2011 AAPM Summer School
Uncertainties in External Beam Radiation Therapy
immediately following the Joint AAPM/COMP Meeting
August 4 - 9, 2011 • Simon Fraser University • Burnaby, BC

LUND UNIVERSITY

Uncertainties in the evaluation of treatment plans

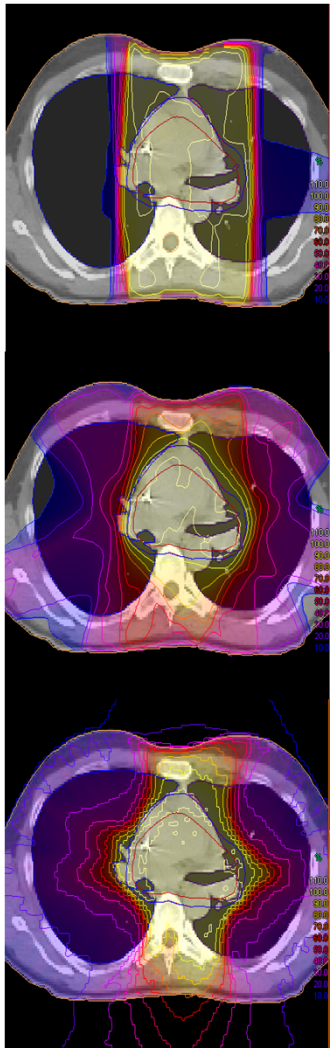
T Knöös[1,2], H Benedek[1], C Ceberg[1,2], P Nilsson[1,2], and K Petersson[2]

[1)]Radiation Physics, Skåne University Hospital and Lund University

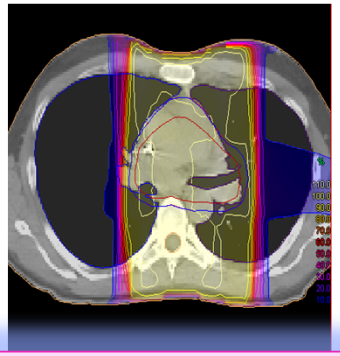
[2)] Medical Radiation Physics, Clinical Sciences, Lund University, Lund, Sweden

Our problem

- Fast technological development
- New innovations
- Wide range of modalities or choices
  - 3D-CRT
  - IMRT
  - Rotational techniques
    - Helical tomotherapy
    - VMAT
  - Robotical systems
    - Cyberknife
  - Etc…



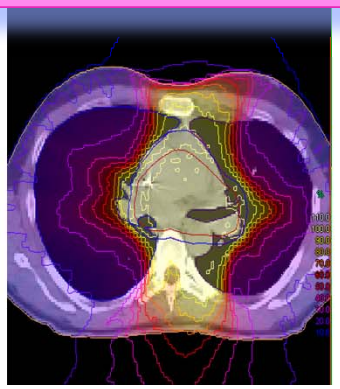
Our problem



- Fast technological development
- New innovations

How to evaluate and select a plan for a specific patient?

  - Helical tomotherapy
  - VMAT
- Robotical systems
  - Cyberknife
- Etc…



Remember also how these modalities are applied

by different

- Beam configuration
- Prescription priorities
- Other modality options

by different

- Users
  - planners/doctors/physicist…

Remember also how these modalities are applied

by different

- Beam configuration
- Prescription priorities
- Other modality options

Uncertainties

by different

- Users
  - planners/doctors/physicist…

What we need?

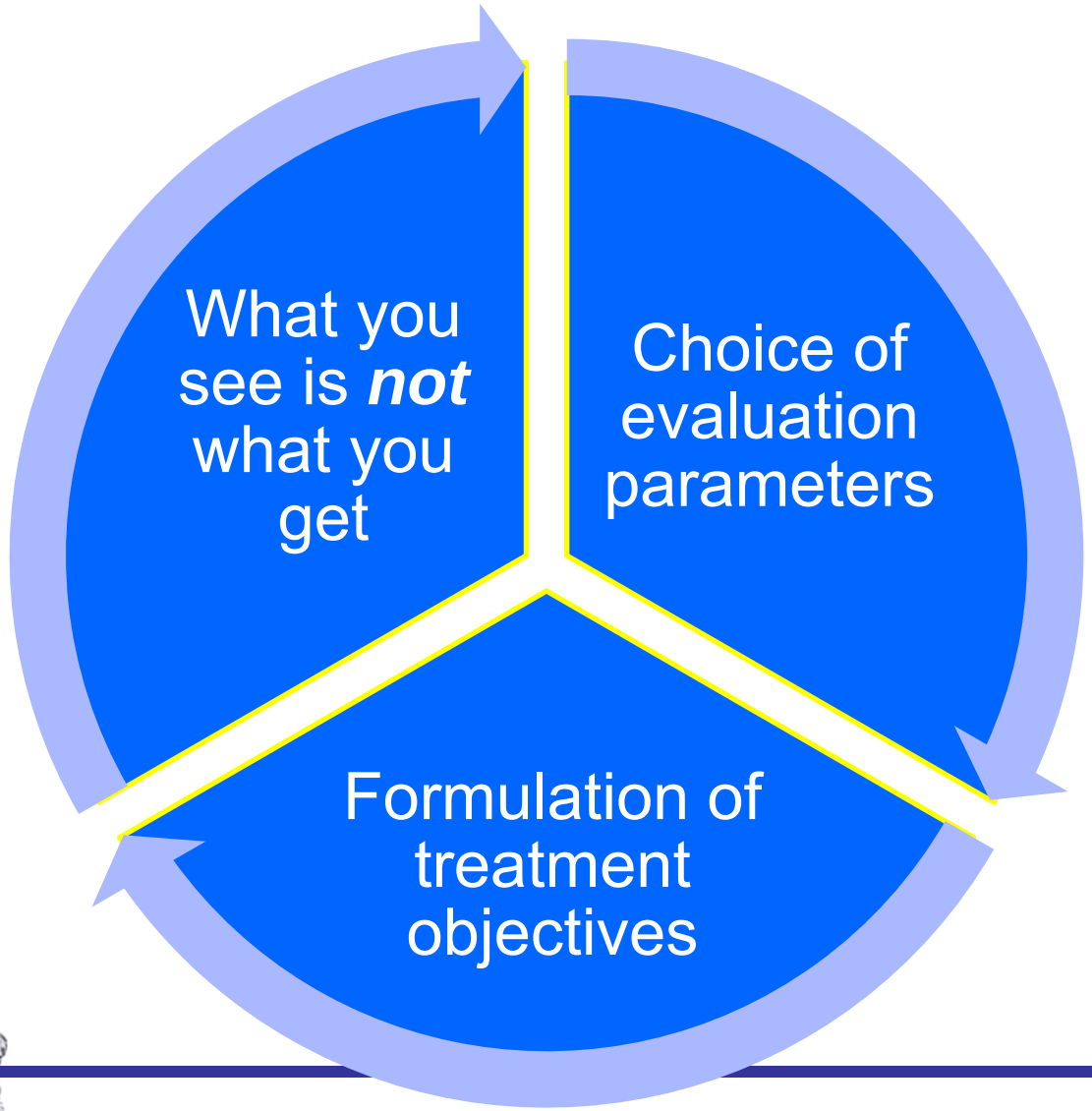
- Tools to evaluate and compare the relative merits of plans from all these different modern treatment modalities
- Tools are needed to select the proper treatment plan for an individual patient
- These tools should also ensure that the department's resources are utilized in an efficient manner, without compromising treatment quality and patient safety.
- For all purposes, it is important that the results of such comparisons are not biased
  - due to limitations or uncertainties of the evaluation method itself
  - OR BY THE USER

Evaluation of treatment plans

- A treatment plan can only be judged by how well it fulfils the prescription
- The evaluation is therefore related to the statement of the treatment objectives.
  - Includes also the estimation of any limitations and uncertainties

