BRACHYTHERAPY Physics Part II

Plan Optimization and treatment planning

Daniel Berger PhD

IAEA

Patient Workflow

Planning and application

Clinical Evaluation
Therapeutic decision making
Patient preparation
Applicator placement

3D imaging (with applicator)

Purpose of imaging
Imaging methodology
Imaging protocols

Contouring

Target and OARs definition

Applicator reconstruction

Defining the source-path
in the individual patient

3D dose planning and reporting

Plan optimisation, evaluation
Final dose prescription
Dose reporting
Plan verification and approval

Dose delivery

Plan Transfer to afterloader
Pre-delivery QC
Dose recording

Post-treatment

Removal of Applicator
Follow-up

Optimization techniques

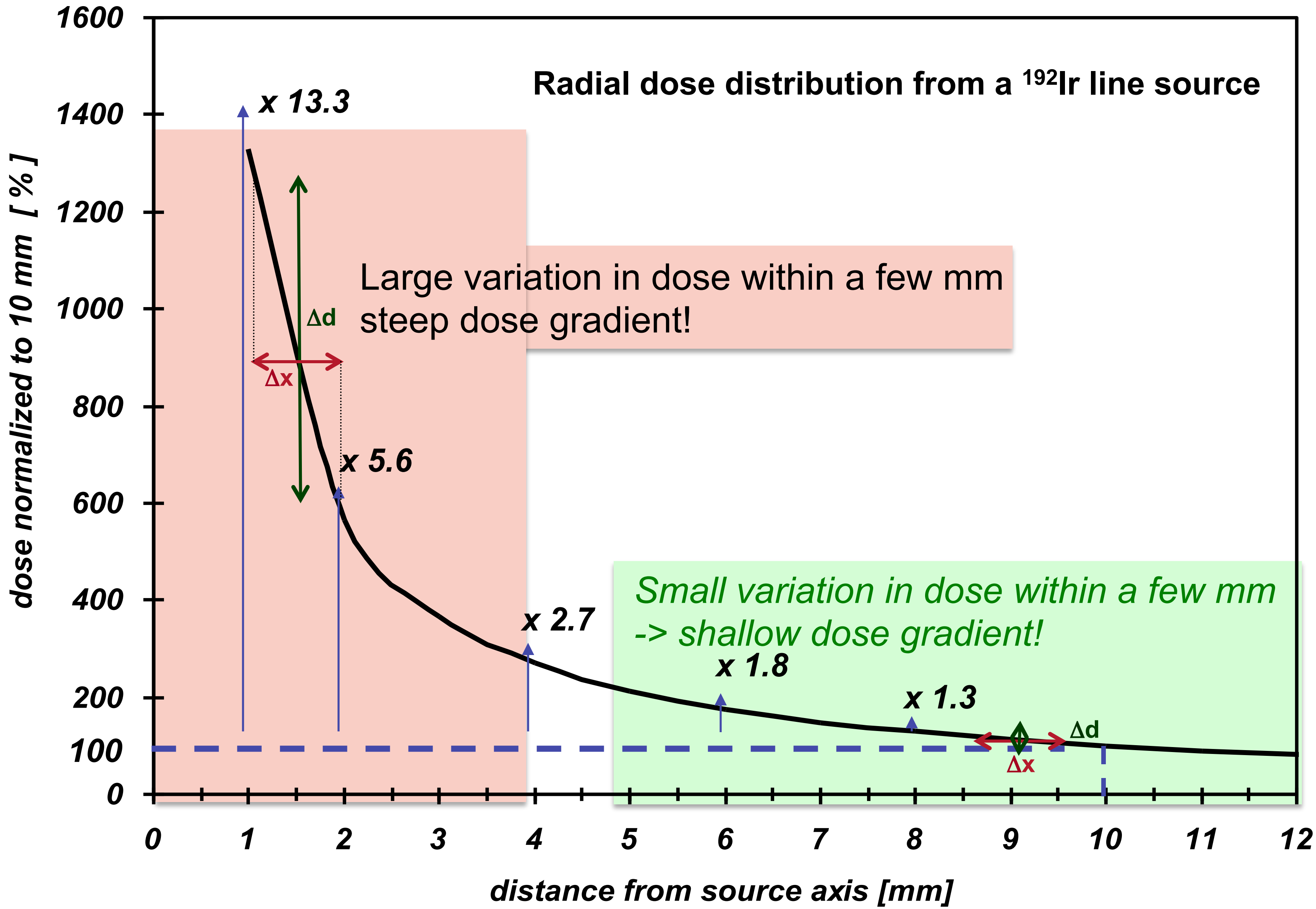
Optimization of the dose distribution through variation of the time the source dwells at each dwell position

Manual optimization

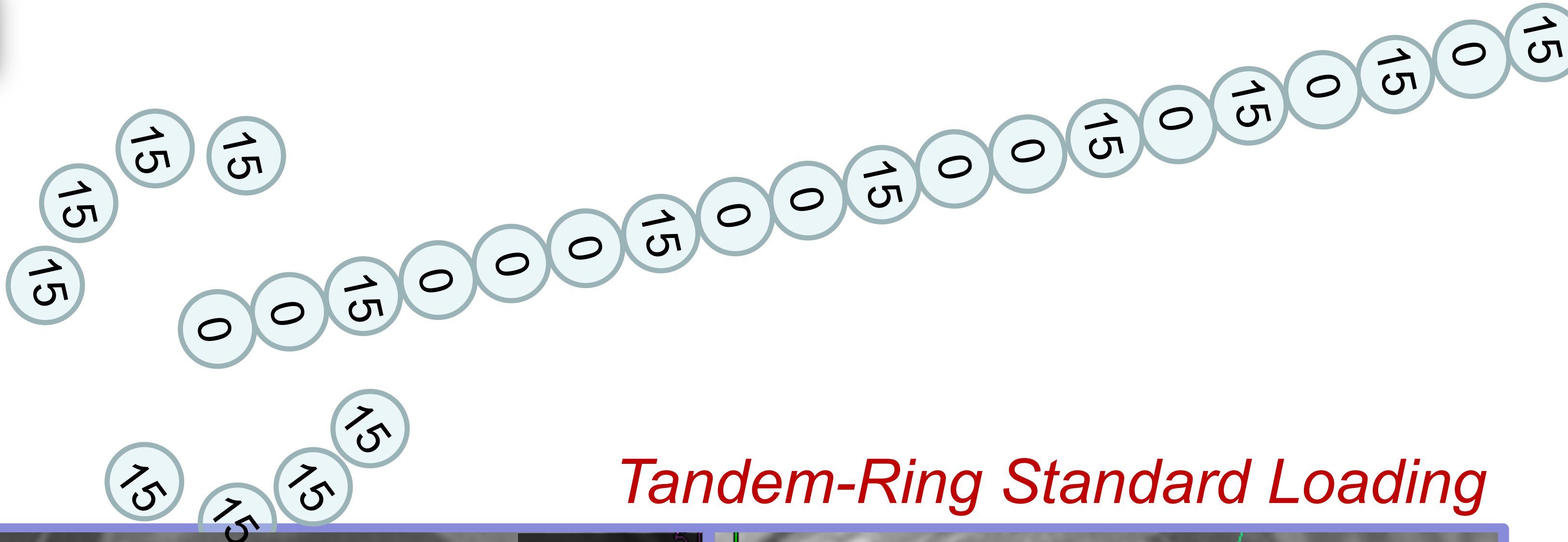
- Relative dwell weights — Normalization point(s)
- Absolute dwell weights (source strength)
- Dose point / geometric -optimization

Graphical optimization / dose shaper

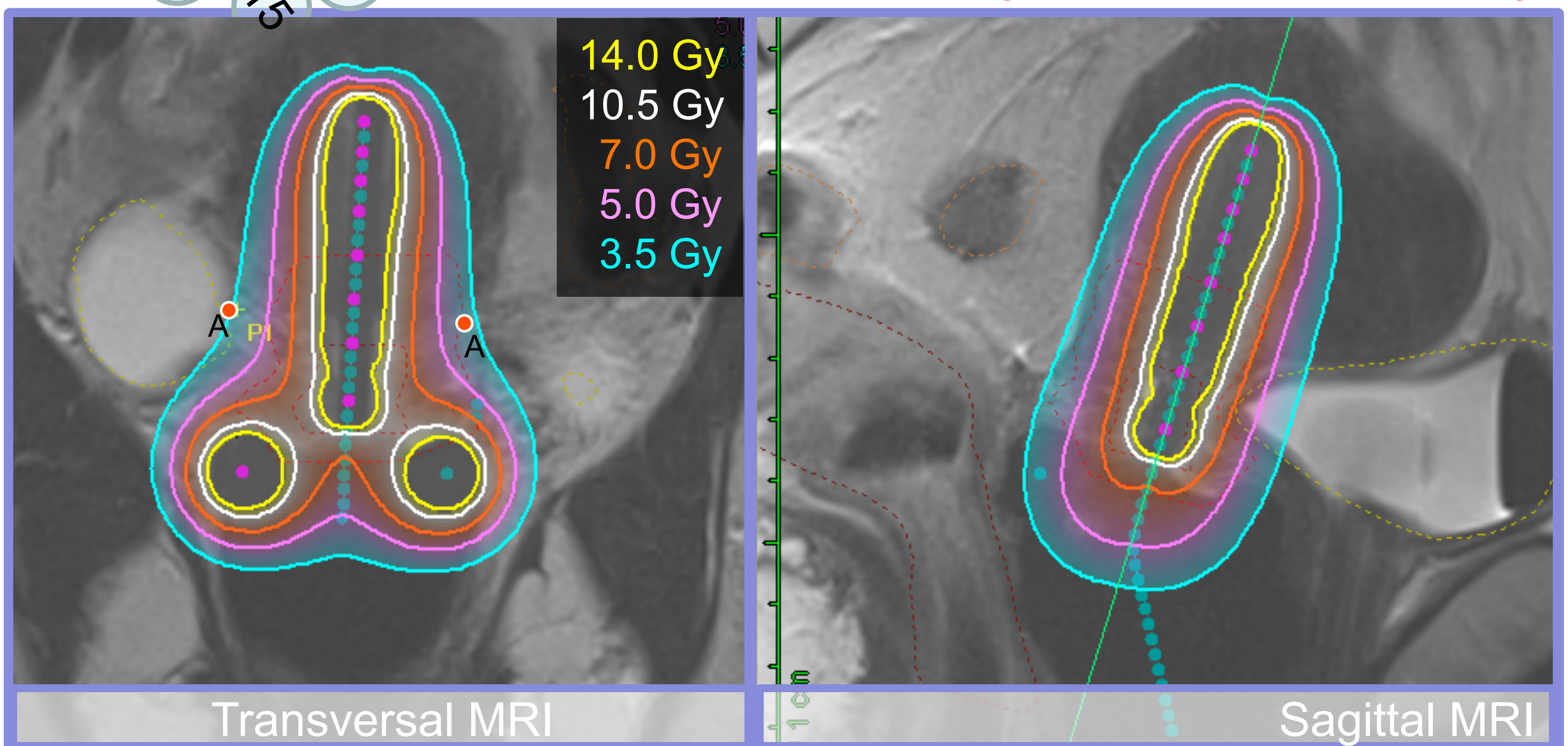
Inverse planning


Radial dose distribution from a ¹⁹²Ir line source
Large variation in dose within a few mm
steep dose gradient!
Small variation in dose within a few mm
-> shallow dose gradient!
x 13.3
x 5.6
x 2.7
x 1.8
x 1.3
Δd
Δx
Δd
Δx
1600
1400
1200
1000
800
600
400
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
dose normalized to 10 mm [%]
distance from source axis [mm]

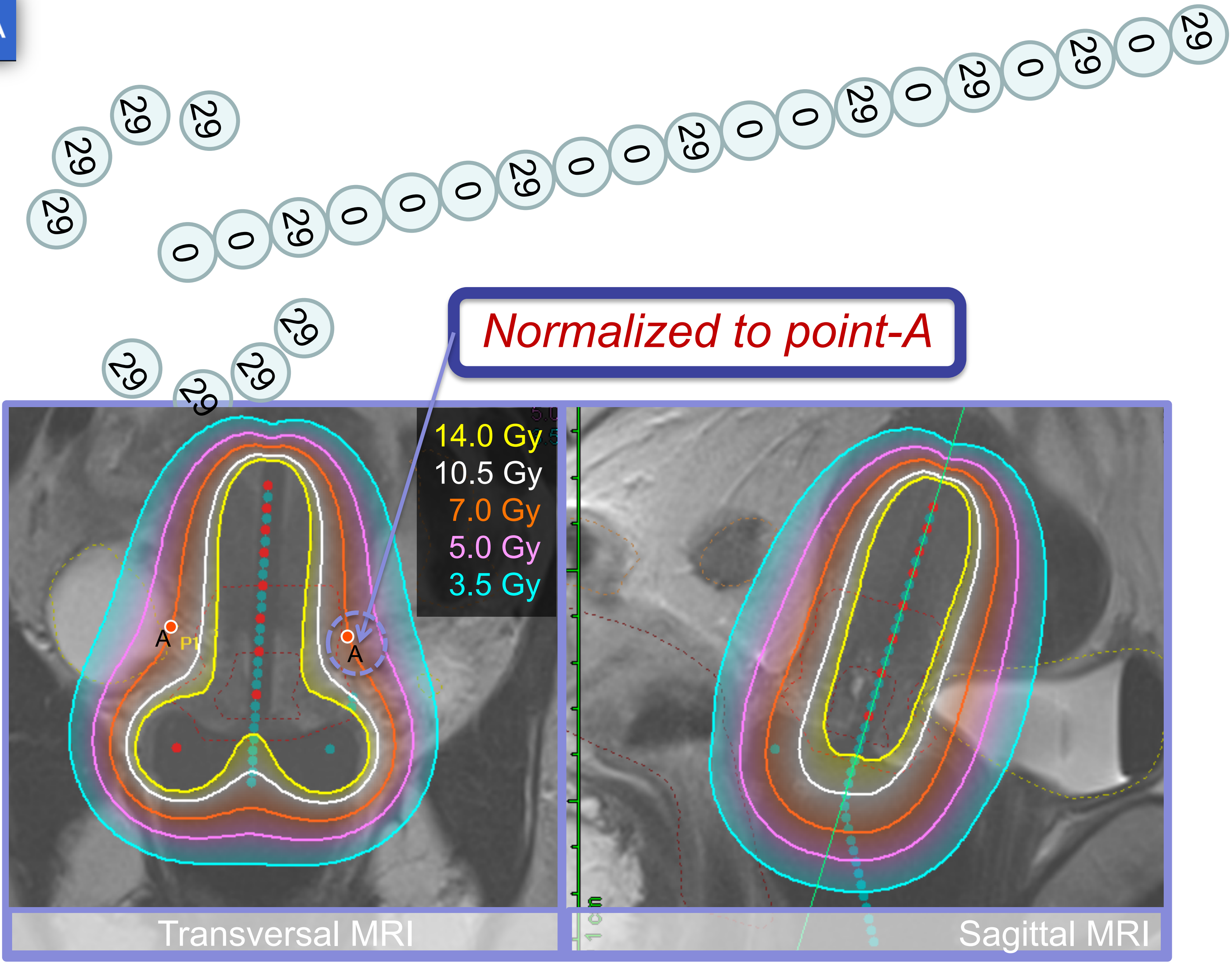
IAEA



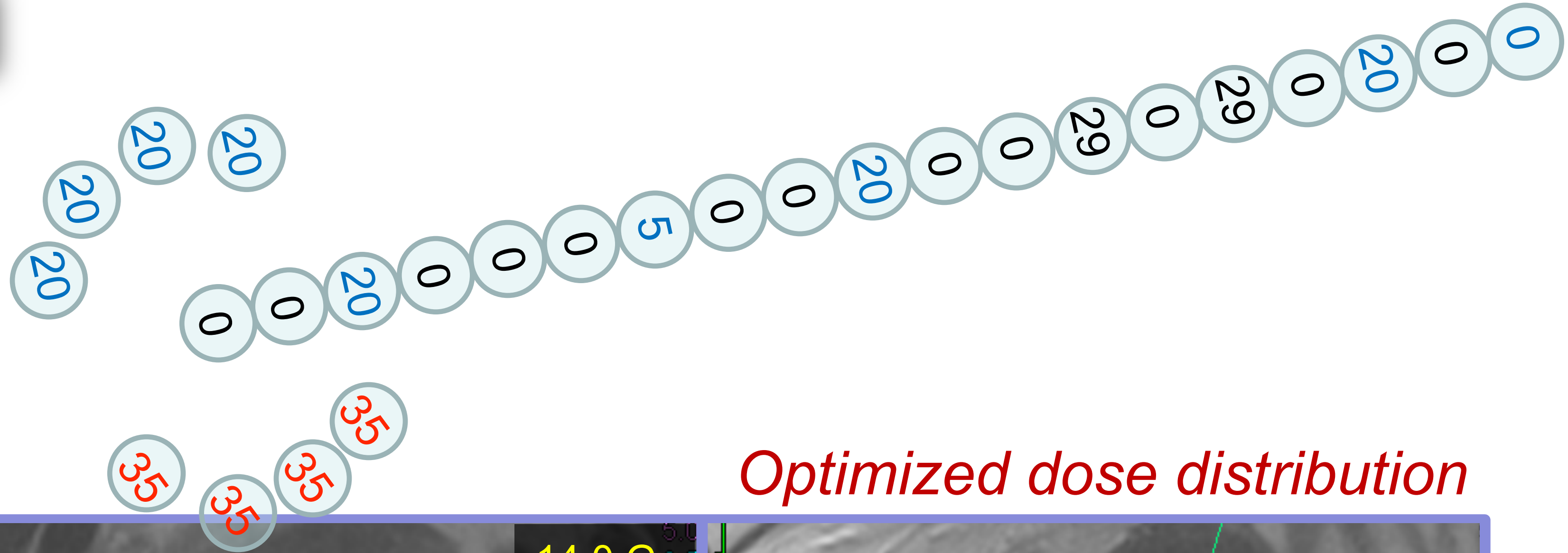
Tandem-Ring Standard Loading



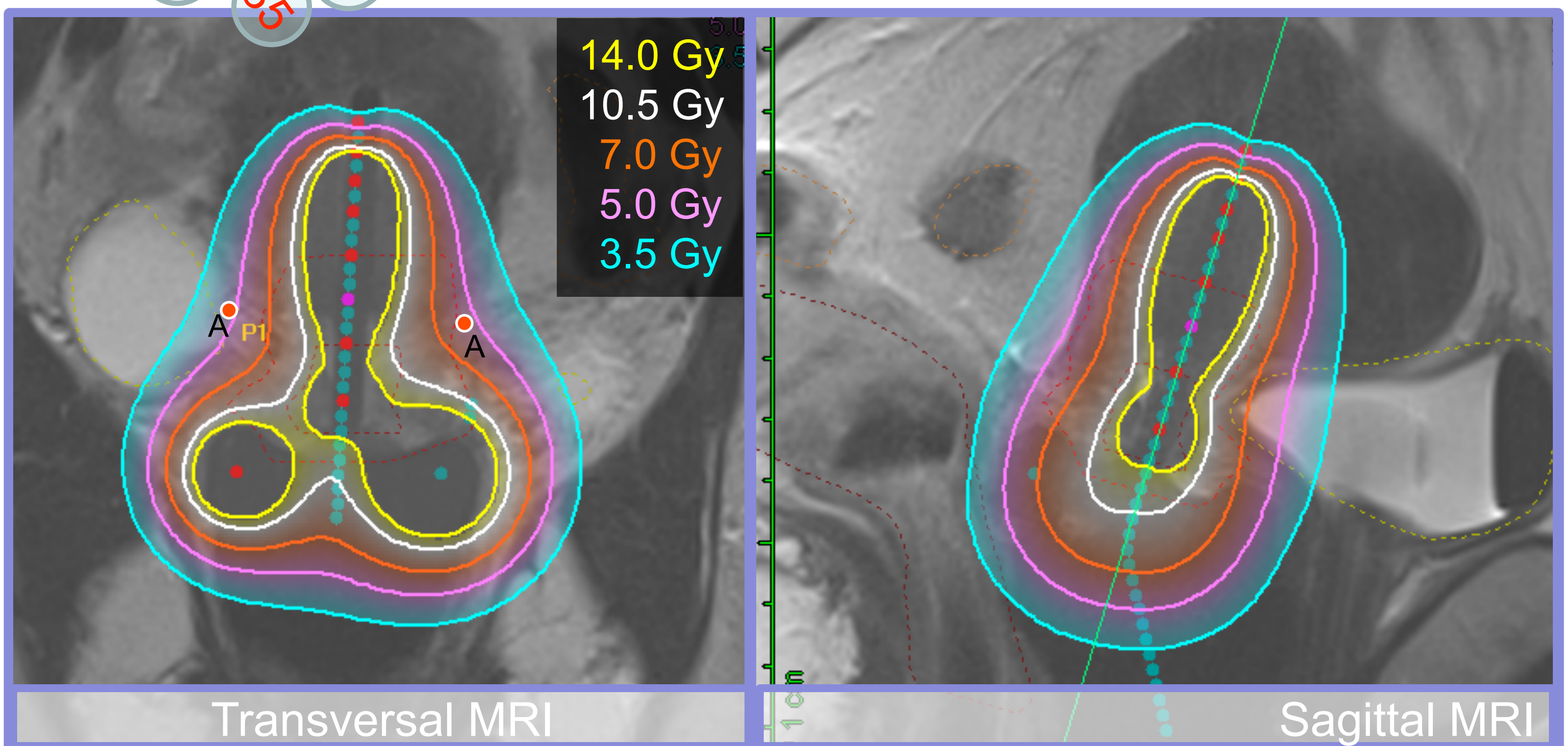
Difference between optimization and normalization



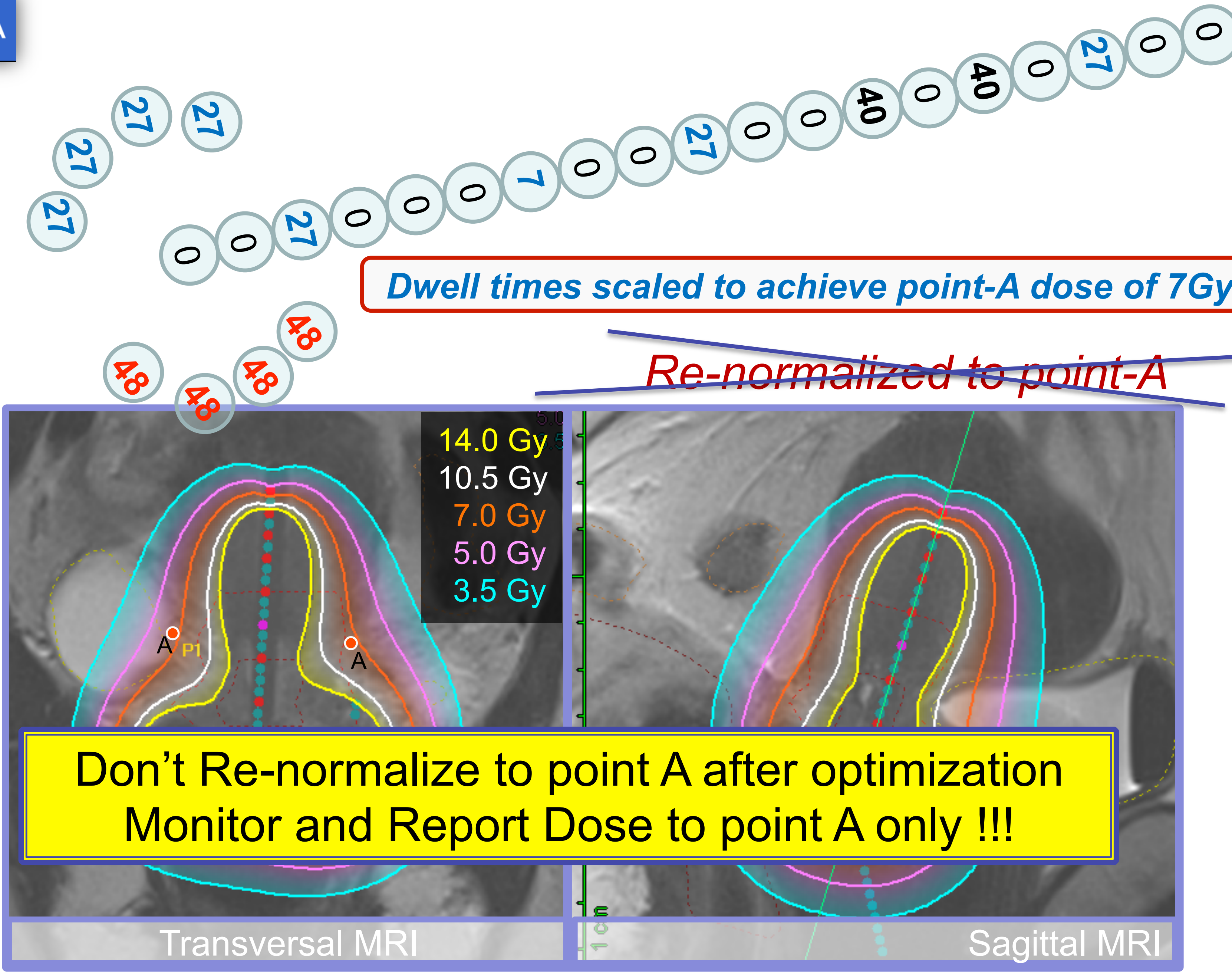
Difference between optimization and normalization



Optimized dose distribution



Difference between optimization and normalization



Dwell times scaled to achieve point-A dose of 7Gy!

