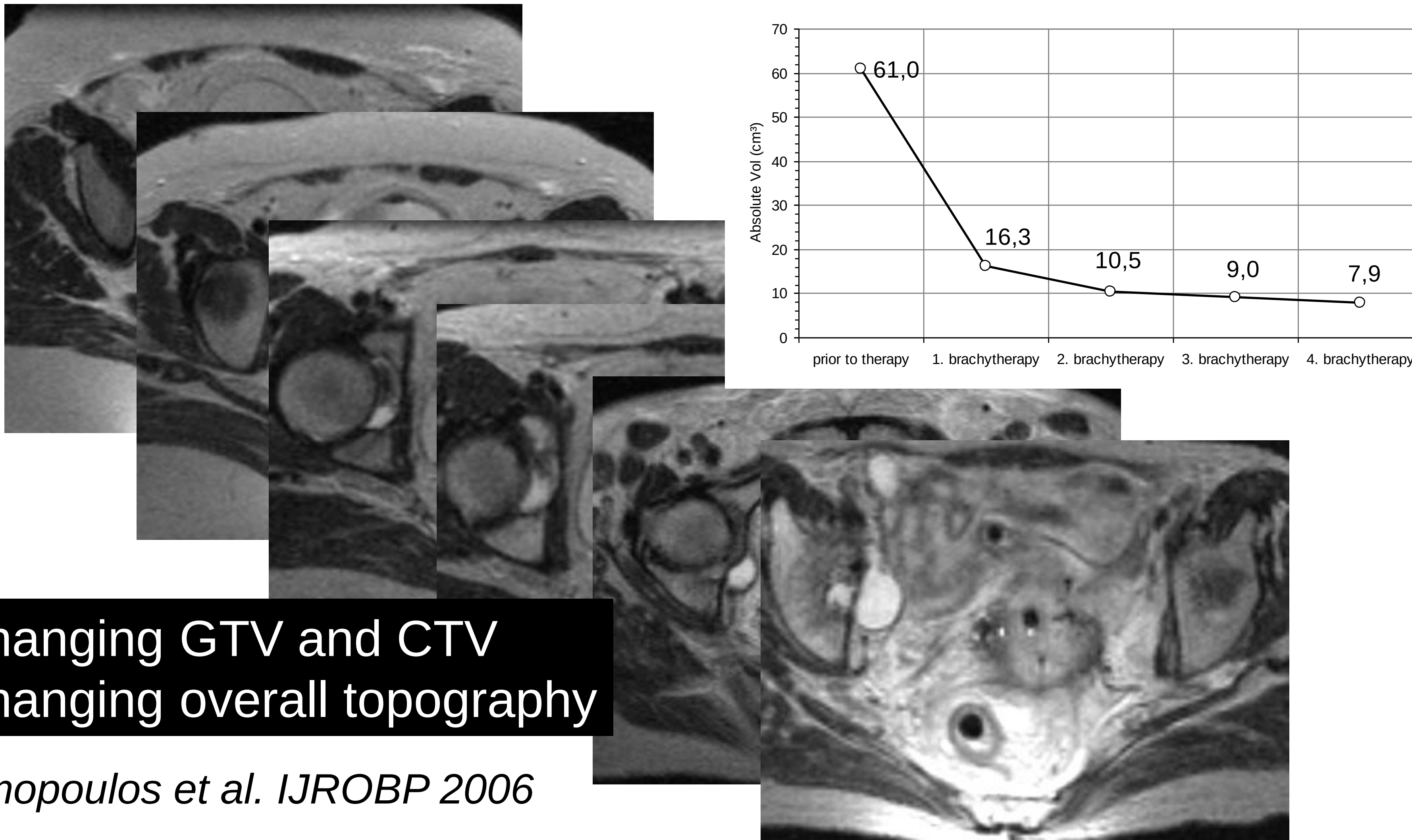


„Vienna prostate waltz “

Linac A
Image guided Radiotherapy

4D – Interfraction change (cervix)

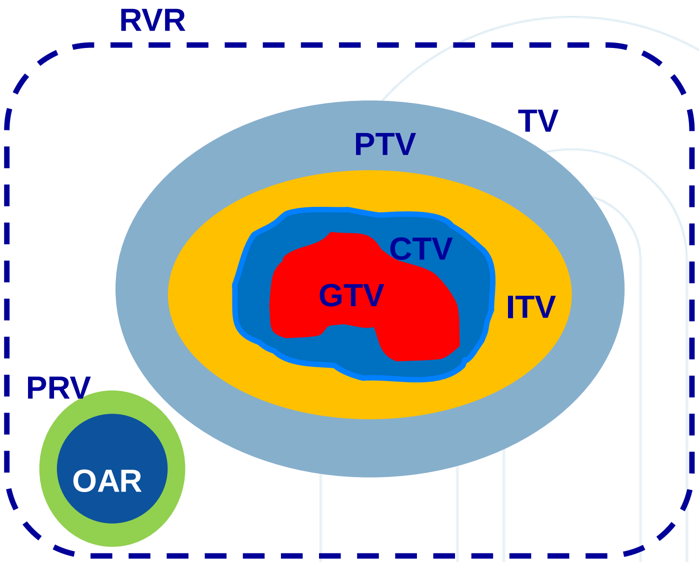
- MRI: Initial tumour extension (3D RT)
- pattern of spread and response (4D RT)
- for adaptive MRI based radiotherapy (BT)

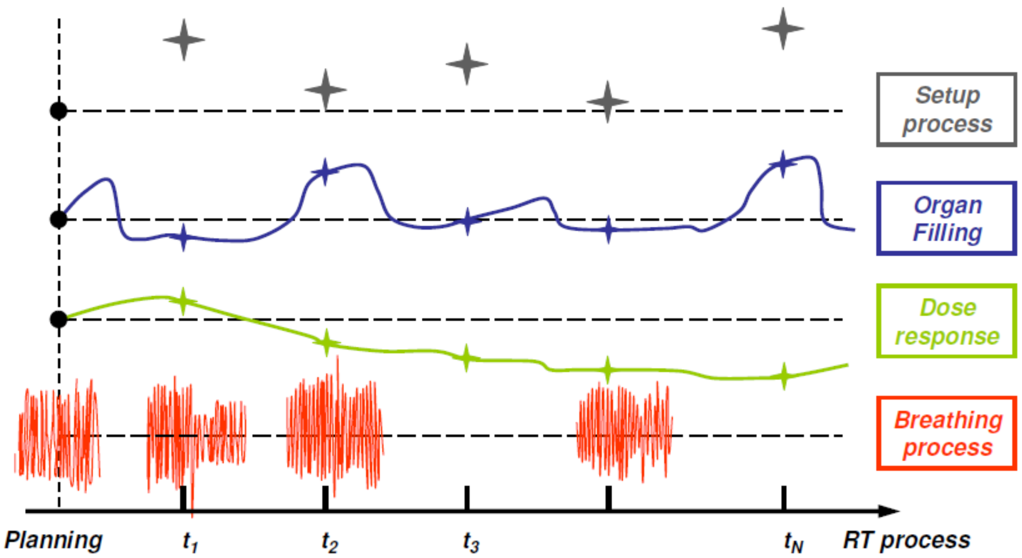


Changing GTV and CTV
Changing overall topography

Dimopoulos et al. IJROBP 2006

ICRU volume concepts (from 62 to 83 and 89)





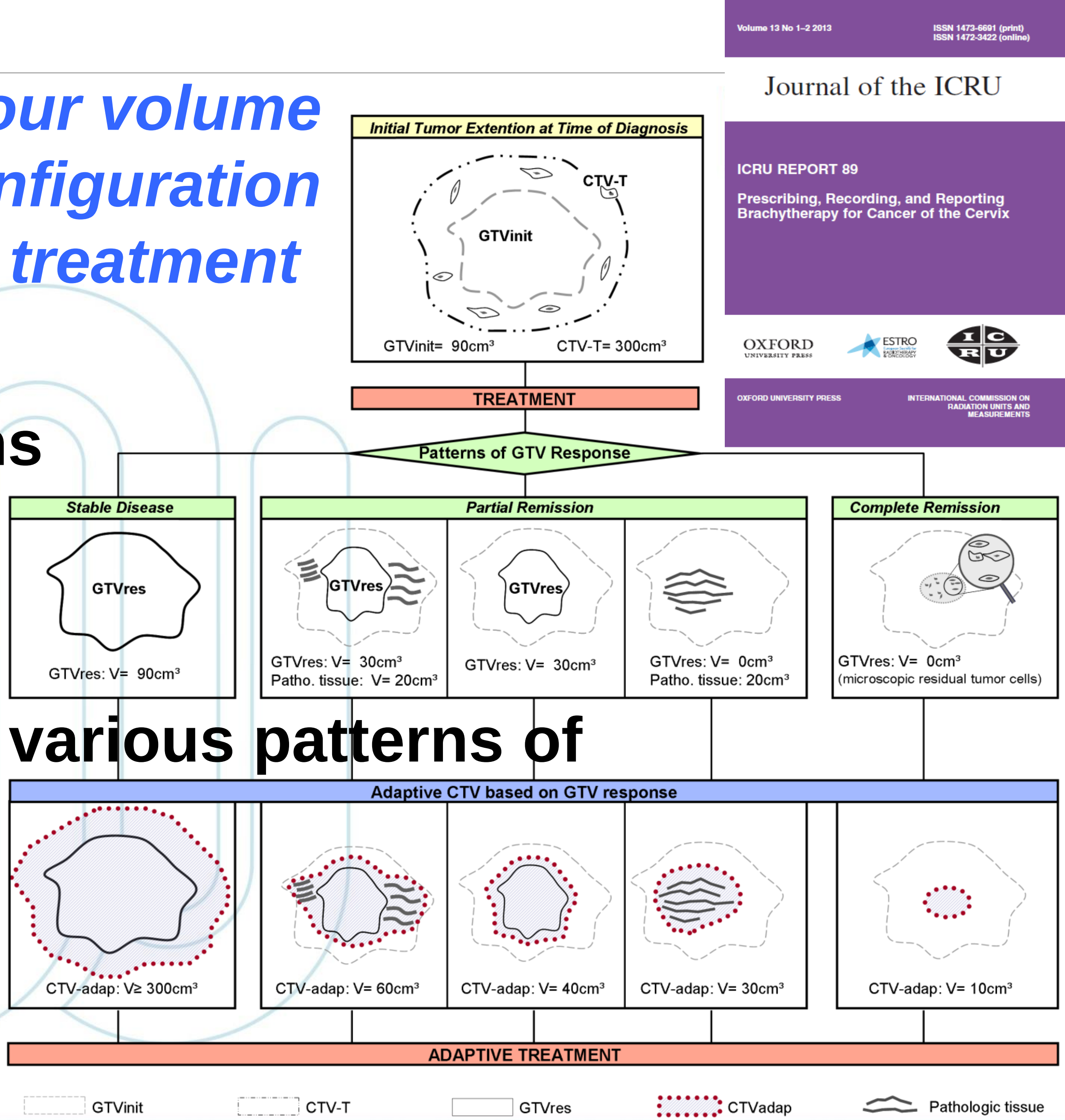
- ICRU concepts have been traditionally based on morphology/anatomy
- Margins account for temporal effects
- Concepts are in transition with subvolumes for GTV defined based on functional imaging, and/or GTV response. . .

Target concepts imply structure boundaries !

change in tumour volume and tumour configuration during treatment

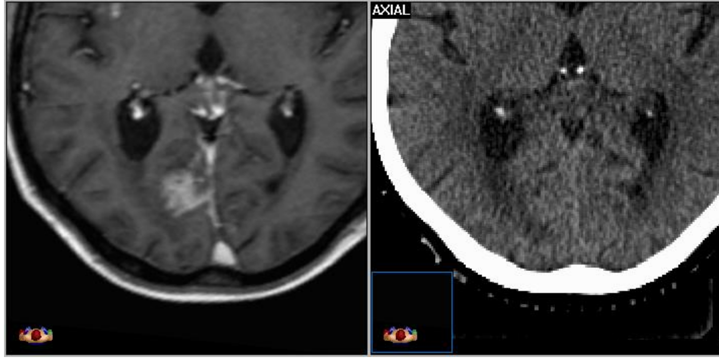
Various patterns GTV response

Corresponding various patterns of adaptive CTVs



ICRU/GEC ESTRO
Report 89
Fig 5.3

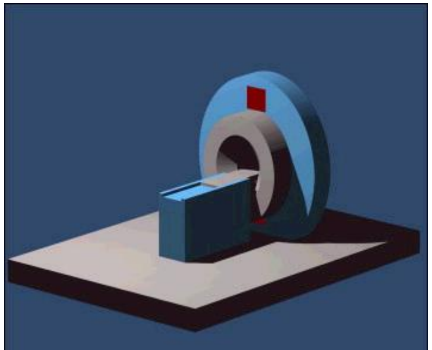
Limitations of CT



- CT in many anatomical sites:
  large inter- & intra-observer variability
- MRI provides improved
  soft tissue contrast with better visiblity
  and a large amount of sequences

<u>Some remarks on MRI</u>

- image distortion evaluation (MRI)
  image co-registration necessary (?)
- MRI+Linac