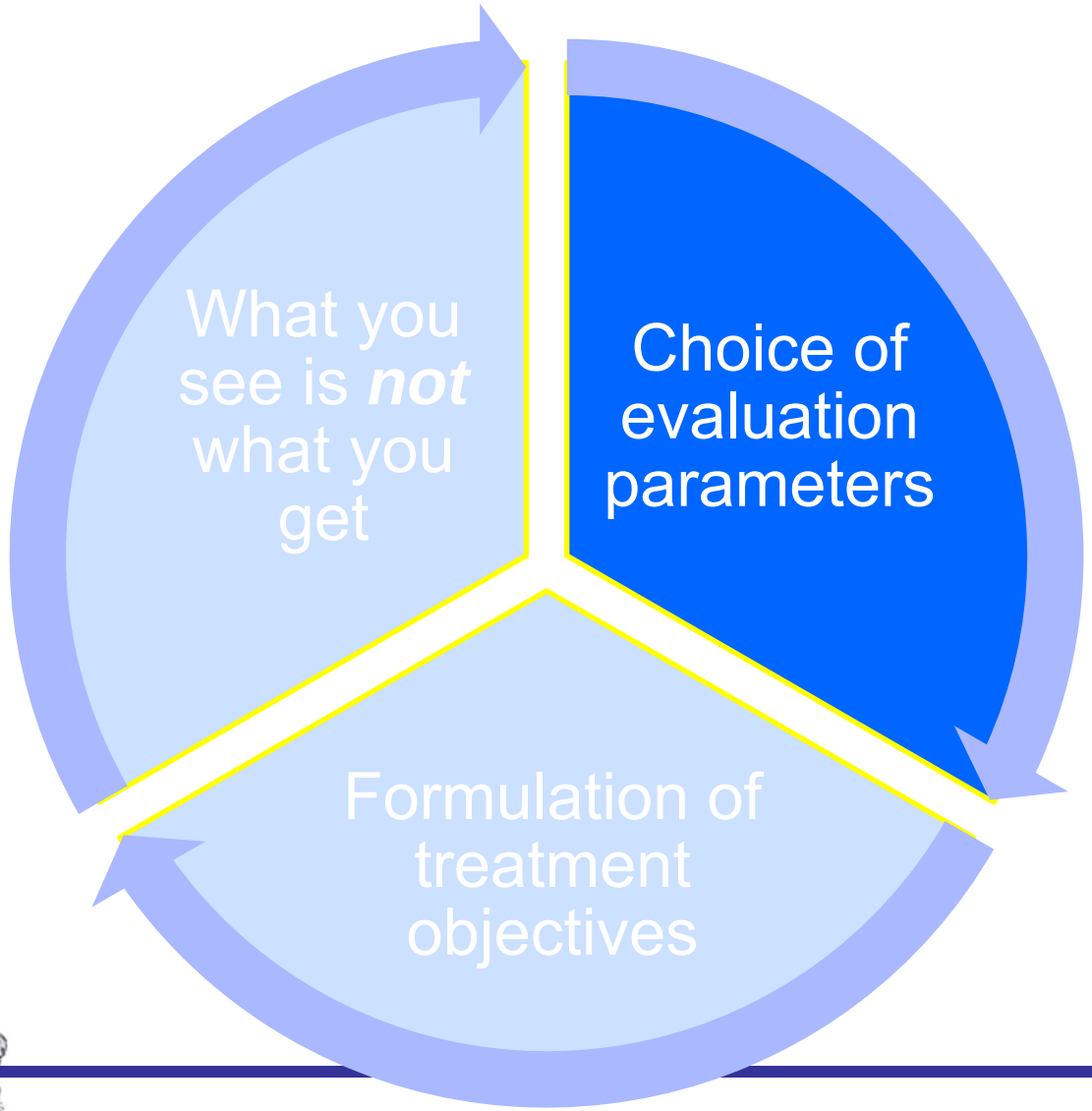
Skåne University Hospital

Evaluation of treatment plans

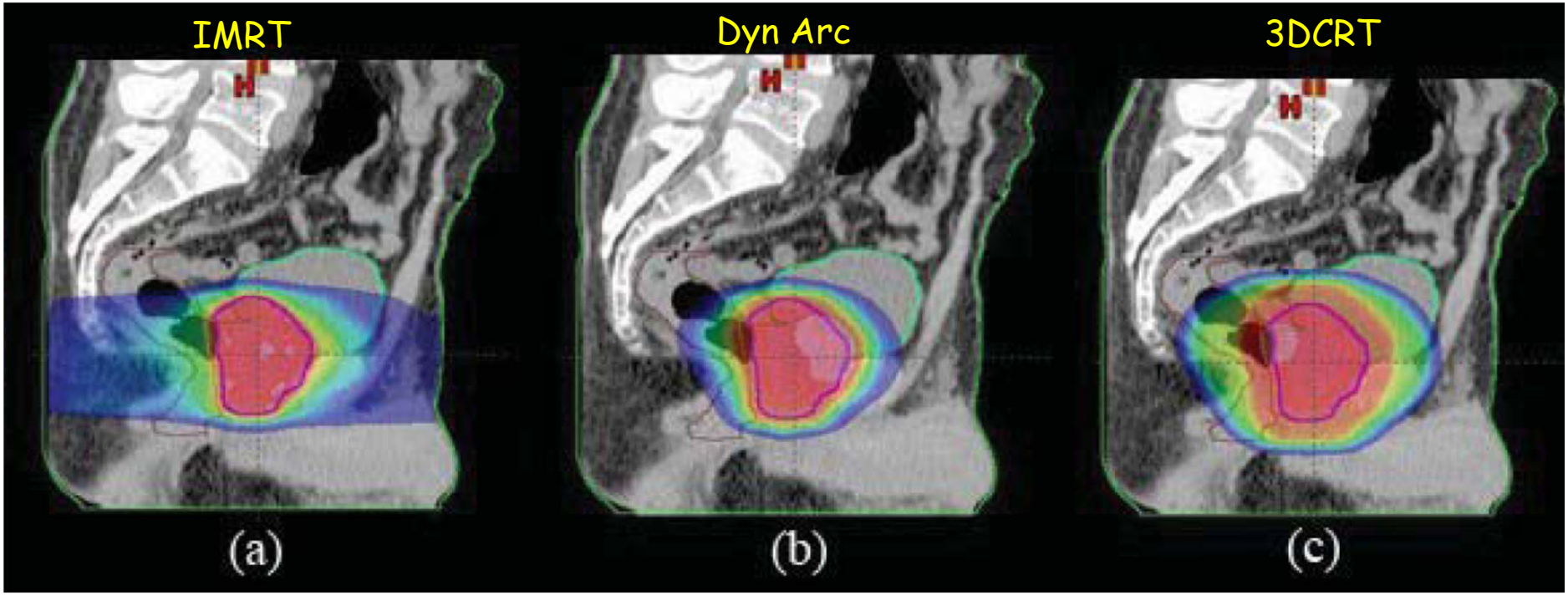


Skåne University Hospital

Evaluation of treatment plans

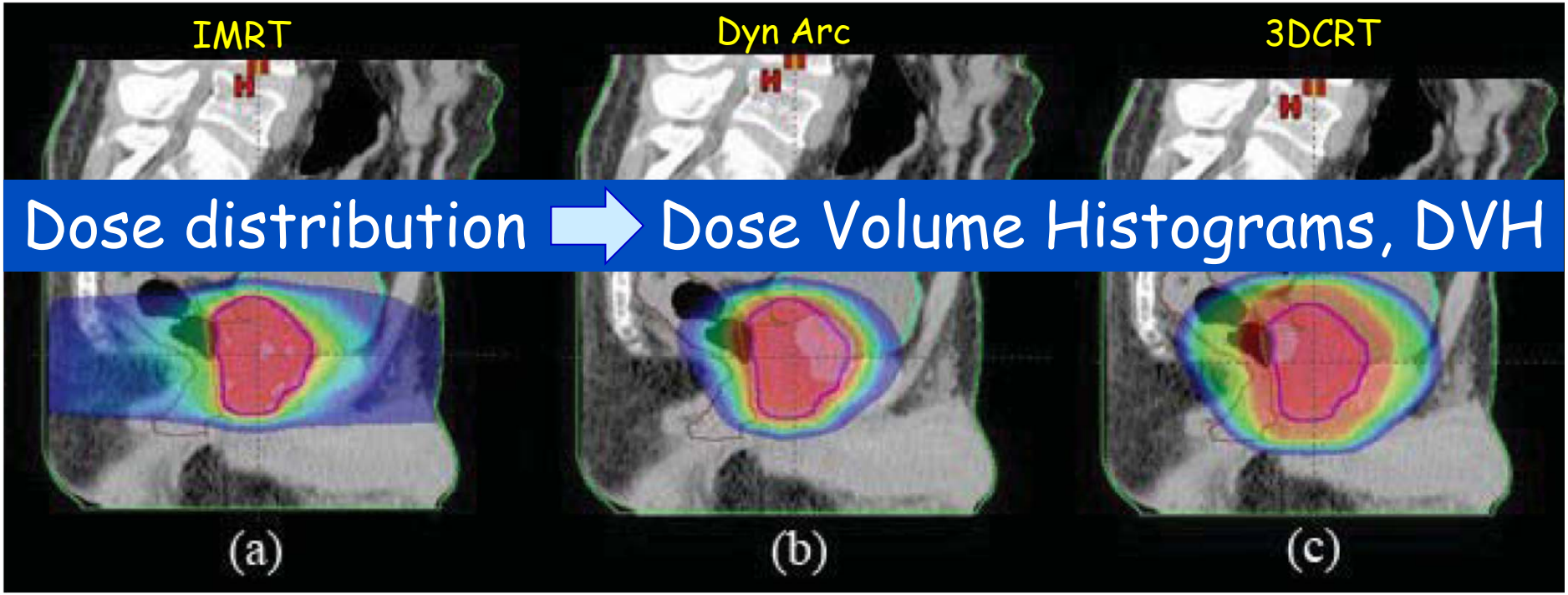


Which plan?



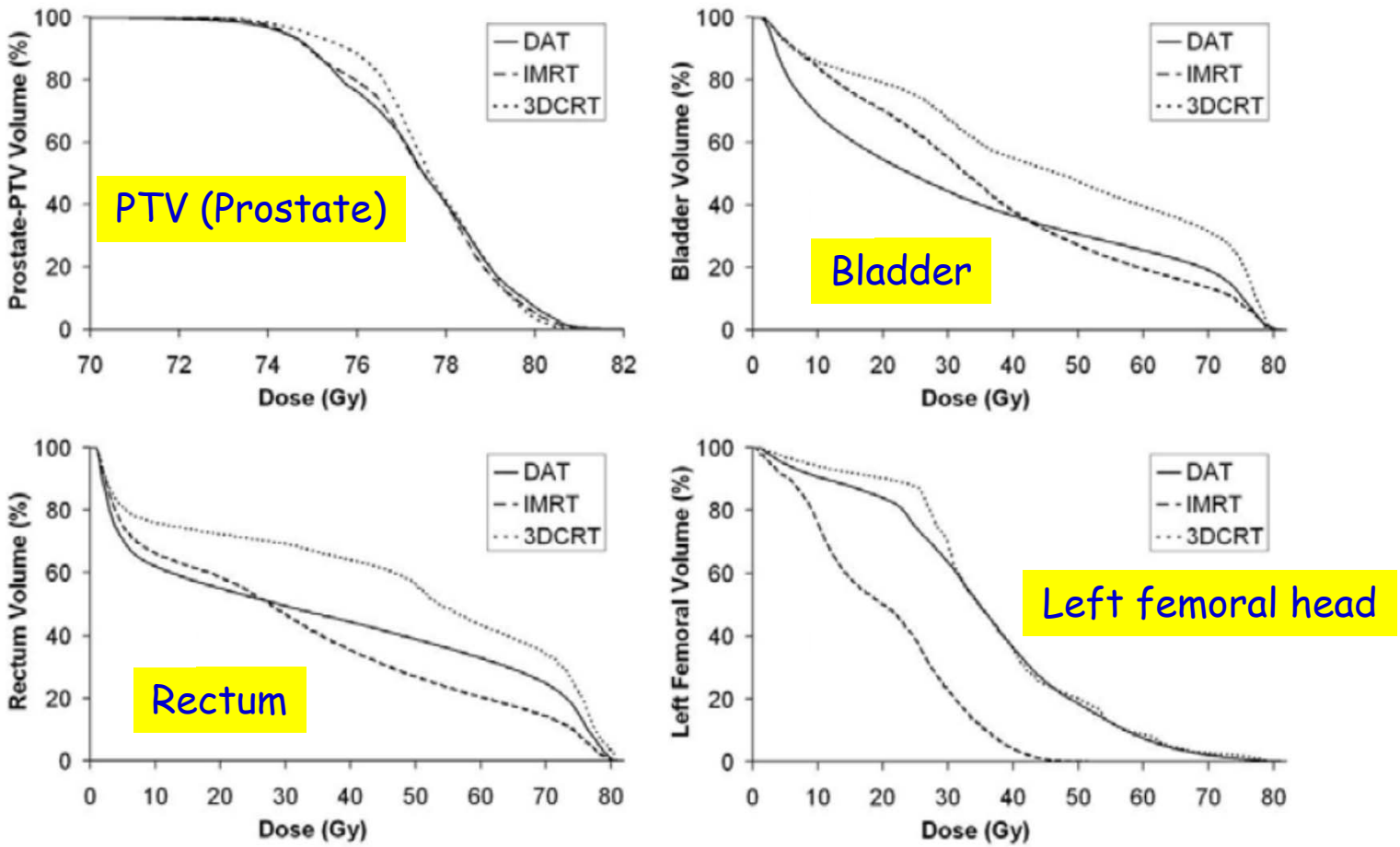
Morales-Paliza et al 2011

Which plan?



Morales-Paliza et al 2011

Compile and use DVHs!

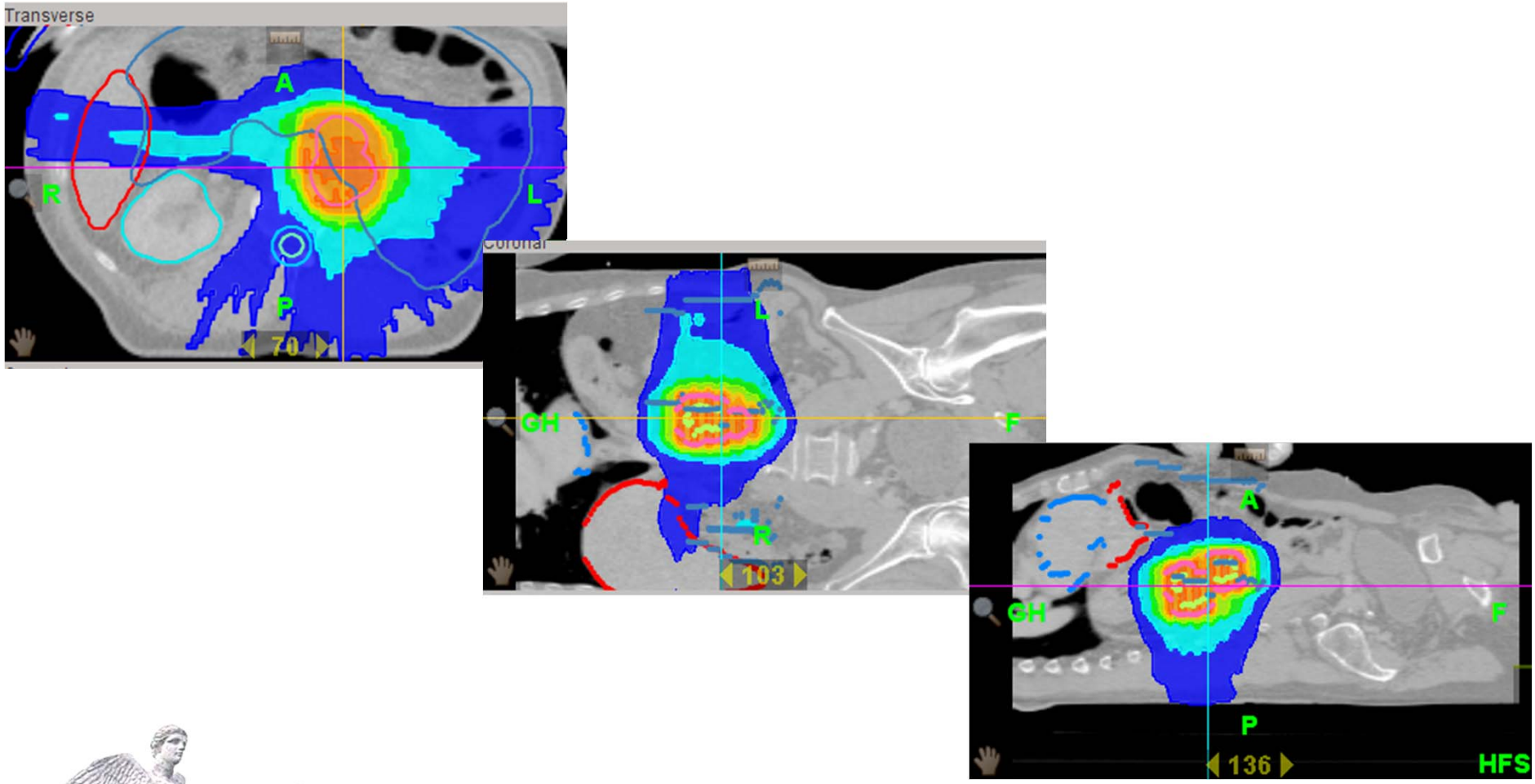


Morales-Paliza et al 2011

Spatial information is lost!