~~Re-normalized to point-A~~

Don't Re-normalize to point A after optimization
Monitor and Report Dose to point A only !!!

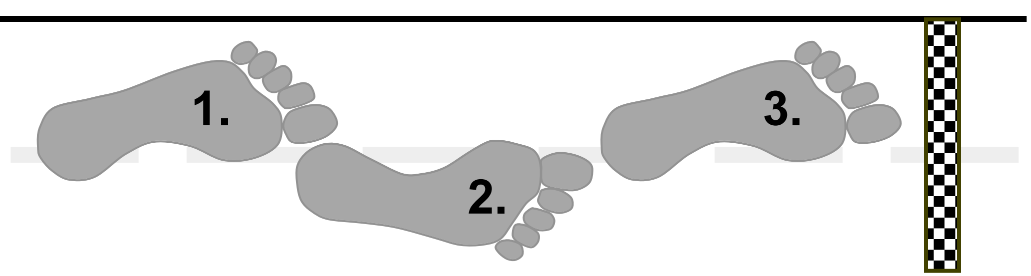
Difference between optimization and normalization

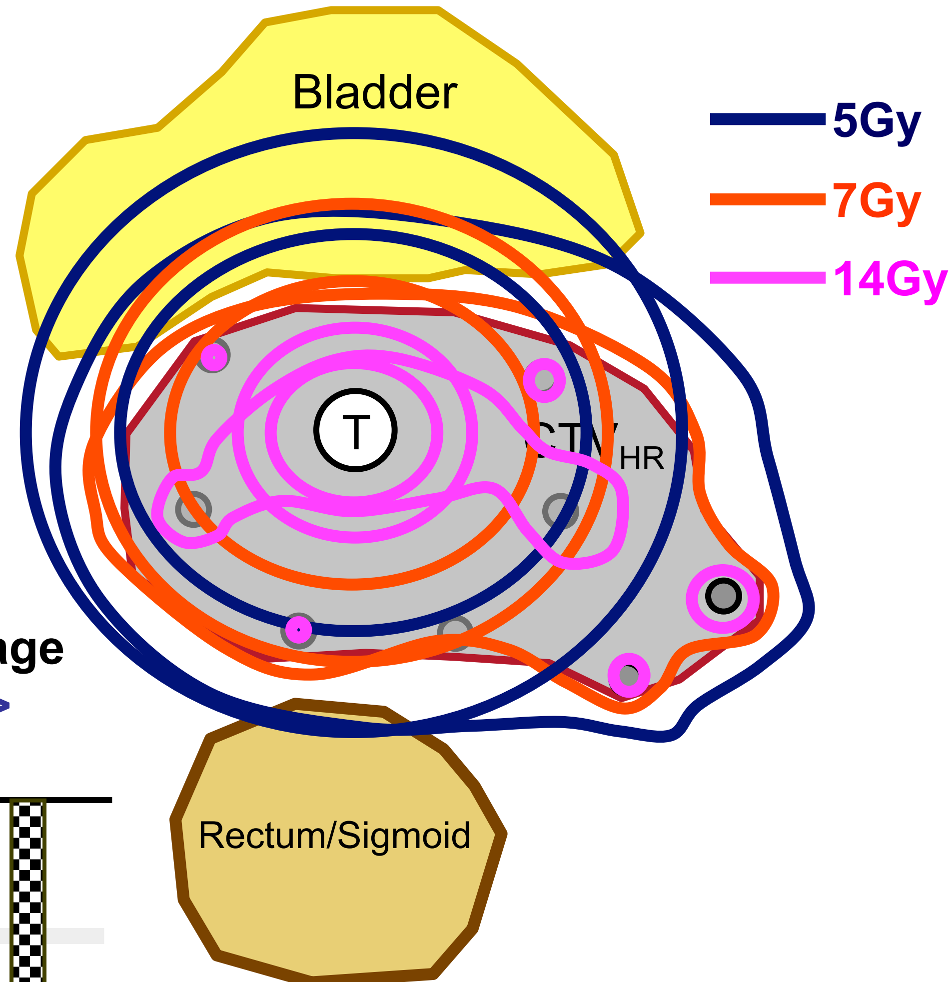
Keep in mind - Daniel's 3 easy steps in Treatment Planning Optimization

1: Apply (institutional) Standard Loading Pattern and normalize to Point A

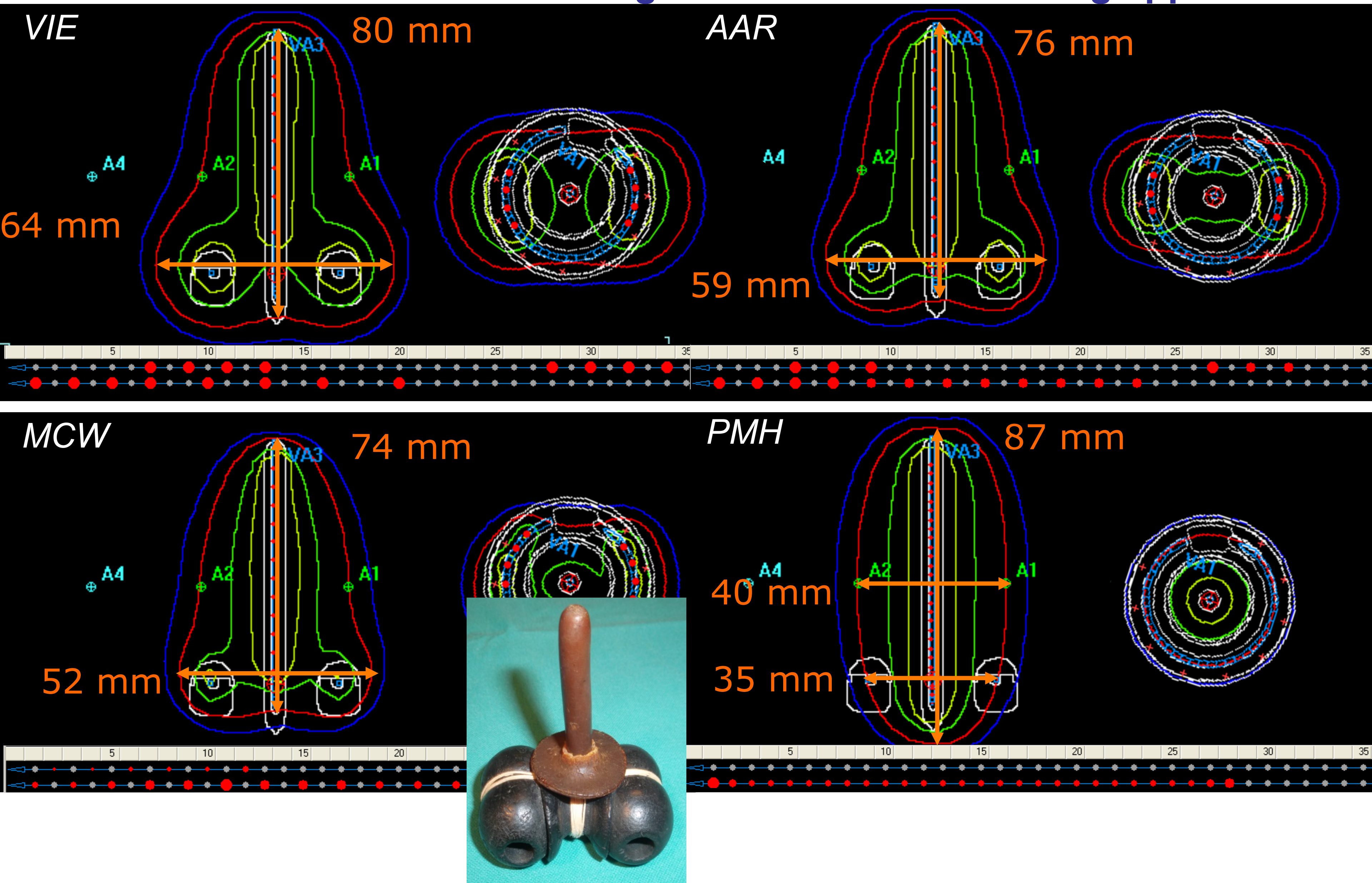
2: Optimize the Intracavitary applicator (T/R, T/O) based on OARs

3: Add the interstitial components (Needles) to increase the target coverage
<Dwell-time is 10-20% of Intracavitary>



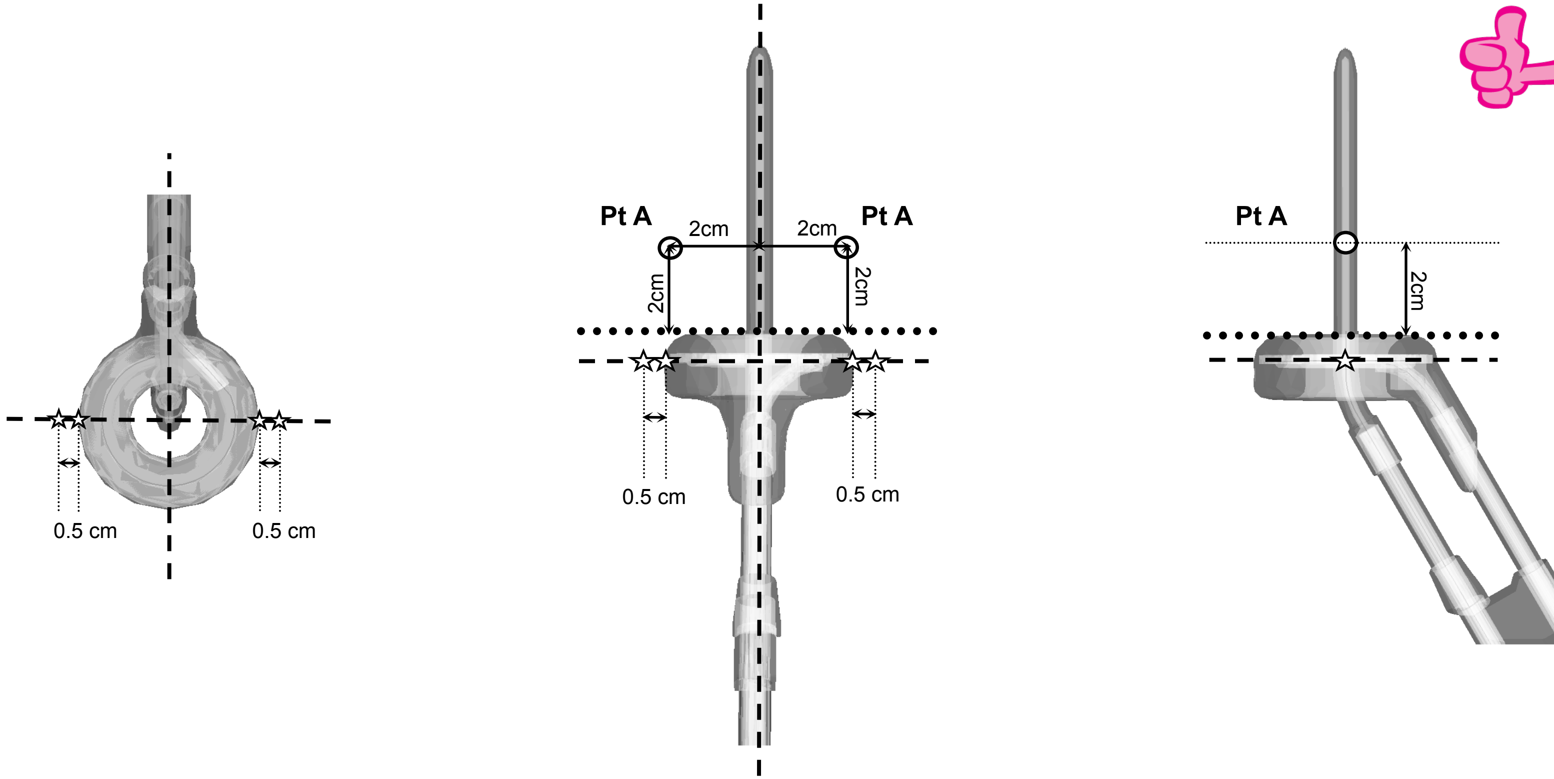


Different Standard Loading Patterns for tandem-ring applicators



RING- applicator

Recall ! Point A - definition

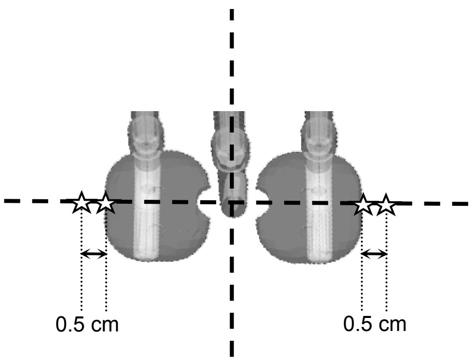


axial

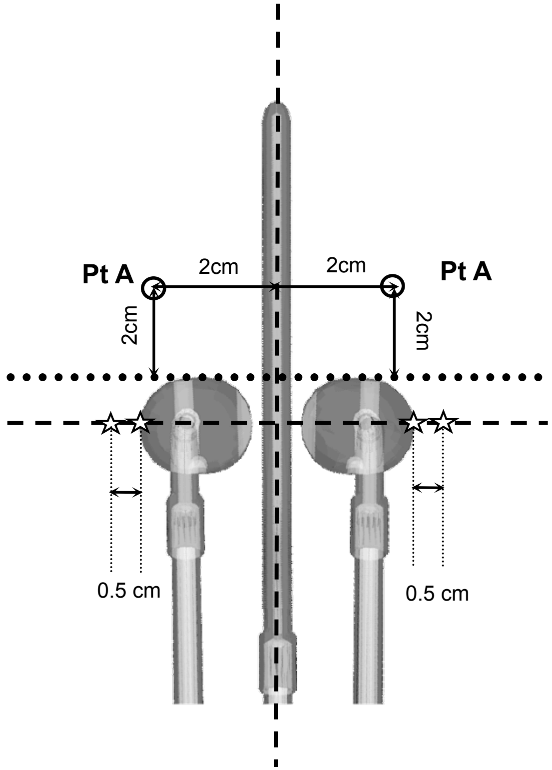
coronal

sagittal

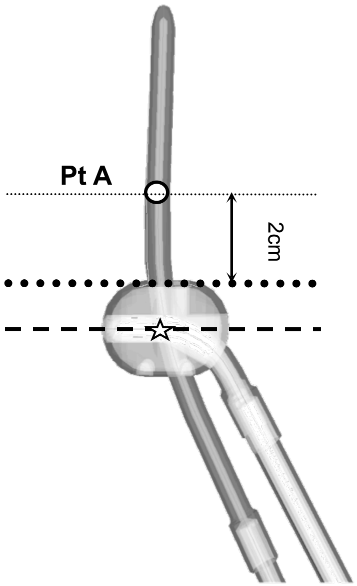
Recall ! Point A - definition



axial



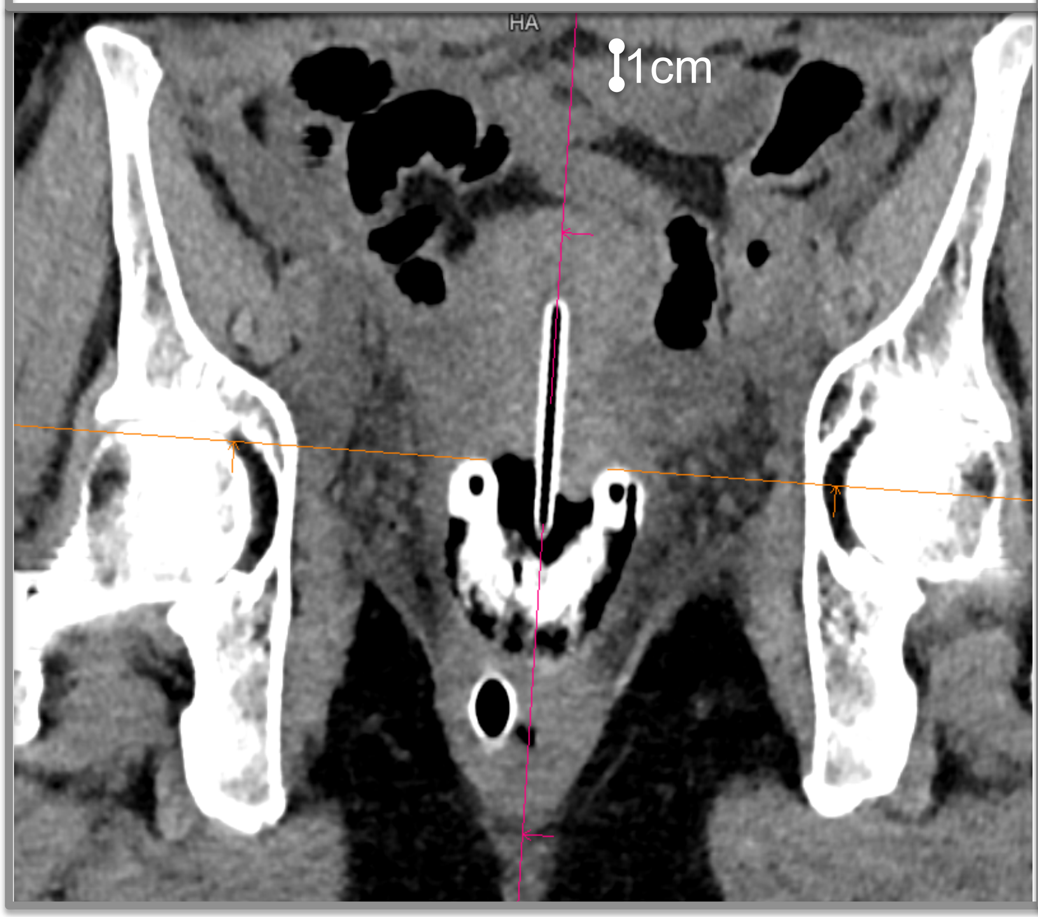
coronal



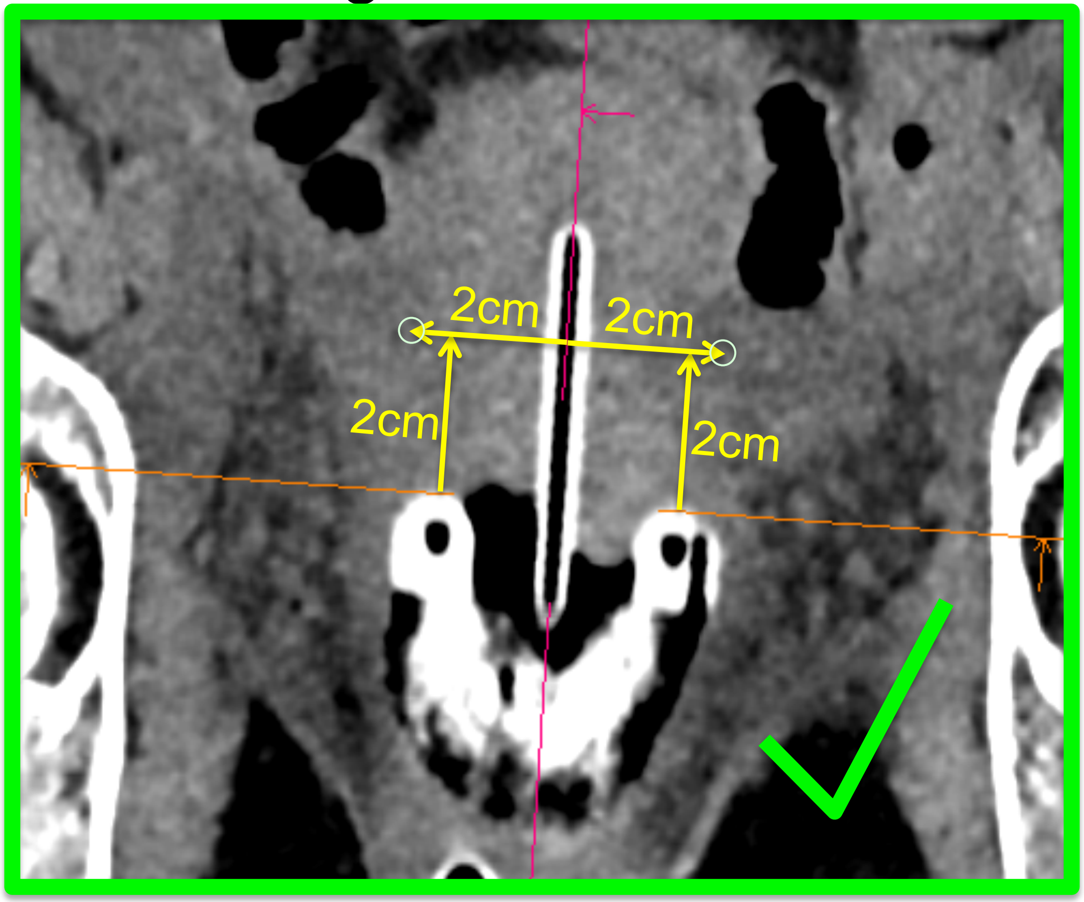
sagittal

Please Define Point A and ICRU reference points

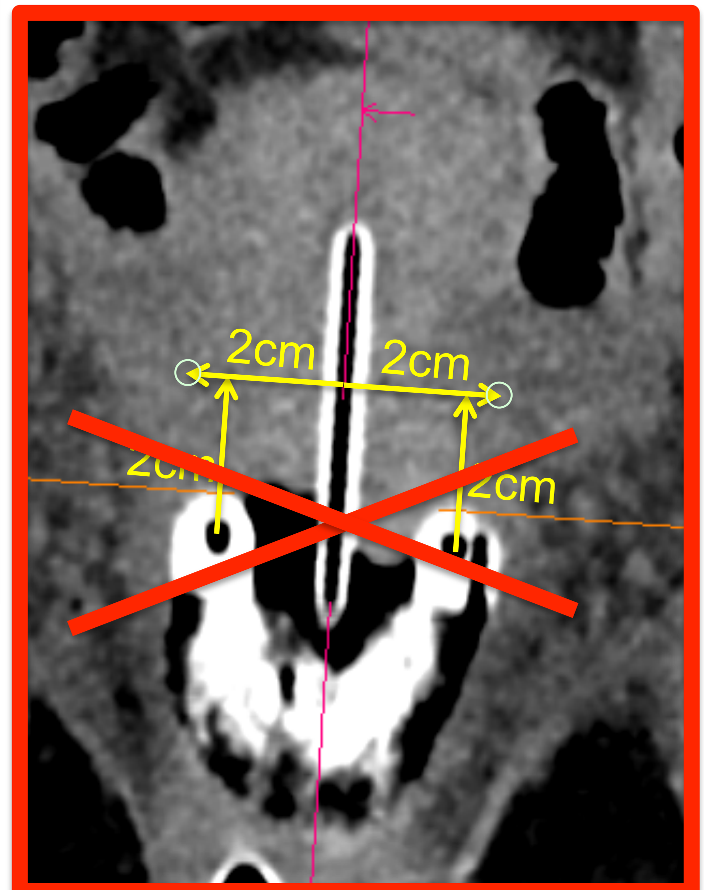
Para-coronal CT	Para-sagittal CT



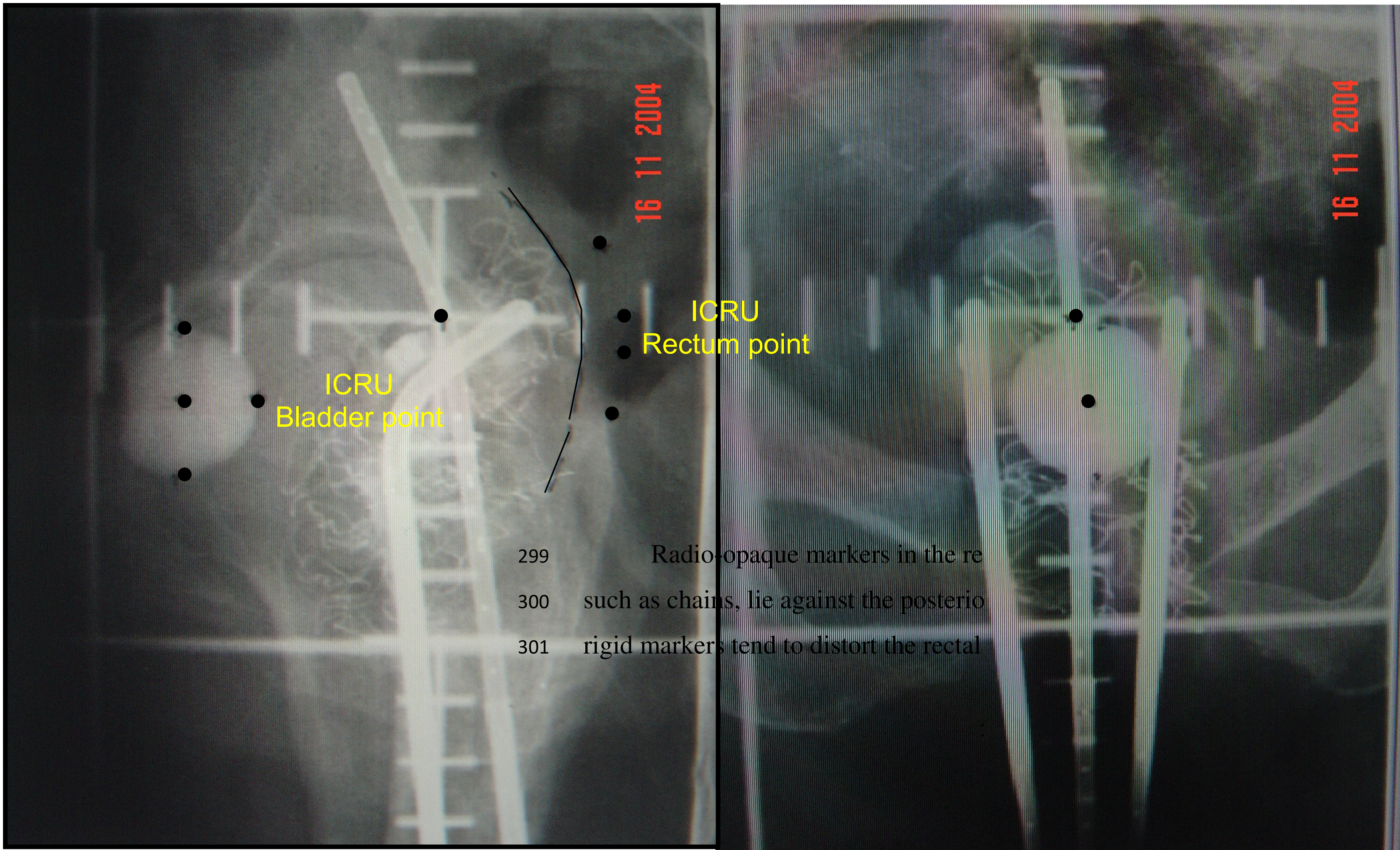
From Ring-Surface 2cm cran.