Lagendijk et al (Green 2(

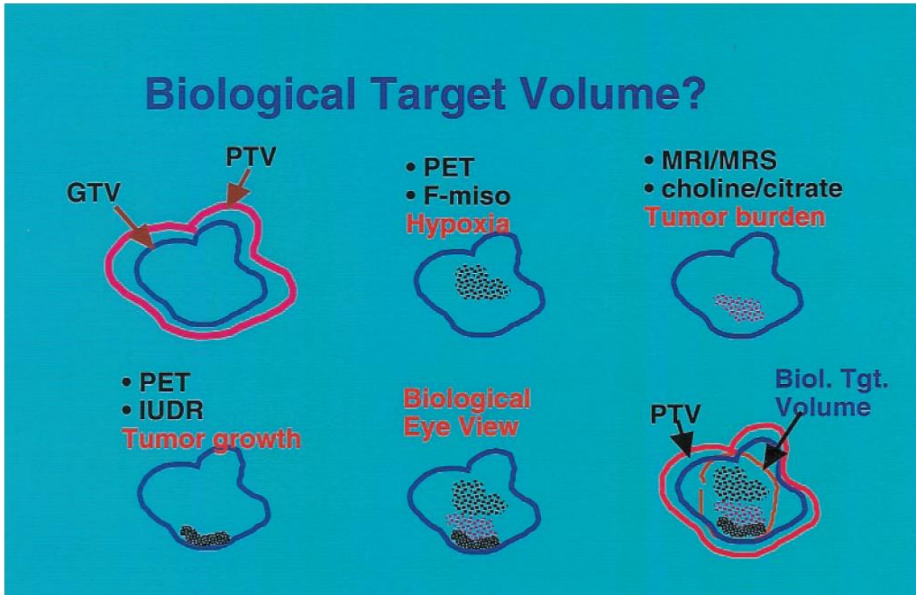
Volume definition

GTV
CTV
OAR

These volumes have an anatomical or physiological basis

- Selection and delineation of the CTV and the OAR is a medical decision,
  - results from a clinical judgment involving many factors, e.g pathology and imaging findings, imaging.
- Delineation of the GTV and the CTV should be independent of the irradiation techniques, and influenced only by oncological considerations

(D3) Determine biological attributes
„bio-imaging“- multimodal imaging



Ling et al. 2000

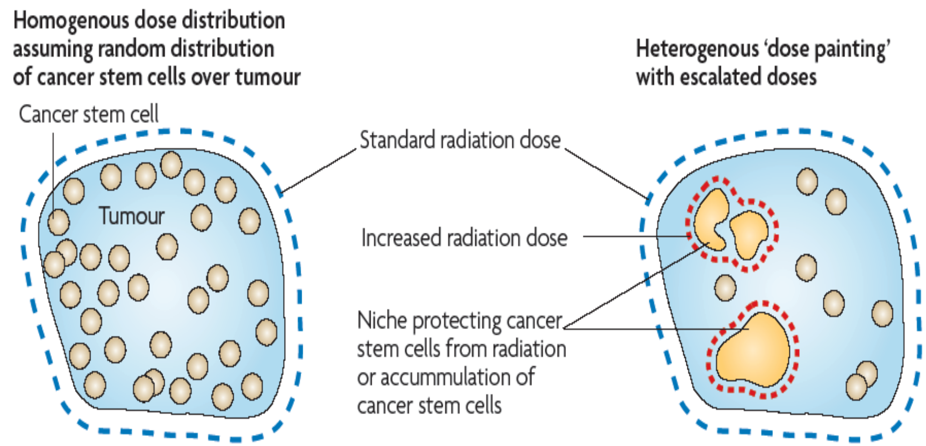
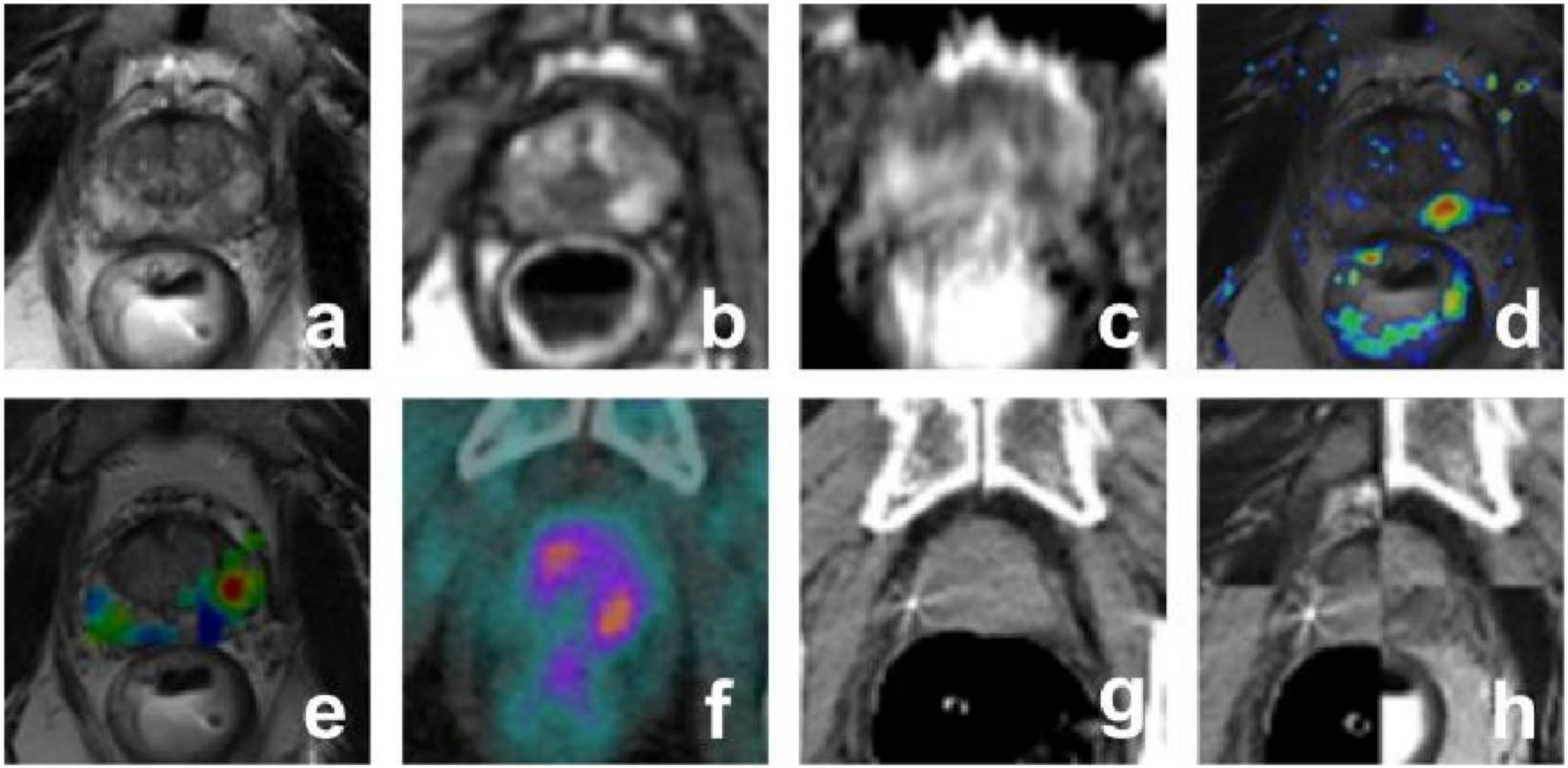


Figure 3 | **The potential importance of stem cell niches for radiotherapy treatment planning.**
a | Standard treatment plans would deliver the irradiation dose with a safety margin homogeneously

Baumann et al. 2008

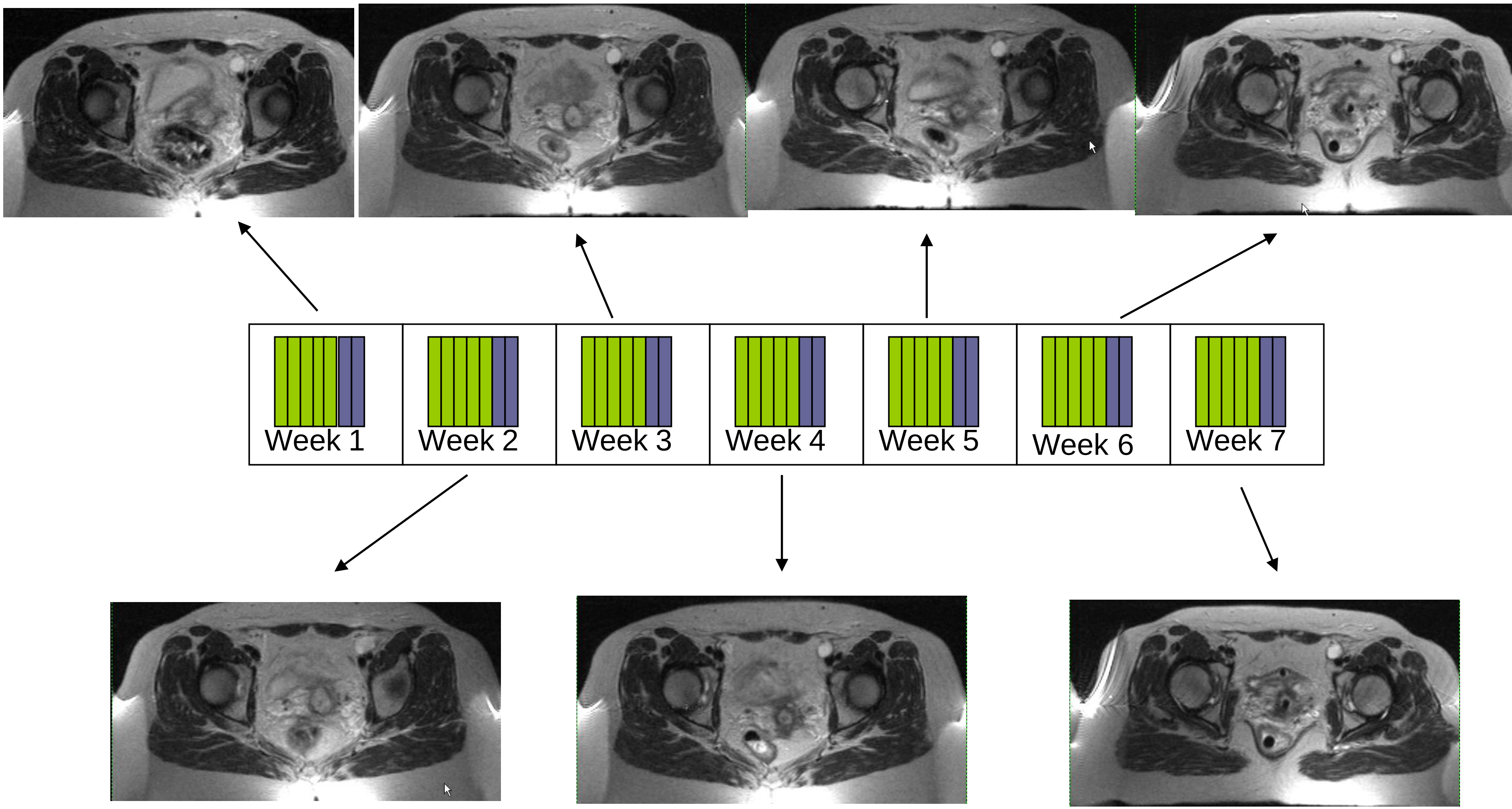
- Tumor hypoxia (H&N, Cervix…)
- Angiogenesis – microvessel density and perfusion (MRI)
- ……Varia……Lactate etc…..

mp-MRI



Supplementary Figure S1: Example of mp-MRI and PET findings for one patient: T2w (a), DCE T1w (b), ADC map (c), K_{trans} map (d) and MRS (Cho+Ci)/Cr ratio map (e). The lesion is visible in the peripheral zone at the right posterior part of the gland. For comparison $[^{11}C]$Acetate PET-CT (f), planning CT (g) and planning CT fused with T2w MR image (h) are shown as well. [1]

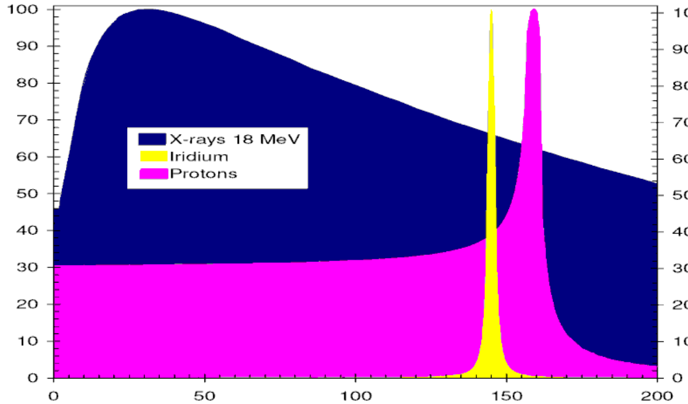
Determine „biological“ attributes from response…

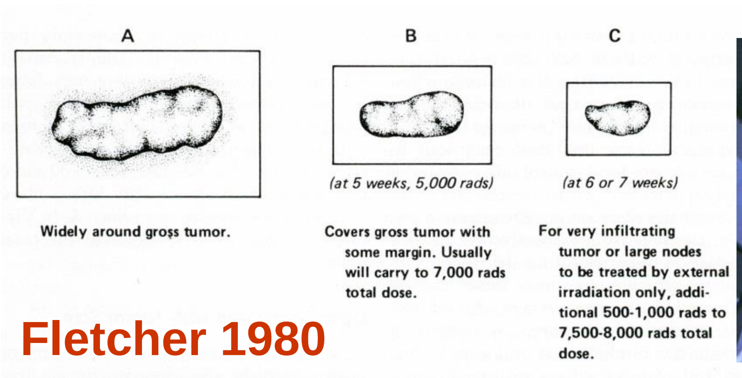


…with repetitive morphologic imaging

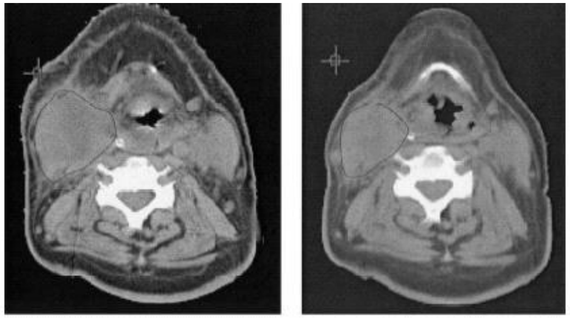
(D4) Dose distribution design

- 2D radiotherapy
- 3D conformal radiotherapy
- Adaptive Radiotherapy („shrinking field technique“)
- IMRT
- VMAT/Tomotherapy
- Dose Boosting/Painting (non uniform)





Fletcher 1980



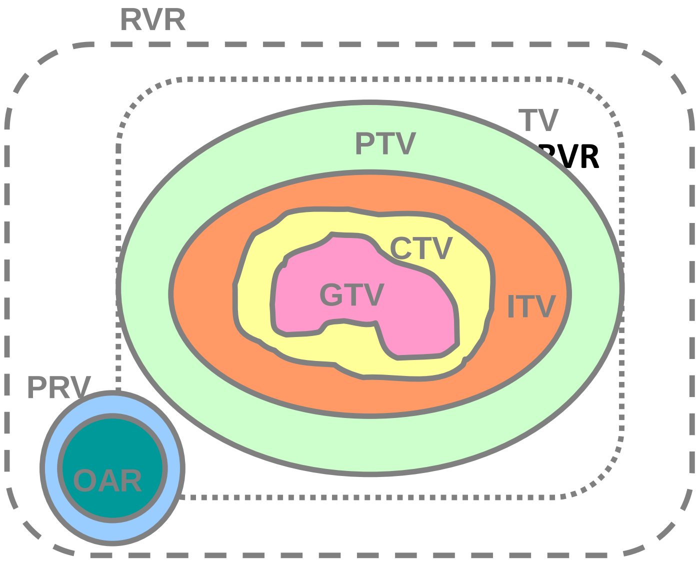
start of treatment – 3 weeks after start
Barker et al 2006

- Image guided Brachytherapy

Geometric concepts

PTV
PRV
ITV

introduced to ensure
that dose delivered to CTV &
OAR match the prescription &
constraints.