- Thorough review of the dose distribution for the whole volume
  - In all available 2D sections
- Hot-spots can appear where you least expect them
- Only a thorough review of the entire plan can show the location of minima and maxima, which can be important information for the RO

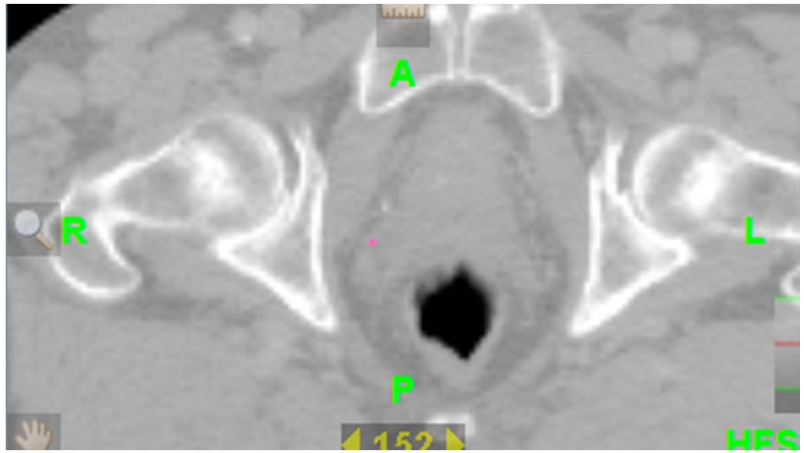
An example from Universitair Ziekenhuis Brussel

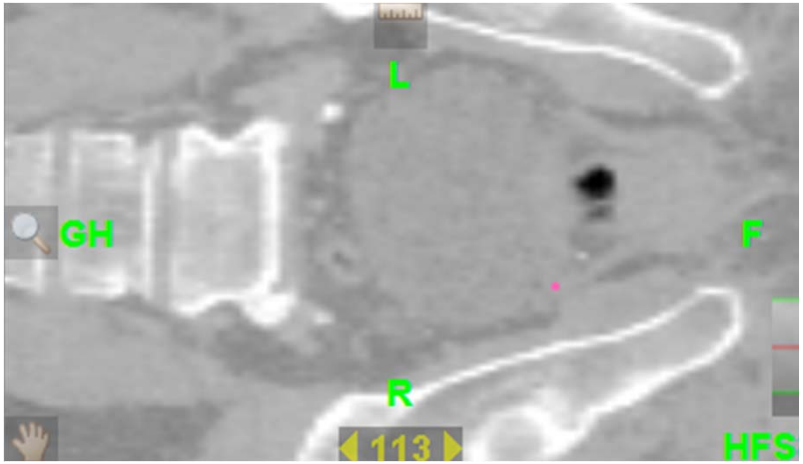


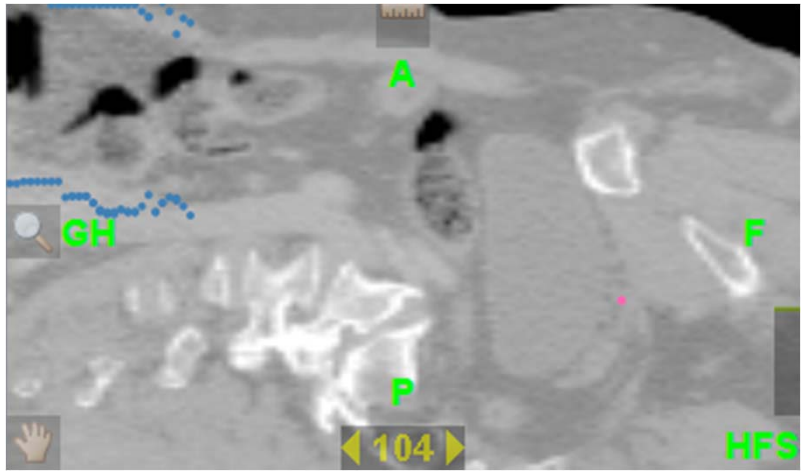
Patient treated for liver met

Images courtesy of Michael Duchateau

Accidential contouring

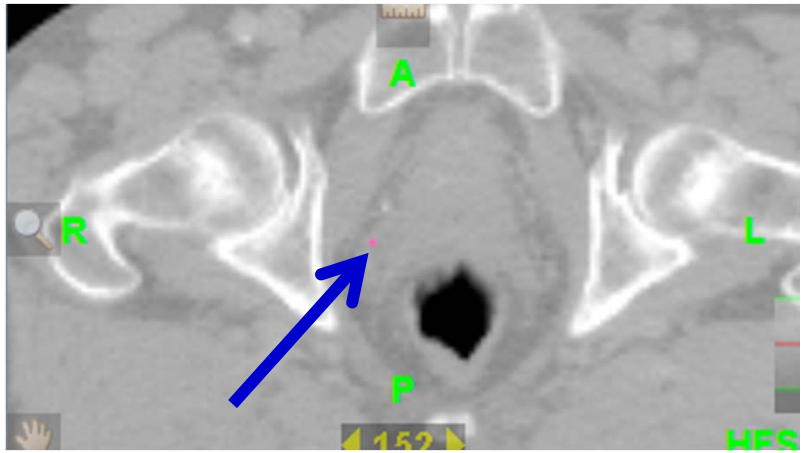


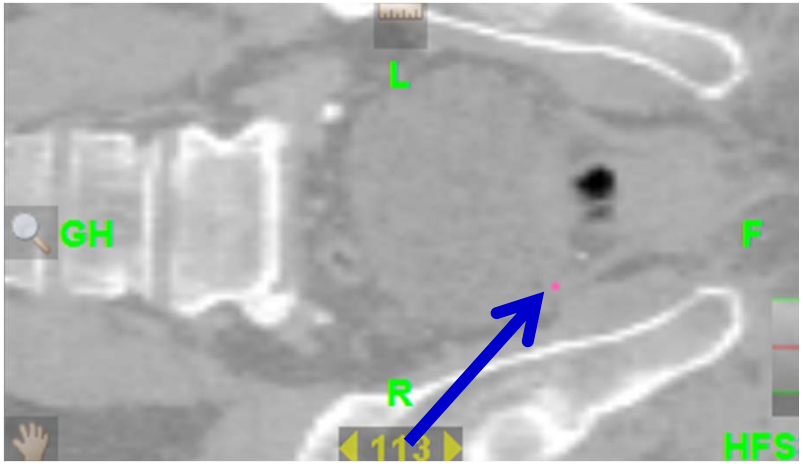


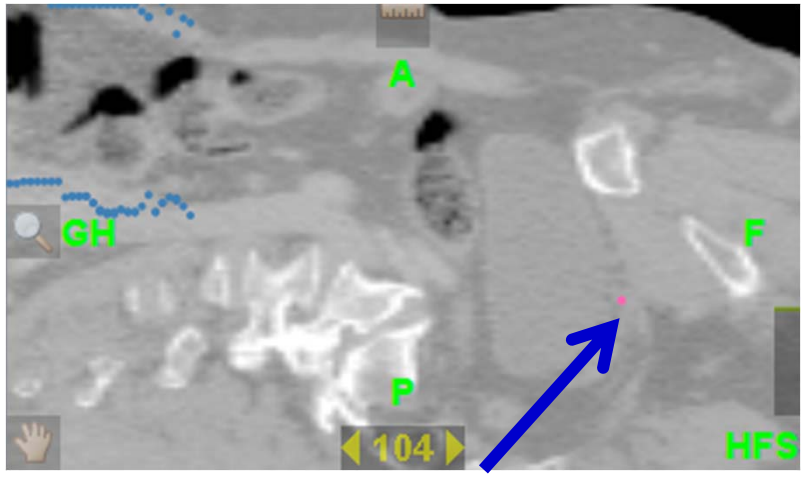


Images courtesy of Michael Duchateau

Accidential contouring



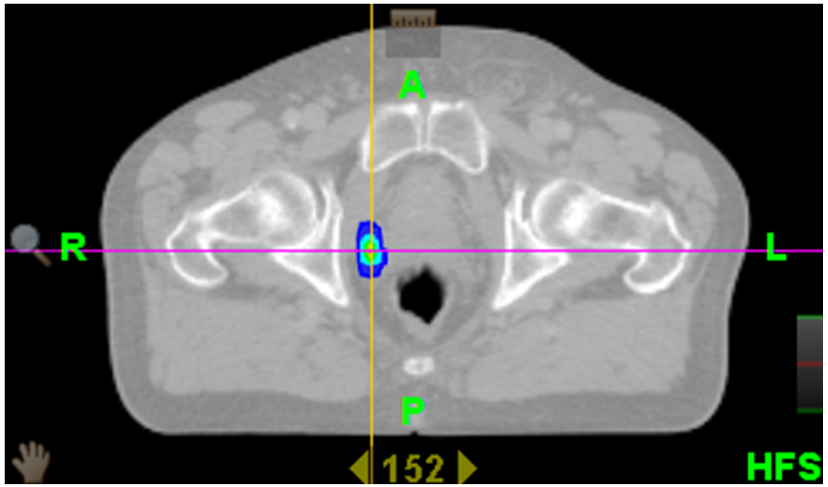


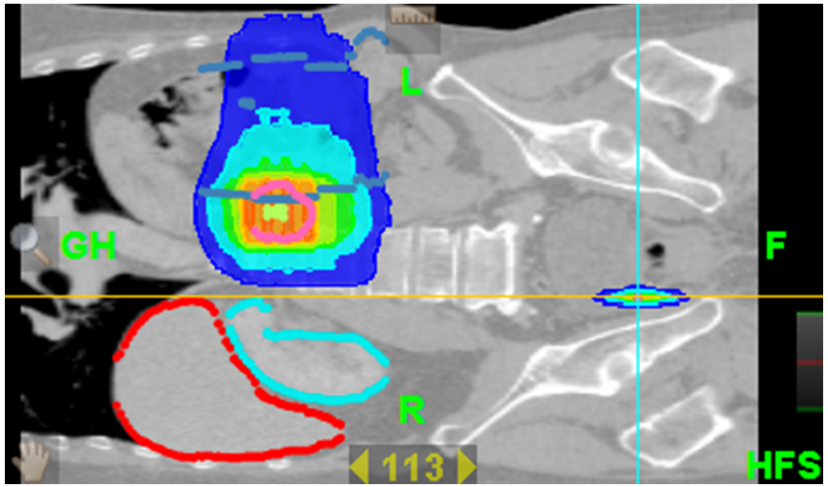


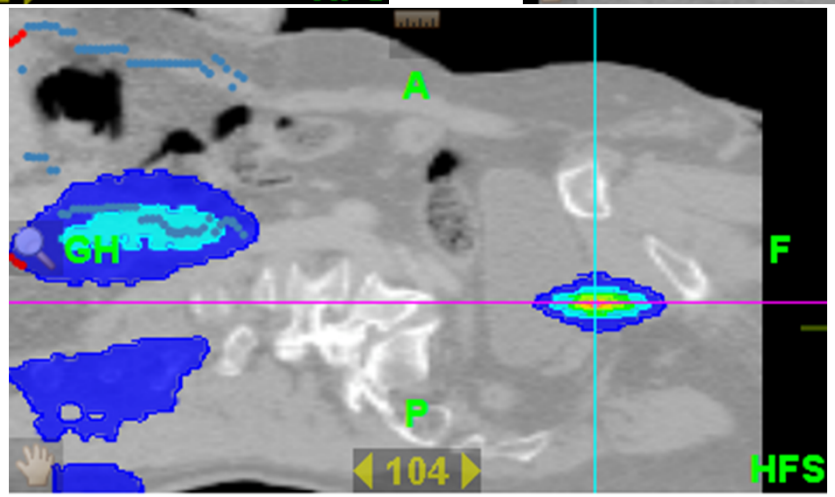
Images courtesy of Michael Duchateau

The resulting plan

Small volumes not revealed in DVHs







Images courtesy of Michael Duchateau

What measures should be used for condensing DVH?

- D_V – absorbed dose in fraction V of the volume of interest
- V_D – volume receiving at least an absorbed dose of D
- Specific for the target volumes
  - Average dose – D_{avg}
  - Median dose – $D_{50\%}$
  - Near minimum dose – $D_{98\%}$
  - Near maximum dose – $D_{2\%}$.
- Usually one also derives “quality” indices
  - Homogeneity index – HI
  - Conformity index – CI
  - Standard deviation
- Some of these metrics are also applied for organs at risk

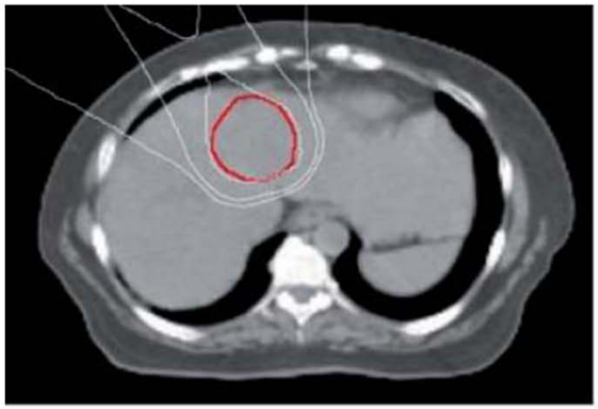
Treatment plans can also be evaluated by biological metrics

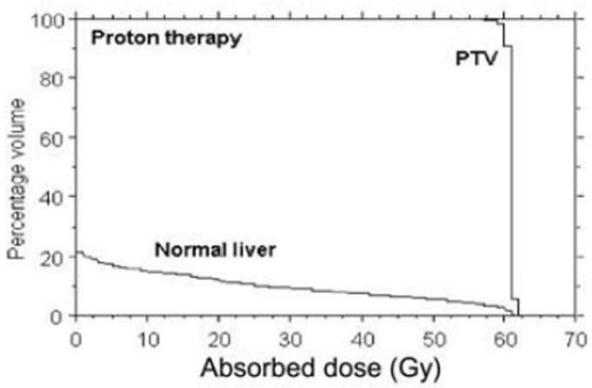
- TCP, NTCP and EUD.