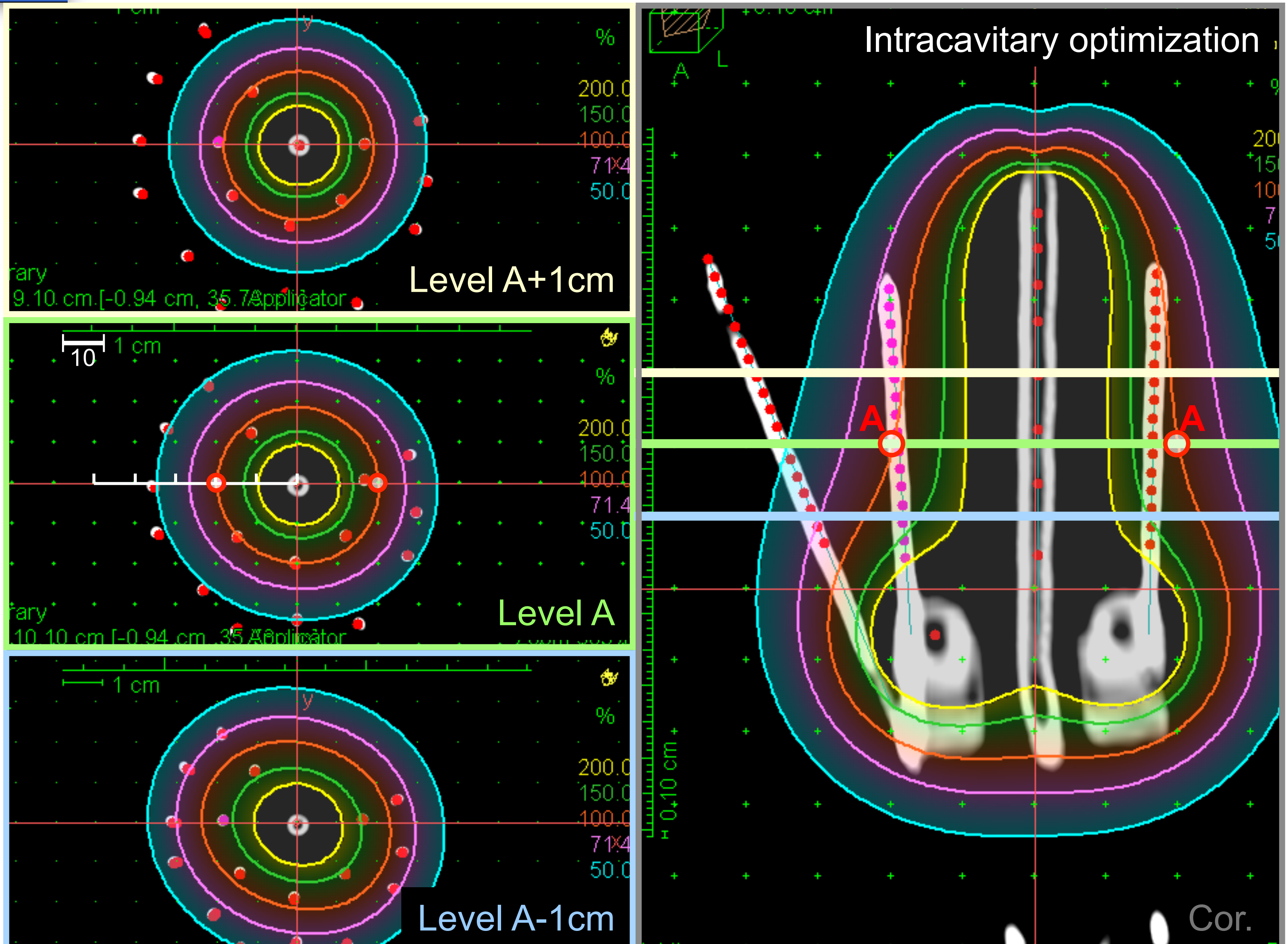


not from sources

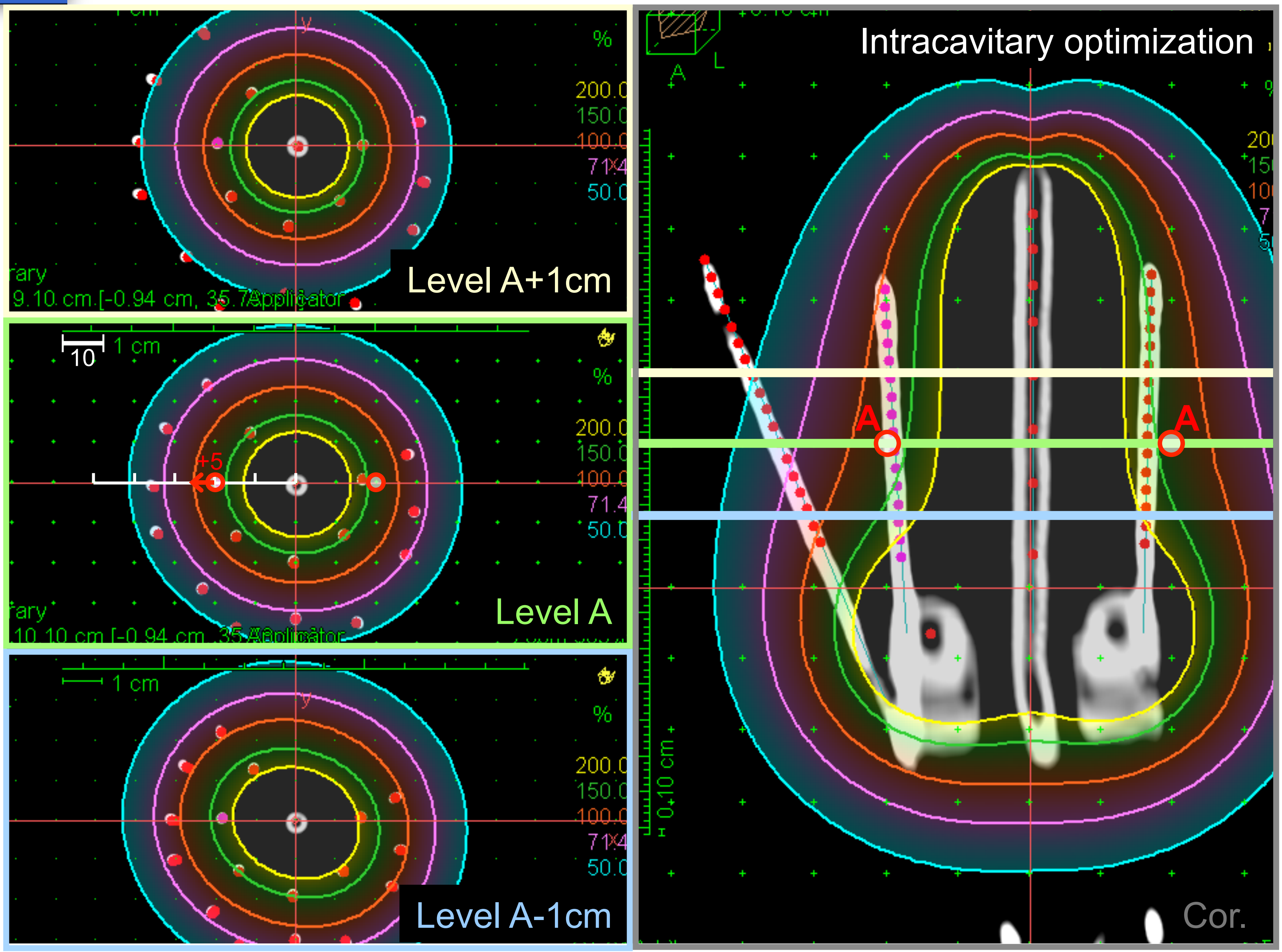


Level 2 based planning know how to define point A

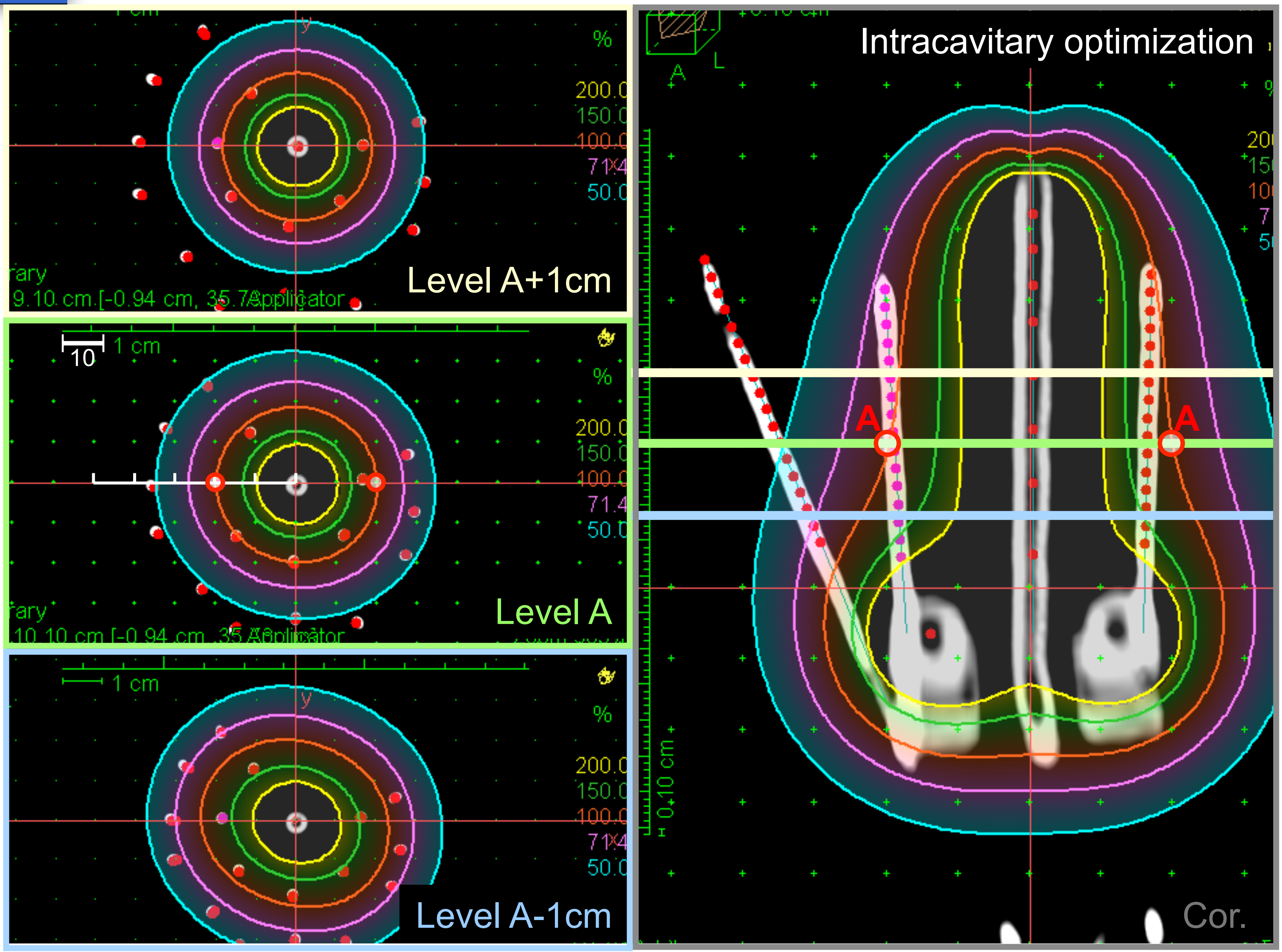




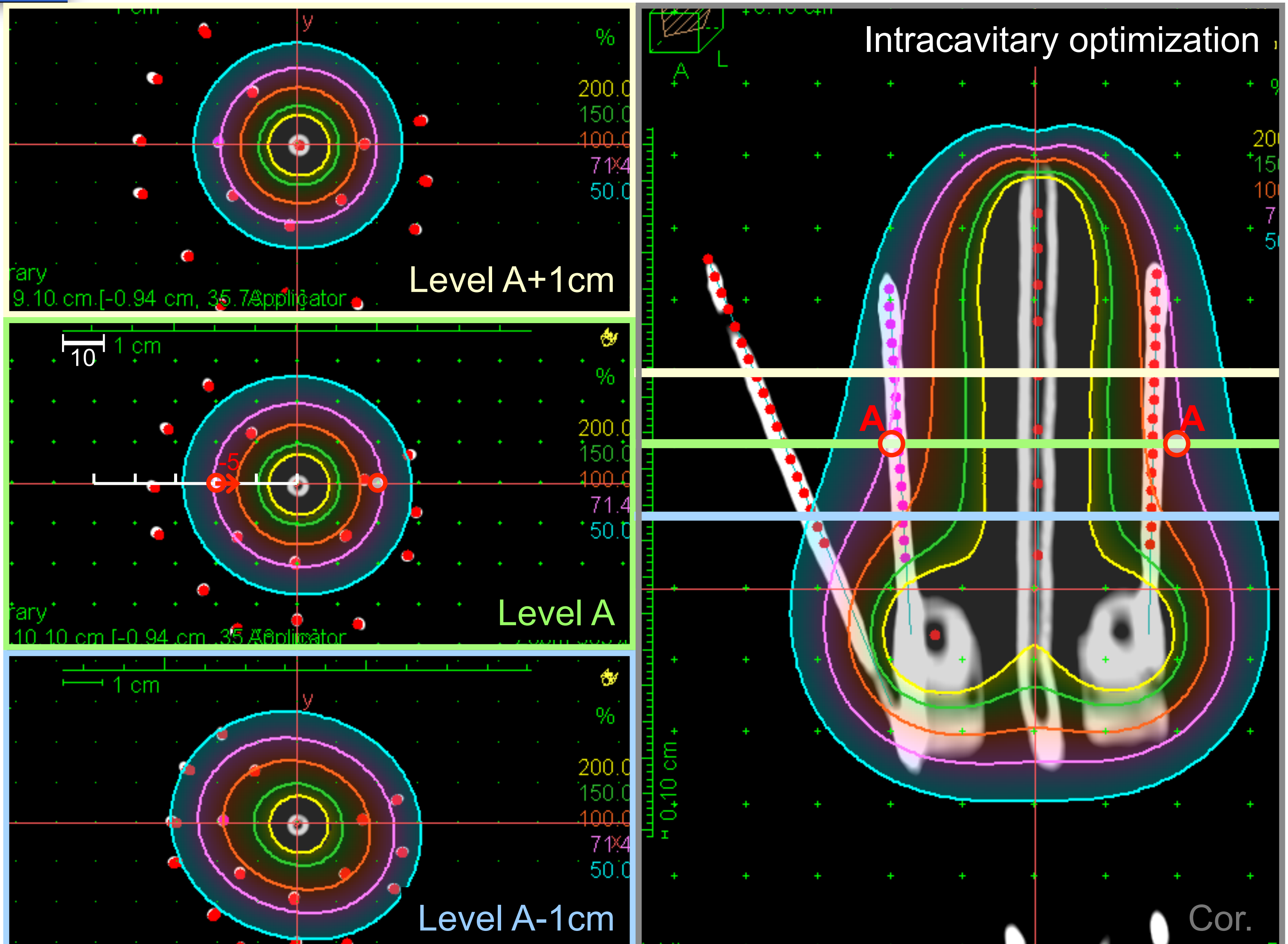
Level A+1cm
Level A
Level A-1cm
Intracavitary optimization
A
A
Cor.
1 cm
10
%
200.0
150.0
100.0
71.4
50.0



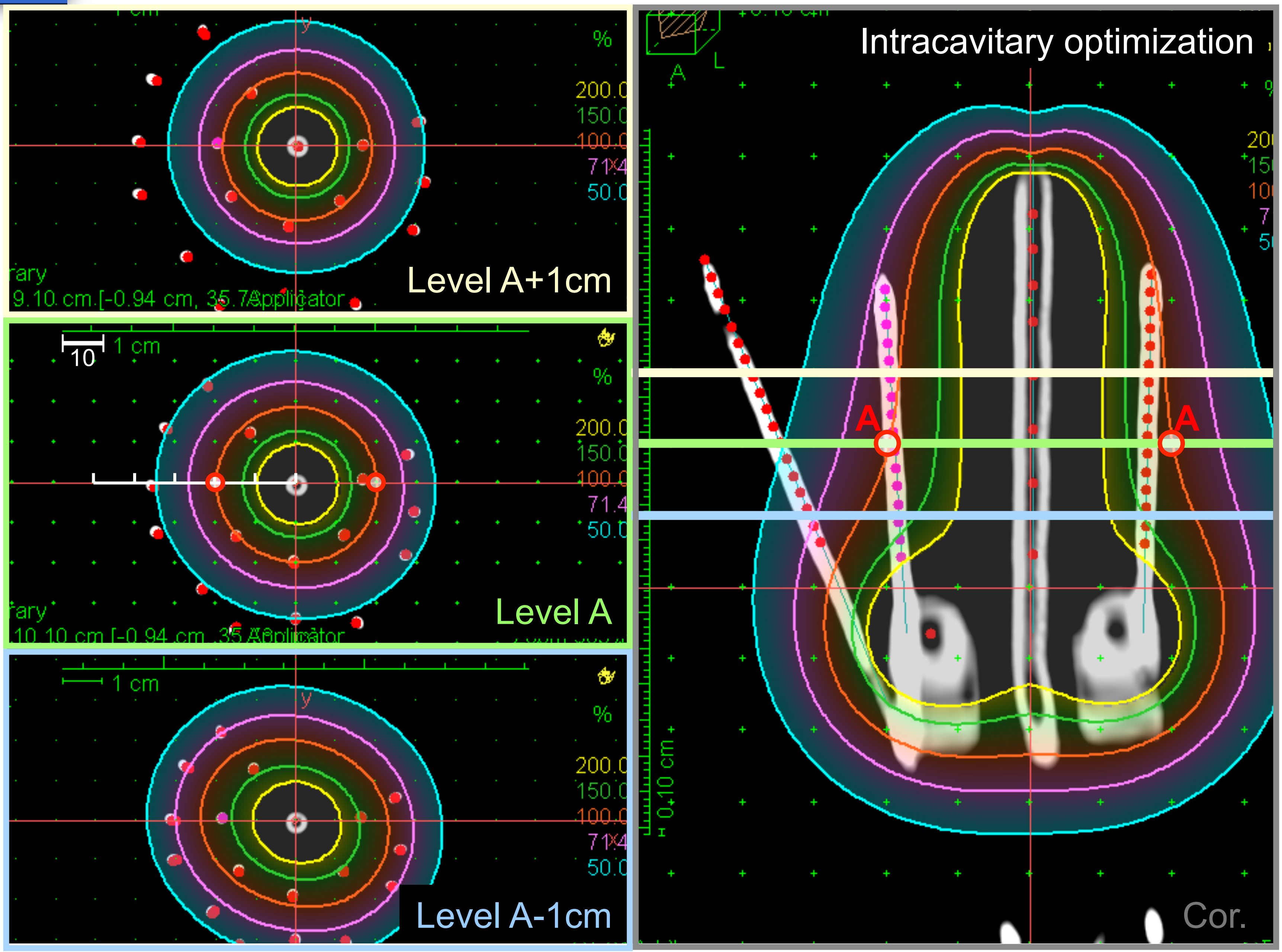
Level A+1cm
Level A
Level A-1cm
Intracavitary optimization
A
A
Cor.
1 cm
10
+5
%
200.0
150.0
100.0
71.4
50.0



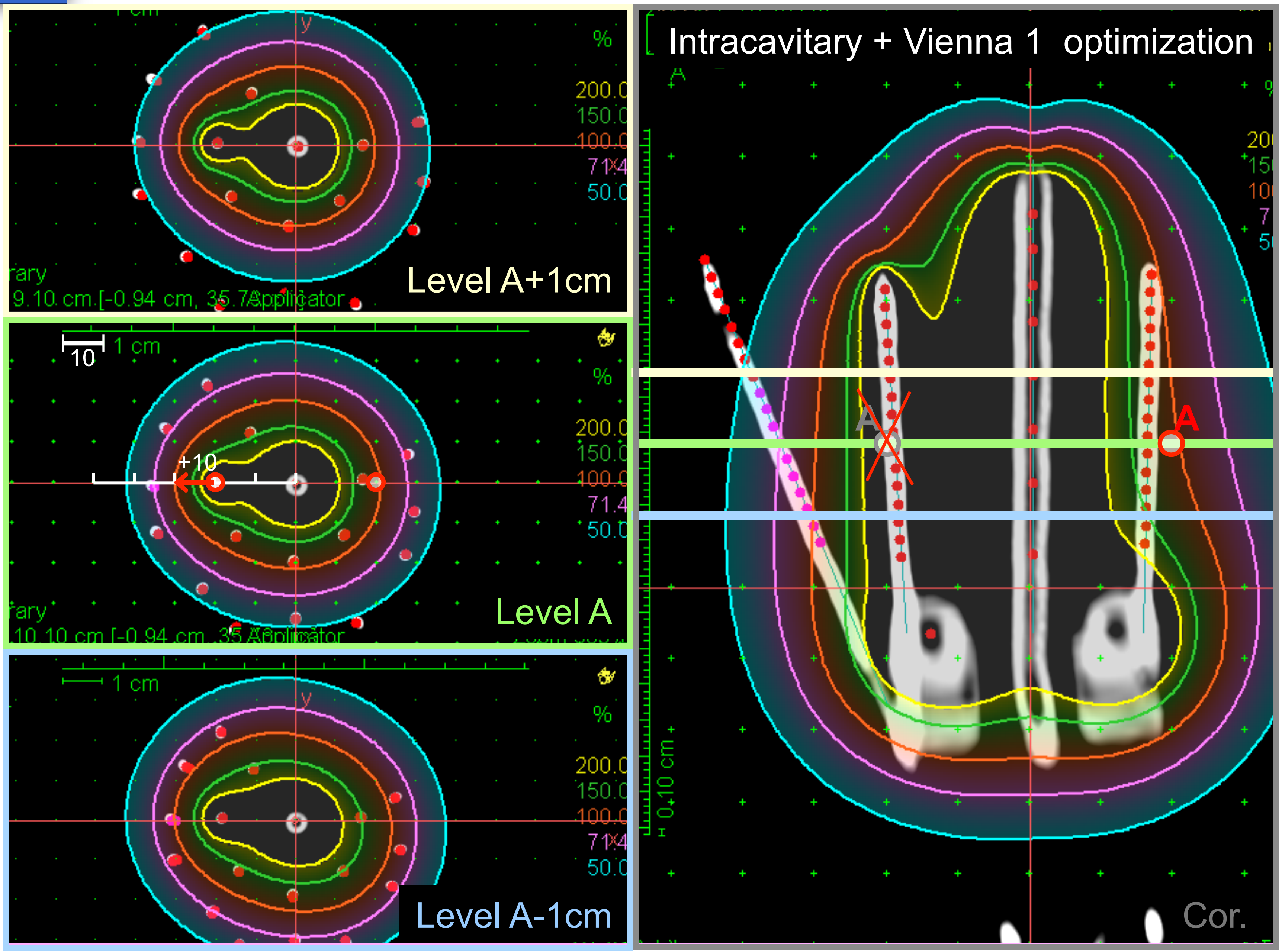
Level A+1cm
Level A
Level A-1cm
Intracavitary optimization
A
A
Cor.
1 cm
%
200.0
150.0
100.0
71.4
50.0