- These volumes may be constructed on TPS automatically with an appropriate margin

Margins

- Most important for clinical radiotherapy.
- Depend on
  - CTV/OAR motion → internal margins (ICRU 62)
  - patient set-up and beam alignment → external margins

- Margins may be non-uniform but should be three dimensional.
- Joint assessment of radiation oncologist and medical physicist
- A reasonable way of thinking would be:

“Choose margins so that the target is in the treated field at least 95% of the time.”

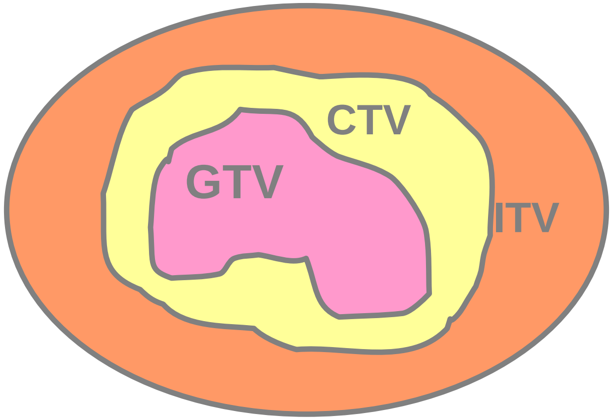
Margins in RO and Image Guidance

© Verellen

Geometric uncertainties are commonly accounted for by margins

Internal Target Volume (ITV)

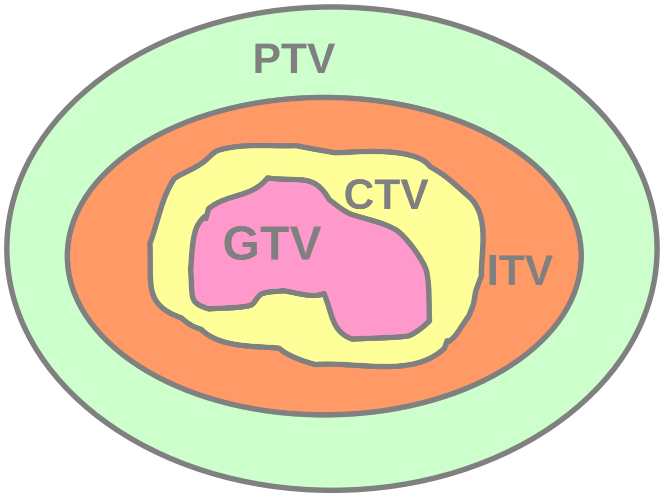
(complex R&D issues)



- ICRU Report 78: “In practice, it might not be necessary to explicitly delineate the ITV, but the IM (as well as the SM) must be taken into account when delineating the PTV.”

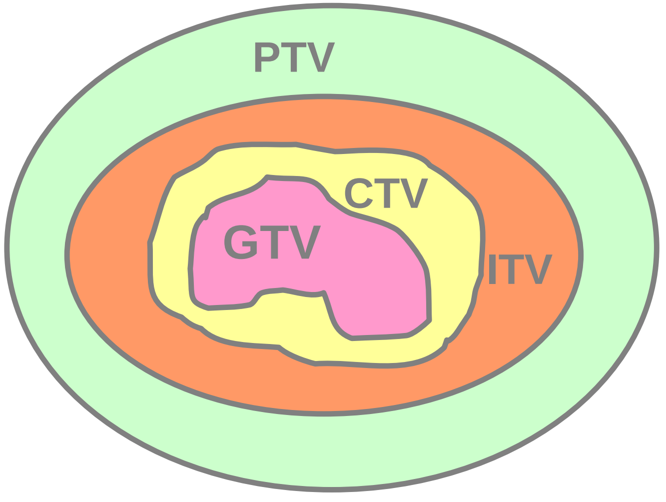
- ICRU Report 83: “The ITV is considered an optional tool in helping to delineate the PTV.”

Planning Target Volume (PTV)



- In contrast to the CTV a geometrical concept.
- It is defined to select appropriate beam arrangements, taking into consideration the net effect of all possible geometrical variations, in order to ensure that the prescribed dose is actually absorbed in the CTV.
- The PTV includes the internal target margin and an additional margin for set-up uncertainties, machine tolerances and intra-treatment variations.

How to define PTV ?



- Analyze ALL uncertainties and use appropriate margin recipe
- Systematic errors (Treatment preparation): setup error, organ motion during planning CT, delineation errors, equipment calibration errors
- Random errors (Treatment execution): inter- & intra-fraction variation

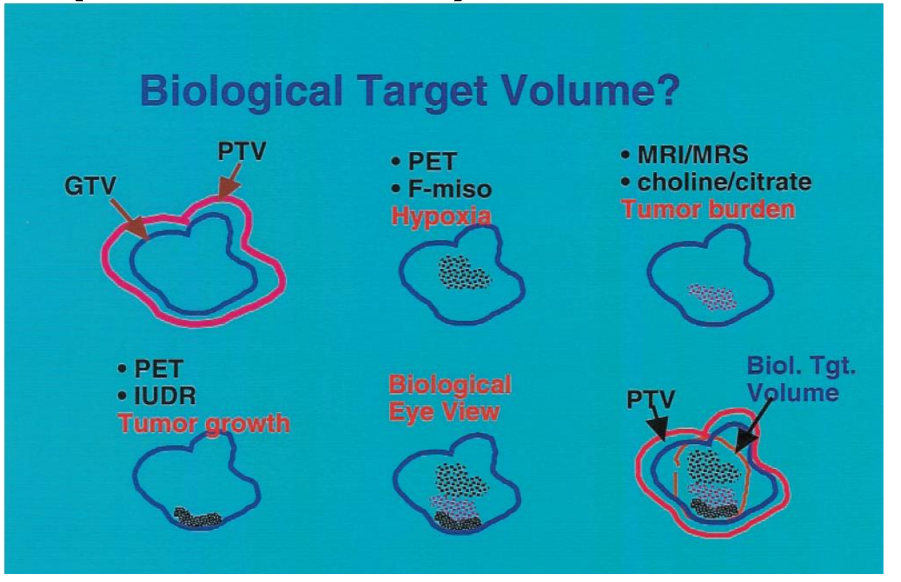
Margins in photon and proton RT
(complex R&D issues)

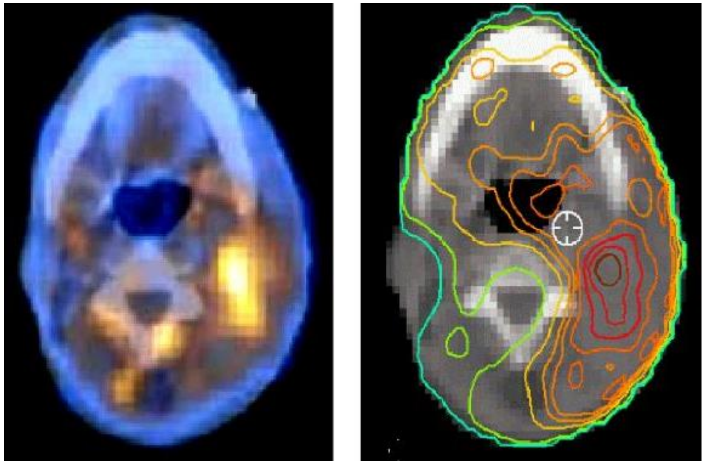
- Report 83 provides margin recipes for PTV and PRV in photon therapy (ref. van Herk, Ten Haken and McKenzie)
- Report 78 „PTV requires different margins lateral, distal and proximal to the CTV. “
- “Daily practice” in PT: Beams can be designed directly for the CTV, taking into account the need for internal and external margins within the aperture design, without reference to a PTV beams.
  - Nevertheless, PTVs must be defined since they are required for reporting purposes.

The delineation of the PTV is a required part of the treatment prescription

Dose Boosting and Painting

- coined by CC Ling et al (Red 2000)
- challenges dogma of homogeneity in target
- functional imaging for volumetric map of radiobiological factors
- lack of clinical trials
  “endpoints”