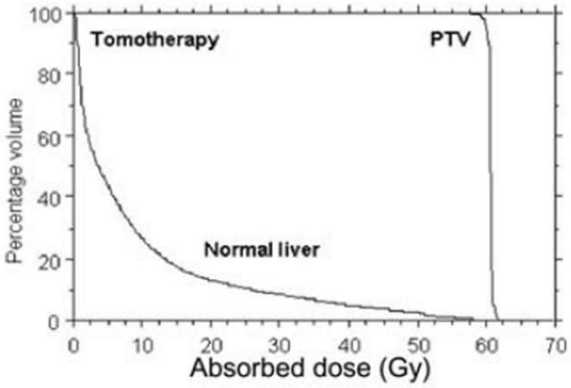
- The uncertainty in the biological models and parameters adds to the dosimetric physical uncertainty discussed above

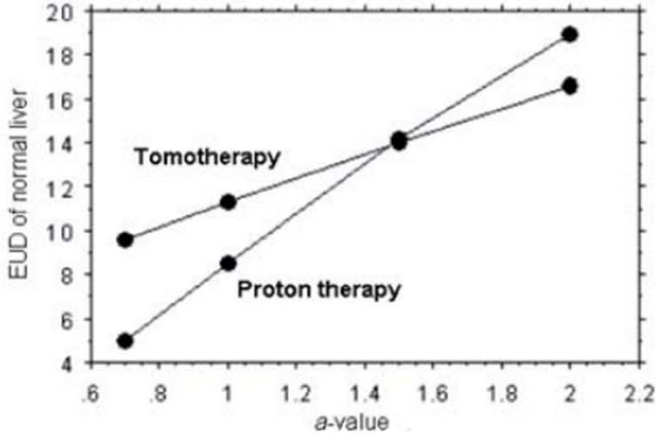
(See the QUANTEC reports, referring to the session during AAPM 2011)

Example of parameter influence





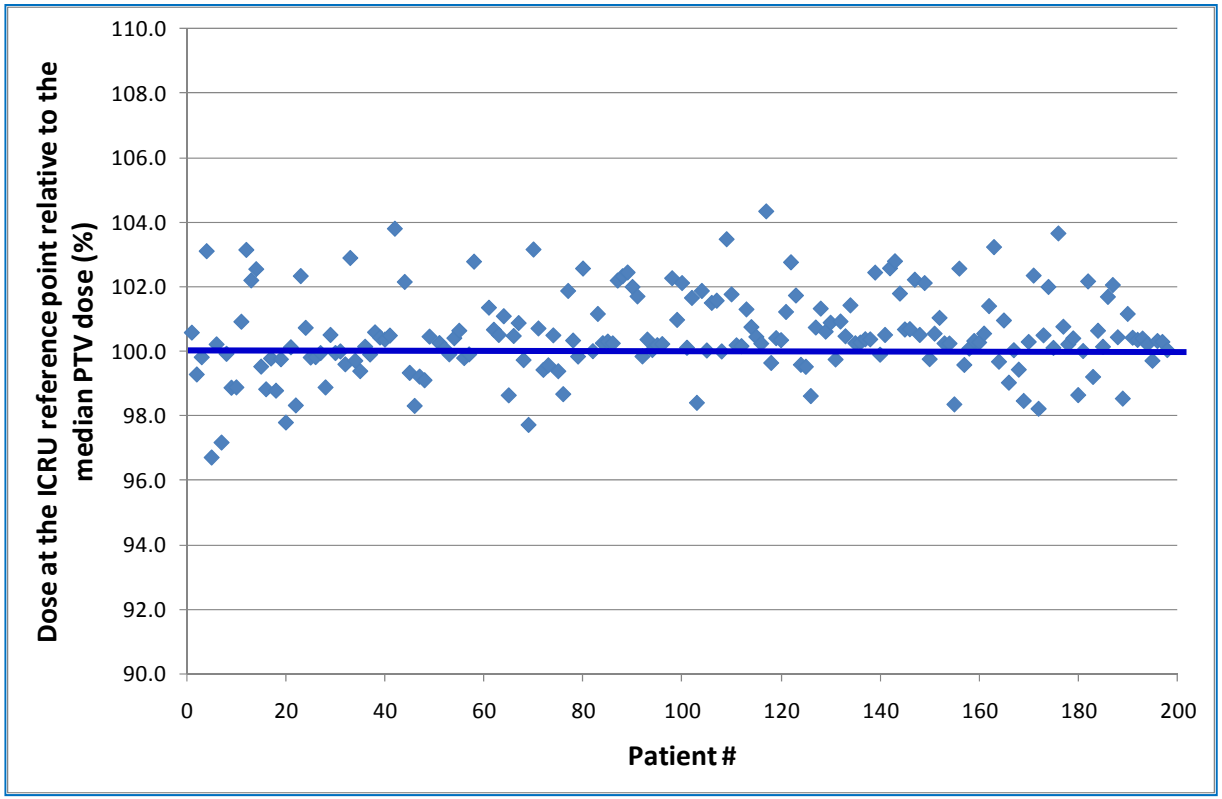




$$EUD = \left(\sum_i v_i D_i^a \right)^{1/a}$$

From ICRU 83

Awareness of normalization

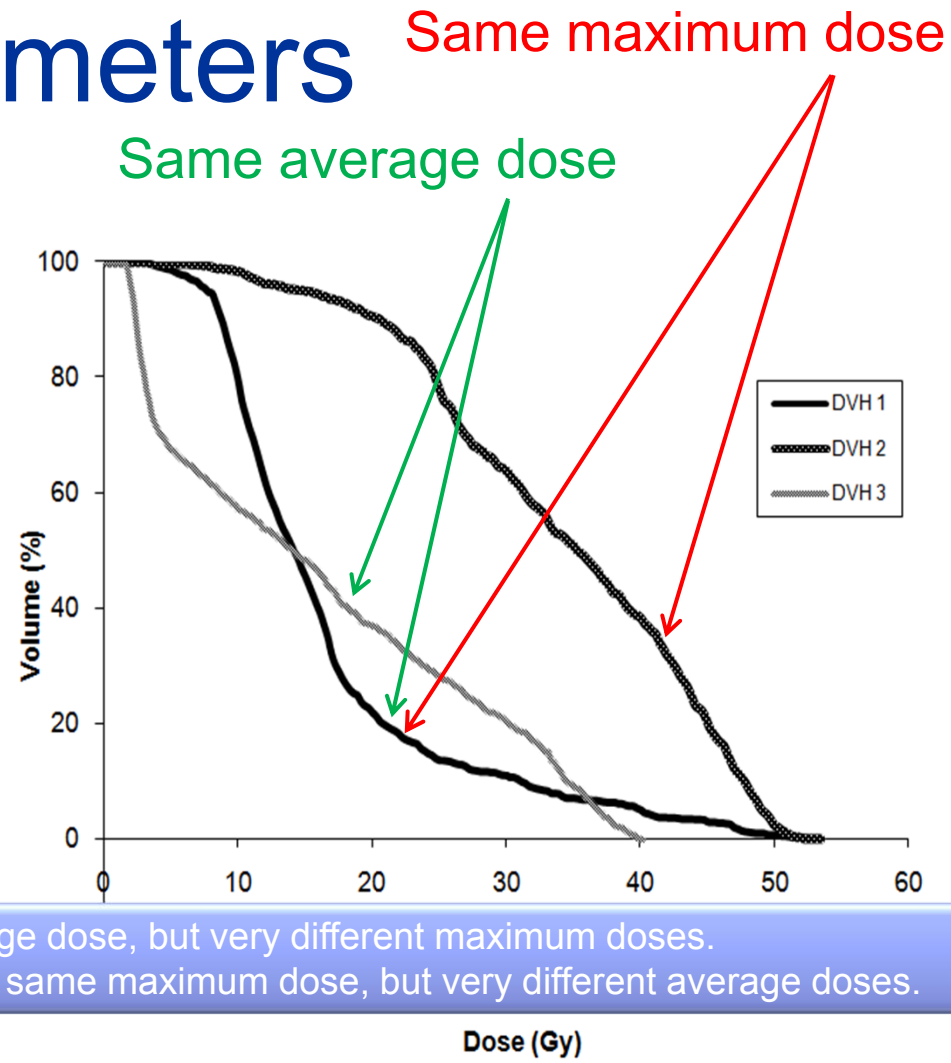


The ICRU point dose for 200 prostate cases when normalized to the median dose in the PTV

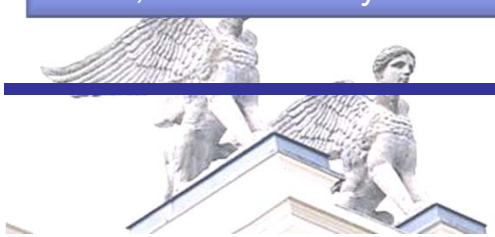
Skåne University Hospital

Choice of evaluation parameters

- Different dose-volume parameters do not correlate
- Evaluation parameters should be based on the treatment objectives

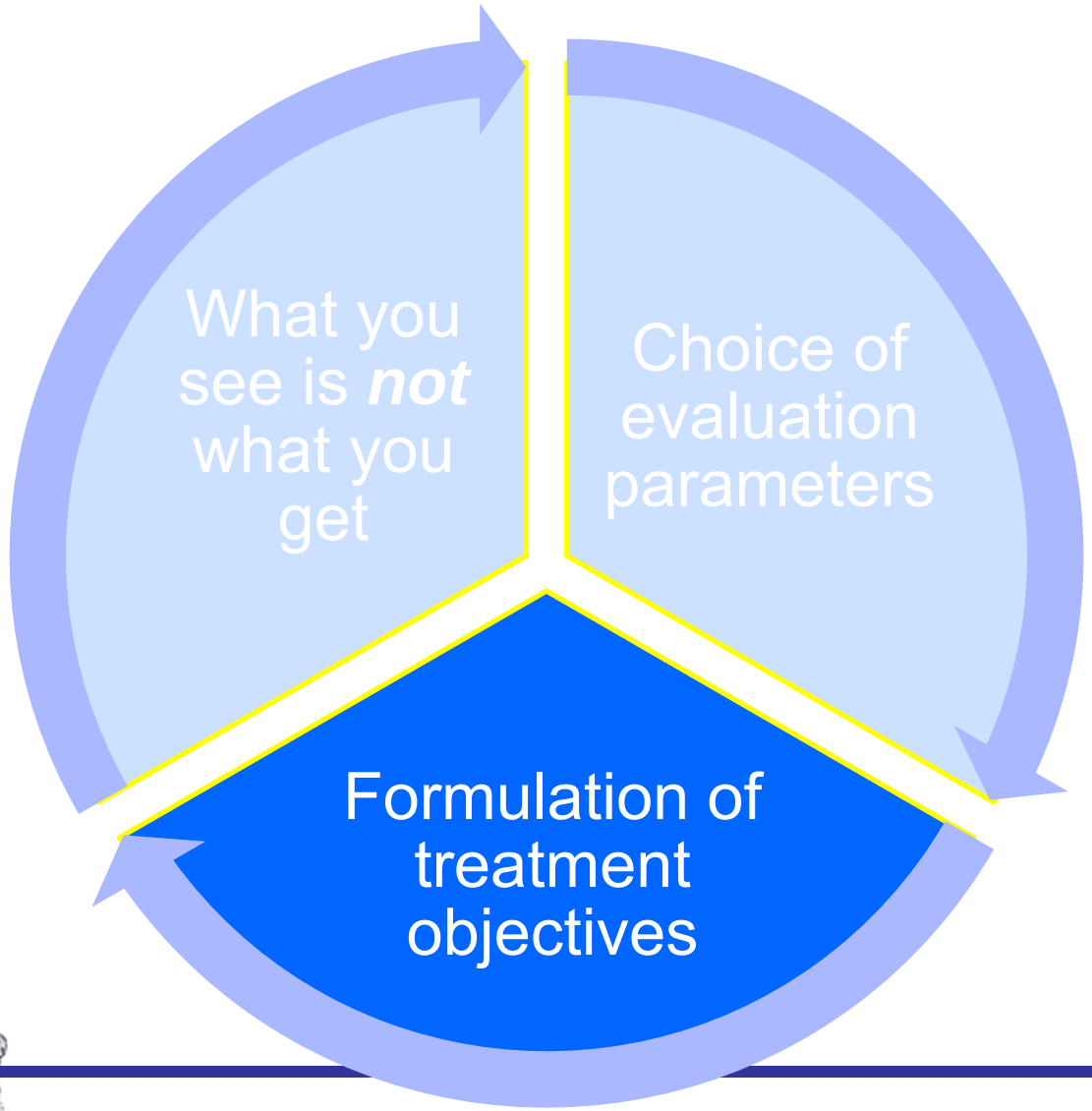


Two DVHs can have the same average dose, but very different maximum doses.
Or, the other way around, two DVHs can have the same maximum dose, but very different average doses.



Skåne University Hospital

Evaluation of treatment plans



Treatment objectives

- Specific treatment objectives
  - A necessity for an adequate evaluation of a treatment plan
- Priority
  - Regarding the relative weighting of the different treatment objectives

Dosimetry guidelines

- Dose constraints – PTV
  - 66-68 Gy /33-34 fractions to macroscopic tumor
  - 66 Gy to microscopic disease
  - 60-66 Gy to volumes of high risk
  - 46-50 Gy at elective lymph nodes
- Volume constraint – PTV
  - Minimum dose – 95%
  - Maximum dose – 107%
- Organs at risk (OR, PRV)

Maximumsdoser til kritiske normalvæv (OR og PRV)

	OR	PRV
medulla spinalis	45 Gy	50 Gy
hjernestamme	54 Gy	60 Gy
chiasma opticum	54 Gy	60 Gy
n. opticus	54 Gy	60 Gy
bagerste del af øjet	45 Gy	50 Gy
forreste del af øjet	30 Gy	35 Gy
indre øre	54 Gy	60 Gy

From a Scandinavian trial - DAHANCA

Dosimetry guidelines

- Dose constraints – PTV
  - 66-68 Gy /33-34 fractions to macroscopic tumor
  - 66 Gy to microscopic disease
  - 60-66 Gy to volumes of high risk
  - 46-50 Gy at elective lymph nodes
- Volume constraint – PTV
  - Minimum dose – 95%
  - Maximum dose – 107%
- Organs at risk (OR, PRV)

Priority?