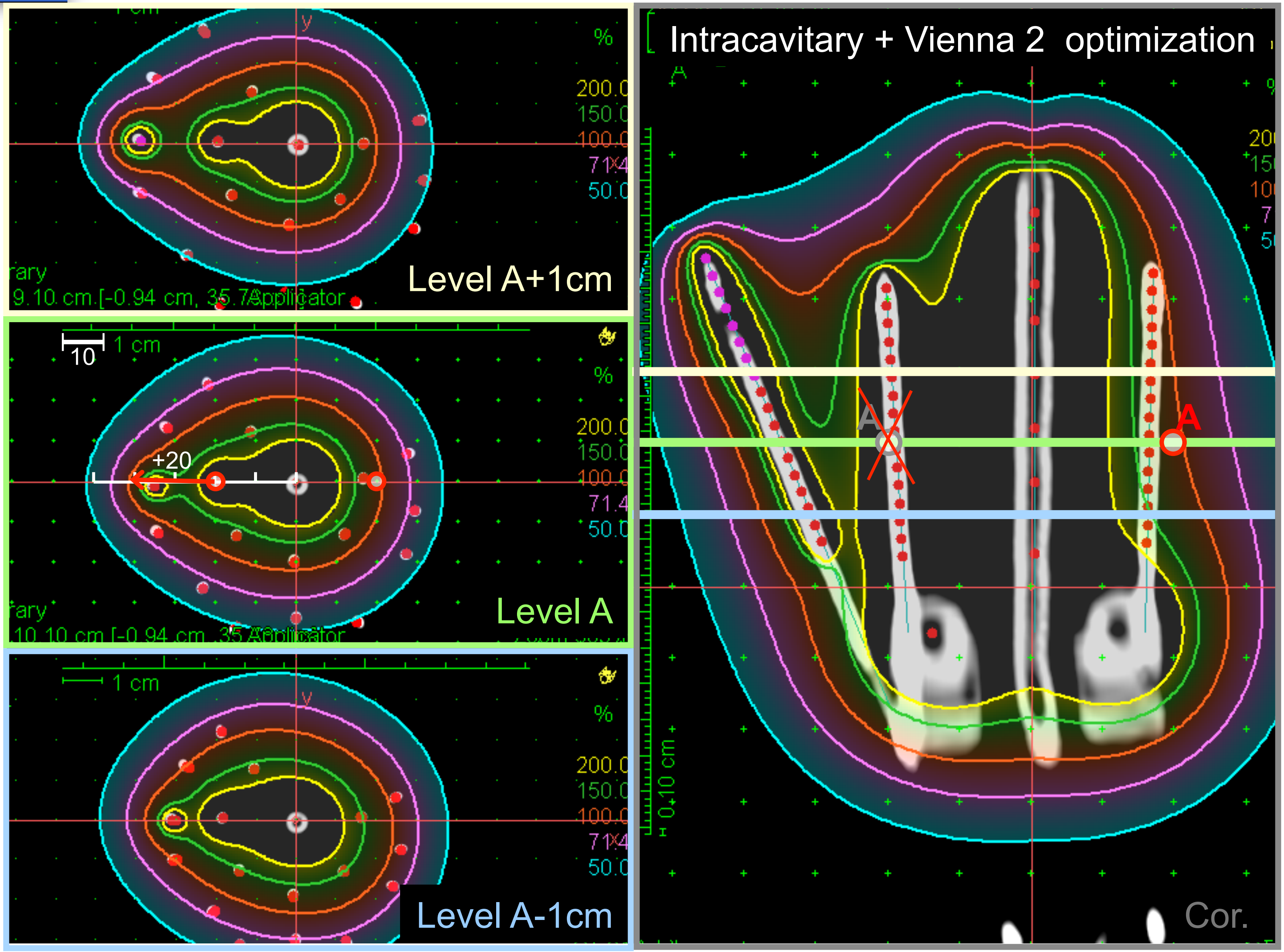
IAEA
Level A+1cm
Level A
Level A-1cm
Intracavitary optimization
A
A
Cor.
1 cm
10
200.0
150.0
100.0
71.4
50.0
%



Level A+1cm
Level A
Level A-1cm
Intracavitary optimization
A
A
Cor.



Intracavitary + Vienna 1 optimization
Level A+1cm
Level A
Level A-1cm
1 cm
10
+10
%
200.0
150.0
100.0
71.4
50.0
A
A
Cor.

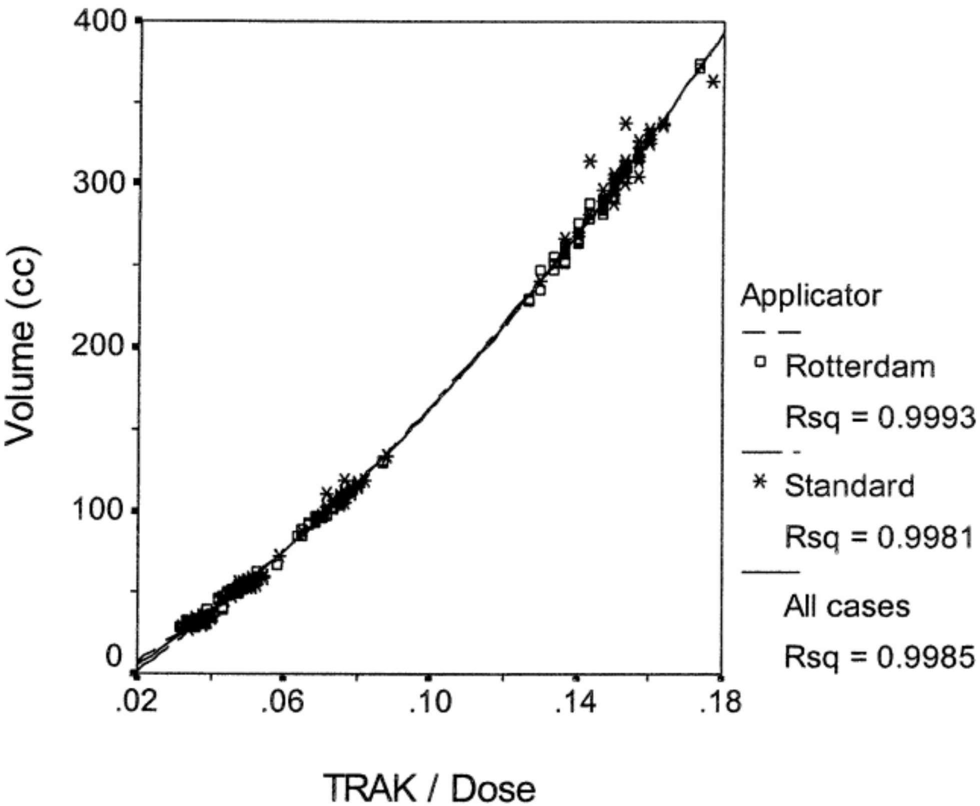

Intracavitary + Vienna 2 optimization
Level A+1cm
Level A
Level A-1cm
1 cm
10
+20
%
200.0
150.0
100.0
71.4
50.0
A
Cor.
0.10 cm

Keep track of your TRAK! Total Reference Air Kerma

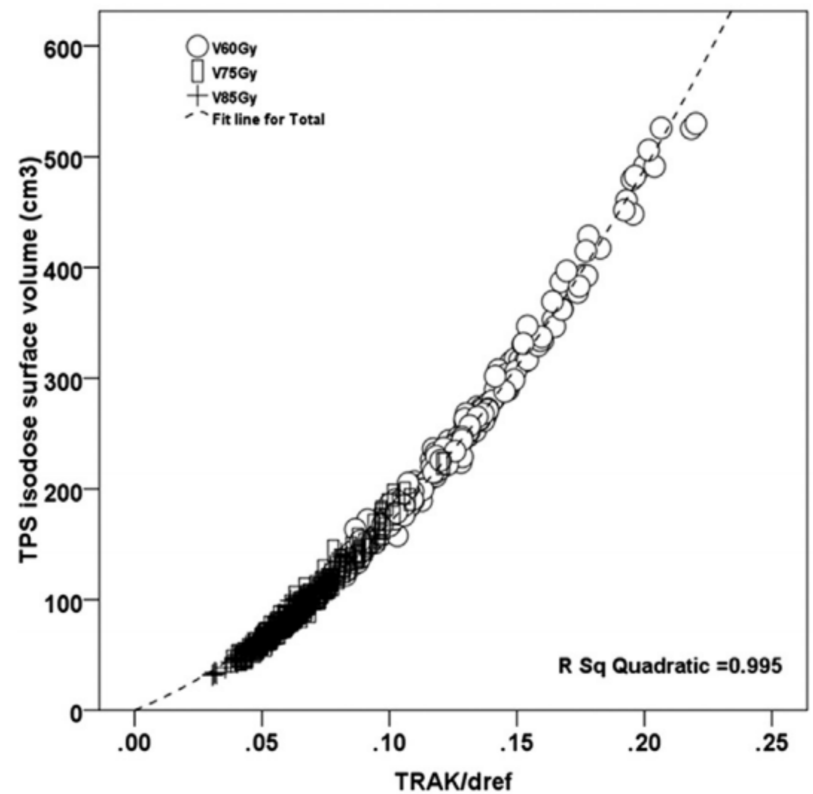
TRAK = $\sum t_i$ * RAKR

RAKR = 4.07 cGy/s (10Ci Ir-192)

$$Vref = 4965\left(\frac{TRAK}{d_{ref}}\right)^{3/2} + \left(\frac{TRAK}{d_{ref}}\right) - 1.5$$

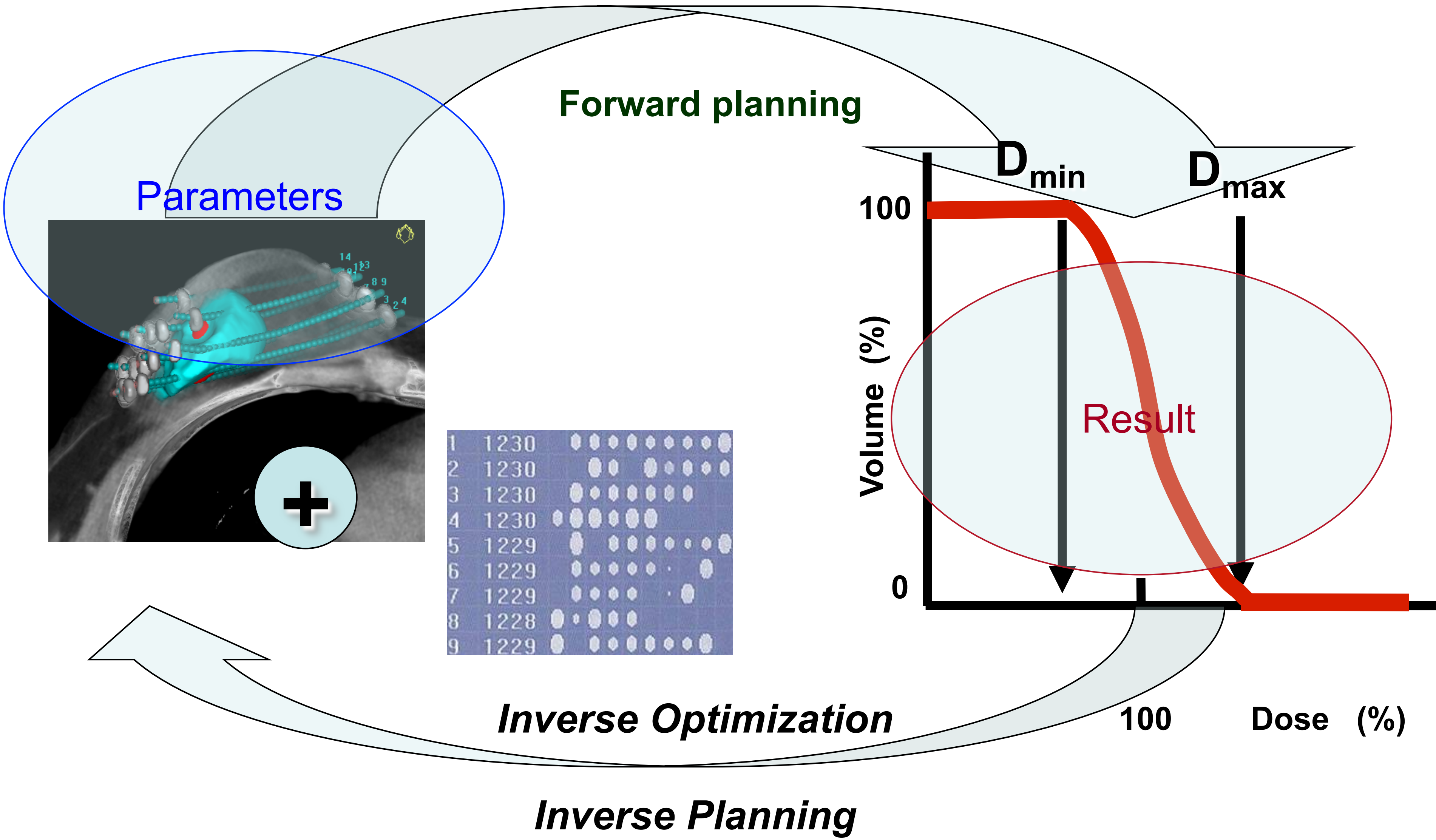


Datta et al, Brachytherapy 2:91–97, 2013



Nkiwane et al, Brachytherapy 16(6):1184-1191, 2017

Treatment Planning



Optimization

Optimization of the dose distribution through variation of the time the source dwells at each dwell position

Relative dwell weights

Normalization point(s)

Absolute dwell weights (source strength)

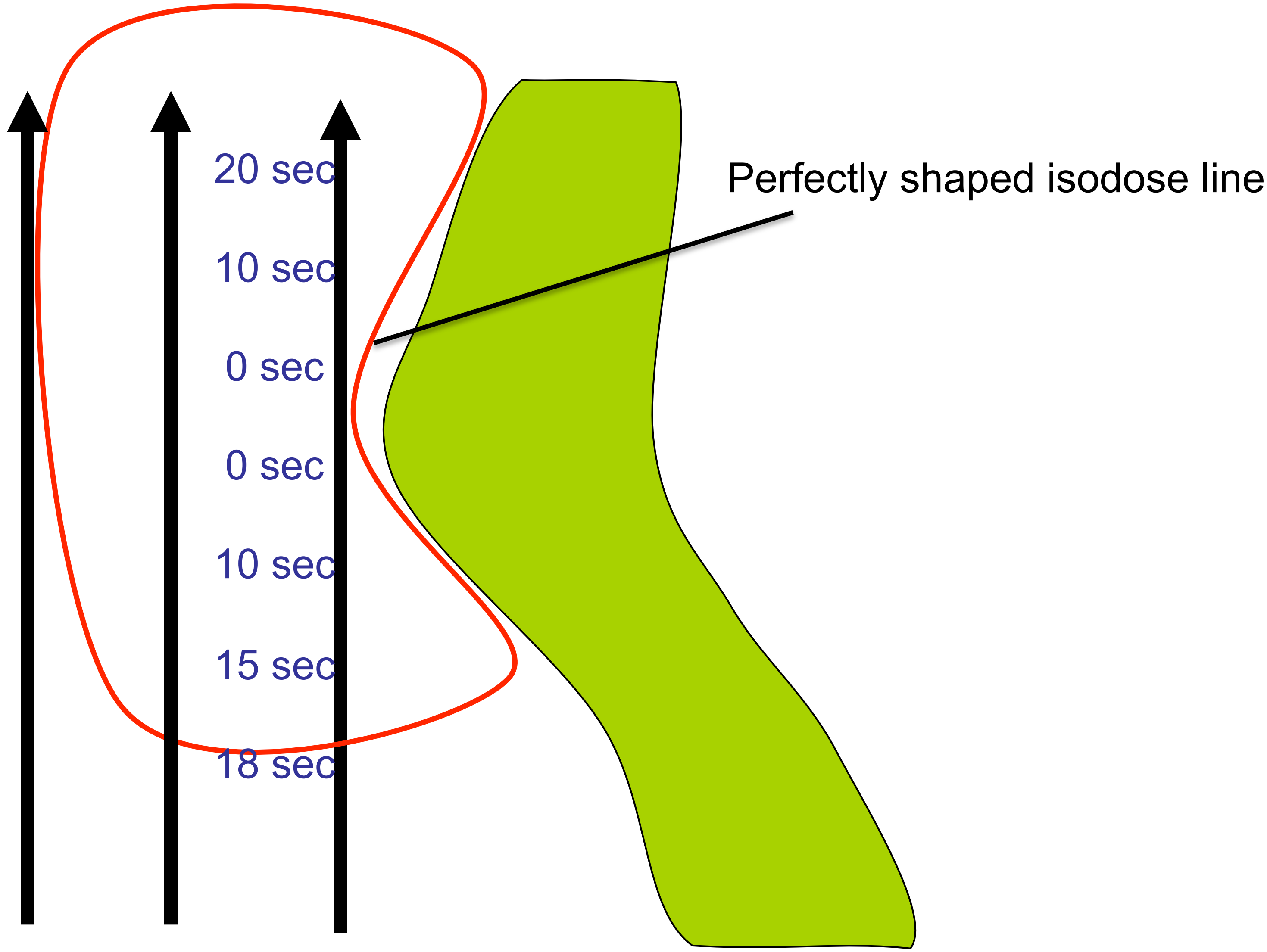
Dose point / geometric -optimization

Manual optimization

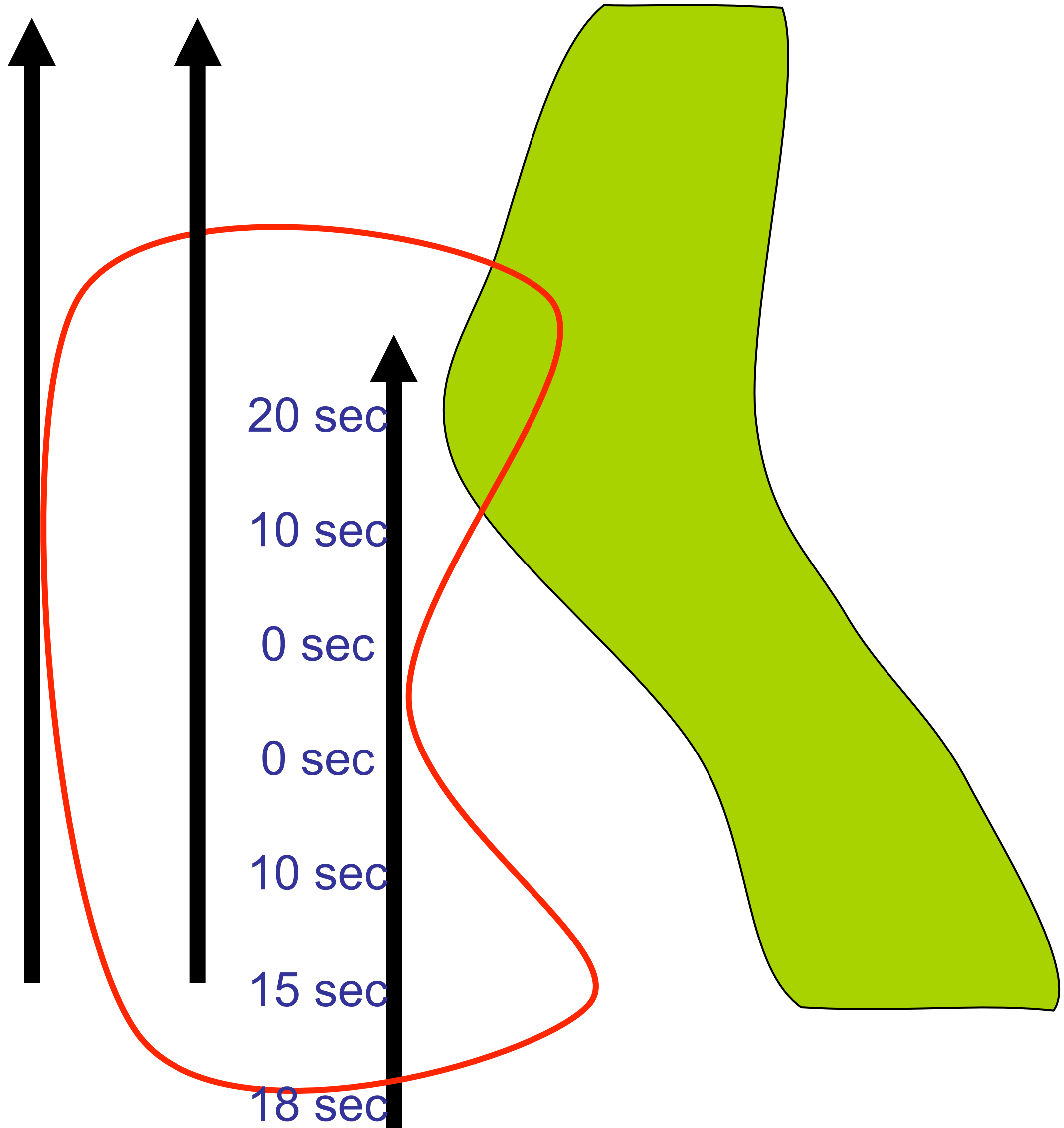
~~Graphical optimization / dose shaper~~

~~Inverse planning~~

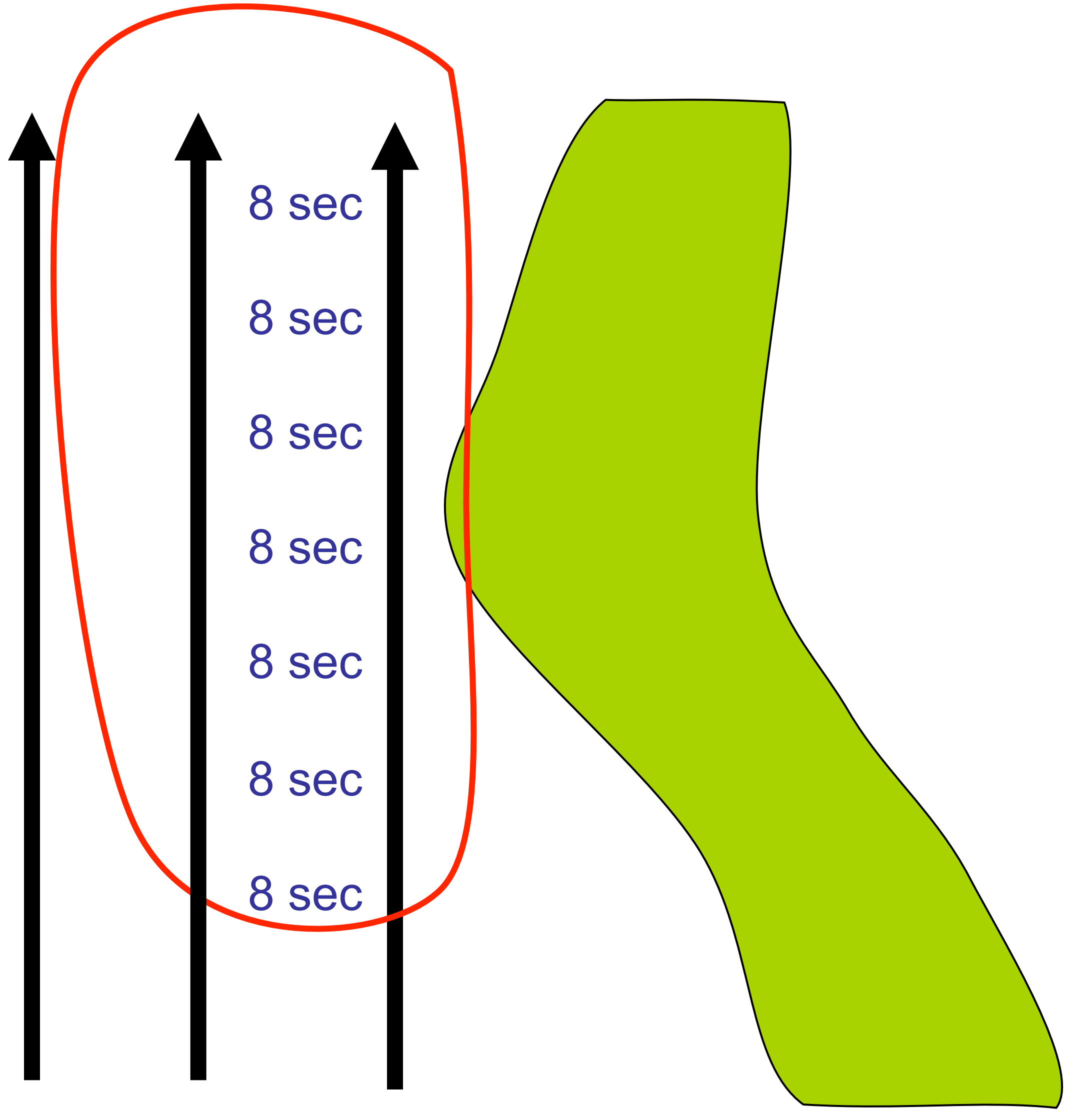
Problems when using graphical or inverse optimization/dose shaping