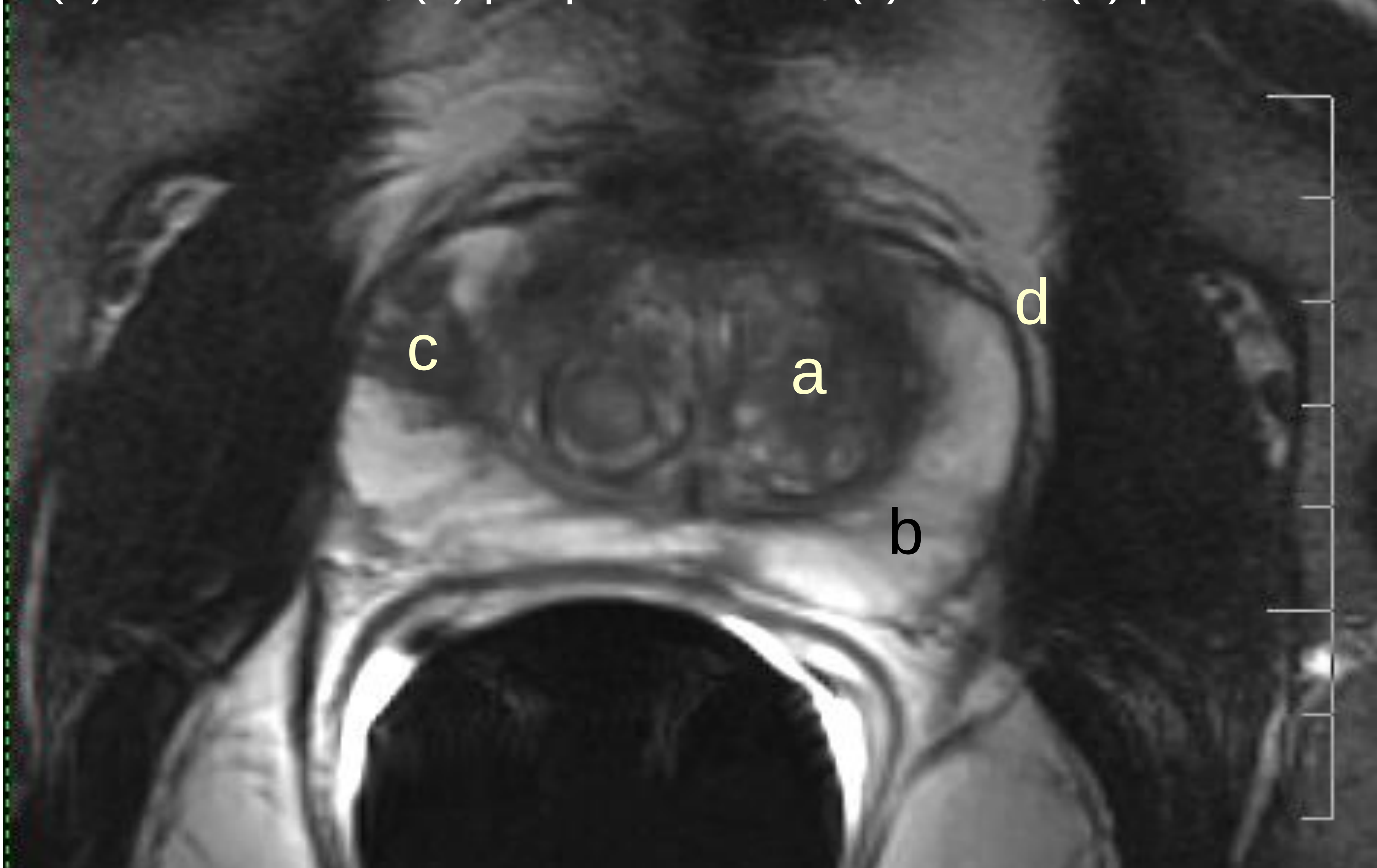


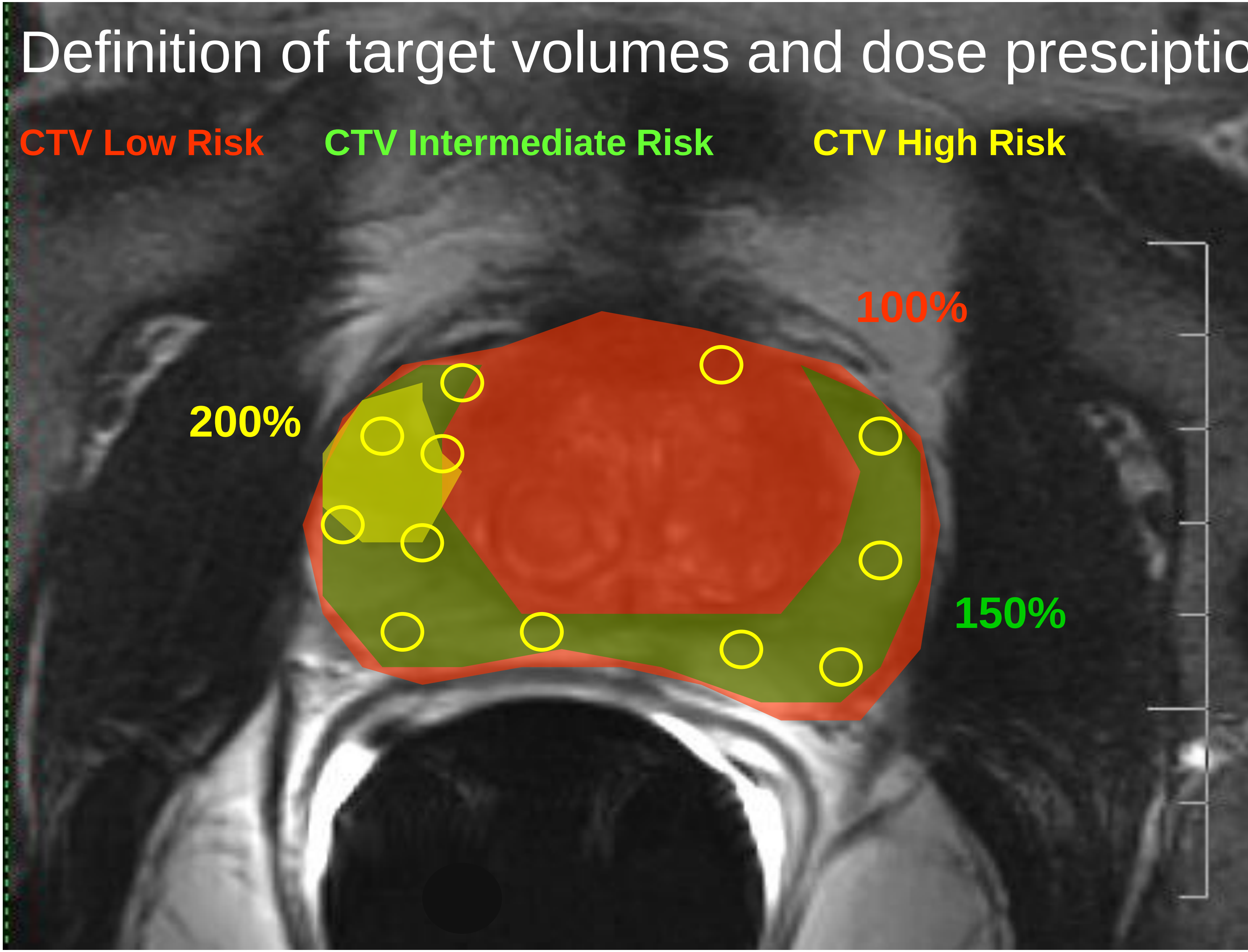


Alber et al (Tübingen)

MR imaging before treatment (T2)

(a) Central lobe, (b) peripheral zone, (c) tumor, (d) prostate.




Definition of target volumes and dose presciptio
CTV Low Risk
CTV Intermediate Risk
CTV High Risk
100%
200%
150%

Dose Painting: where?

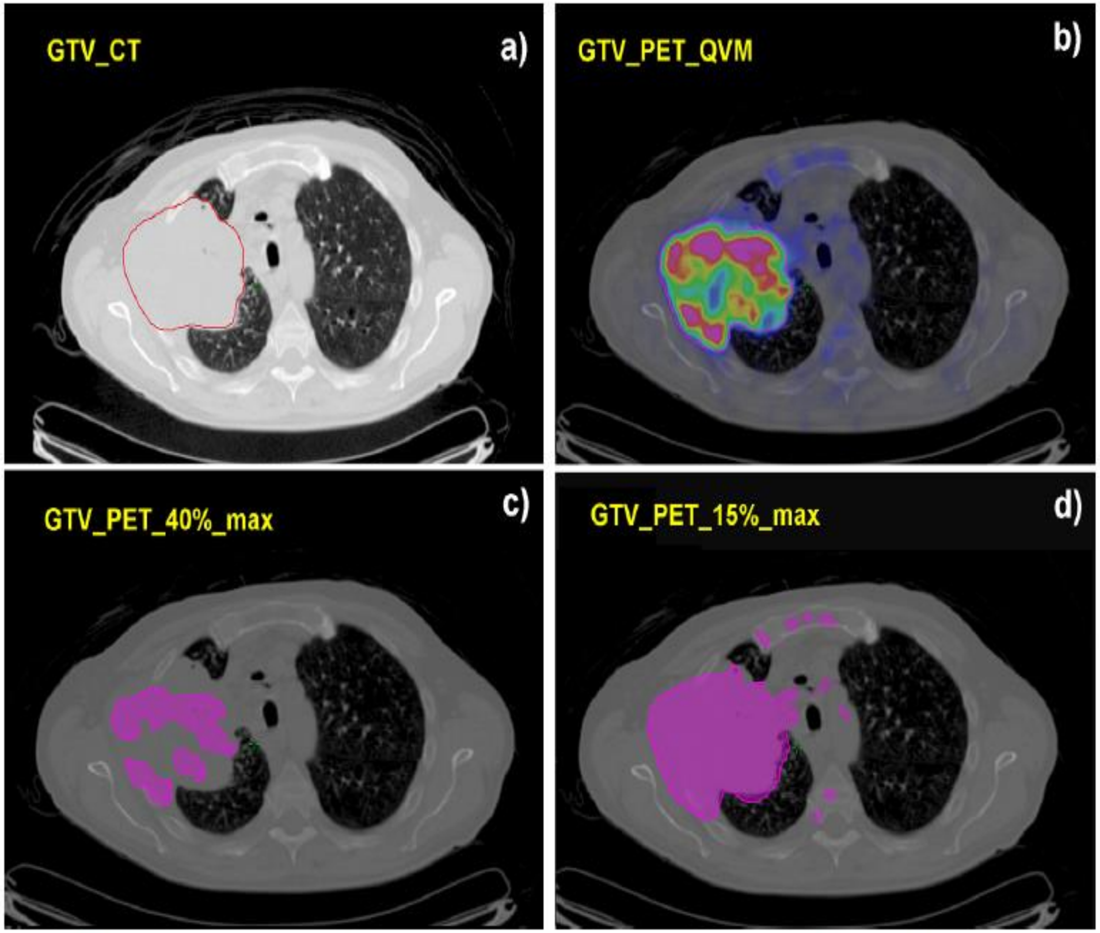


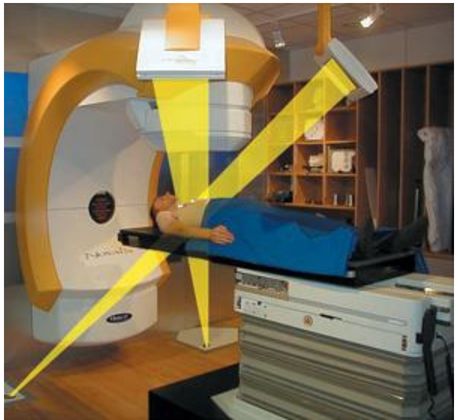
Fig. 2. Segmentation of target volumes. (a) Computed tomography-based gross tumor volume (GTV_CT) outlined by radiation oncologist. (b) Positron emission tomography-based gross tumor volume (GTV_PET) outlined by same radiation oncologist. QVM = qualitative visual method. (c) Positron emission tomography-based volume, outlined using gross tumor volume 40% maximal uptake method (single maximum) (GTV_PET_40%_max). (d) Positron emission tomography-based volume, outlined using gross tumor volume 15% maximal uptake method (single maximum) (GTV_PET_15%_max).

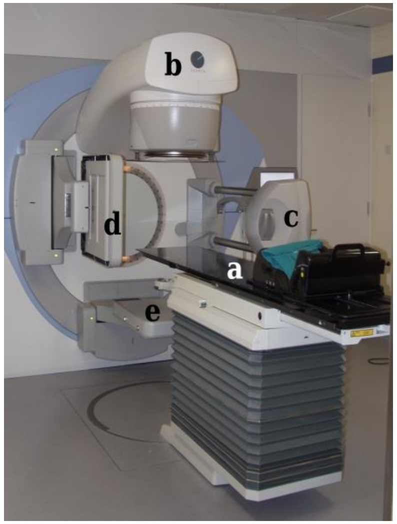
Devic S et al 2010 IJRBP

(D5) Dose delivery assurance („IGRT“)

- near real-time imaging during treatment delivery
- Ideally:
  - 3D volumetric study of soft tissue structures
  - efficient acquisition and comparison
  - process for clinically meaningful intervention
- commercial systems

  only partly achieve these needs

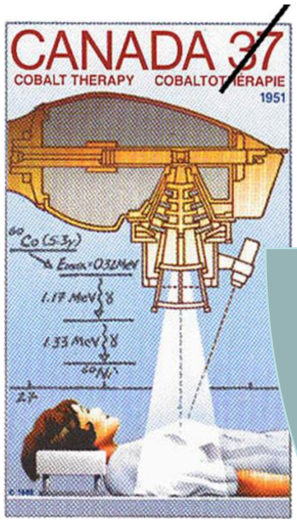




(Short) History of IGRT

1951: *The very beginning …*

intended +/- 1cm



A (short) history of image-guided radiotherapy

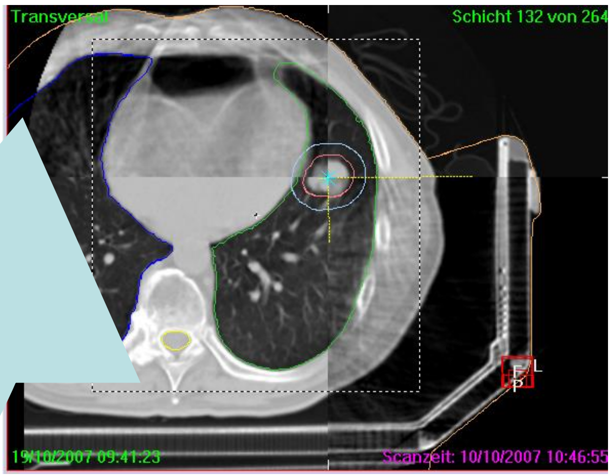
Dirk Verellen*, Mark De Ridder, Guy Storme

UZ Brussel, Oncologisch Centrum, Radiotherapie, Belgium

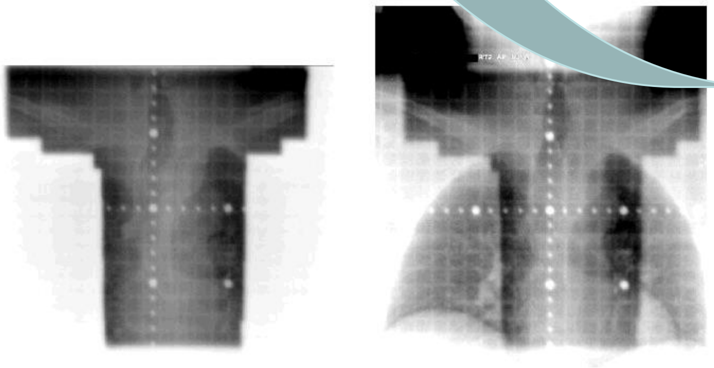
Radiotherapy and Oncology 86 (2008) 4–13