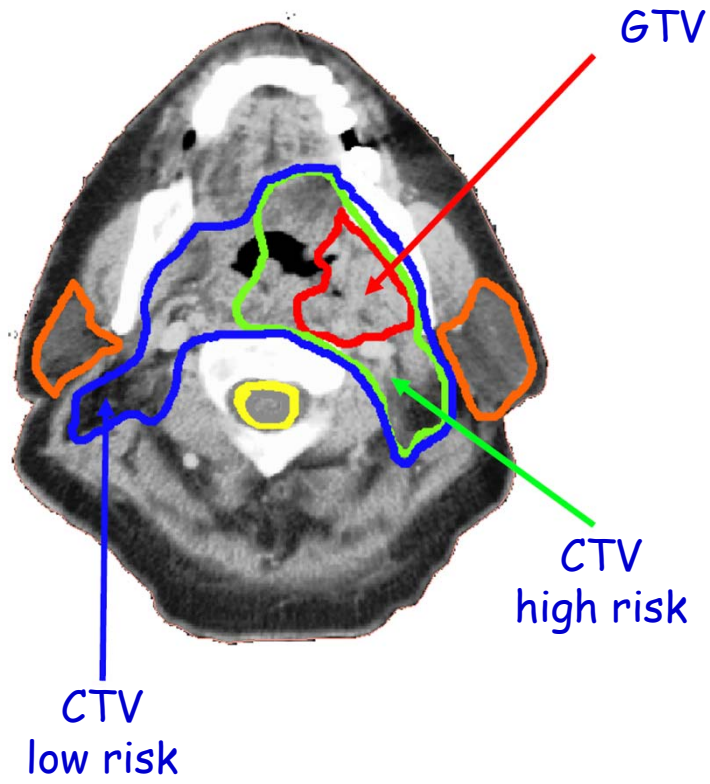
Maximumsdoser til kritiske normalvæv (OR og PRV)

	OR	PRV
medulla spinalis	45 Gy	50 Gy
hjernestamme	54 Gy	60 Gy
chiasma opticum	54 Gy	60 Gy
n. opticus	54 Gy	60 Gy
bagerste del af øjet	45 Gy	50 Gy
forreste del af øjet	30 Gy	35 Gy
indre øre	54 Gy	60 Gy

From a Scandinavian trial - DAHANCA

Priority -YES

- 1st priority
  - Critical normal tissue:
    - Medulla
    - Brain stem
    - Chiasma opticum
    - N. opticus
    - Dorsal part of the eye for the “best” eye
- 2nd priority
  - Cover of PTV
    - PTV-T
    - PTV-E-high risk
    - PTV-E-low risk
- 3rd priority
  - Less critical normal tissue
    - Inner ear
    - Gl. Parotis
    - Larynx
    - Frontal part of the eye



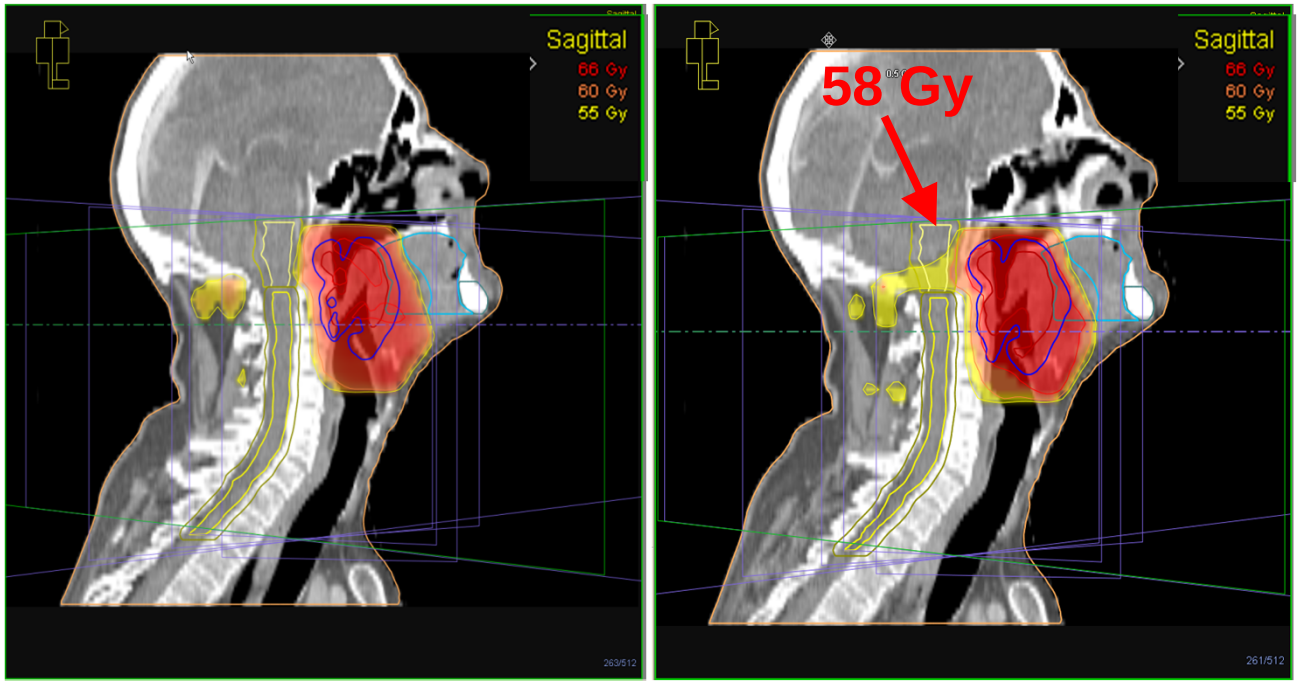
From a Scandinavian trial - DAHANCA

Another example with a detailed and prioritized dose prescription

Priority	Volume	Objective or constraint
1	CTV	$D_{min} \geq 95\%$, $D_{min} \geq 74$ Gy
2	PTV	$V_{95\%} \geq 95\%$ $V_{74Gy} \geq 95\%$
3	Rectum	$V_{90\%} \leq 15\%$ $V_{70Gy} \leq 15\%$
4	PTV	$D_{99\%} \geq 90\%$ $D_{99\%} \geq 70$ Gy
5	Rectum	$V_{75\%} \leq 35\%$ $V_{59Gy} \leq 35\%$
6	Femoral heads	$D_{max} \leq 70\%$ $D_{max} \leq 55$ Gy
7	Rectum	$V_{65\%} \leq 45\%$ $V_{51Gy} \leq 45\%$
8	Body	$D_{max} \leq 105\%$ $D_{max} \leq 82$ Gy

From a Scandinavian Prostate Study

Are the objectives appropriate?

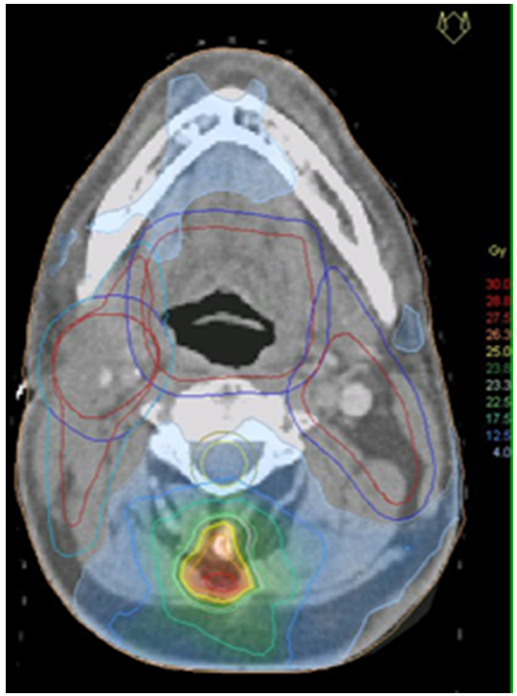


Any region that is not explicitly constrained may be used by the optimizer, and this may give unexpected results. As for instance in this case, where a hot spot has appeared in the brain stem.

From Per Engström

Skåne University Hospital

Do we need constraints for normal tissue?



Difference dose distribution
for treatment plans optimized
with or without
normal tissue constraints

Treatment objectives should be specific and complete;
in principle they cannot be too detailed

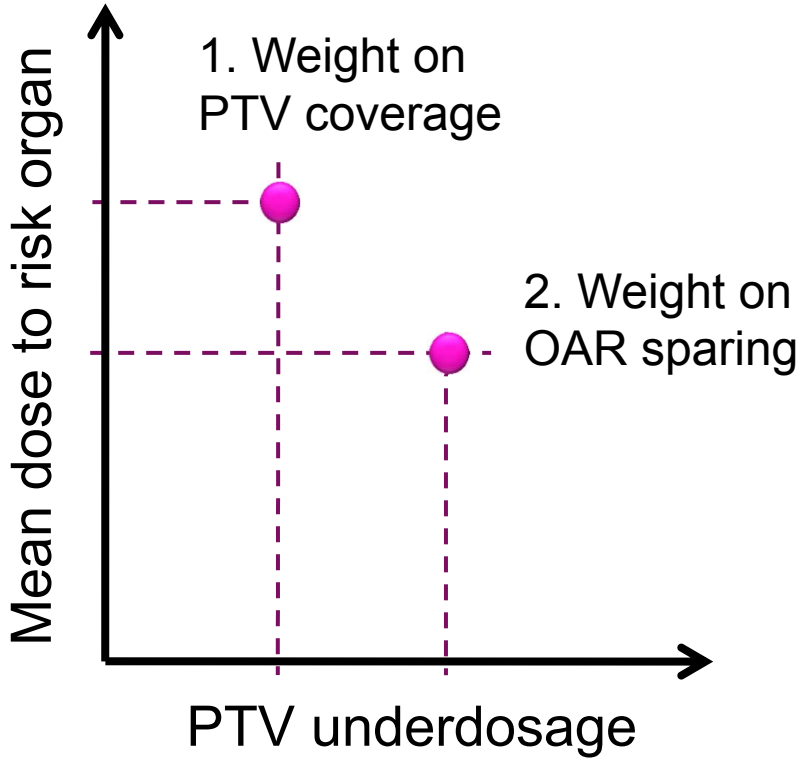
The dilemma!

- We usually have mutually conflicting objectives
  - **Under** dosage of PTV – adequate dose to tumour
    vs
  - **Over** dosage of OR – spare the healthy tissues
- Choose the “best” plan

From the same prescription…

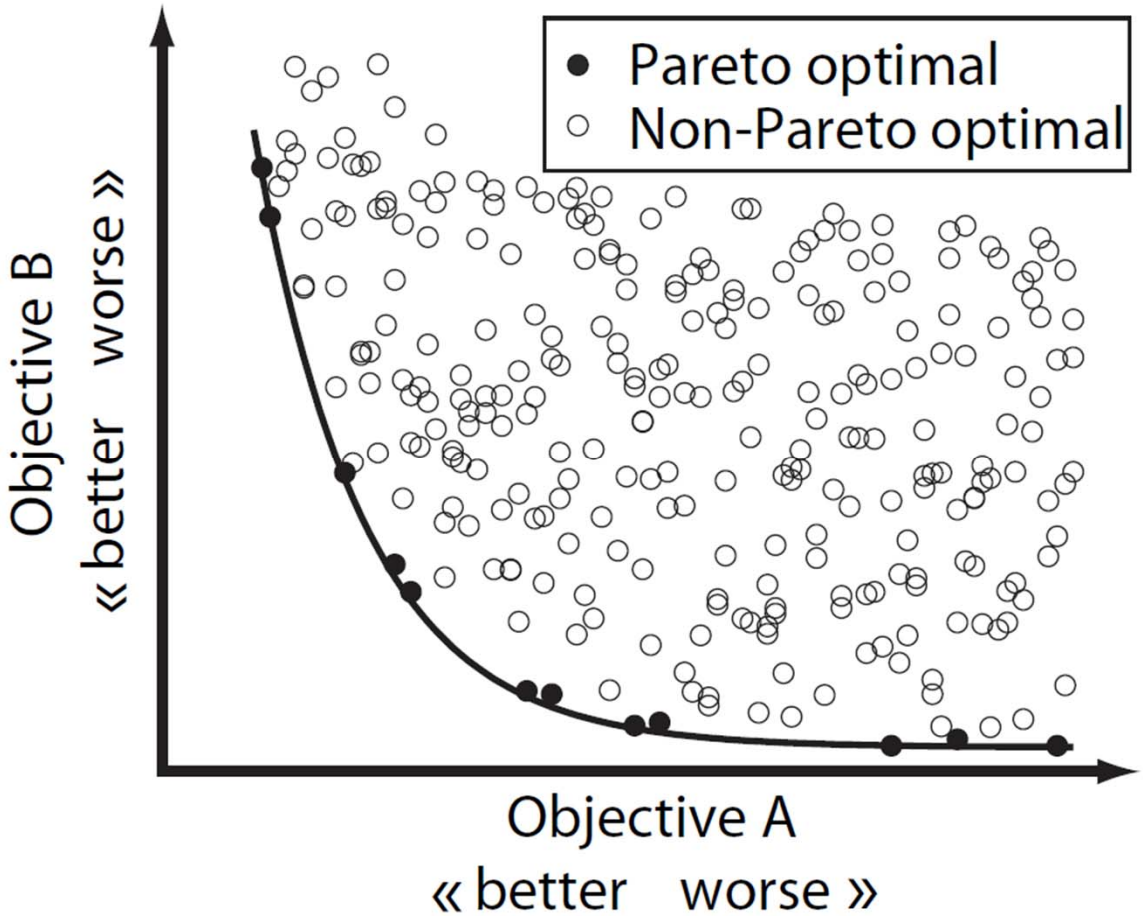
1. A plan that emphasizes good target coverage, while letting the dose to the risk organ increase slightly