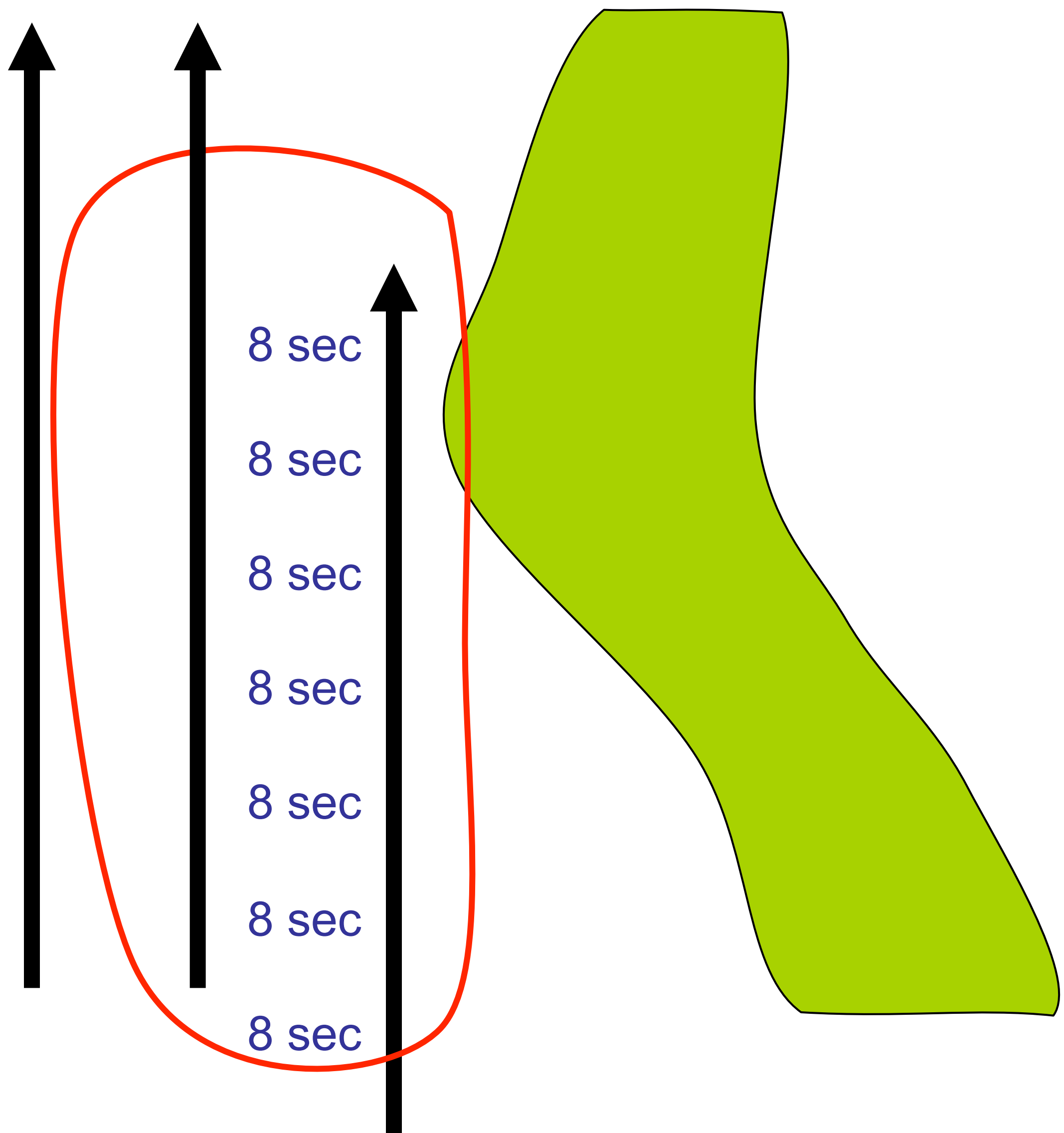
Problems when using graphical or inverse optimization/dose shaping



Problems when using graphical or inverse optimization/dose shaping

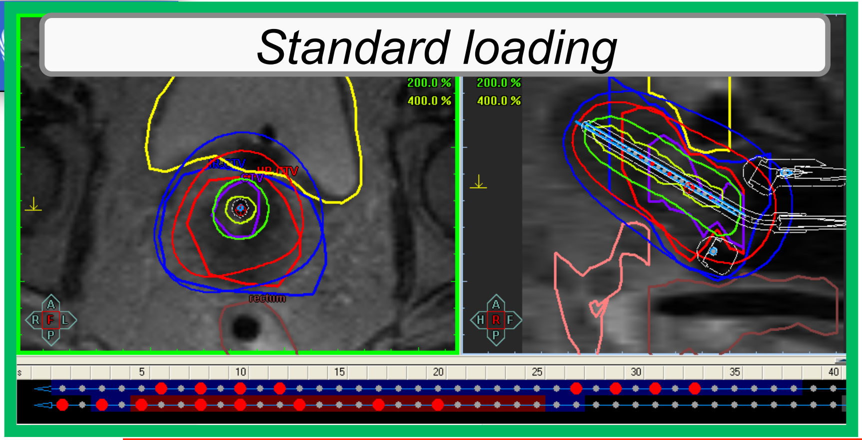


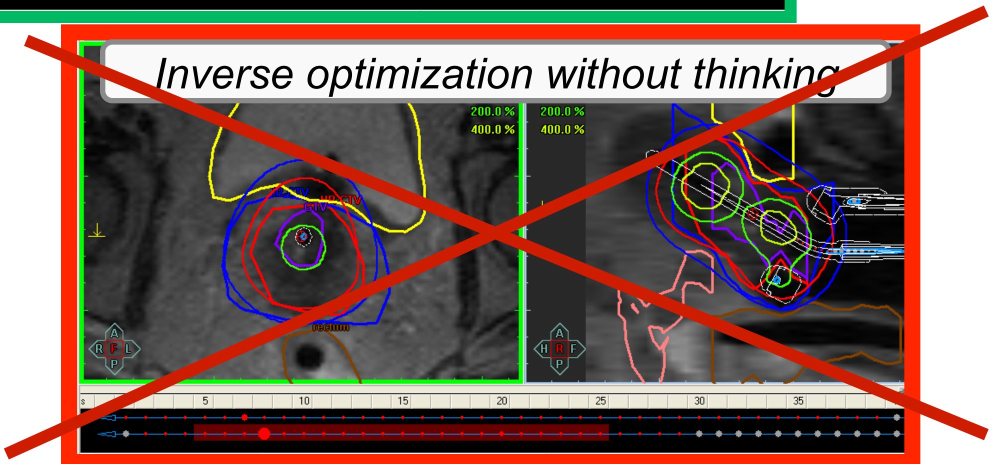
Problems when using graphical or inverse optimization/dose shaping

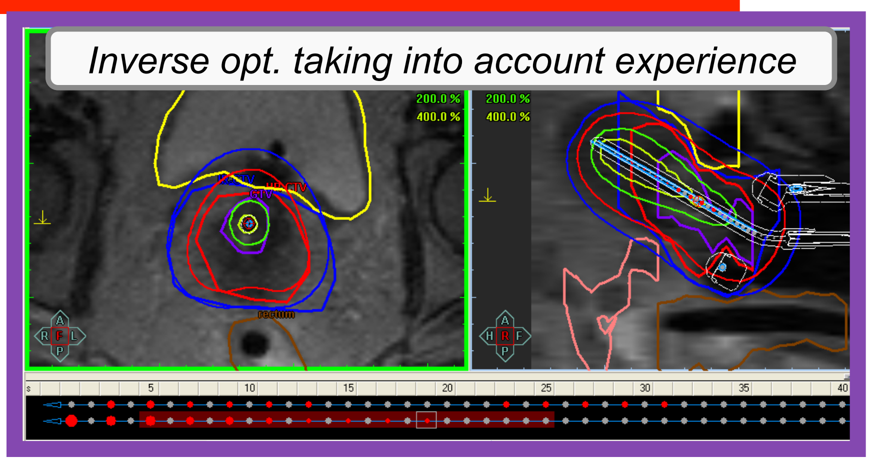


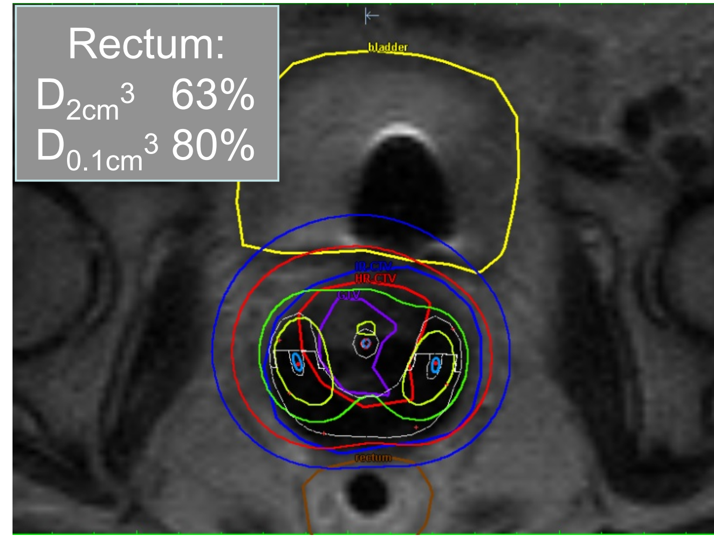
Be Careful with inverse optimizer in GYN

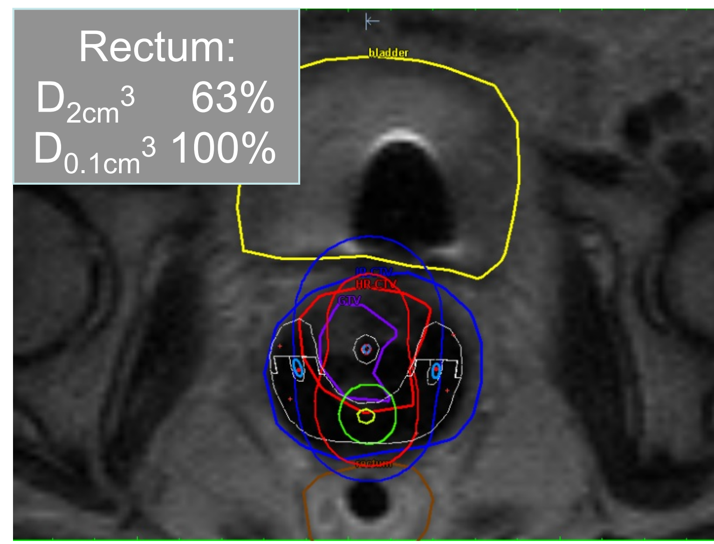
Limited parameter set and dose constraints





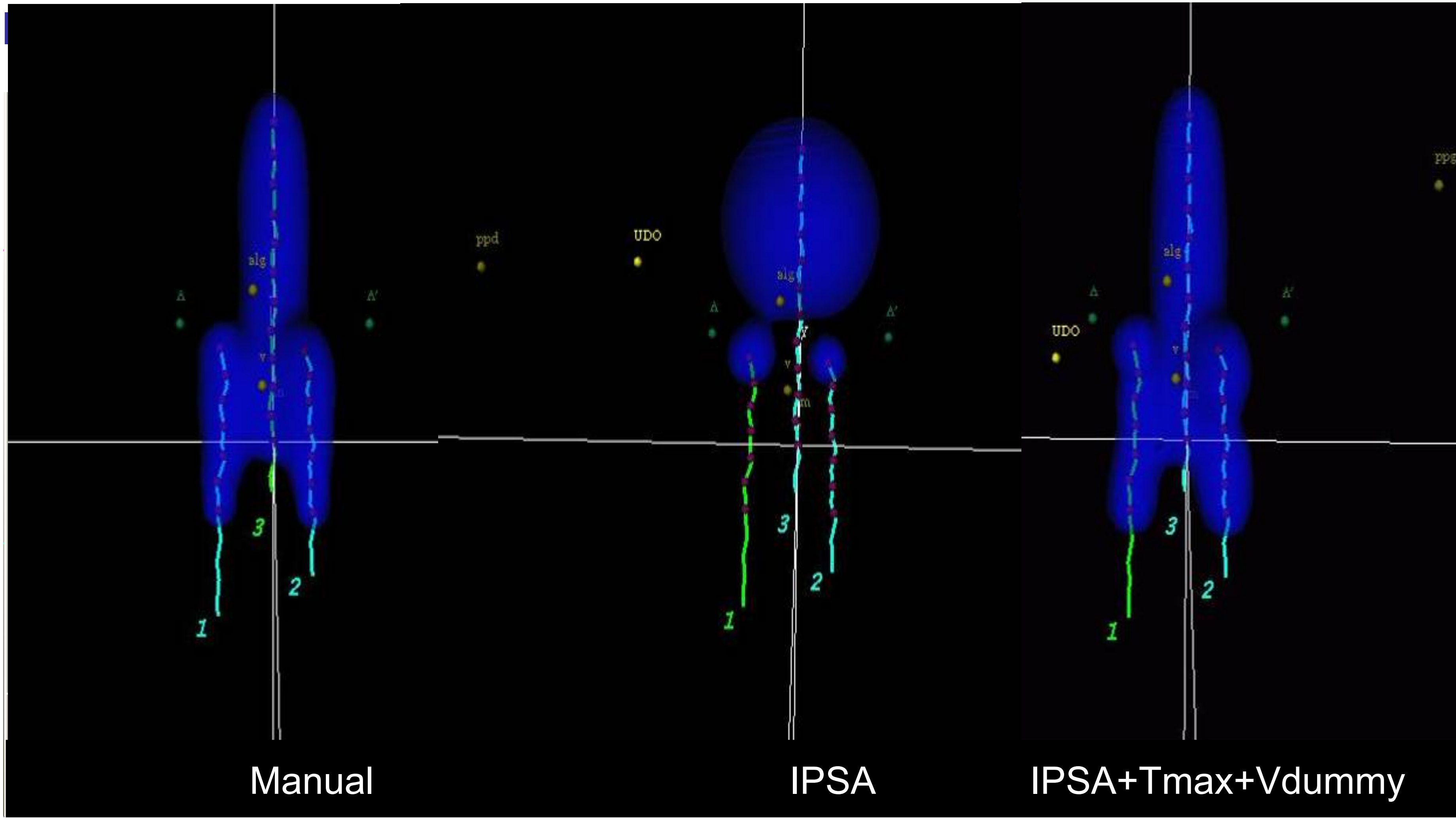






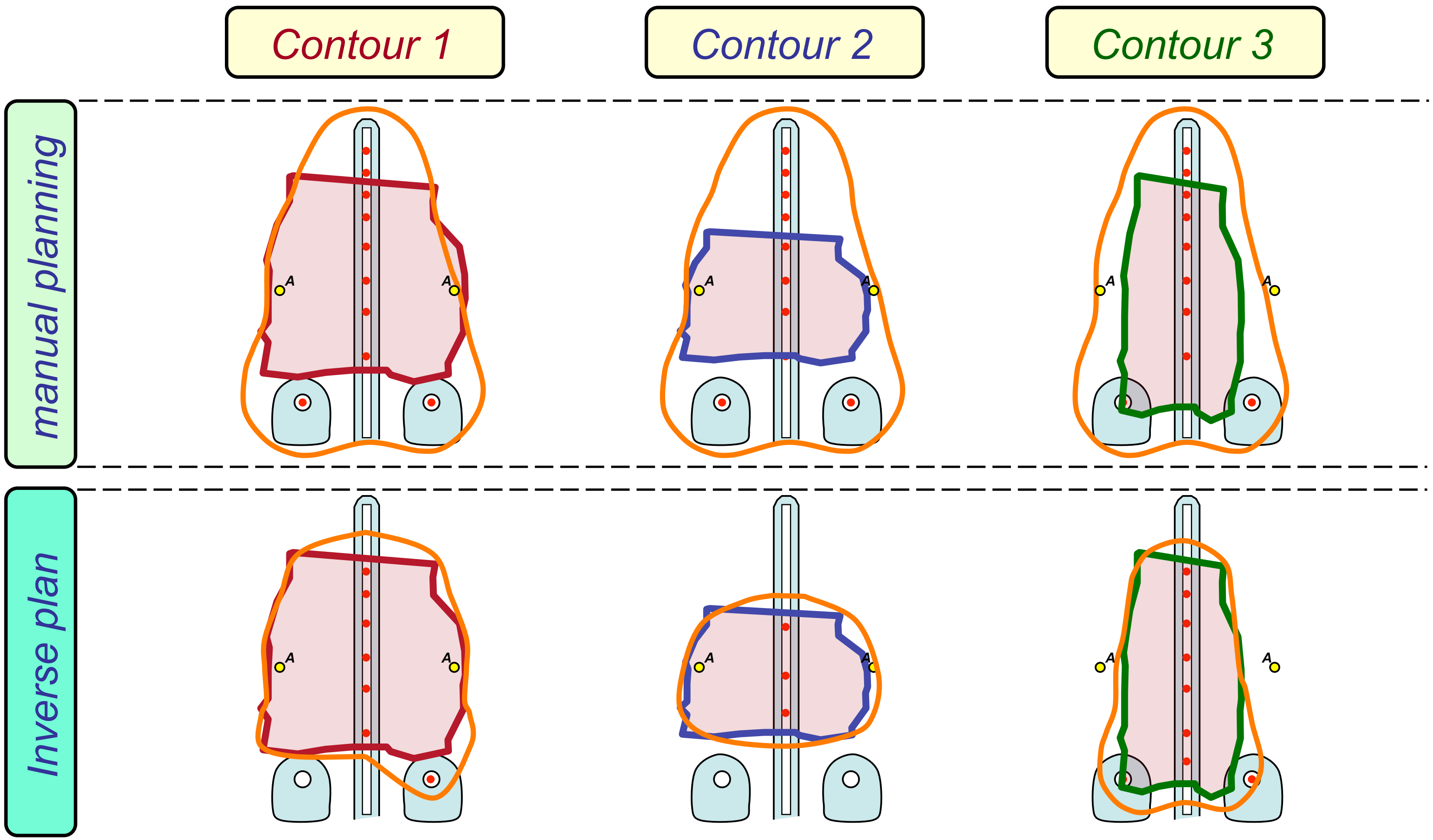
Images provided by C. Kirisits   Jamema SV et al 2010   Trnková P et al 2009

Inverse Optimisation



Int.J Radiat Oncol Biol Phys. 2007 Nov 1;69(3):955-61.
Inverse planning approach for 3-D MRI-based pulse-dose rate intracavitary brachytherapy in cervix cancer.
Chajon E, Dumas I, Touleimat M, Magné N, Coulot J, Verstraet R, Lefkopoulos D, Haie-Meder C.

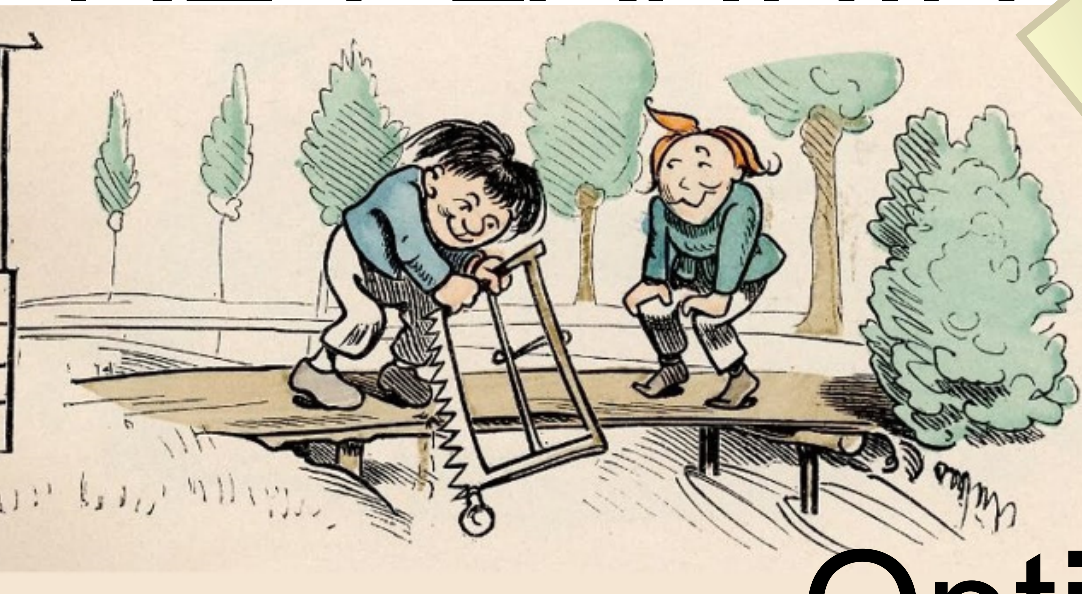
Pitfalls when using Inverse Planning: the plan will be adapted to the contour



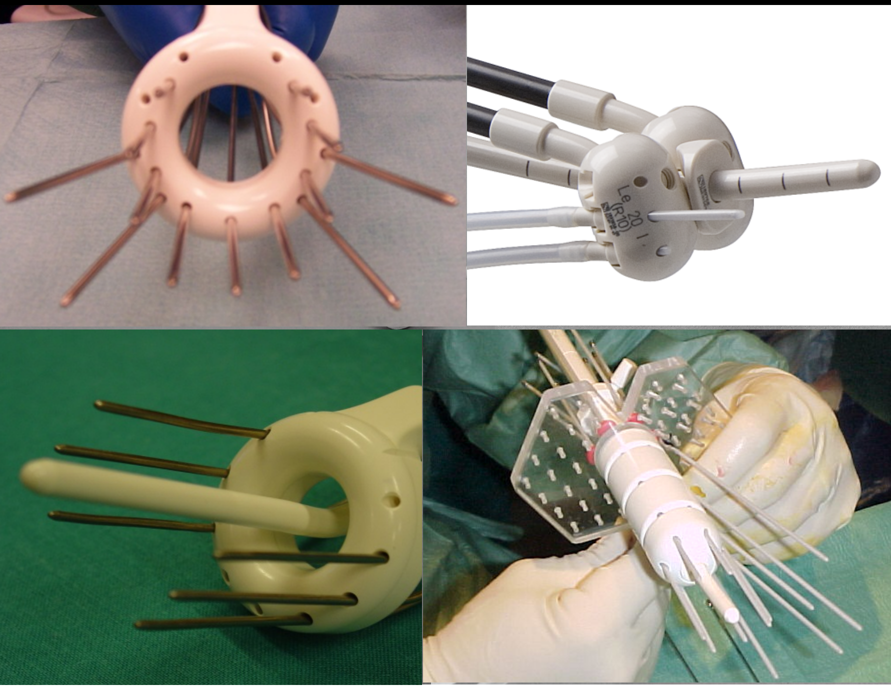
Conclusion – optimisation techniques

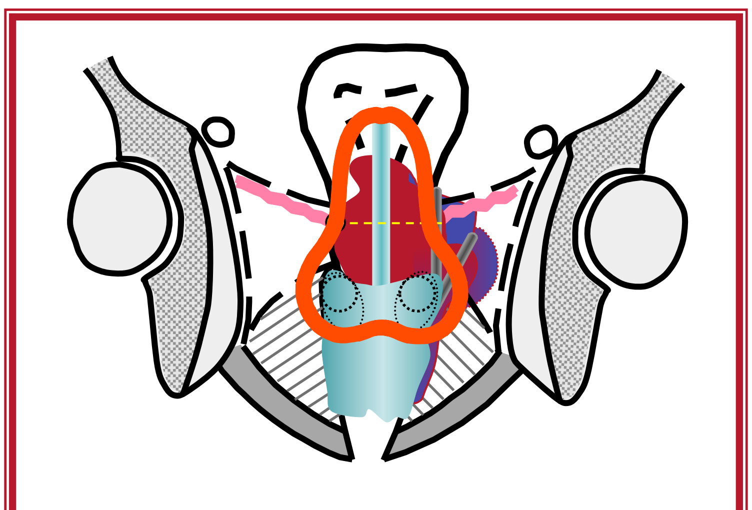
Manual	**Conservative and "safe"** **Iterative procedure** **Dependent on experience of dose planner**
Graphical	**Fast for small adaptations and fine tuning after manual opt** **Beware of:** **-dwell times** **-deviations from standard loading**
Inverse	**Fast** **Requires extra contouring + manual adaptations** **Beware of:** **-dwell times** **-high dose regions** **-dose to non-contoured tissue** **-deviations from standard loading**