„State of the Art“ in IGRT: <u>CBCT</u>

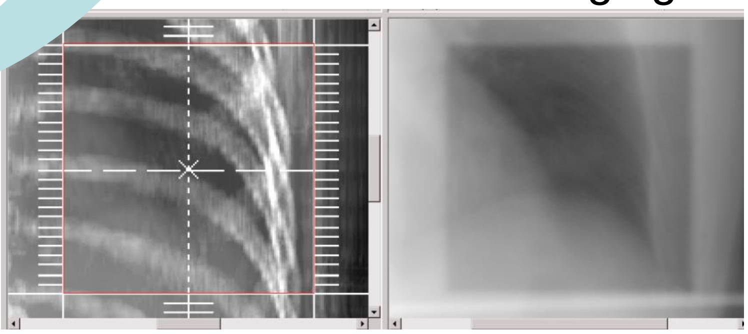
achieved +/- 1mm



Since ***1969***: X-ray localisation film



Since [illegible]: Electronic Portal Imaging Device

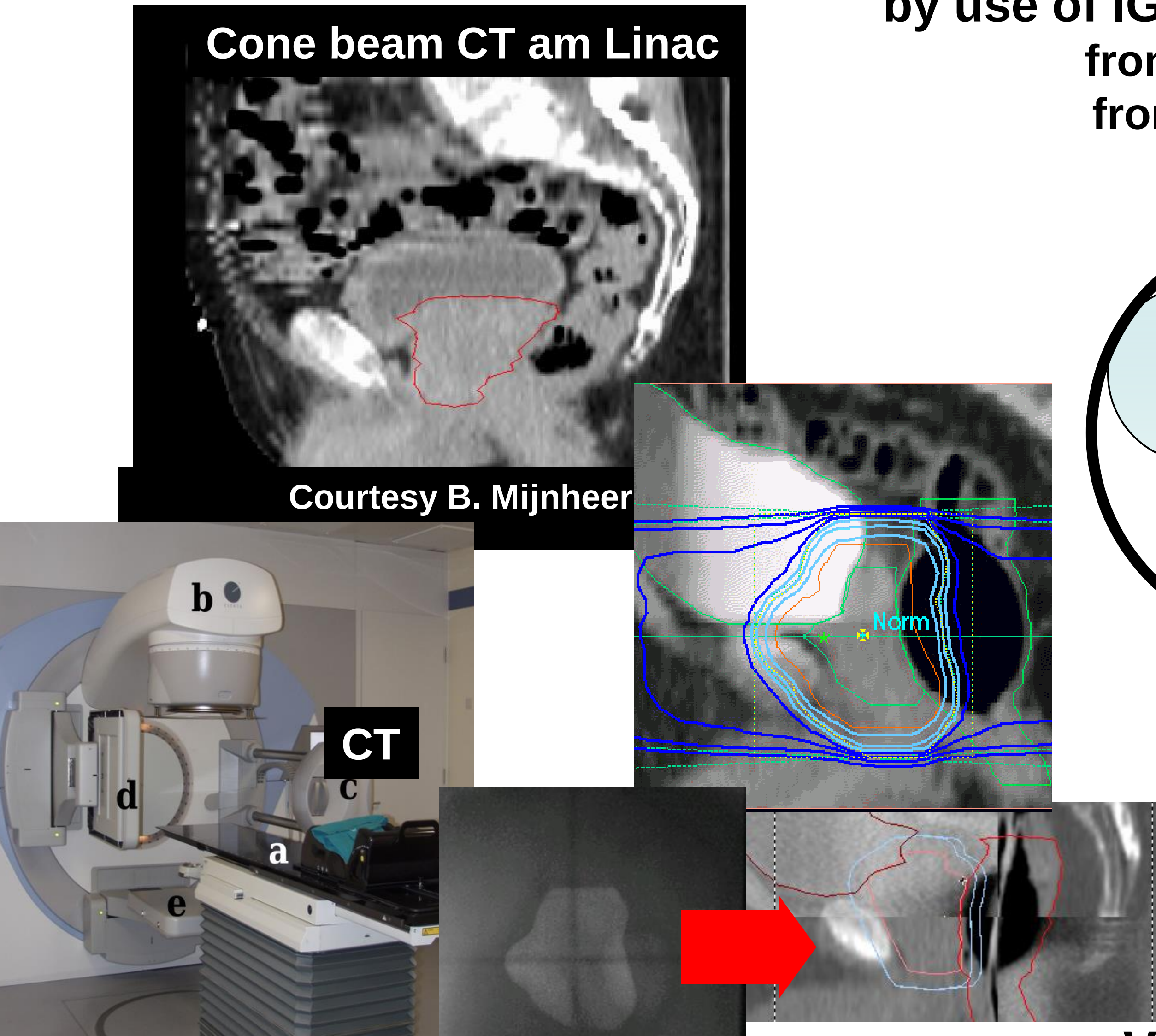


Where do we need what (R&D)?

- Where there is little movement, e.g. brain, (H&N)
  - bony landmarks
  - 2D MV, kV imaging with „well-thought-out“ correction protocol probably sufficient
- Where targets move relative to bony anatomy
  - 2D imaging with radio-opaque markers
  - no info on normal tissue or tumor conformation
- Where targets move relative to OAR:

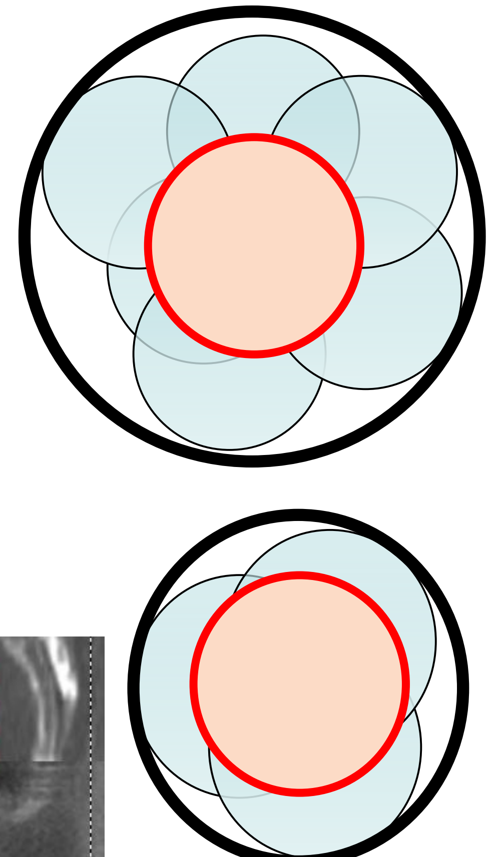
  3D imaging for comparison (e.g. SRT lung, liver)
  - online imaging → systematic and random errors corrected

„dancing PROSTATE“
„Amsterdam prostate waltz“



Reducing safety-margins by use of IGRT (CTV-PTV/IORV)

from 5 to 2-3 mm
from 10 to 7 mm

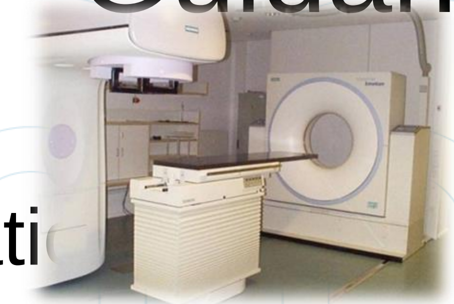


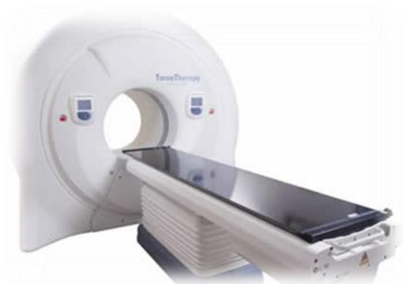
„Vienna prostate waltz “

Linac A
Image guided Radiotherapy

Today's Technology for Image Guidance

- Beam quality
  - MV (3 – 6 MV)
  - kV (80 – 130 kV)
- Beam collimati
  - CBCT
  - FBCT
- Dimensions
  - 2D
  - 3D
- Rail-track-, ceiling/floor-, gantry-mounted

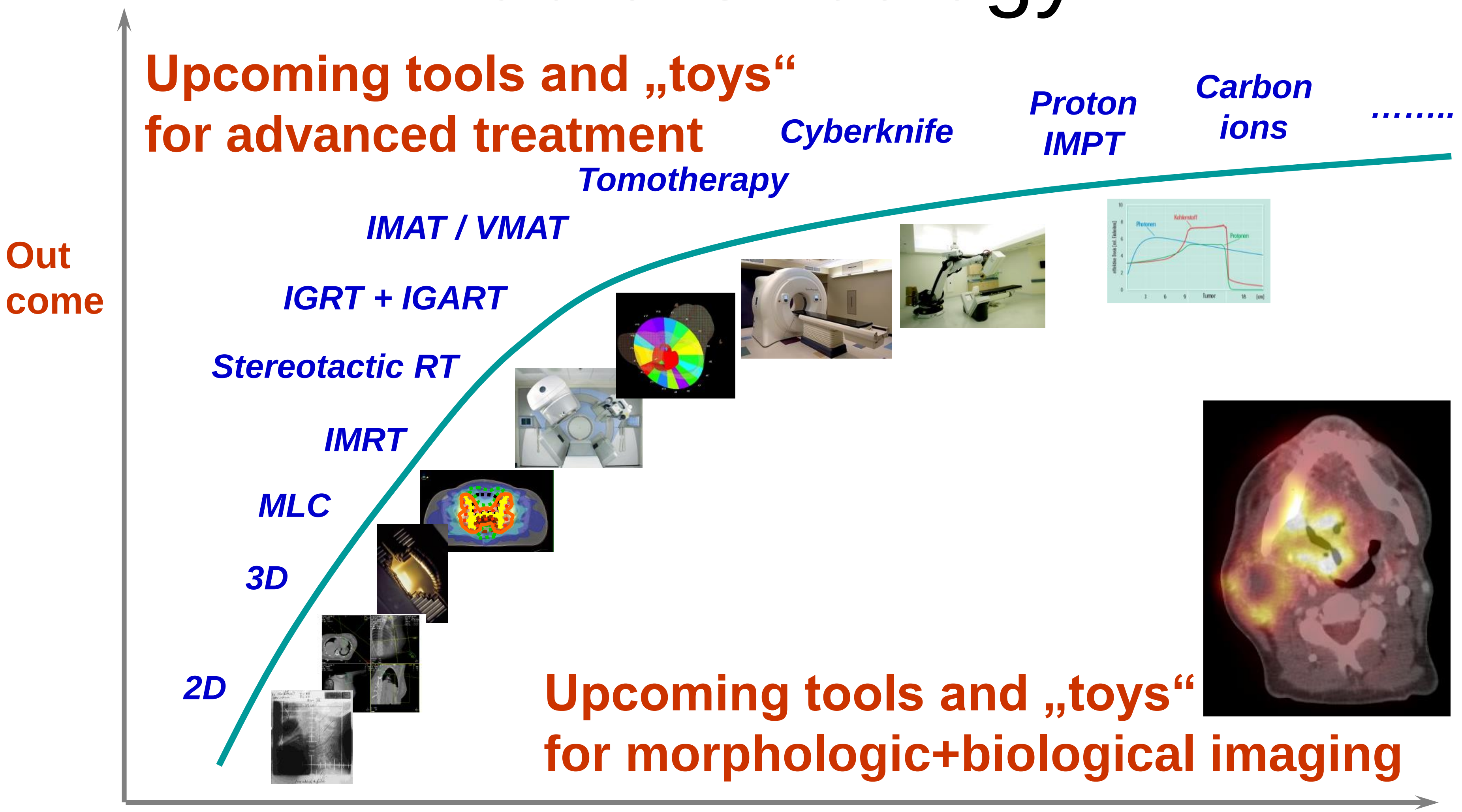




Current IGRT technology on/in the linac is X-ray based

Maximal conformity at maximal costs ?

Radio-Oncology



Courtesy Dietmar Georg, Vienna

Image Guided Radiotherapy (IGRT)

- Reduction of setup and internal margins
- Reduction of side effects
- Enables dose escalation

- Room or rail-track mounted system
- Gantry or couch mounted system

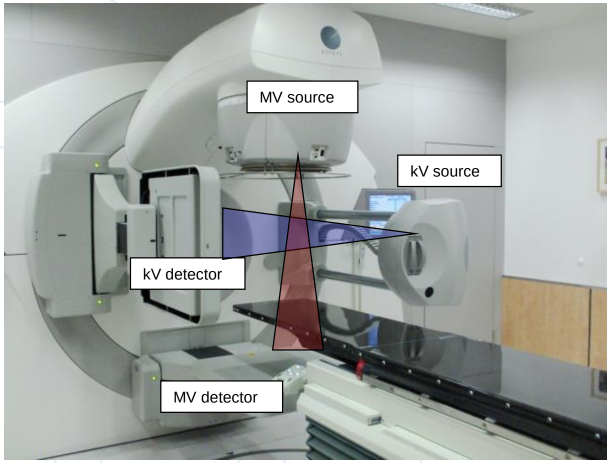
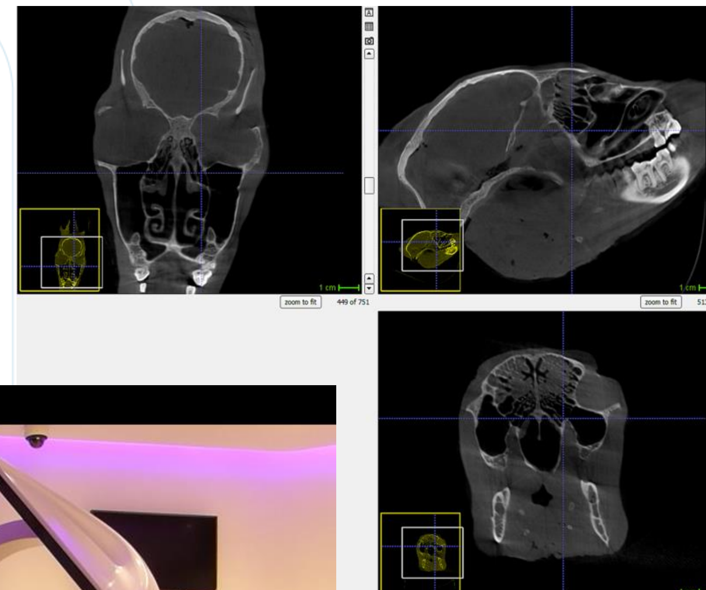


Image Guidance in proton therapy

- Example MedAustron: Imaging Ring (MedPhoton)



(D6) Deciphering treatment response

(CR, PR, SD, PD/ time pattern)

Standard:

- **Morphological changes;**

  clinical exam., light imaging (endoscopy), US/CT/MR

Upcoming:

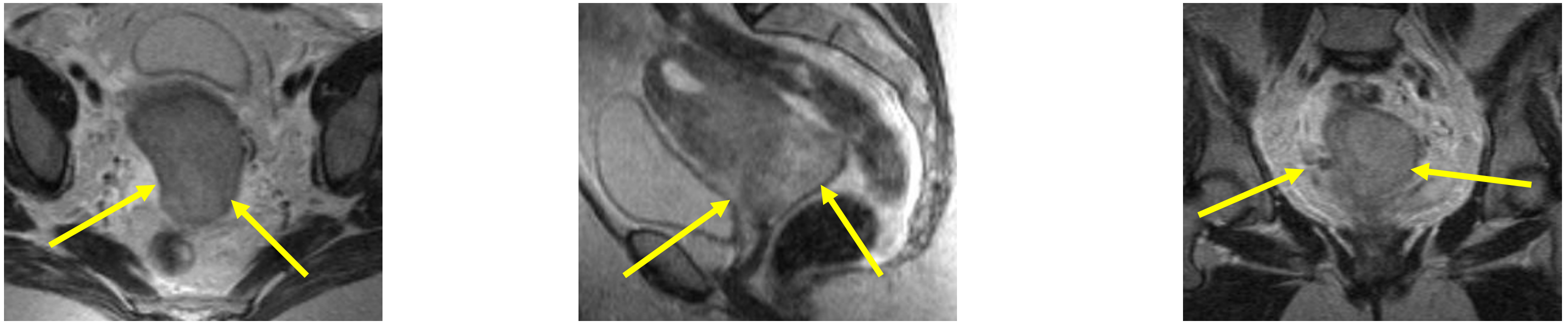
- Comparision pre- at and post treatment functional imaging (FDG)-PET CT, fMRI

Present Developments

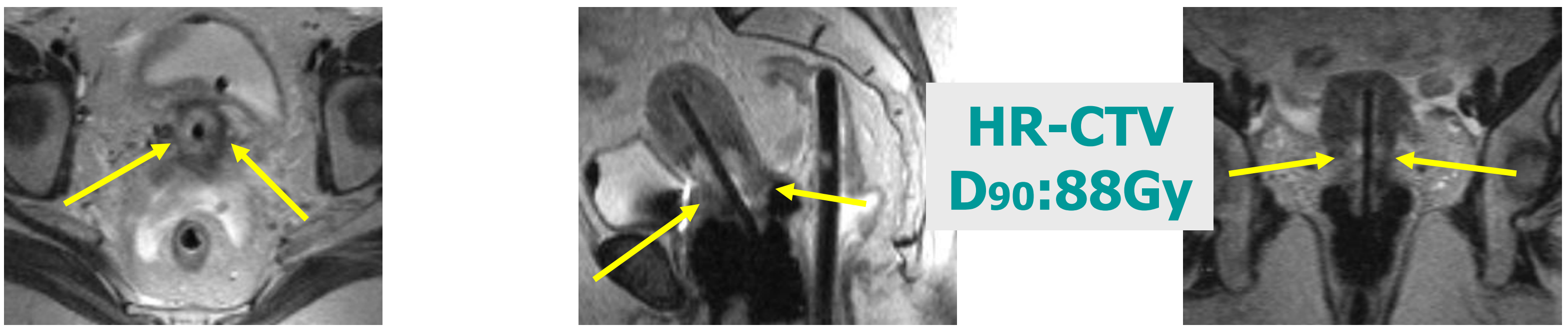
- Measurement of RT induced metabolic changes (cellular proliferation - FLT, Apoptosis,…)
- ADC (apparent diffusion coefficent) DWI,, K trans, (DCE) etc.

STAGE IIB: 5 cm WIDE, SUFFICIENT RESPONSE (12/2002)

At diagnosis: 5 cm wide, 5 cm thick, 7cm high: 88 cm^3



At first BT:2 cm x 3 cm x 3 cm, 9 cm^3, good remission, sufficient for intracavitary BT



HR-CTV D_{90}:88Gy

6 months after treatment: Continuous Complete Remission

3/2005: CCR: local control

RadiotherOncol 2005

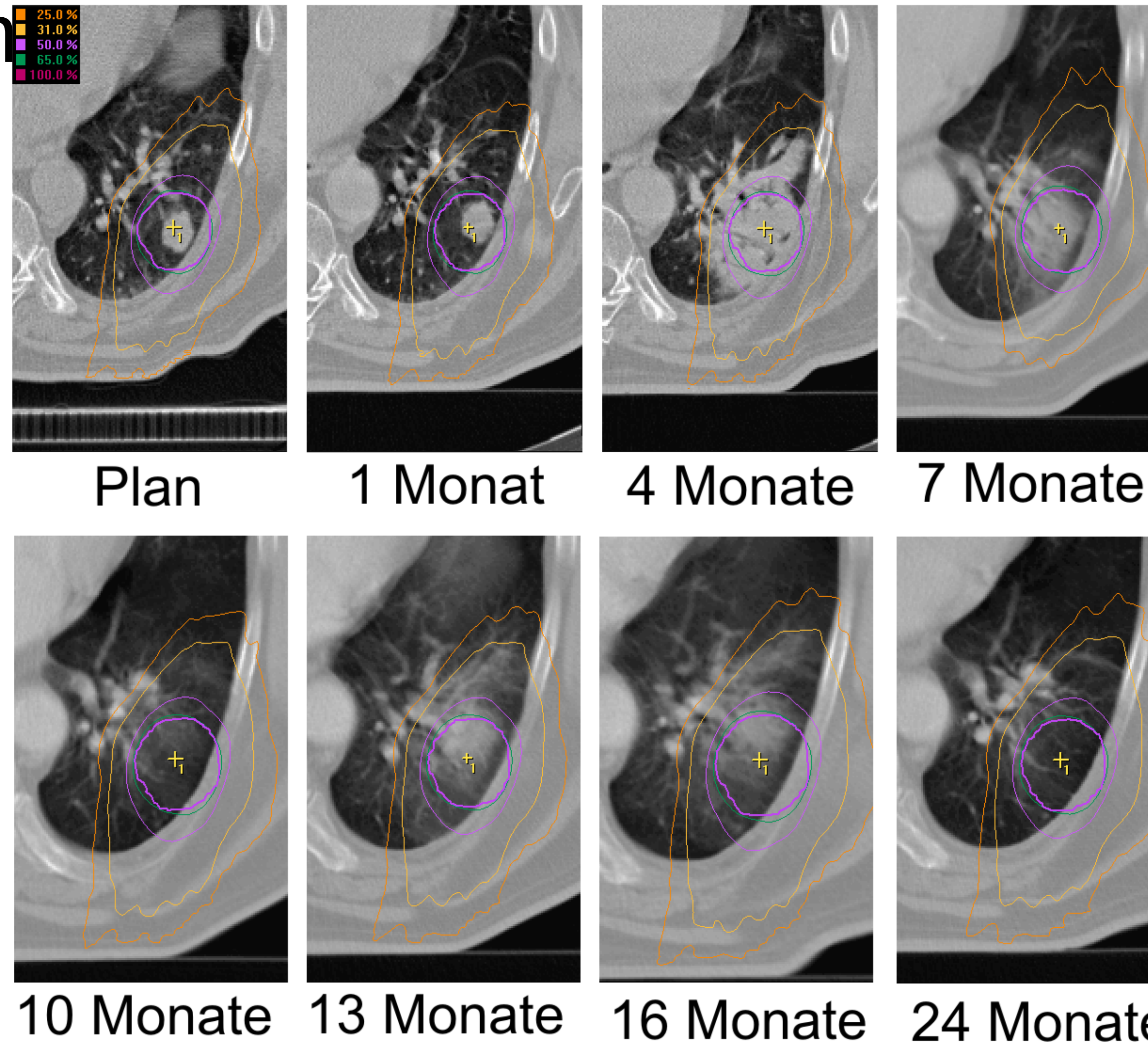
(D7) Diagnosis of outcome (after treatment)

Image assessment after certain time intervals

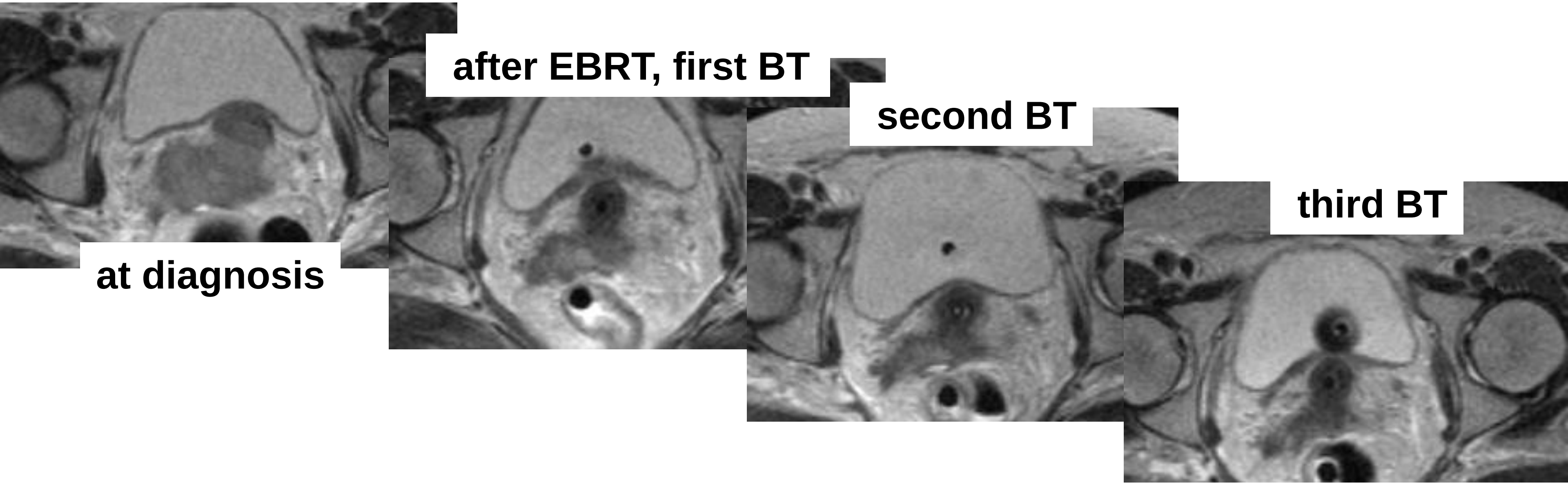
- Tumour remission (complete)
- Lung fibrosis (transient)

after

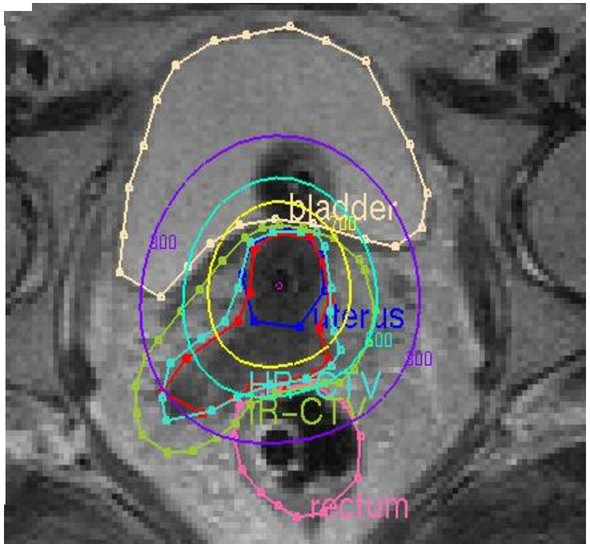
Definitive Stereotactic RT in T1 lung cancer



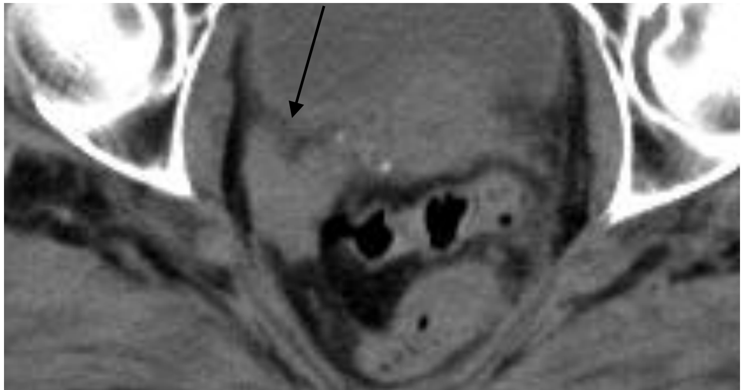
Stage IIIB, 6 cm, insufficient response (9/2000)
no adapatation of application technique
Intracavitary BT alone



Optimisation based on intracavitary BT alone
HR CTV
D90: 67 Gy

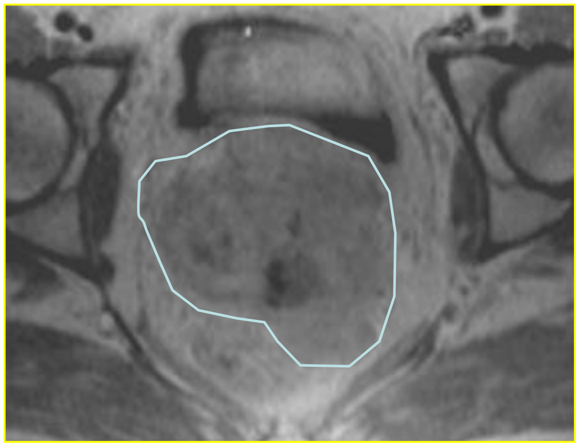


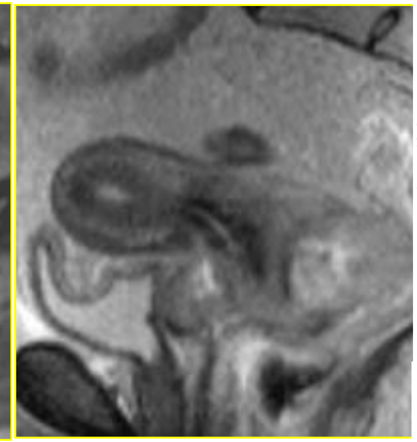
Parametrial/pelvic wall recurrence 8/2001