2. A plan that emphasizes a low dose to the risk organ, but then at the expense of less target coverage



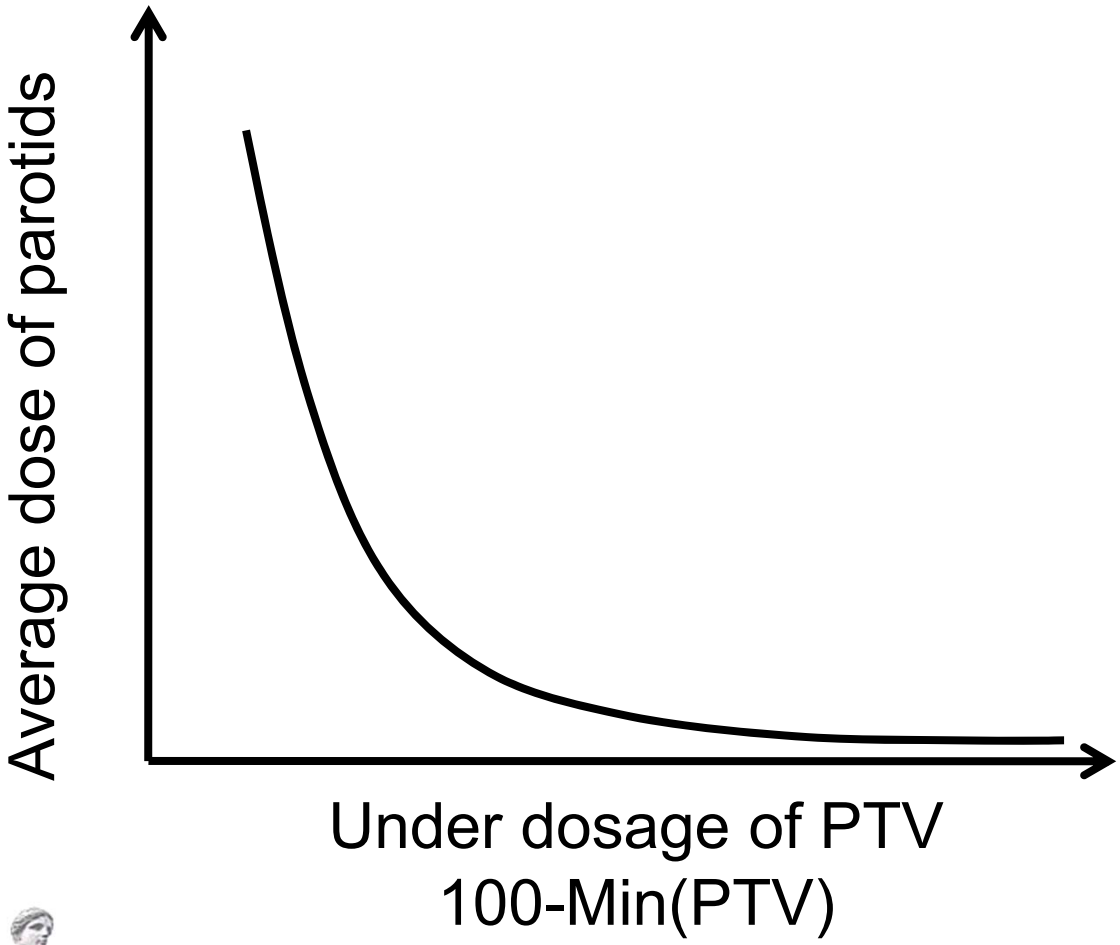
Relative importance of the conflicting objectives is seldom BUT SHOULD BE described in protocols

Pareto optimal plans in multi objective optimisation

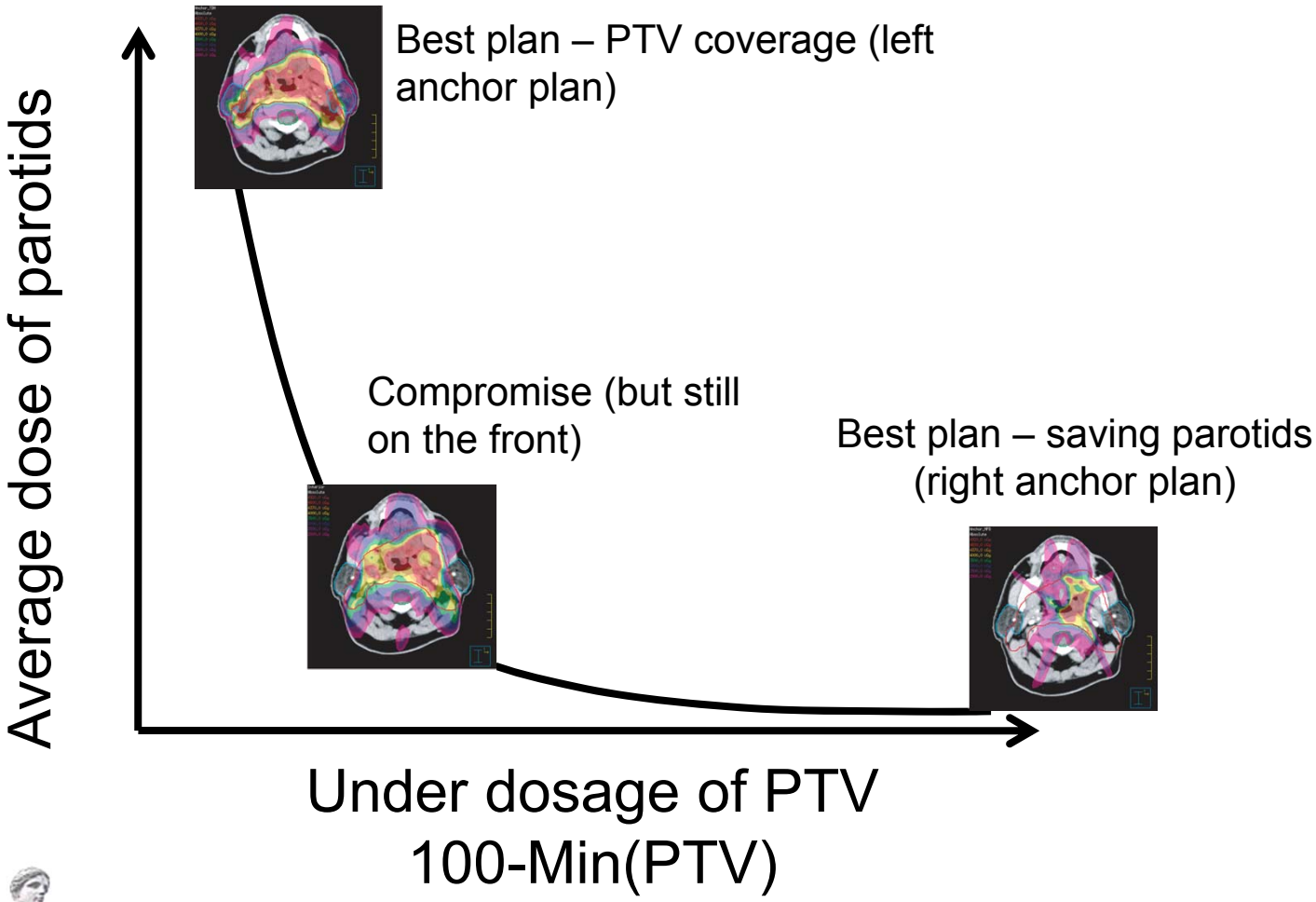


Ottosson et al 2008

Pareto optimal plans in multi objective optimisation



Pareto optimal plans in multi objective optimisation

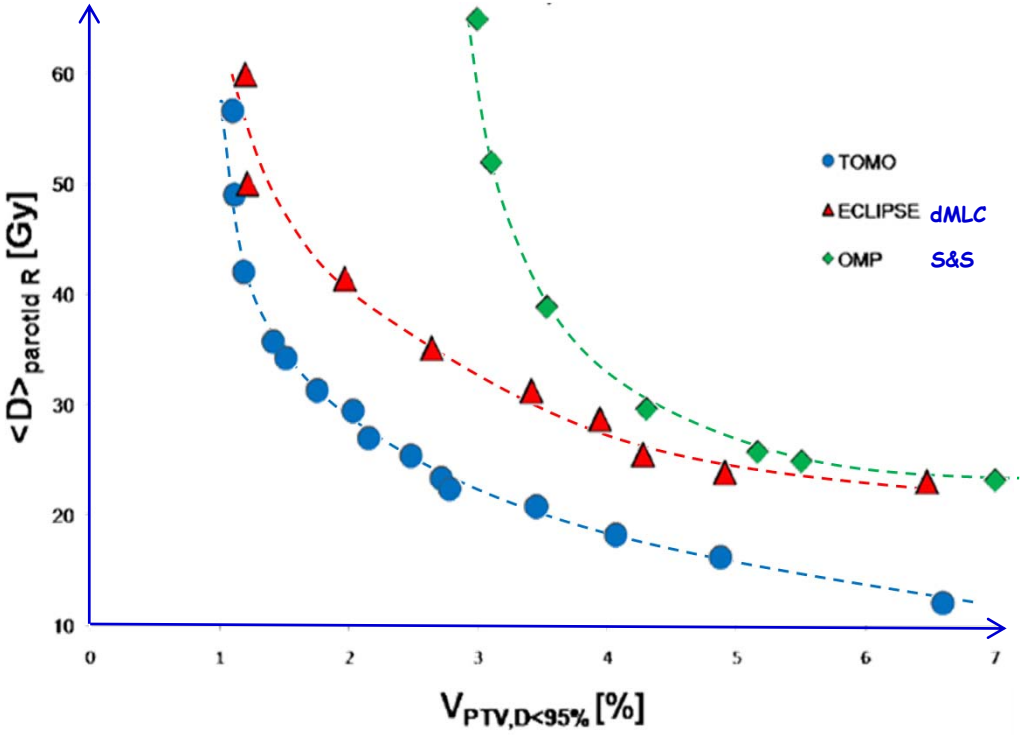


Based on a paper by Hoffman et al 2006

Skåne University Hospital

Ambiguity in comparisons of treatment modalities

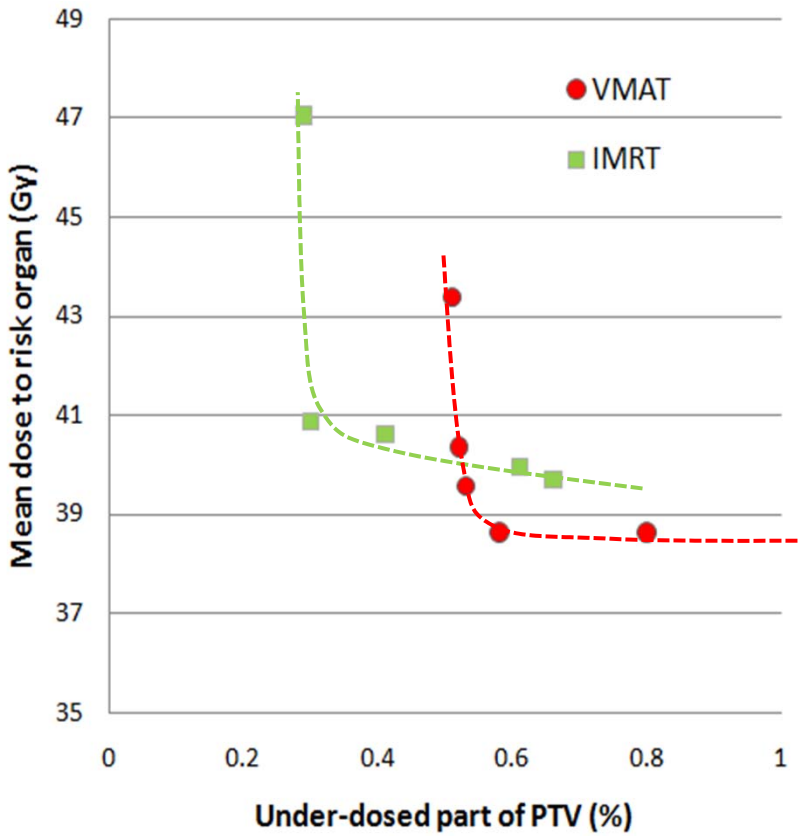
IMRT vs. helical tomotherapy for a head-&-neck cancer case