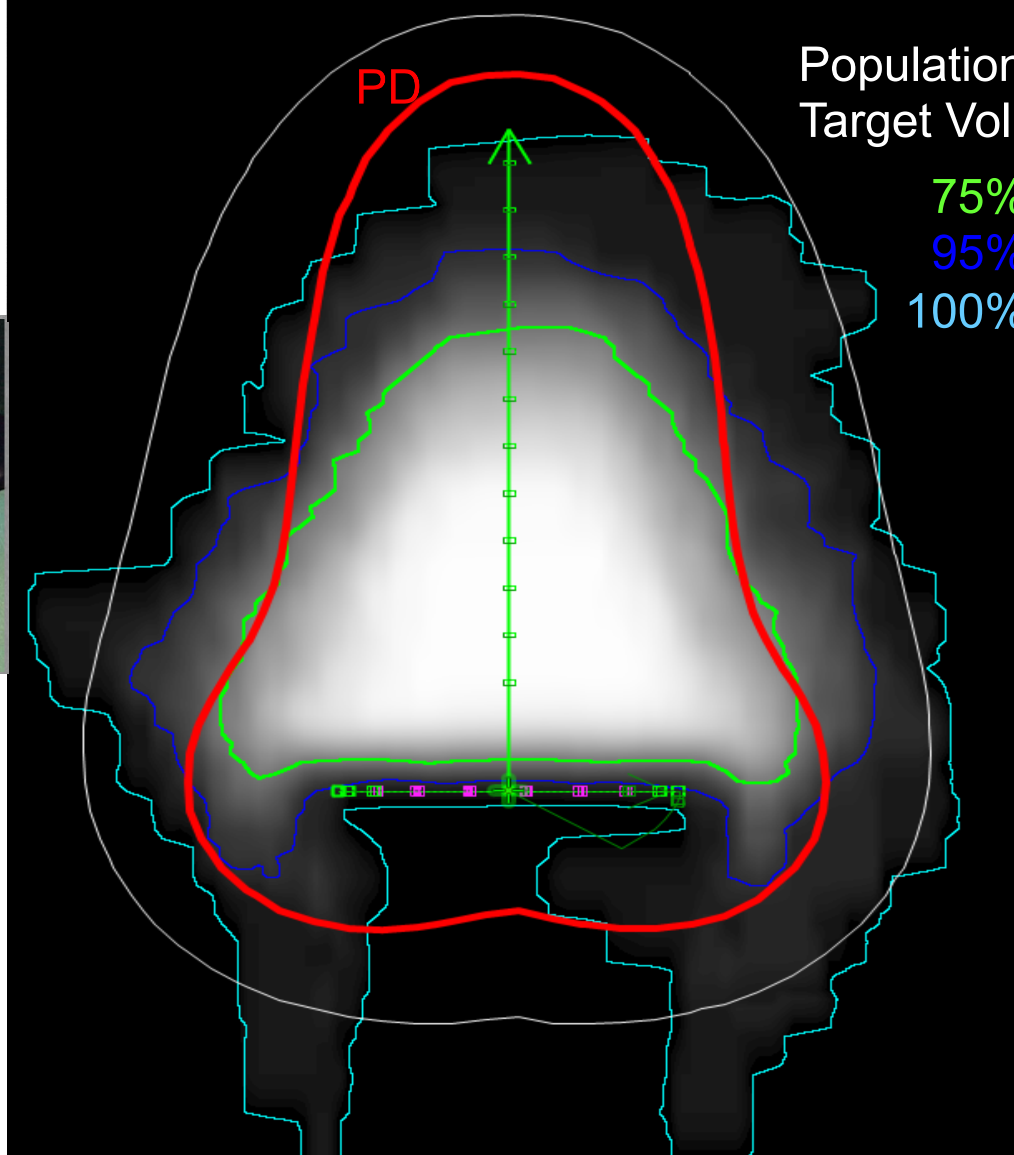
PRE-PLANNING



Optimal solution

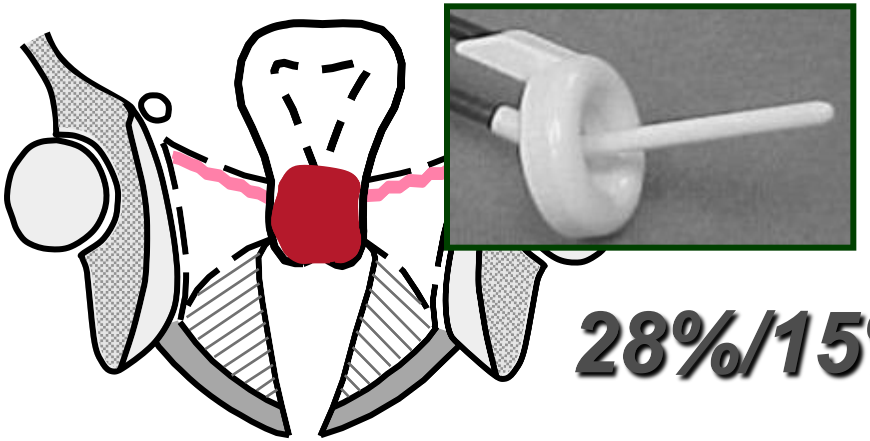






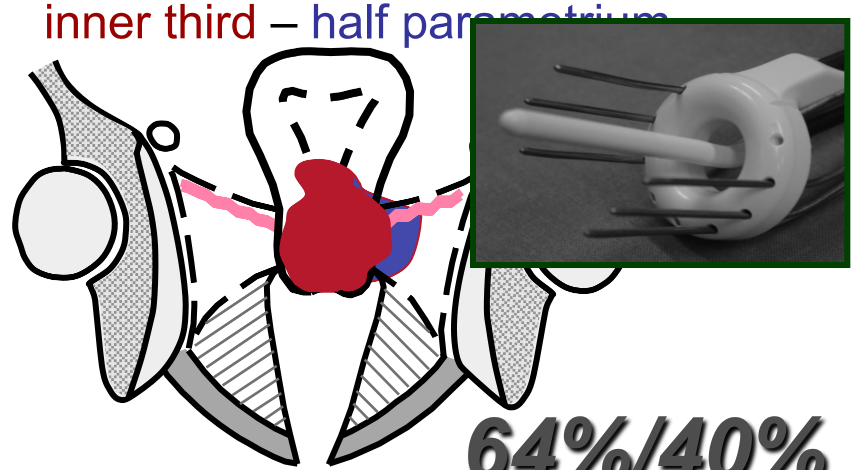
Petric P, et al. GEC ESTRO, Porto 2009, Supported by Varian

Tumour limited to cervix



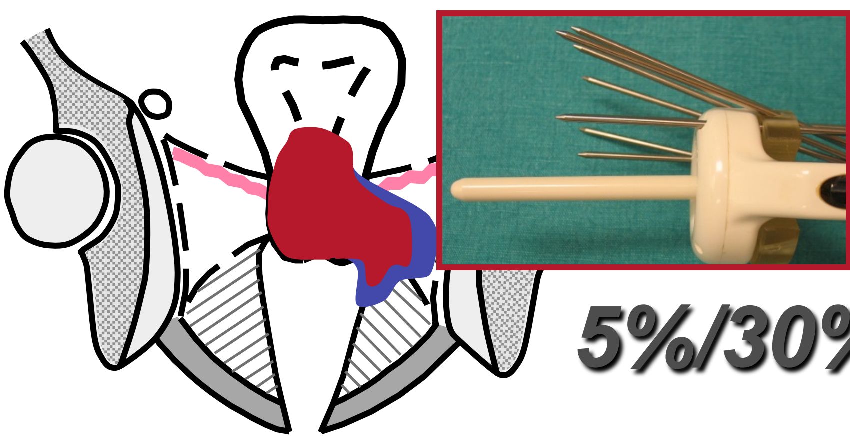
28%/15%

Cervical tumour with parametrial infiltration
inner third – half par



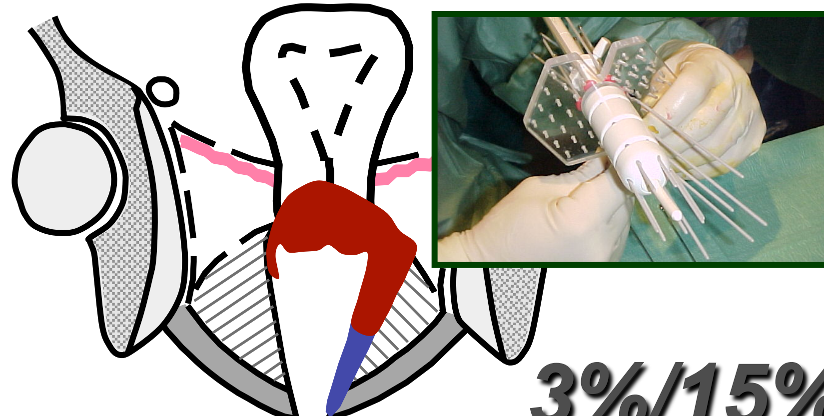
64%/40%

Cervical tumour with parametrial infiltration
half parametrium – pelvic wall



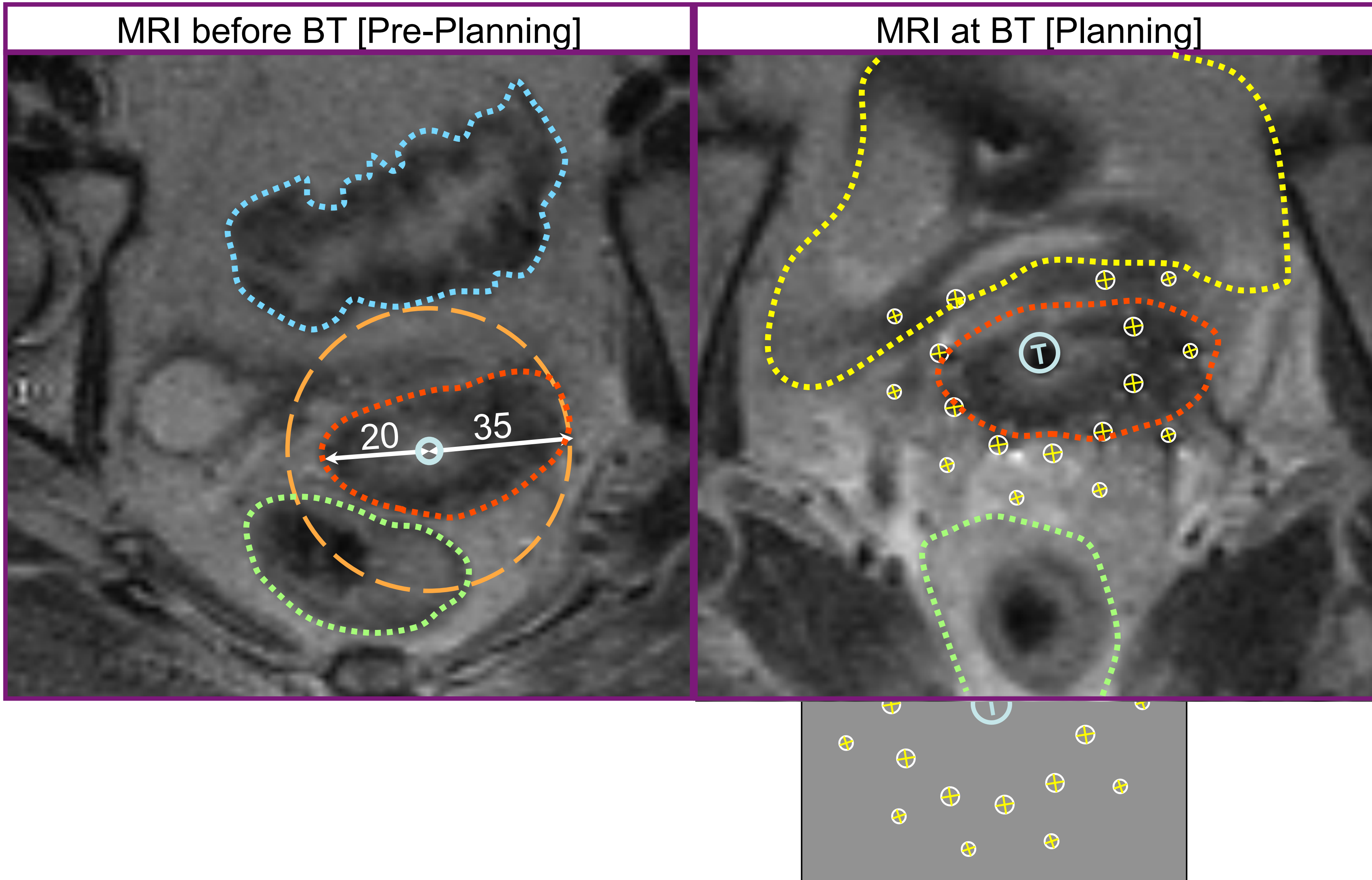
5%/30%

Cervical tumour with vaginal infiltration
upper half parametrium– distal vagina

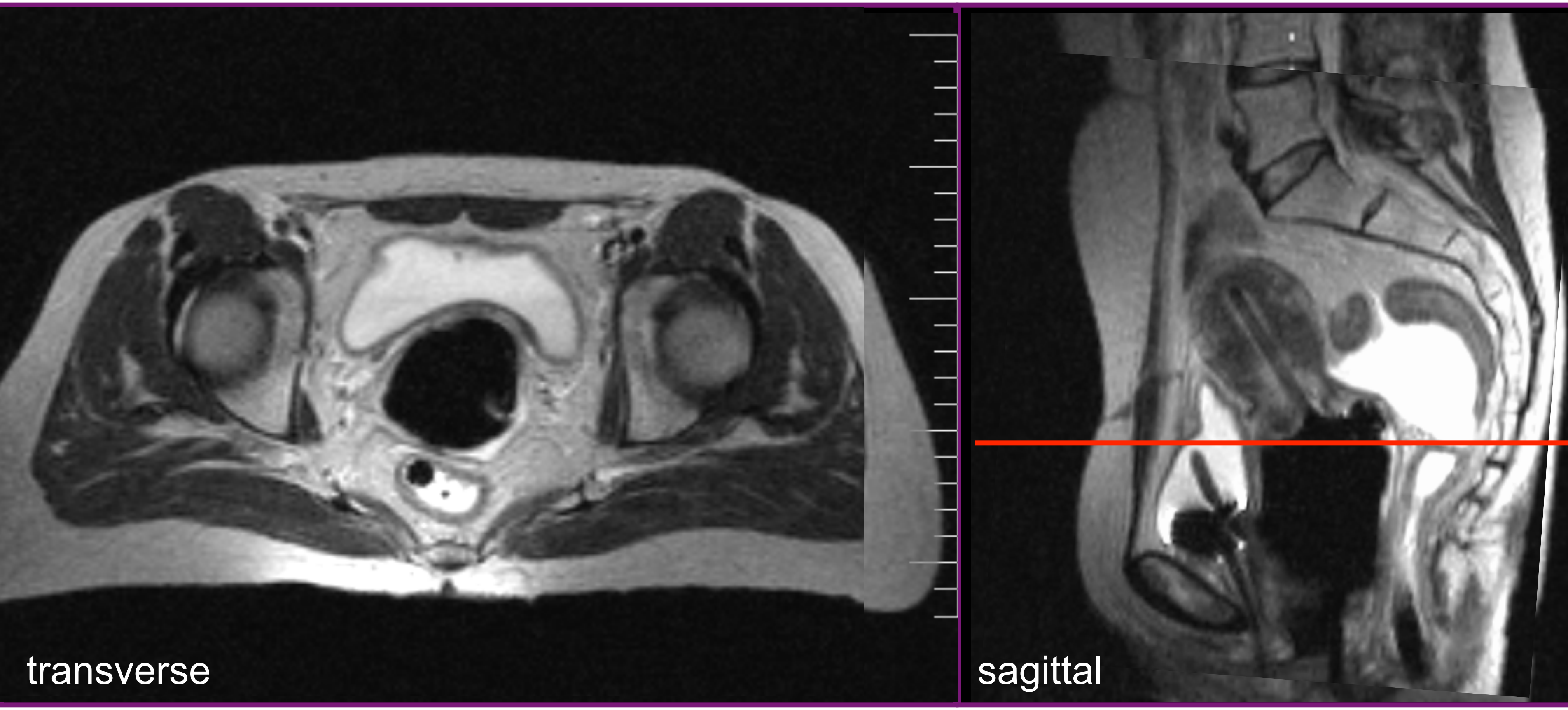


3%/15%

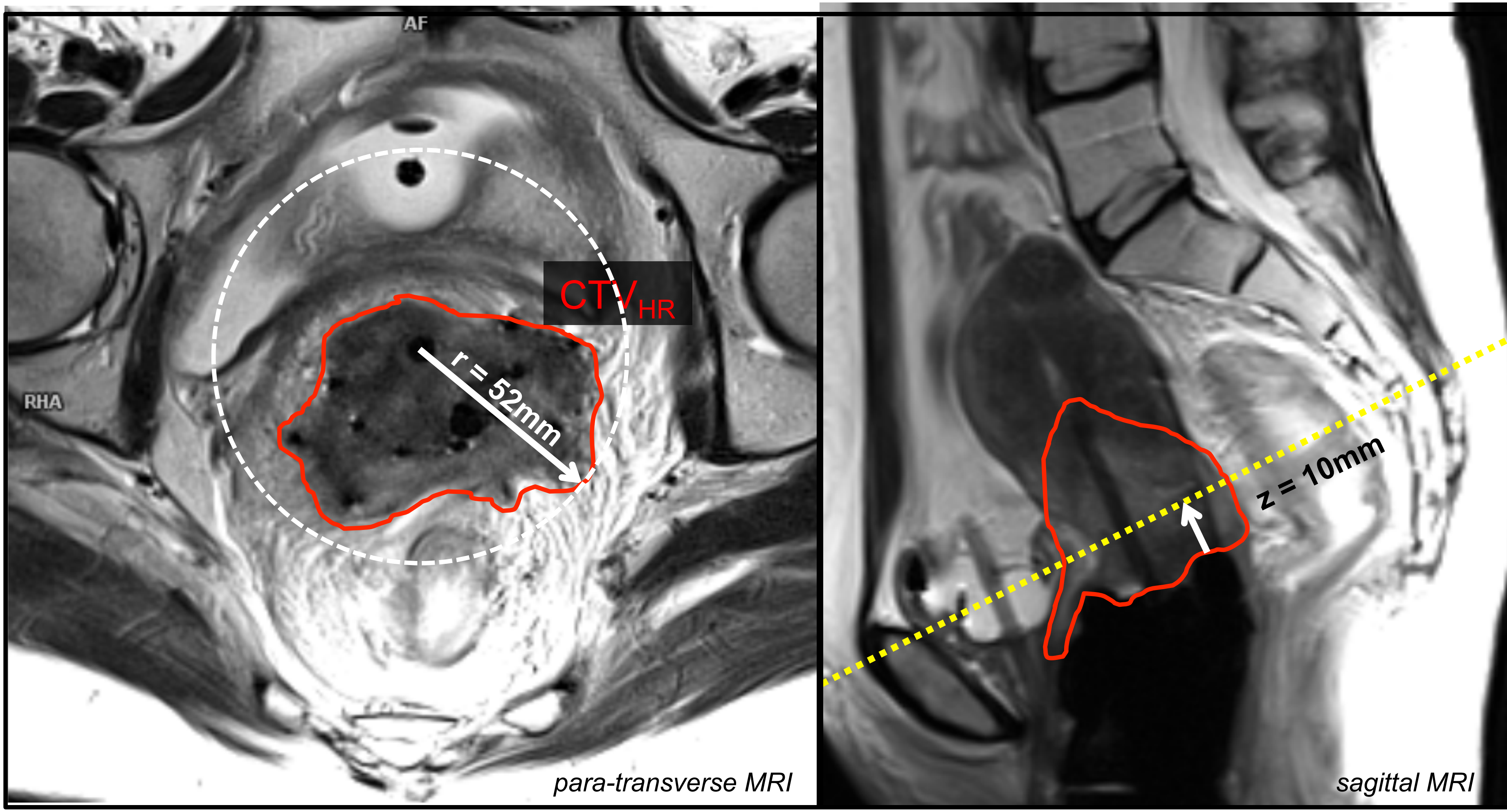
Frequency of tumor seen at BT for Europe/Asia


MRI before BT [Pre-Planning]
MRI at BT [Planning]
20
35
T

before during brachytherapy

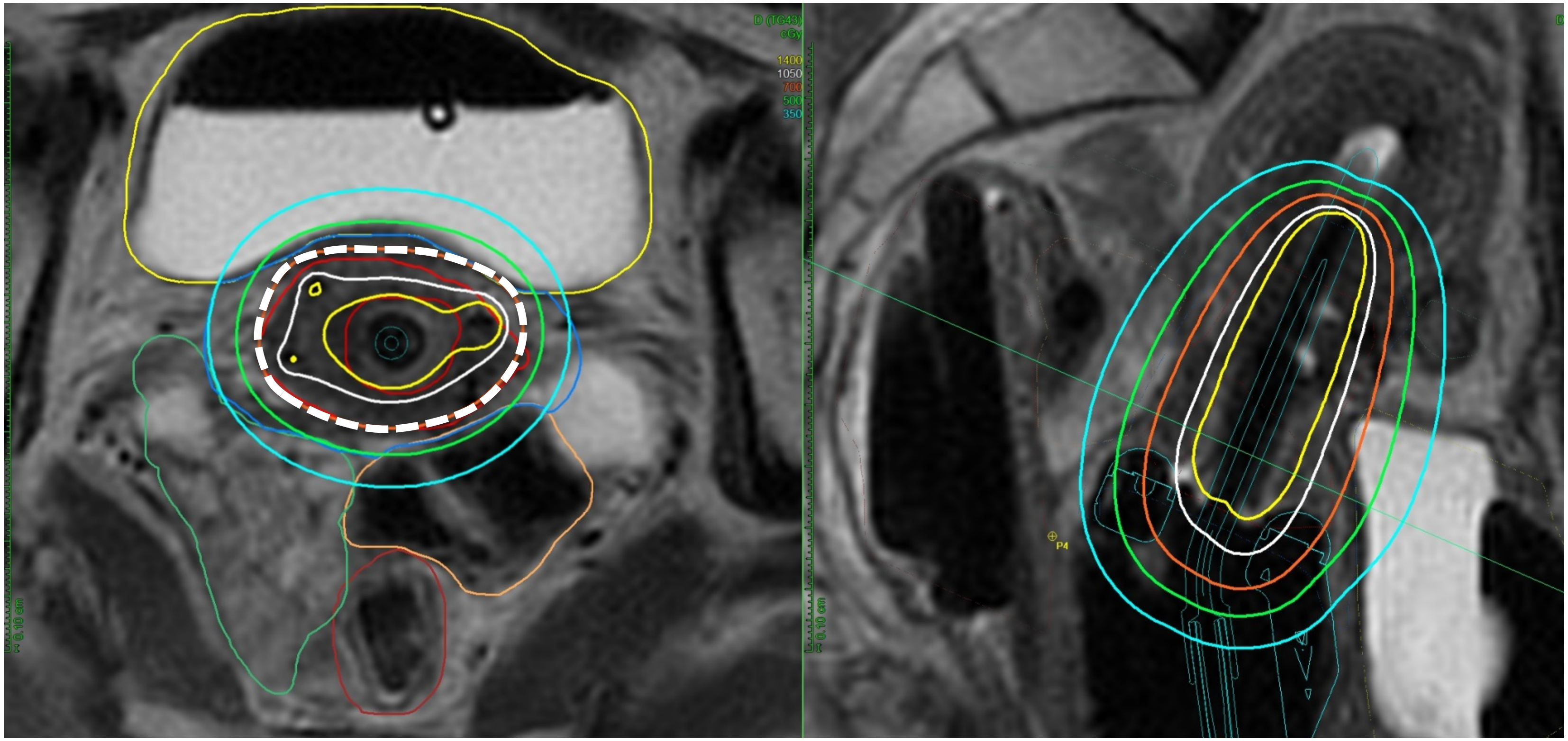


Definition of a new indicator for Preplanning is the Maximum Distance to the edge of the CTV_{HR}