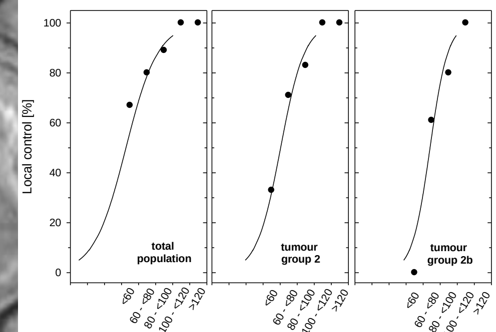


4D analysis of tumour spread, target coverage and recurrence
Insufficient Tumour remission (cervix cancer stage IIIB):
no adaptation of application technique
topographical correlation to DVH parameters

Diagnosis

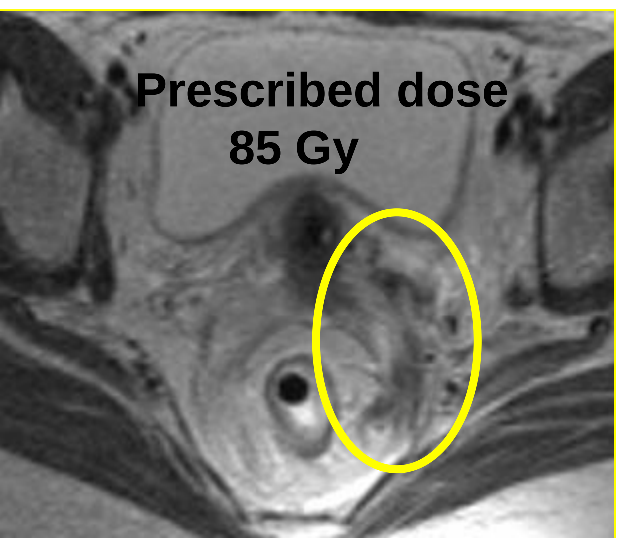




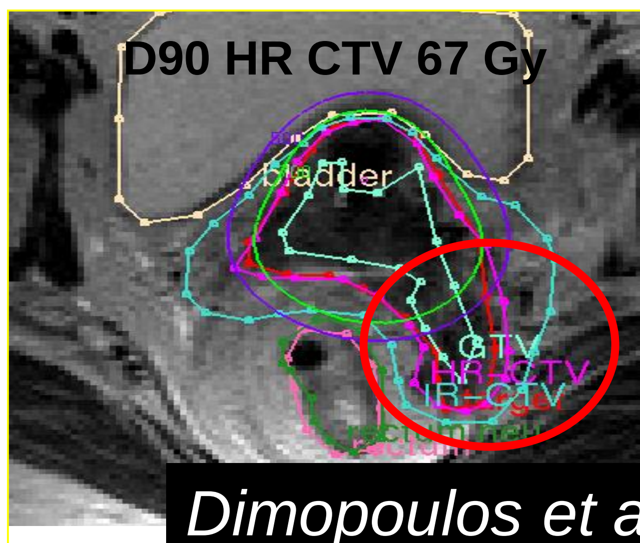


Dimopoulos et al. 2010

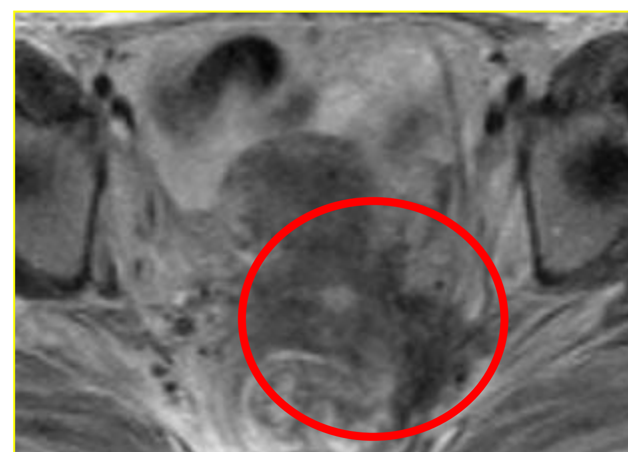
At Brachytherapy



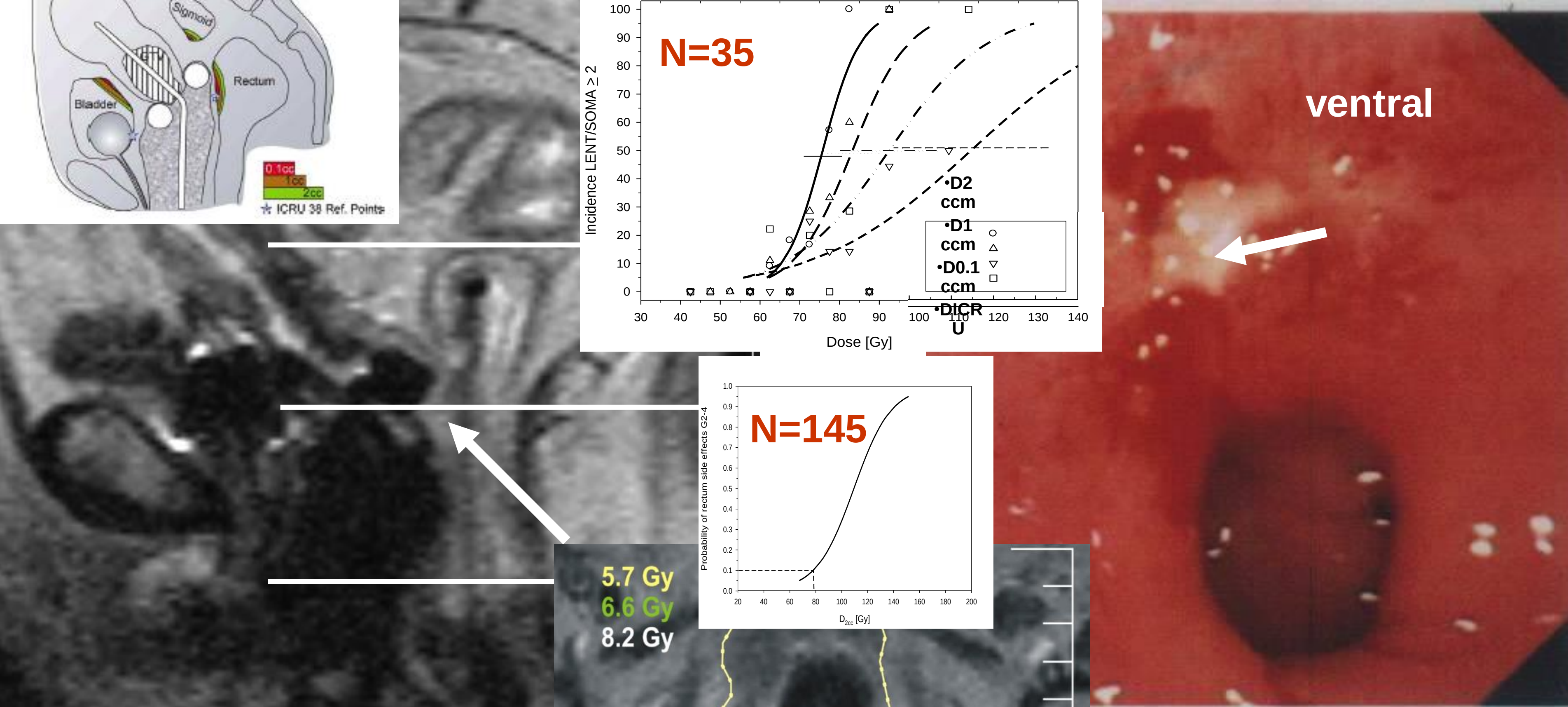
Brachytherapy (standard)

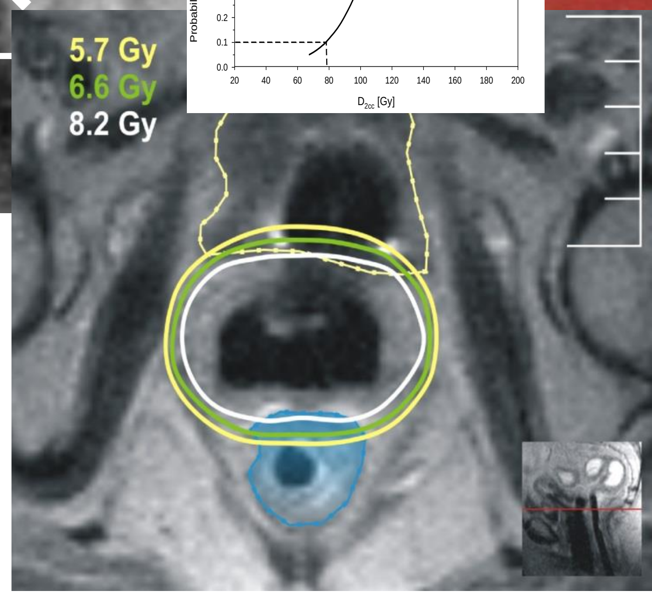


9 mths later: Recurrence



Dimopoulos et al. GEC-ESTRO 2005





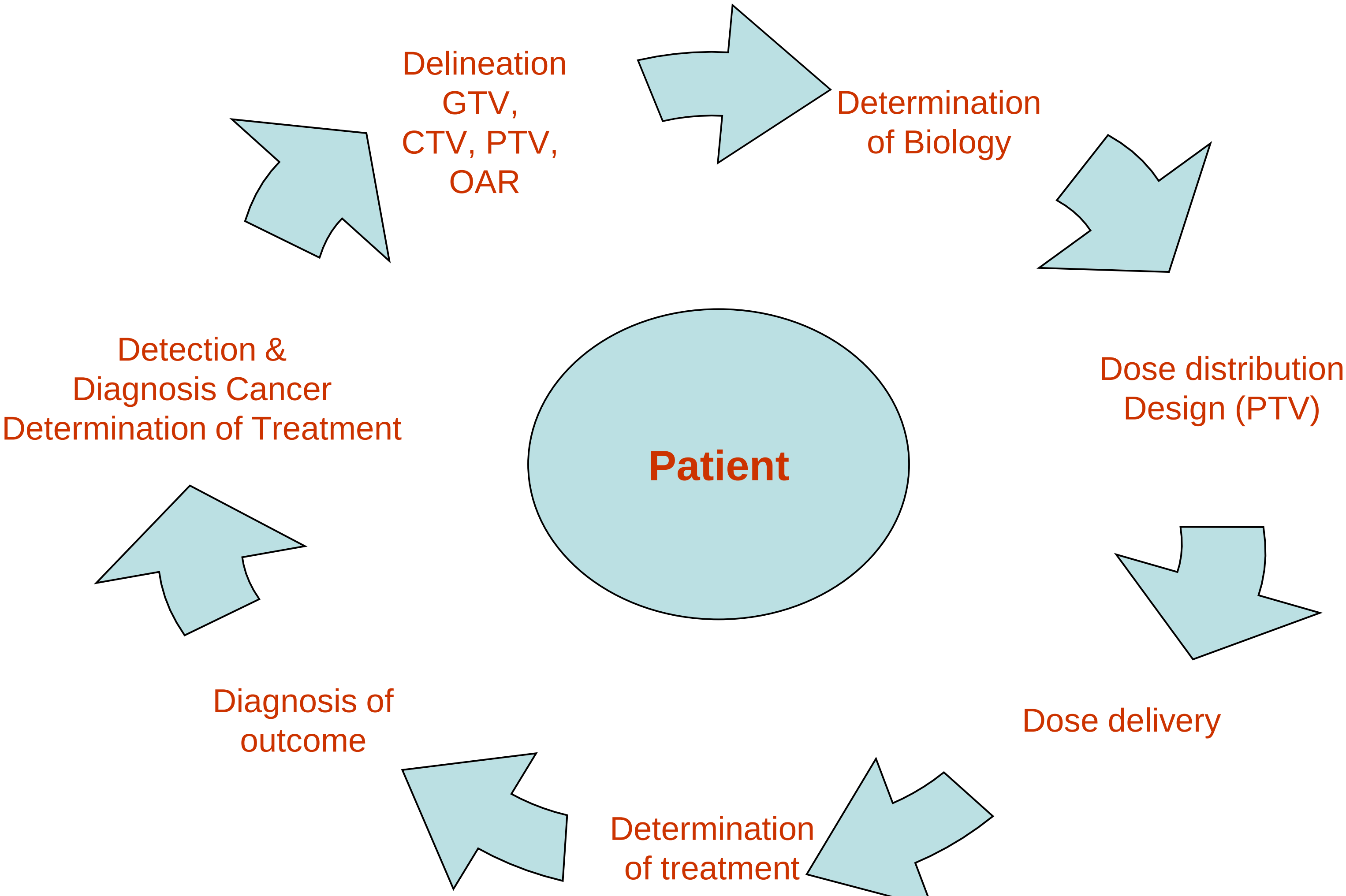
Example of one patient with rectal ulceration in distal rectum at the anterior rectal wall. The location of this ulceration corresponded to the small area of 0.1cc of rectum receiving a dose of 108 Gy EQD2.