From Benedek et al., 10th biennial ESTRO, 2009

Another example

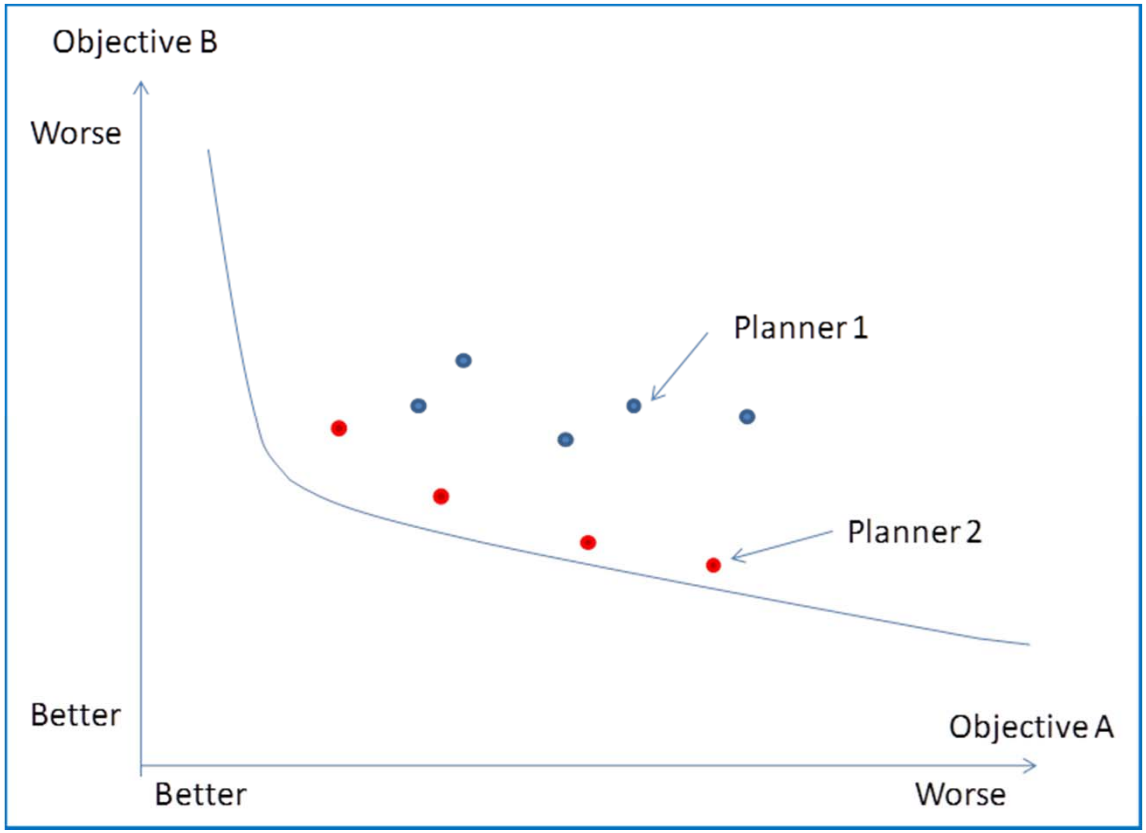
Anal cancer, with sparing of the small bowels (OMP)



Comparisons between different systems based on single plans are at best unfair, but also that it may be grossly misleading, see any paper comparing modalities

From Hunor Benedek

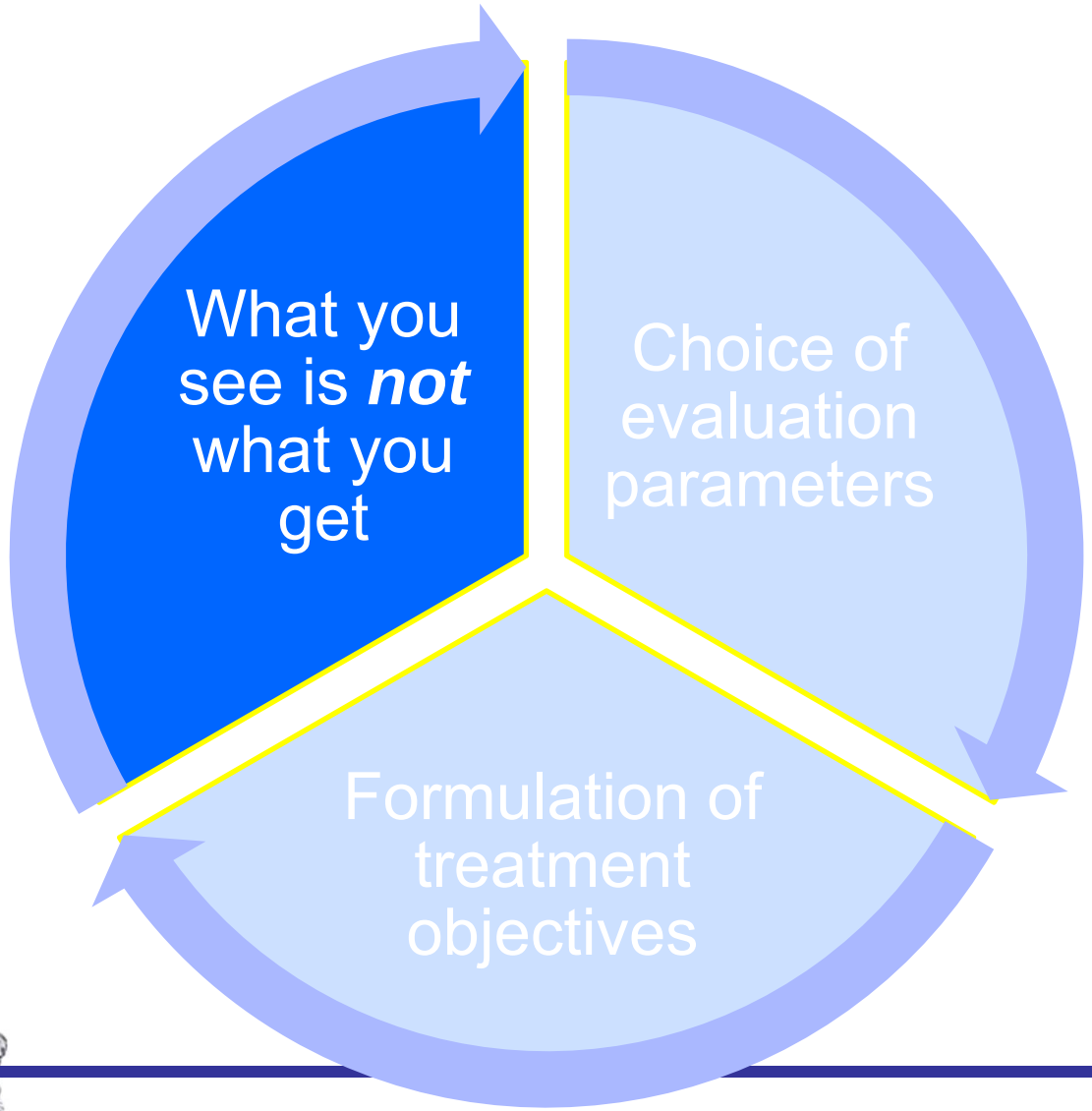
Uncertainty – have we achieved as good plan as possible?



Different planners may you work differently

Skåne University Hospital

Evaluation of treatment plans



What do we deliver?

Patient
- Immobilization
- Intra and inter motion

Models
- Dose calculation algorithms
- Optimization
  - System/process
  - Algorithm

Delivery system
- Stability
- Accuracy and precision

What do we deliver?

Patient
- Immobilization
- Intra and inter motion

Models
- Dose calculation algorithms
- Optimization
  - System/process
  - Algorithm

Delivery system
- Stability
- Accuracy and precision

→ **Uncertainties**

What do we deliver?

Pa

- Immobilization

Mo

ainties

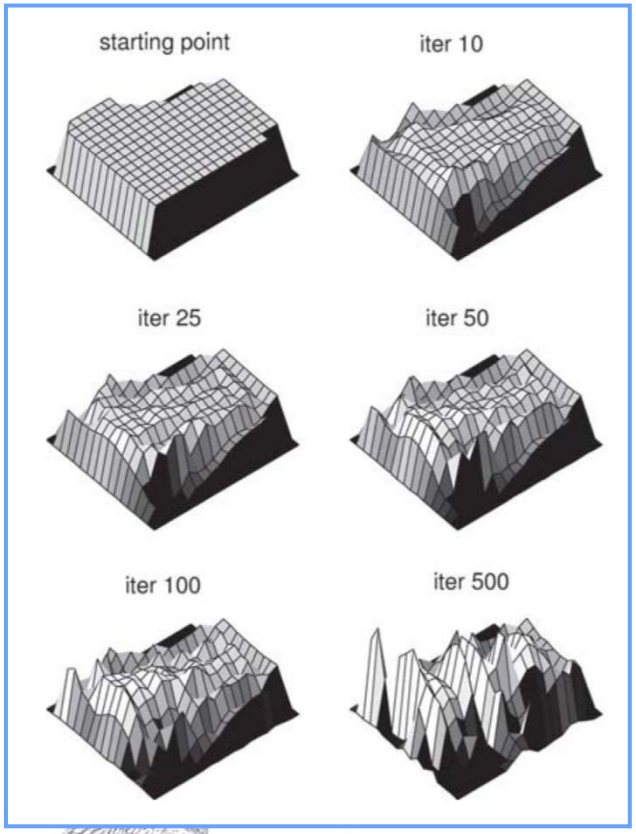
Delivery system

- Stability
- Accuracy and precision

What You See Is NOT What You Get

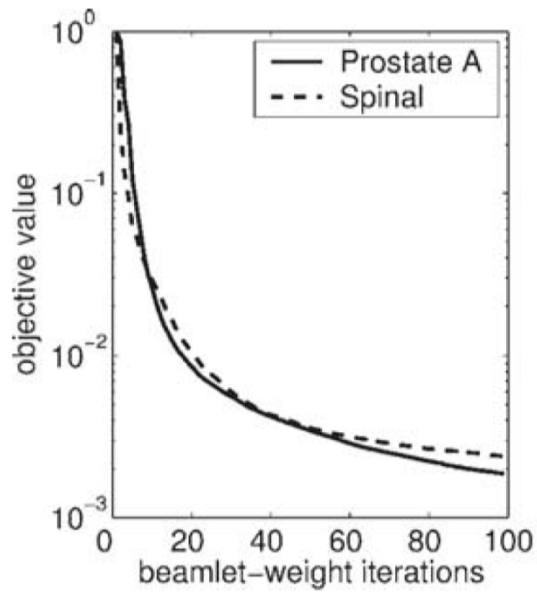
Driving optimization to far…

Intensity modulation of one field

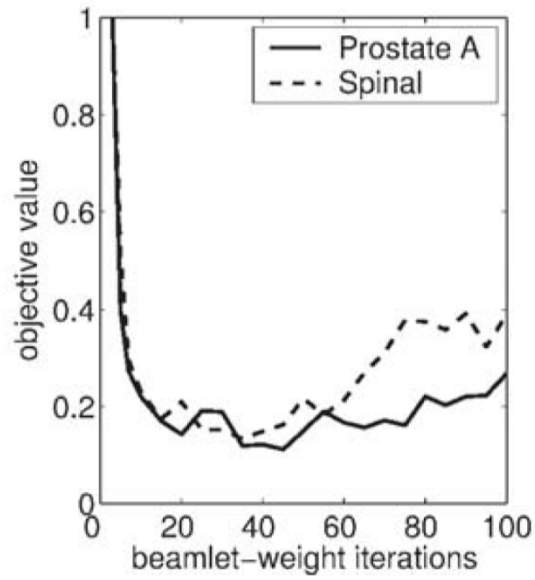


…will undoubtedly lead to jagged intensity patterns and deterioration of the final plan quality.