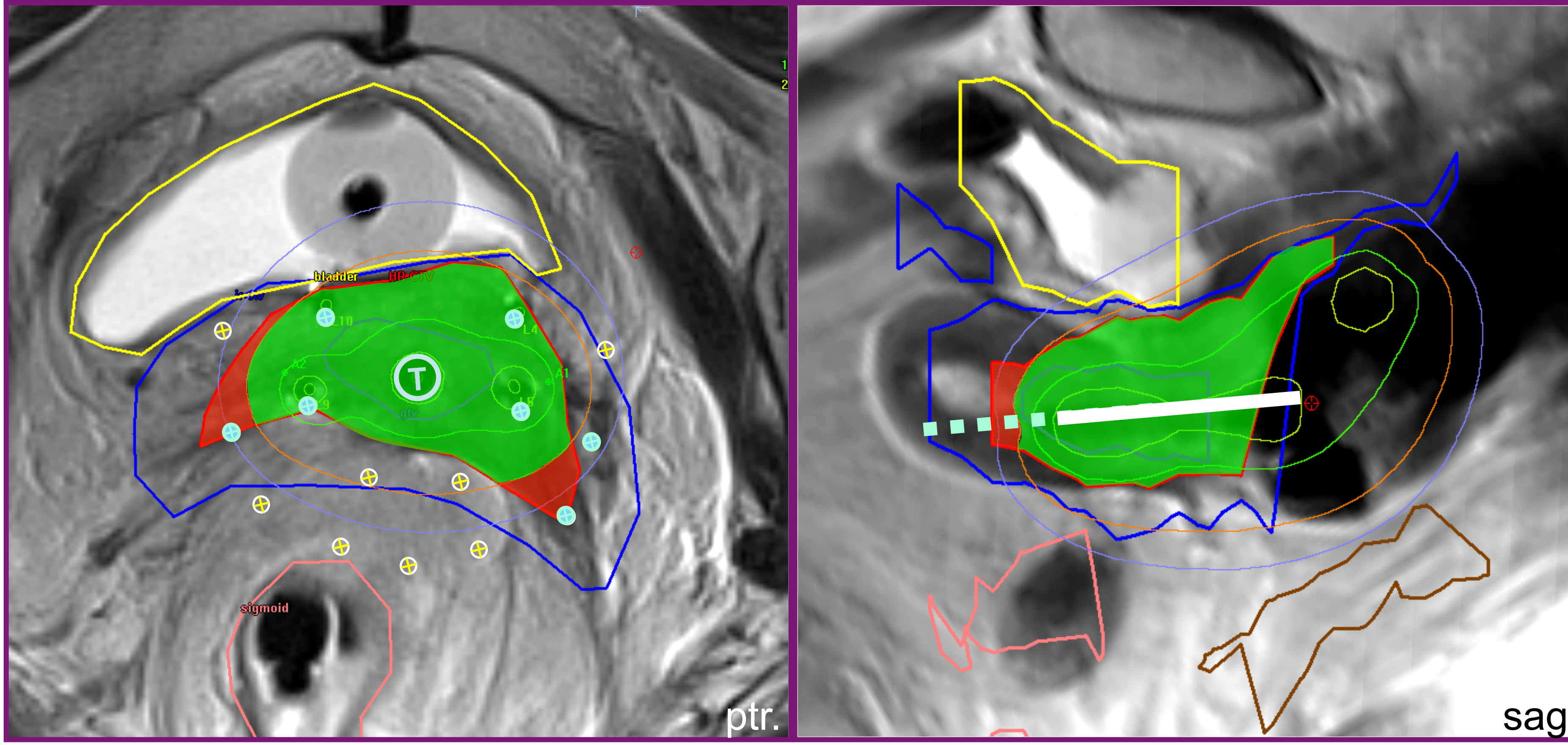


Picture taken from D.Berger et al. Vienna II applicator , to be published soon

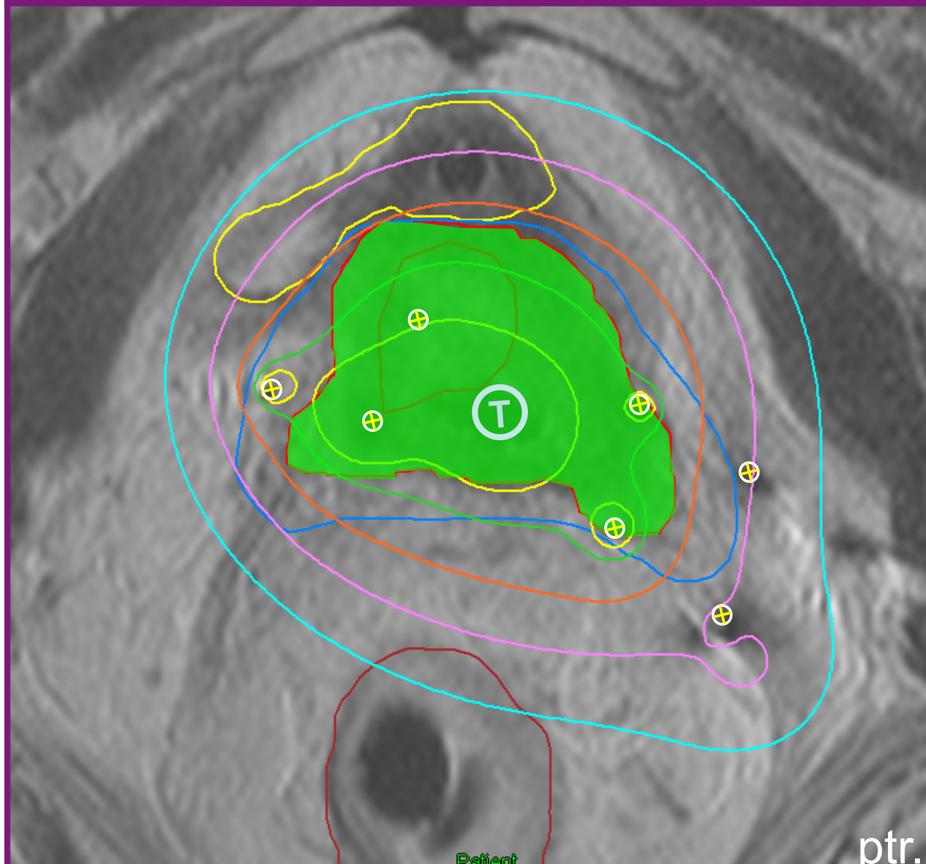
Definition of a new indicator for Preplanning is the Maximum Distance to the edge of the CTV_{HR}

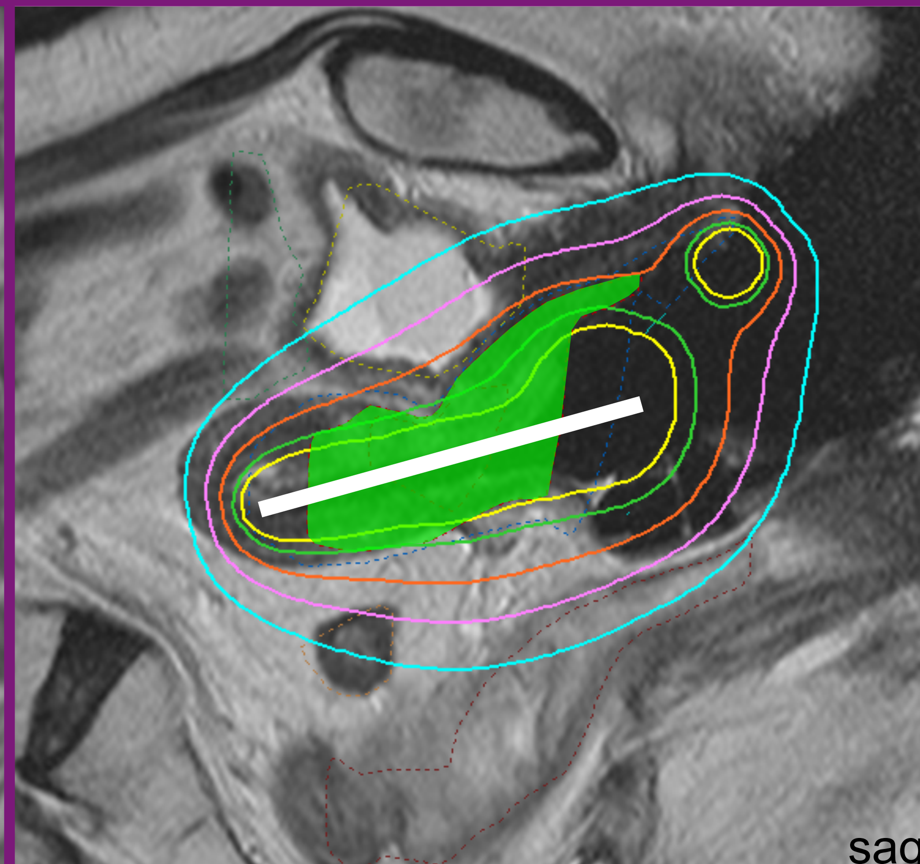


Pre-Planning using information from the 1st Brachytherapy Implant



Achieving from the 1st BT Implant an improved 2nd BT Implant





Prescribing, Recording and reporting: GEC ESTRO and ICRU 89

GEC ESTRO recommendations II

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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Journal of the ICRU

ICRU REPORT 89

Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix

OXFORD UNIVERSITY PRESS

INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

Need for common terminology according to ICRU reports on proton treatment and IMRT

- **Planning aim**
  - Set of dose and dose/volume constraints for a treatment
- **Prescribed dose**
  - Finally accepted treatment plan (which is assumed to be delivered to an individual patient)
- **Delivered dose**
  - Actually delivered dose to the individual patient

Evaluation / Reporting

2D — Clinical GYN examination, Radiographic imaging (w/o add. 3D Imaging at time of diagnosis)

3D — Clinical GYN examination, Volumetric imaging (MRI,CT,US,PET,CT) at time of Diagn. and BT

Level 1 **Minimum** standard for reporting

- 2D → TRAK, Point A, Bladder ref.point, Rectum ref.point
- 3D → TRAK, Point A, $D_{0.1cm^3}$, D_{2cm^3} for bladder, recum and sigmoid (bowel)

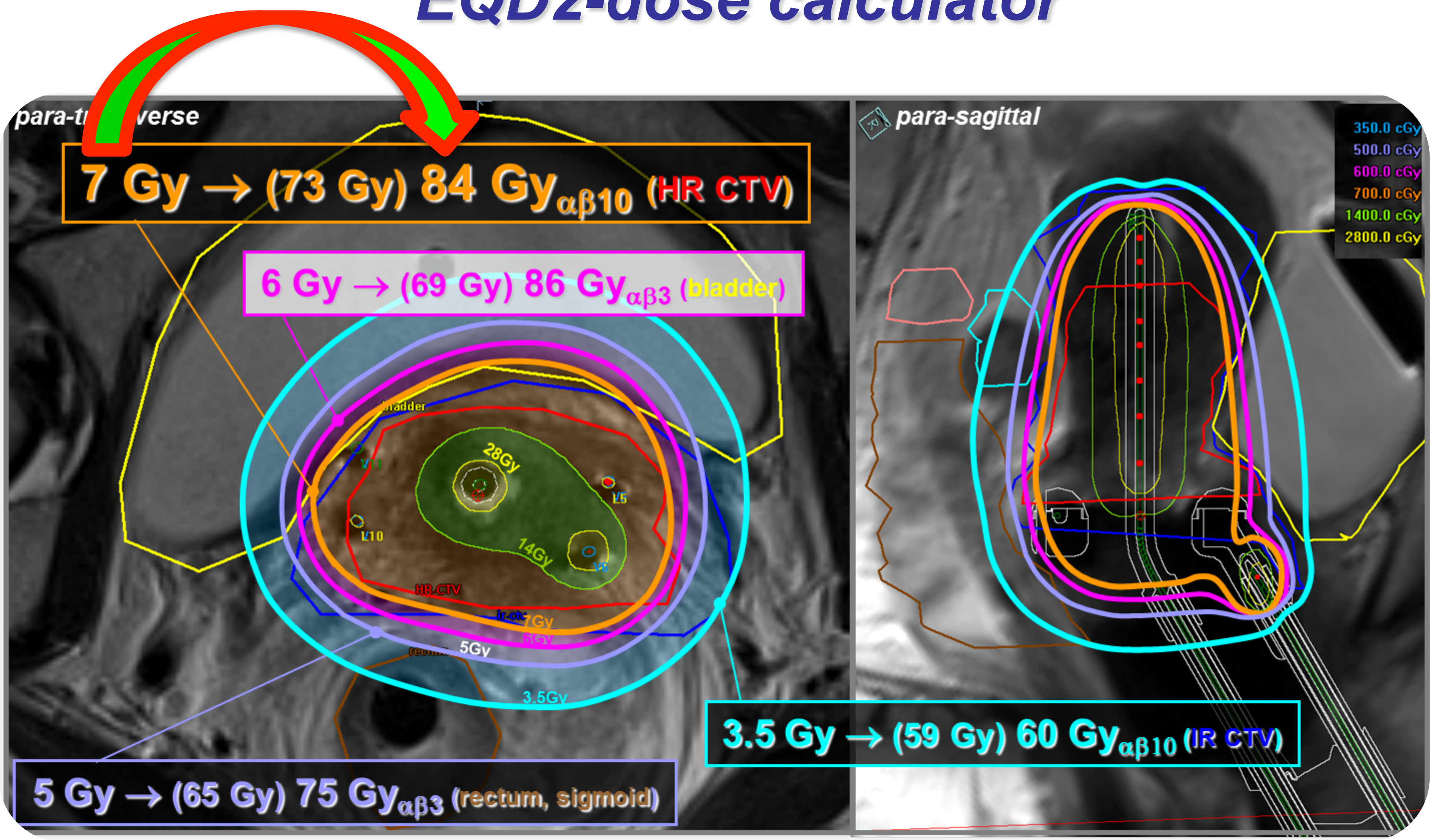
Level 2 **Advanced** standard for reporting

- 2D → Target: near minimum dose to vol. def. as CTV_{HR} according to estimated Width and Thickness — Vagina: dose points at level of sources (lat. 0mm,5mm) Low and mid vagina as an astemiate for the applied Contribution from EBRT and BT (PIBS,PIBS±2cm)
- 3D → Target: CTV_{HR} D98, D90, D50 or CTV_{IR} D98, D90 GTV at time of BT D98, patholo. Lymph nodes D98 — Vagina: dose points at level of sources (lat. 0mm,5mm) Low and mid vagina as an astemiate for the applied Contribution from EBRT and BT (PIBS,PIBS±2cm)

Level 3 **Research** oriented reporting

- 2D → Pelvic wall points Lymphatic trapezoid — Length of treated vagina (85Gy/60Gy-EQD2) Sigmoid point?, additional OAR points (e.g. anus)
- 3D → Target: CTVIR D98, D90 GTV at time of BT D90 DVH parameters for the PTV Pathological lymph nodes D50 — OAR: Baldder and rectum reference (ICRU) points Dose to OAR subvolumes and spatial distribution within OAR -> Dose-Vol. and Dose-Surface Histrograms Bladder trigonum or neck point; Anal dose point Intermediate and low dose assessment (DV and VD) Dose profiles

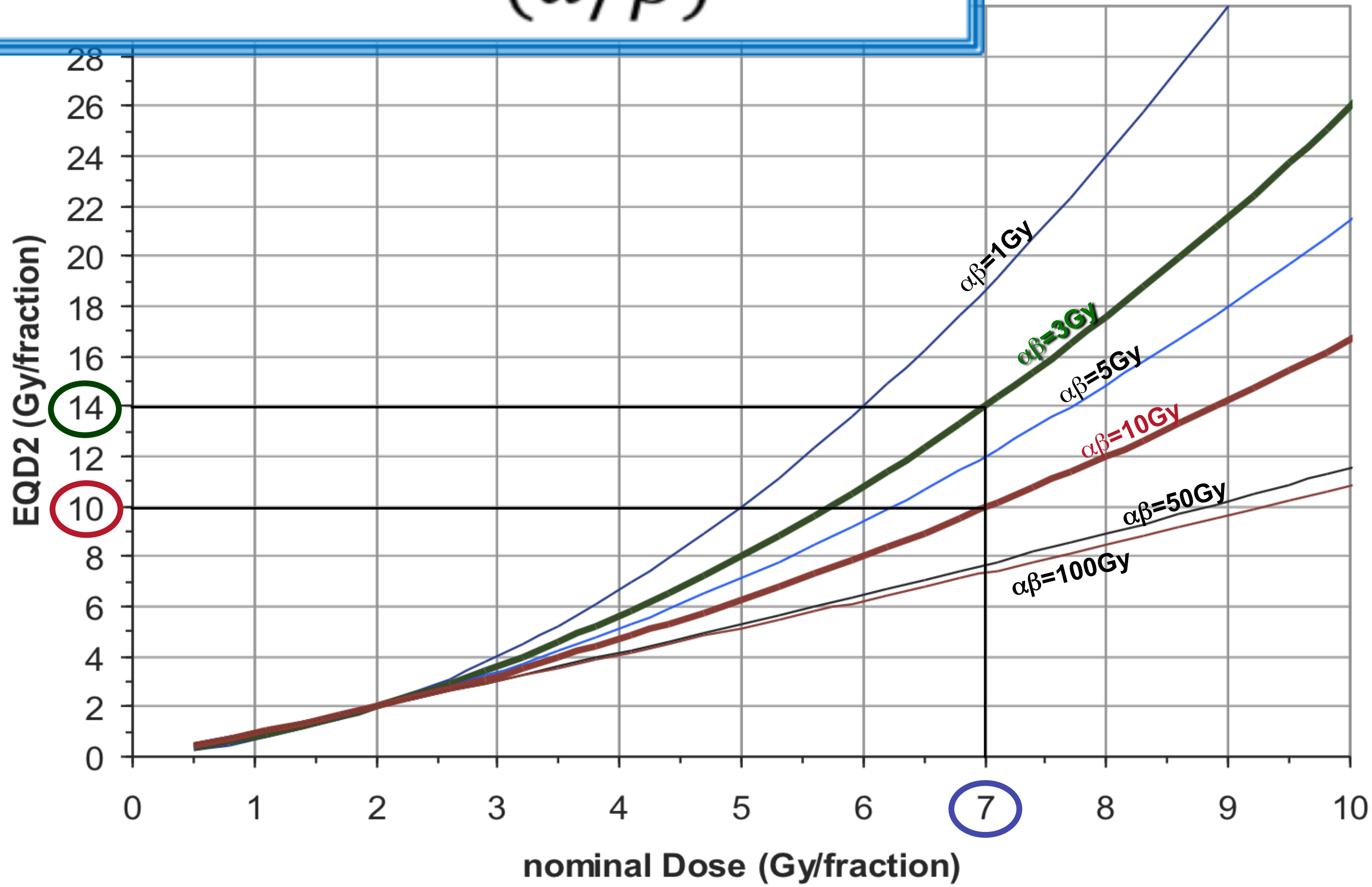
Reporting Dose using the
EQD2-dose calculator



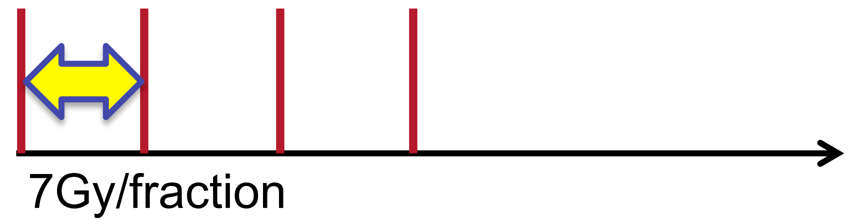
$$D_{isoE} = \frac{nd \cdot (1 + \frac{d}{(\alpha/\beta)})}{1 + \frac{2}{(\alpha/\beta)}}$$

"EQD2"

dose



Repair
time between fractions



Time between fractions should be long enough to enable full sublethal damage repair (min. ~ 8 - 12 hours)

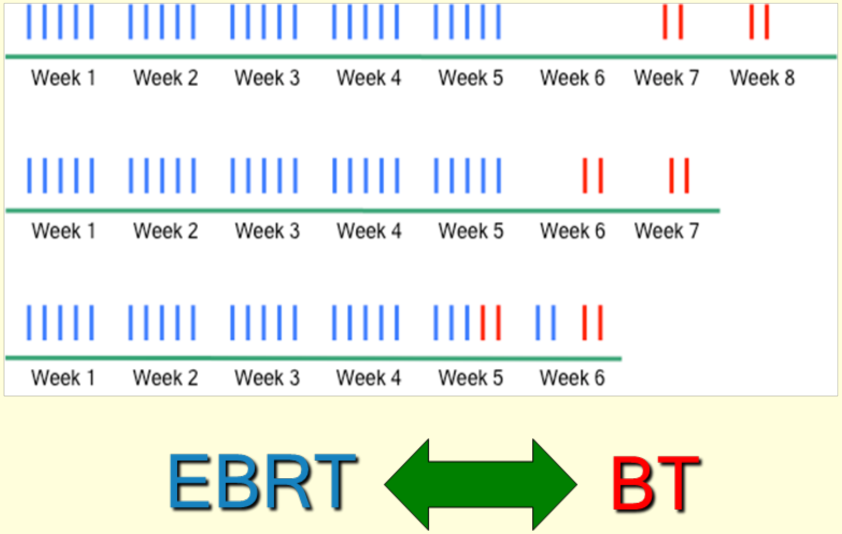
Repopulation
– changing the overall treatment time -

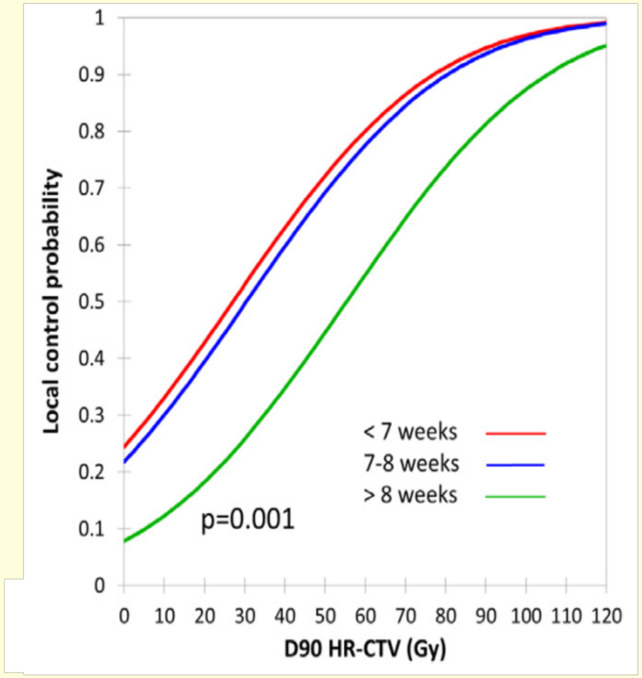
Influencing the Local Control rate / Dose

- Increasing OTT by one week is equivalent to a loss of 5 Gy in CTV_{HR} D90

Tanderup et al Radiother Oncol, 2016

- Timing of the BT boost?





Mazeron et al, Radiother Oncol 2015

„Per day delay in overall treatment time results in loss of ~ 0.3 – 0.8 Gy/day“

Repopulation
– changing the overall treatment time -

In

Per day delay in overall treatment time will results in ~1% loss of local control

Therefore try to ***stay within 50 days*** (OTT) **or** compensate by **increasing the dose**

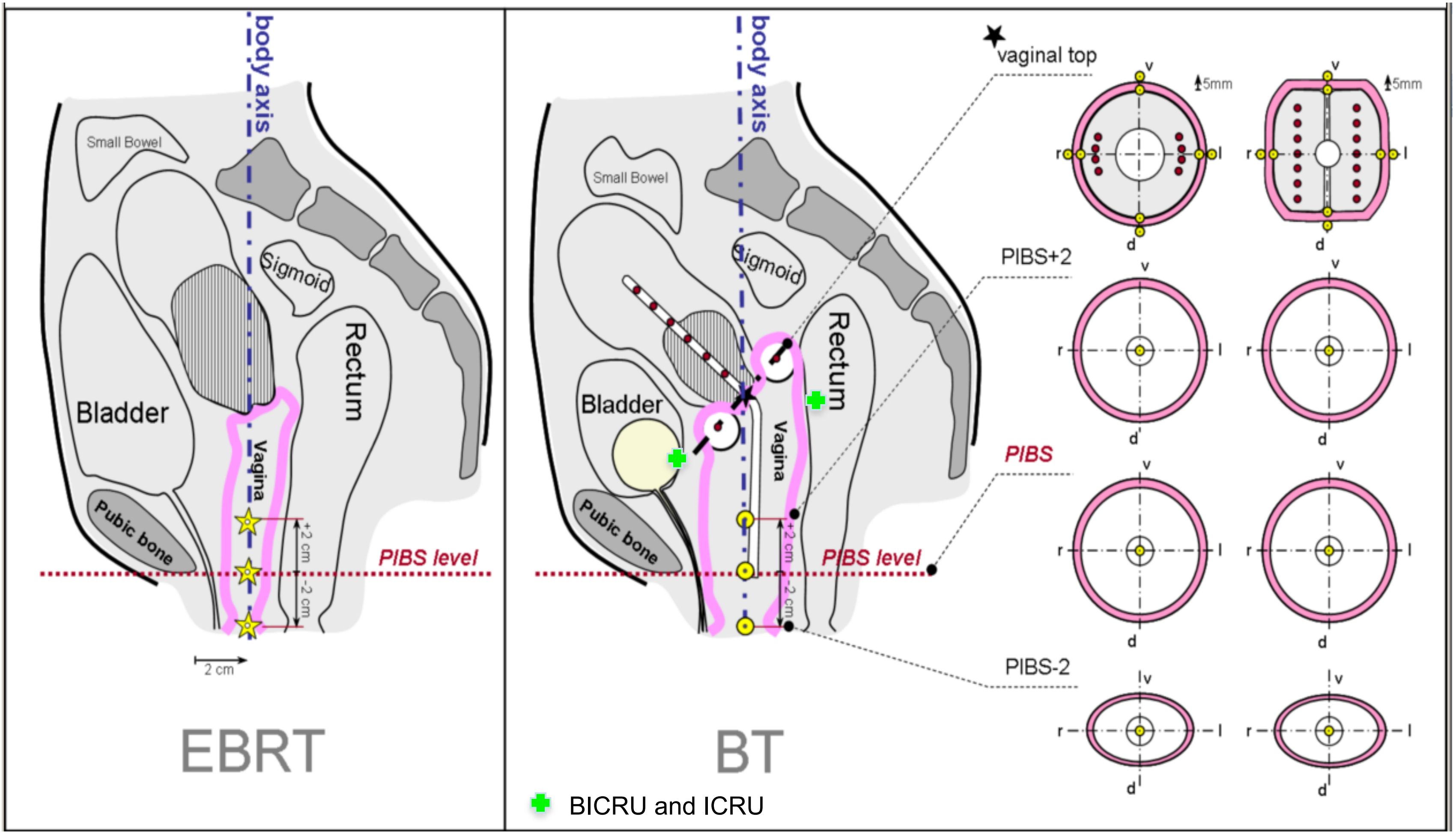
„***Clinical experience*** is more important“ !