D2cc= 81 GyEQD2
D1cc= 90 Gy EQD2
D0.1cc= 108 Gy EQD2

high dose area corresponding to 0.1cc

P. Georg et al. R&O/IJROBP 2009/2010

Imaging-Cycle



modified from Greco & Ling Acta Oncol 2008

IGRT: a comprehensive view (7D): activities within this overall frame

- Detection/Diagnosis cancer, Determinat. treatment
- Delineation of target (CTV/PTV), Organs at Risk
- Determining biological attributes
- Dose distribution design (PTV)
- Dose delivery assurance
- Determining treatment response
- Diagnosis of outcome (recurrence/morbidity)

Major clinical relevance

modified from Greco&Ling 2008

Mulitmodal Imaging

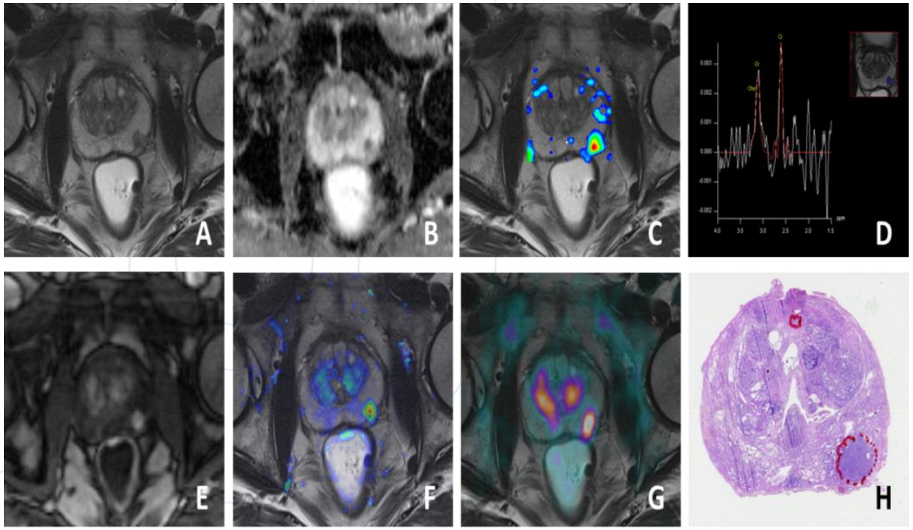
Research

Work in progess

Multiparametric imaging

- **Combining image-derived parameters to increase diagnostic accuracy**
  - ➔ **improved sensitivity and specificity due to complementary information**
  - ➔ **reduced patients burden: cost- and time-effectives**
  - ➔ **suitable for diagnosis and treatment planning**

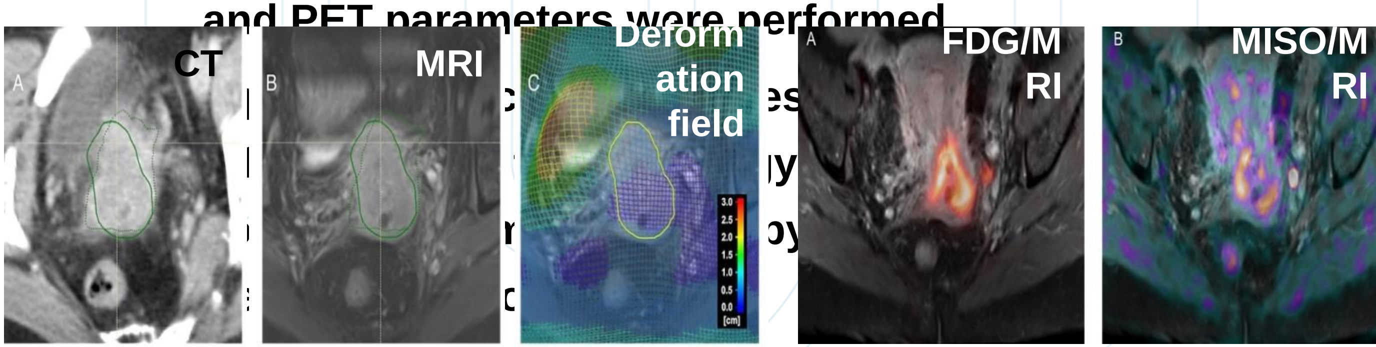
- **Multiparametric?**
  - ➔ **anatomy**
  - ➔ **Vascularization**
  - ➔ **Perfusion/permeability**
  - ➔ **cellularity/proliferation**
  - ➔ **chemical composition**



Polanec S. and Andrzejewski P. et al (submitted)

Cervix cancer (CCa) characterization with mpMRI and [^{18}F]MISO and [^{18}F]FDG

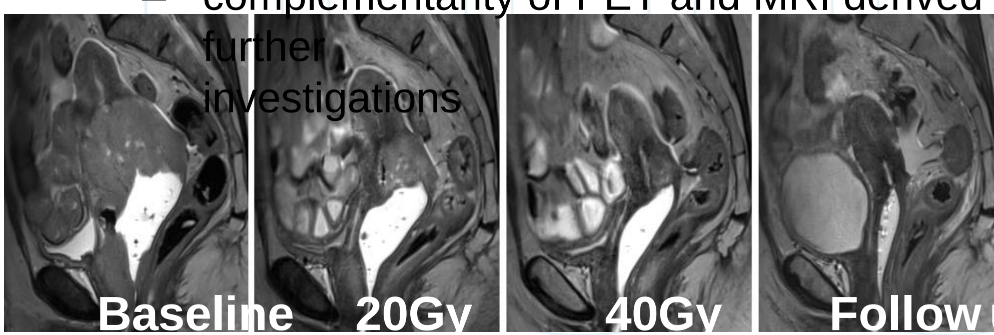
- **Dataset: 11 CCa patients scanned with mpMRI, [^{18}F]MISO and PET [^{18}F]FDG in two separate scanners**
  - ➔ **demonstrated feasibility of multiparametric [^{18}F]MISO/FDG PET-MRI**
  - ➔ **assessed for tumor volume, enhancement kinetics, diffusivity, and [^{18}F]FDG/ [^{18}F]MISO-avidity**
  - ➔ **descriptive statistics and voxel-by-voxel analysis of MRI and PET parameters were performed**

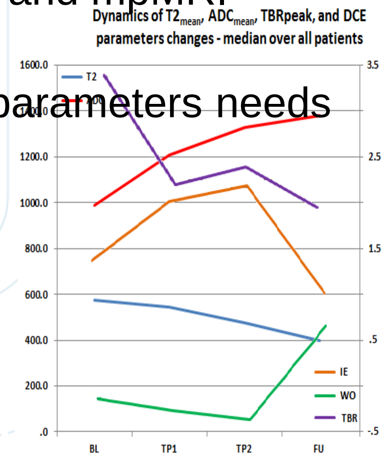


Pinker K. et al 2016

Early CCa treatment response with mpMRI and [^{18}F]MISO

- Dataset: 6 CCa patients undergoing chemoradiotherapy, scanned with mpMRI and [^{18}F]MISO PET in two separate scanners in 4 time-points
  - demonstrated feasibility of multiparametric [^{18}F]MISO PET-MRI EBRT response assessment
  - high patient drop-out rate – study moved to PET/MR
  - spatio-temporal variation of hypoxia in between scanning timepoints
  - no voxel-wise correlation between hypoxia and mpMRI parameters
  - complementarity of PET and MRI derived parameters needs further investigations

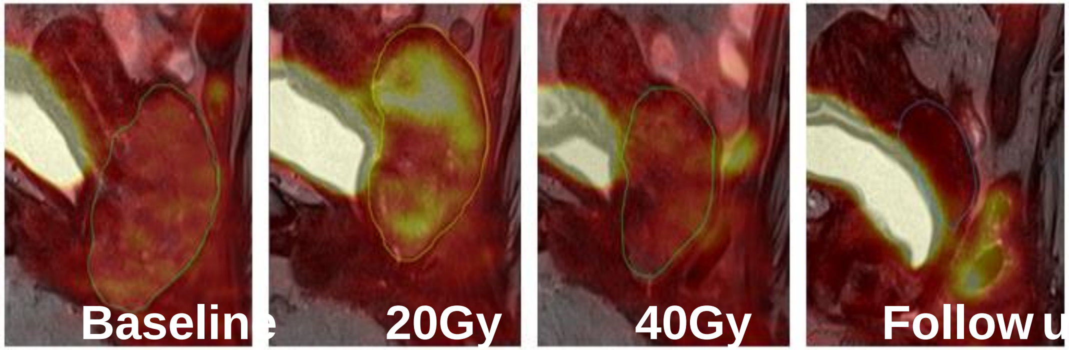




Georg P. et al – manuscript in preparation

Early CCa treatment response with hybrid PET/MR using [^{18}F]MISO

- Recruitment ongoing: 2 patients underwent full protocol, 2 patients in progress, mpMRI and [^{18}F]MISO PET scans performed on a hybrid PET/MR scanner in 4 timepoints
  - ethics committee amendment approved, new SOP and imaging sequences for the PET/MR, technical developments to adjust the scanner for RO needs
  - demonstrated feasibility of multiparametric [^{18}F]MISO PET/MR for EBRT response assessment (patient position as at treatment)
  - decreased patient drop-out rate (1 patient resign due to chemotherapy side effects)

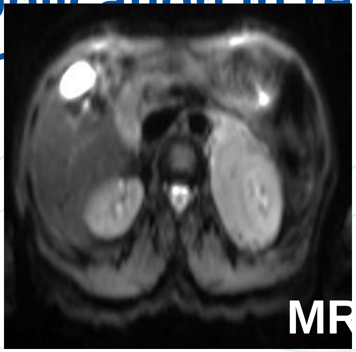


Daniel M. et al - ÖGMP Jahrestagung 2016

Implementation of new PET tracers (pilot study)

- **Early cancer treatment response using ^{68}Gd-Pentixafor (hybrid MR-PET)**
  - based on 85 studies and over 11000 patients data: ***„CXCR4 over-expression is associated with poor prognosis in cancer”*** *Zhao H, et al 2015*
  - can be used as discriminator of necessity for more aggressive treatment
  - potential use in radiotherapy response assessment

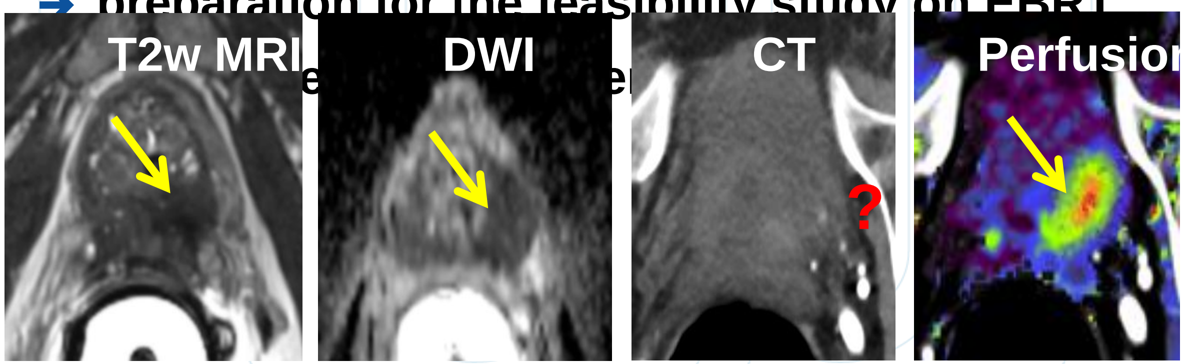
- **Cooperation with Division of Nuclear Medicine - ethics committee application in revision for patients with cancer**
  - lung
  - pancreas
  - head and neck



Courtesy A. Haug

PCa characterization with CT perfusion (pilot study)

- **To implement CT perfusion imaging protocol in diagnosis and treatment assessment of PCa**
  - ➔ **ongoing recruitment for the pre-RT baseline CT perfusion**
  - ➔ **optimization of the CT perfusion protocols on two diagnostic CT scanners**
  - ➔ **preparation for the feasibility study on EBRT**



Courtesy P. Apfaltrer and F. Baar

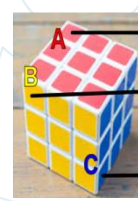
Imaging data analyses

- Based on descriptive statistics
  - ➔ **performed in predefined regions of interest (ROIs)**
  - ➔ **geometrical parameters (volume, distance etc.)**
  - ➔ **grey level or biologically modeled quantitative parameters statistics (mean, max, min etc.)**

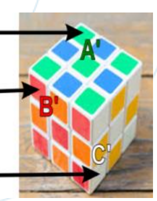
Prostate
NM PETresampled (PET AC)

Role	Dataset	Method	Min	Max	Mean	Volume	Units
Planning	CTresampled (CT REFORMATTED)	HU	-948.0	3065.0	36.8	16.1cm³	HU
[illegible]	*PETresampled (PET AC)*	*SUV BW*	*1.0*	*3.2*	*1.8*	*16.1cm³*	*g/ml*

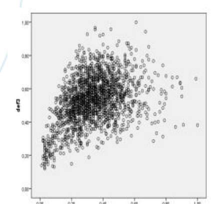
- Based on voxel by voxel analyses
  - ➔ **spatial correlation as additional degree of freedom**
  - ➔ **requires good spatial agreement between investigated modalities (fusion or hybrid imaging)**
  - ➔ **provides information on ROI's heterogeneity**



PRIMARY



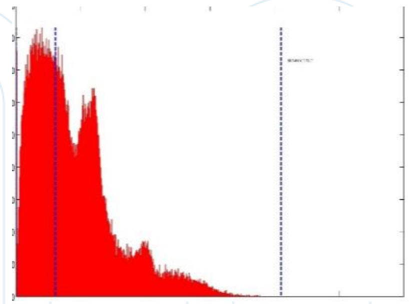
SECONDARY



SCATTER PLOT

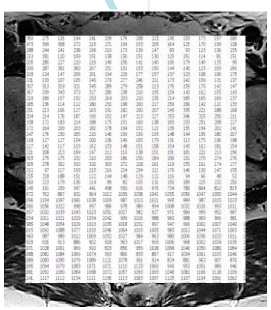
Imaging data analyses – textural features

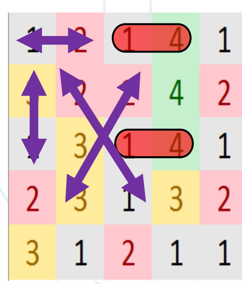
- Based on image histogram (1st order statistics)



- Median
- Minimum
- Maximum
- Skewness
- ...

- Based on gray-level co-occurence matrices (2nd order statistics)





	1	2	3	4
1	1	2	2	2
2	2	1	1	1
3	2	2	0	0
4	2	1	0	0

- Entropy
- Autocorrelation
- Cluster prominence
- Cluster shade
- ...

Association between pathology and texture features of mpMRI of the prostate