Optimal fluence



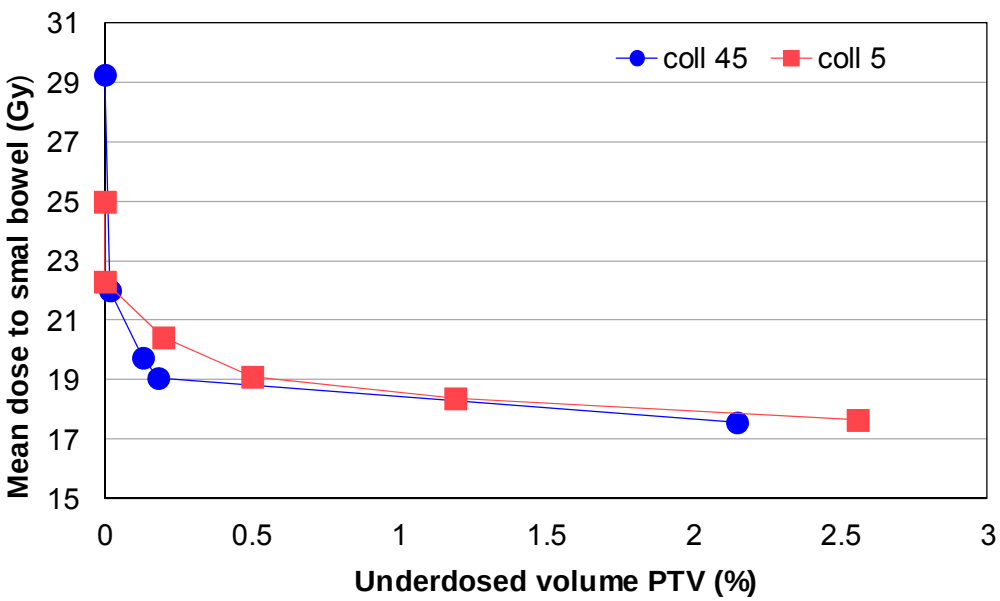
After MLC sequencer



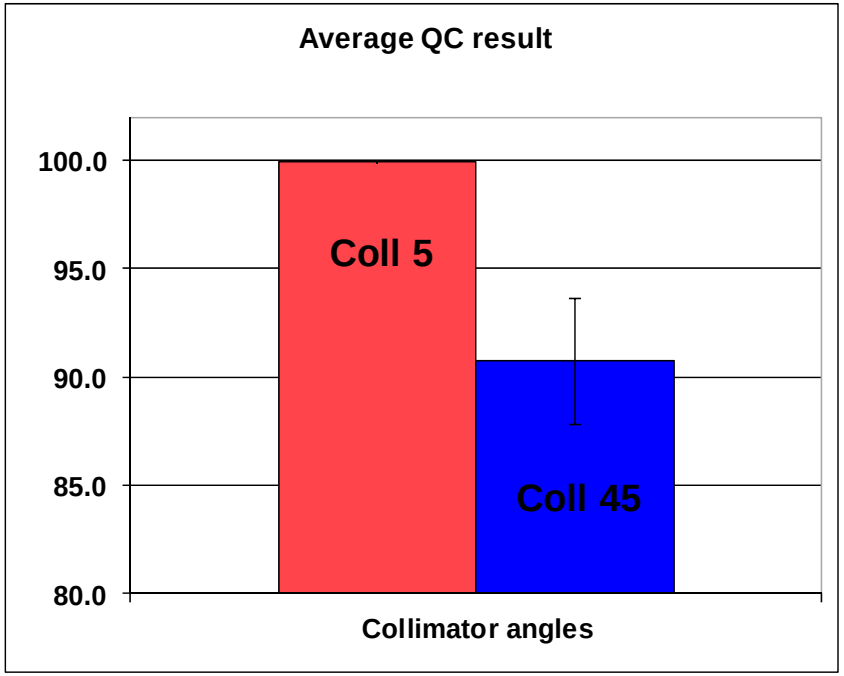
Carlsson and Forsgren Med Phys 2006

Do we really deliver?

VMAT, Elekta, MasterPlan



Pareto sets for two different collimator angles. The plans have increasing OAR weights from left to right.
It is clear that the 45-degree plans are slightly better than the 5-degree plans, with higher PTV coverage and less dose to the small bowel.



The average QC results with a Delta4 detector, (3%/3mm). The error bars are 1 standard deviation.

From Benedek et al, 2011, Poster at AAPM 2011

Better is best?

CLINICAL INVESTIGATION **Prostate**

CONFORMAL ARC RADIOTHERAPY FOR PROSTATE CANCER: INCREASED BIOCHEMICAL FAILURE IN PATIENTS WITH DISTENDED RECTUM ON THE PLANNING COMPUTED TOMOGRAM DESPITE IMAGE GUIDANCE BY IMPLANTED MARKERS

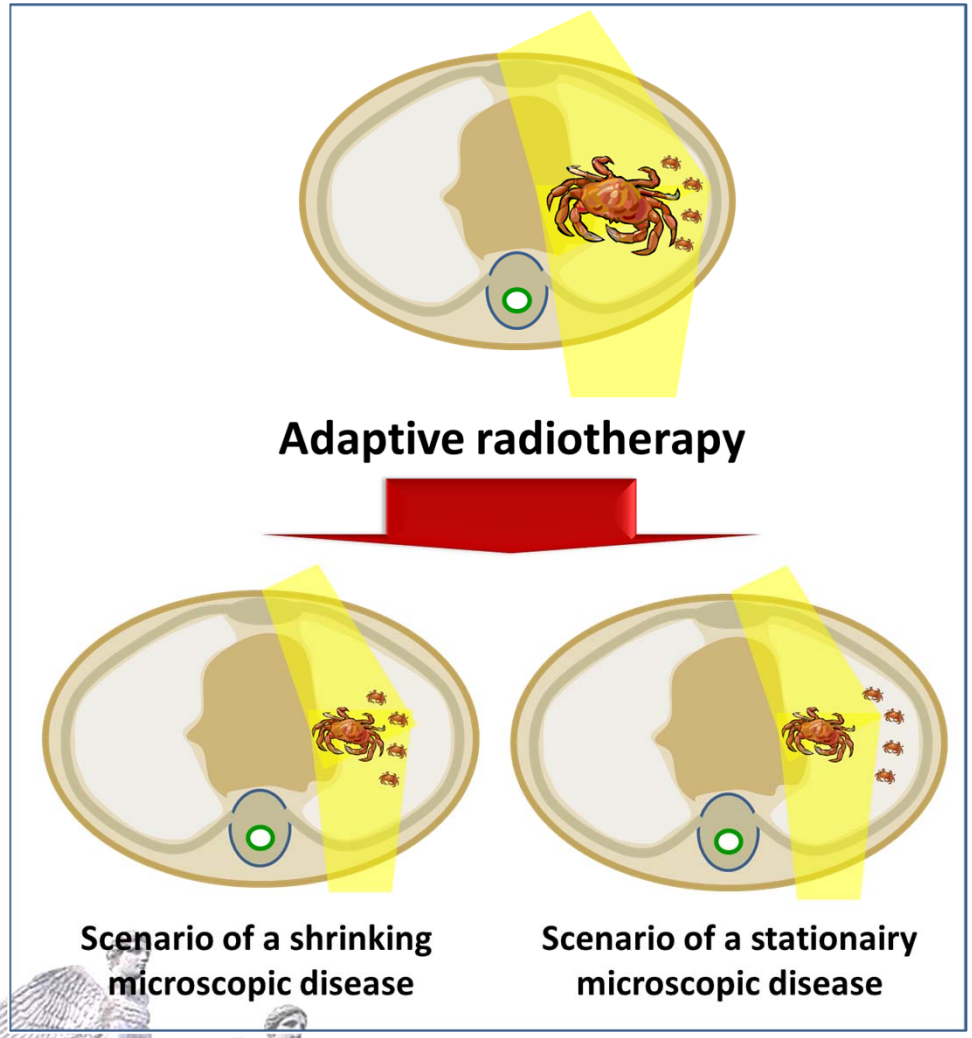
BENEDIKT ENGELS, M.D., GUY SOETE, M.D., PH.D., D. VERELLEN, PH.D., AND GUY STORME, M.D., PH.D.

Department of Radiotherapy, University Hospital Brussels, Brussels, Belgium

The Red Journal

The study illustrates the potential danger
of image guidance techniques
to create a false sense of confidence
as to possible margin reduction around the CTV.

Adaptive radiotherapy

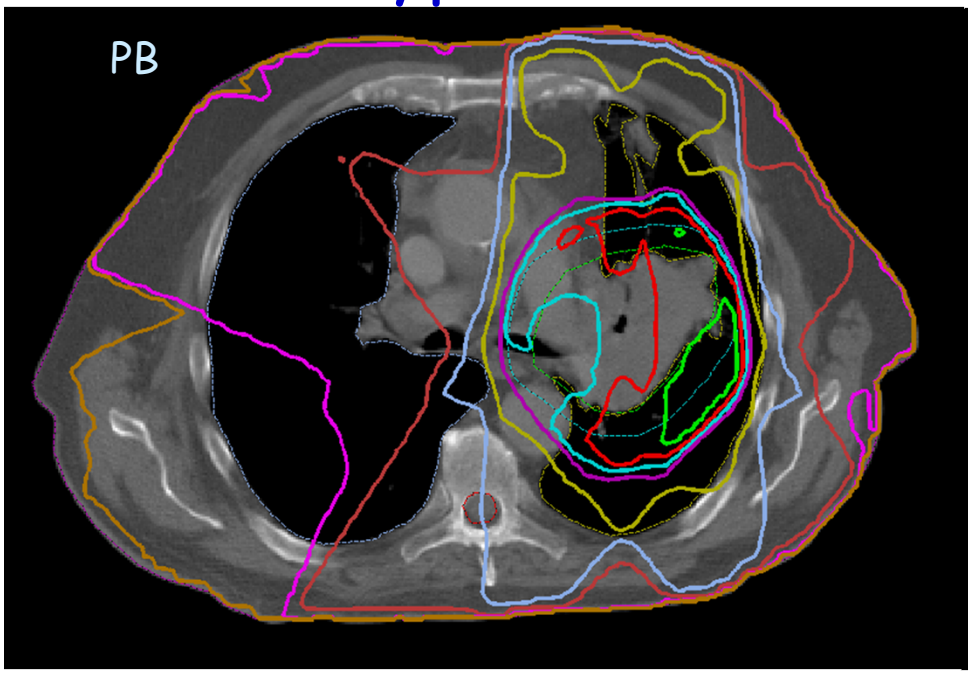


Should we cone down or not when we see tumour shrinkage???

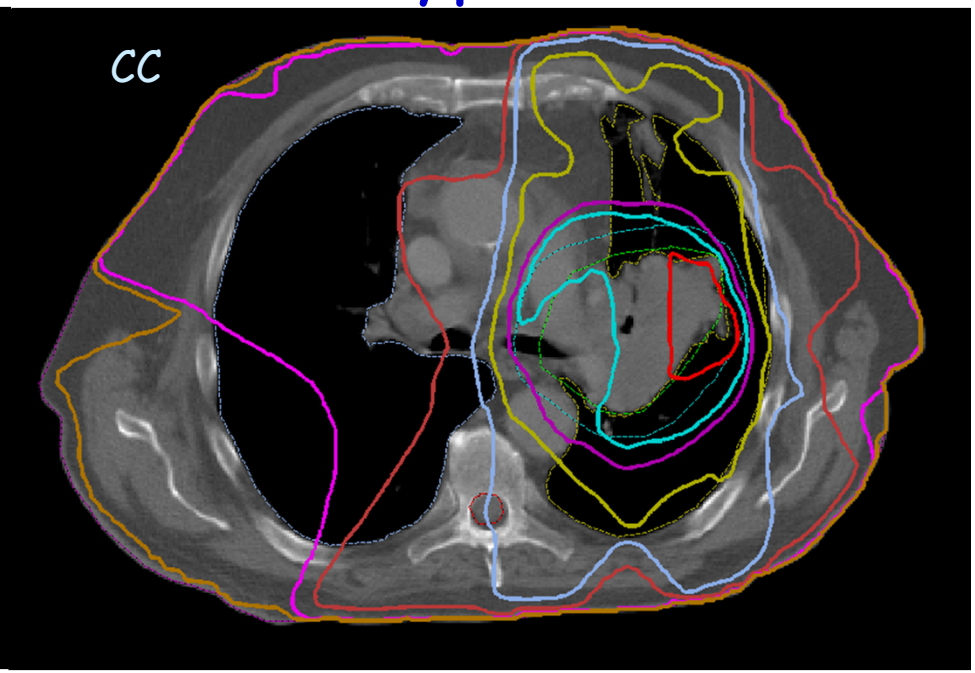
Graphics from Matthias Guckenberger

Dose calculation

Type a



Type b



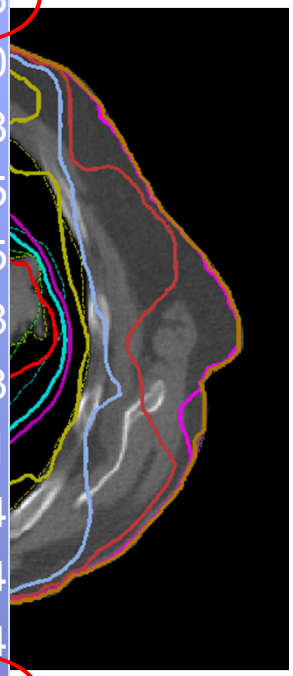
Knöös et al 2006 PMB

Dose calculation

	6X		18X	
	Type a	Type b	Type a	Type b
Mean	100.0	97.5	100.0	96.3
SD (Mean)	2.1	1.1	1.7	2.0
Max	103.9	99.0	102.4	97.8
Min	97.0	96.5	96.6	94.5
D95	92.7	91.3	95.2	91.5
D5	106.2	102.8	104.4	99.8
D5-D95	13.5	11.6	9.2	8.3
"SD"	3.4	2.9	2.3	2.1
Pulm Dx D50	7.6	7.4	7.8	7.4
Pulm Dx D5	30.9	29.8	30.1	28.4
Pulm Dx D1	43.8	41.8	41.6	39.4
Pulm Sin D50	14.2	19.7	15.7	20.6
Pulm Sin D5	103.7	96.3	101.3	91.9
Pulm Sin D1	107.9	100.0	104.3	95.9

PTV dose

Lung dose



Knöös et al 2006 PMB

Summary

- Evaluation of treatment plans depends on treatment objectives
- Ensuring that treatment objectives are
  - Specific
  - Measurable
  - Attainable
- may help avoiding pitfalls in comparing dose distributions for Radio-Therapy

Summary

- Evaluation of treatment plans depends on treatment objectives
- Ensuring that treatment objectives are
  - Specific
  - Measurable
  - Attainable
- may help avoiding pitfalls in comparing dose distributions for Radio-Therapy

Skåne University Hospital

LUND UNIVERSITY

Remember

The plan to choose is the one that do NOT decrease the outcome for the specific patient

Thanks - The Lund Team