Medu

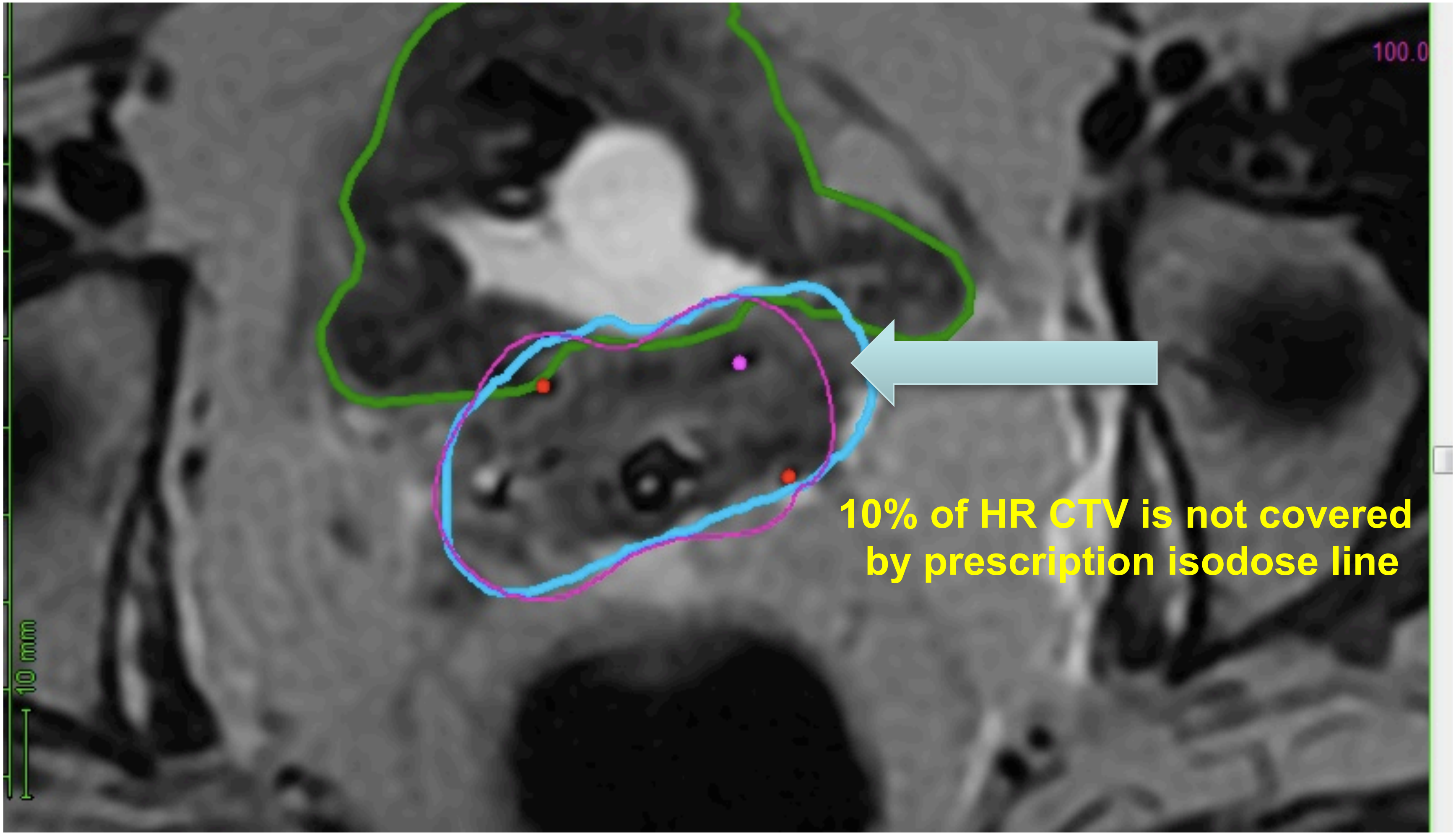
* Pooled estimate from a review of studies in the literature. ** T_k is the assumed time for the onset of accelerated proliferation. Reference details are available from Søren Bentzen and Michael Baumann.

„Per day delay in overall treatment time results in loss of ~ 0.3 – 0.8 Gy/day“

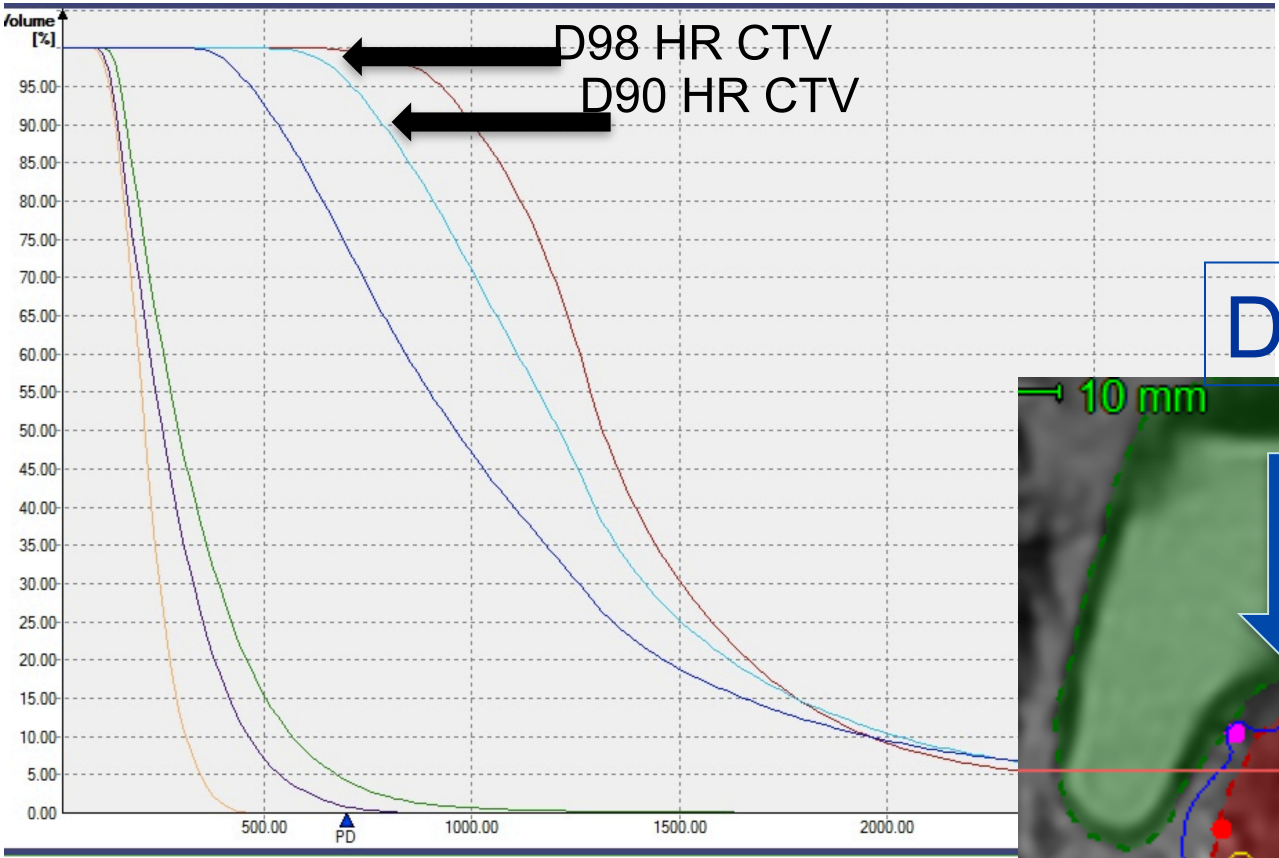
„ICRU 89“ Reference Points

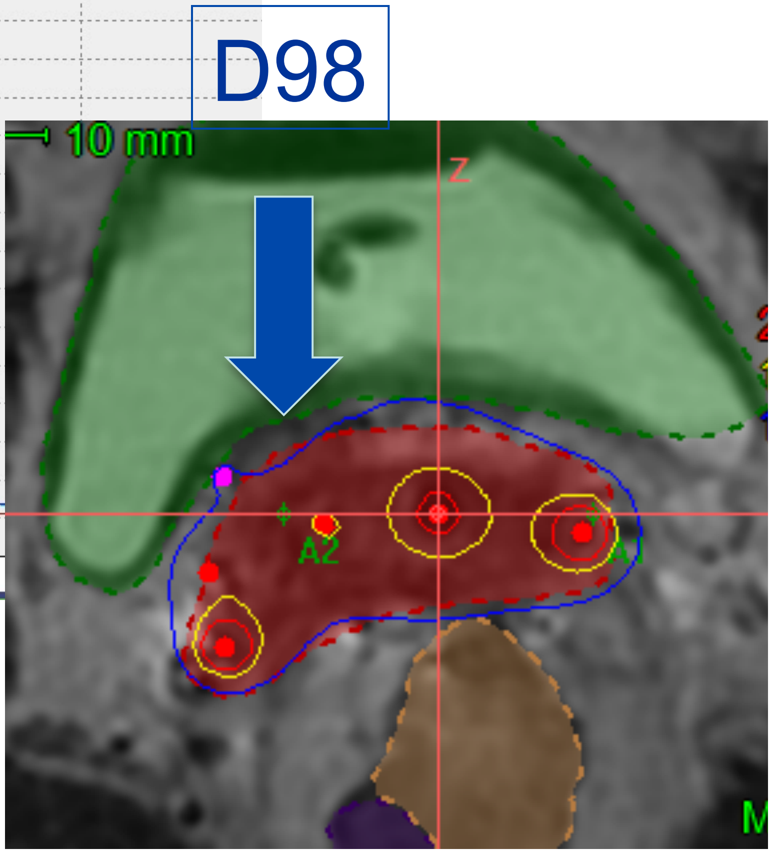


HR CTV D90 – 7.1 Gy



HR CTV D90 & D98





Planning issues

- *Perform pre-planning* by reviewing sectional images (MRI) to assure appropriate implant quality(dimensions in relation to your isodose lines: width, thickness, height to cover the target and respect OARs)
- Take into account the "off-set" (distance: tip – 1st Dwell) when defining the *needle insertion depth*
- *Follow the tradition*: 3 major steps of treatment planning optimization
- Watch „*High Dose Volumes*" – *keep them small* and review the dose distribution (isodose-lines) with regards to recurrences
- *Keep bladder/rectum filling reproducible – for imaging and treatment delivery -> filling protocols*
- *QA* for "complex" implants: double-check the reconstruction channel mapping: catheter to transfer-tube

Checklist
for individual brachytherapy treatment plan verification

	Yes	No
1. Demographic data of patient is correct (name, date of birth, unique patient ID)	☐	☐
2. Image sequence(s) is/are correct (identity, quality, slice thickness) and imported.	☐	☐
3. In case of MRI, imported sequence order is: first "para-transverse" (delineation) followed by para-coronal, sagittal, strict axial or transverse, any other .	☐	☐
4. Applicator reconstruction is correct	☐	☐
1. Indexer lengths	☐	☐
2. Off-sets (distance from applicator surface to most distal source position)	☐	☐
3. Chanel mapping correct (E.g. 1-right ovoid, 2-left ovoid, 3-tandem)	☐	☐
5. Delineation of target(s) and/or OAR(s) is/are existing and consistent with the clinical protocols.	☐	☐
6. Dose prescription follows the clinical protocol (E.g. D90, Point A, 5mm tissue depth)	☐	☐
7. If applicable, prescription point(s) is/are correctly placed	☐	☐

Checklist
for individual brachytherapy treatment plan verification

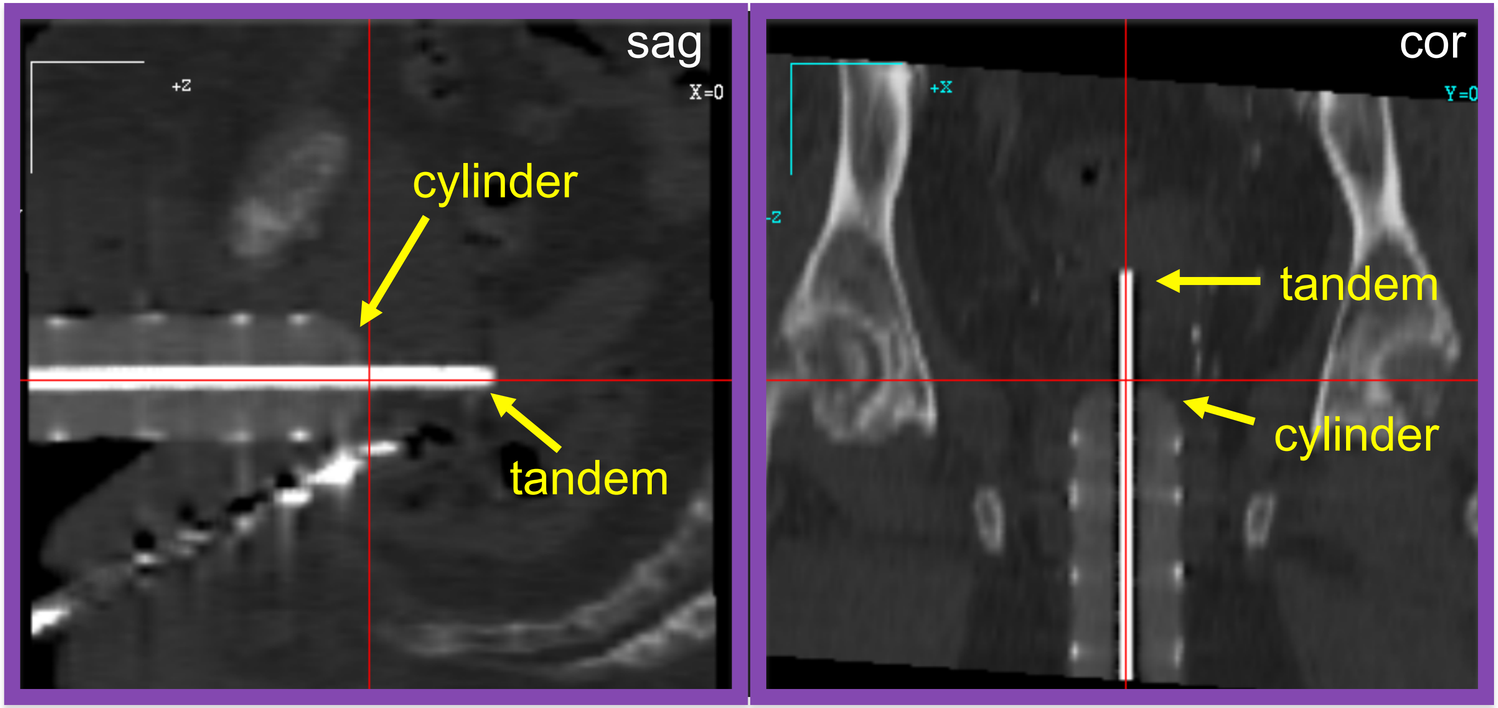
	Yes	No
8. Dose reporting points defined (E.g. ICRU, Point-A, -B, Applicator surface points)	☐	☐
9. DVH parameters are reported (Targets: D90,D98,D50,D100, OARs: $D_{0.1cc}$ D_{2cc})	☐	☐
10. Magnitude of TRAK and reference volume is reasonable according to the tumour site	☐	☐
11. Planning source strength in units of <cGy m^2 /h>	☐	☐

12. Patient specific comments:

Treatment plan approval signatures:

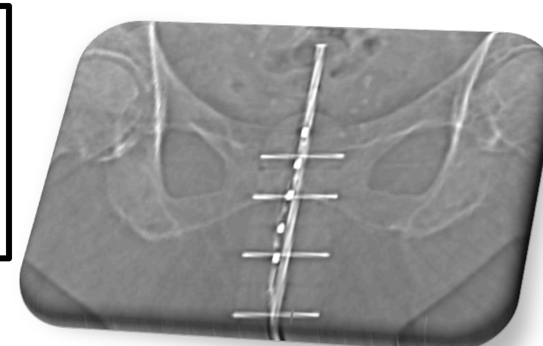
Physicist in charge of BT	*Date dd/mm/jjjj*	*Physician in charge of BT*

BT Abandoned ? -> Fixation of Vaginal-cylinder



"STOP" the patient can not be treated like that..

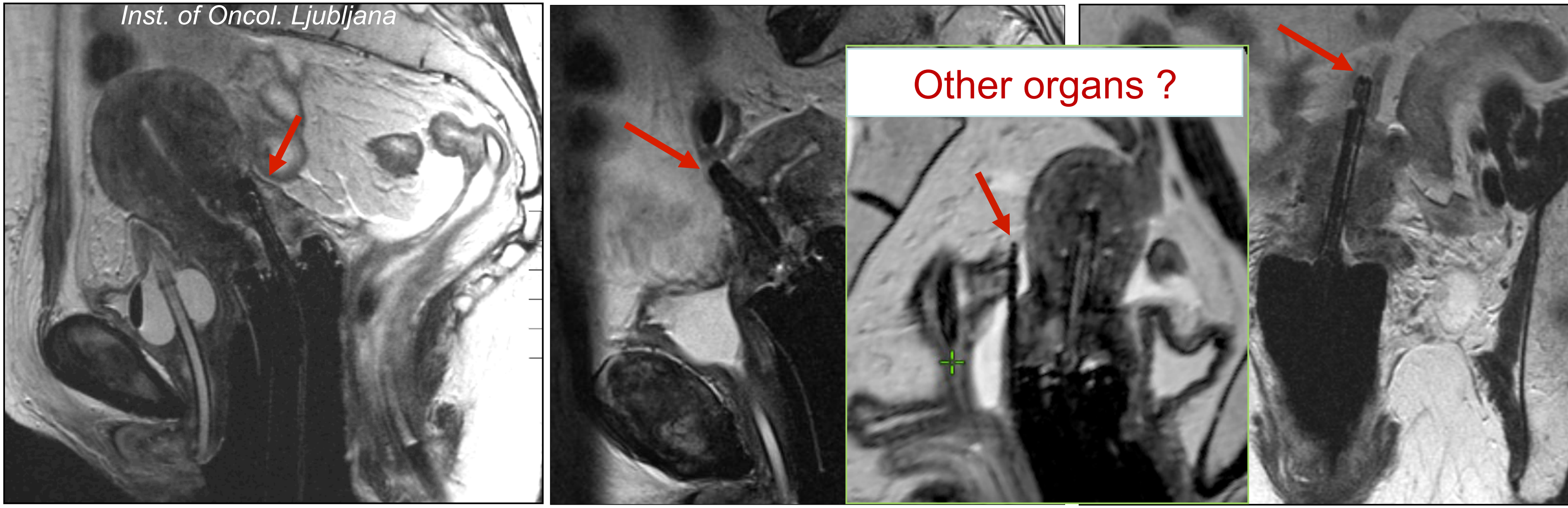
Re-insert the applicator !
For further improvement, check the fixation of the applicator and measure known distances



This can easily be detected by using planar films for verification

BT Abandoned ? -> Uterine Perforation

Reported incidence of uterine perforations: up to 15%!



"No" not necessarily - it is of course not optimal – Nevertheless, as long as the tandem is somewhere in the target these source positions might be used for treatment planning accordingly and ...

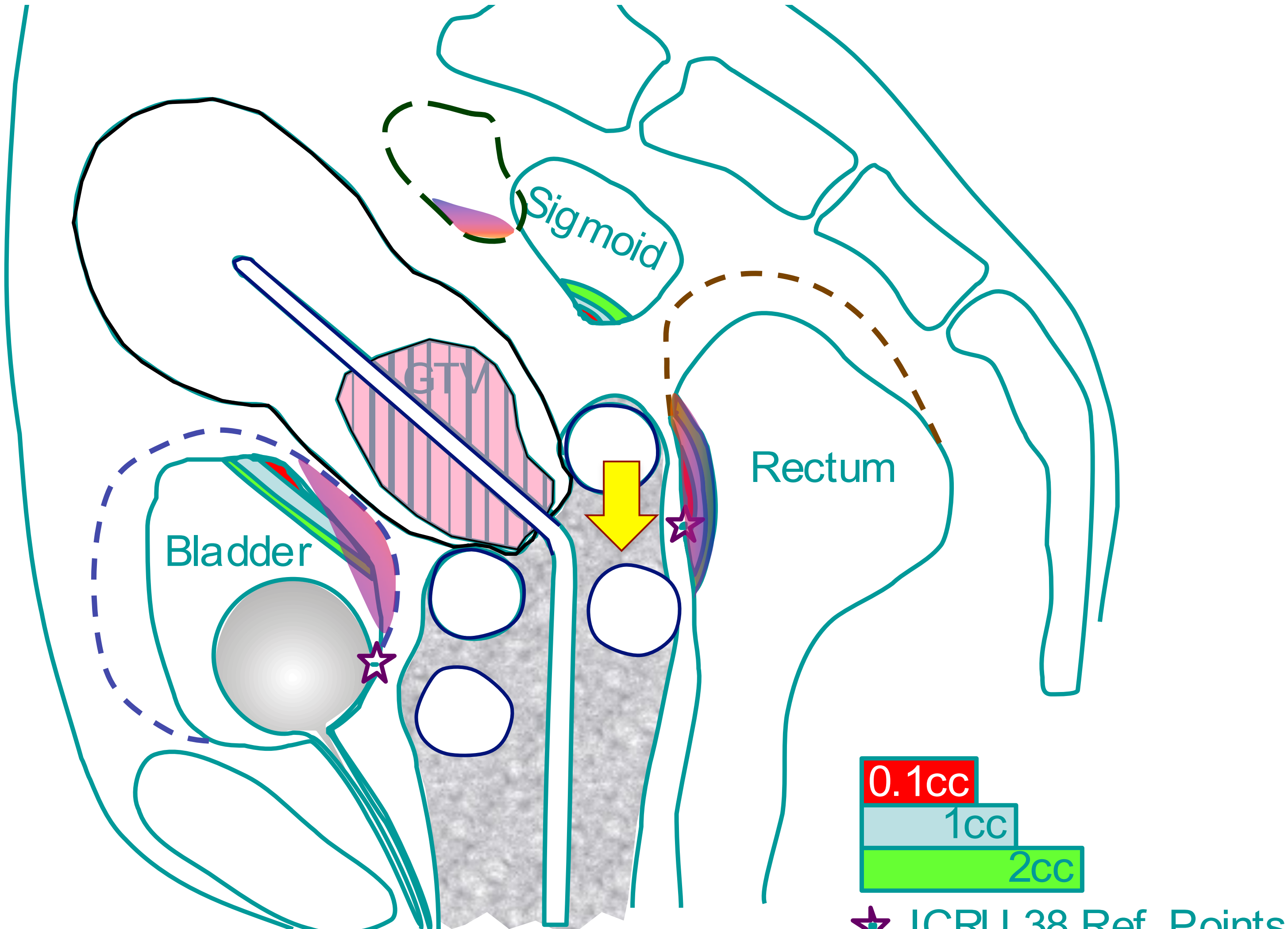
The use of Ultrasound reduces chance of perforation!

Irwin W, et al. Gynecol Oncol 2003
Sharma DN, et al. Gynecol Oncol 2010
Davidson MTM, et al. Brachytherapy 2008
MIlman RM, et al. Clin Imaging 1991

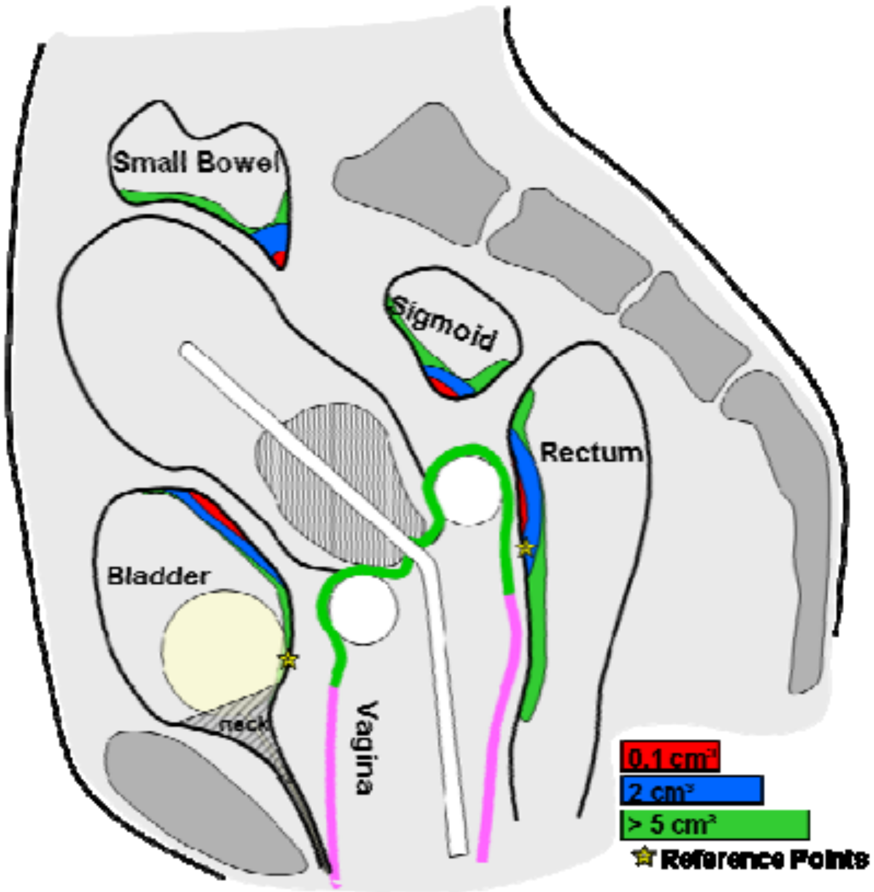
Jhingran A, Eifel PJ. IJROBP 2000
Barnes EA, et al. Int J Gynecol Cancer 2007
Lanciano R, et al. IJROBP 1994

Courtesy P.Petric

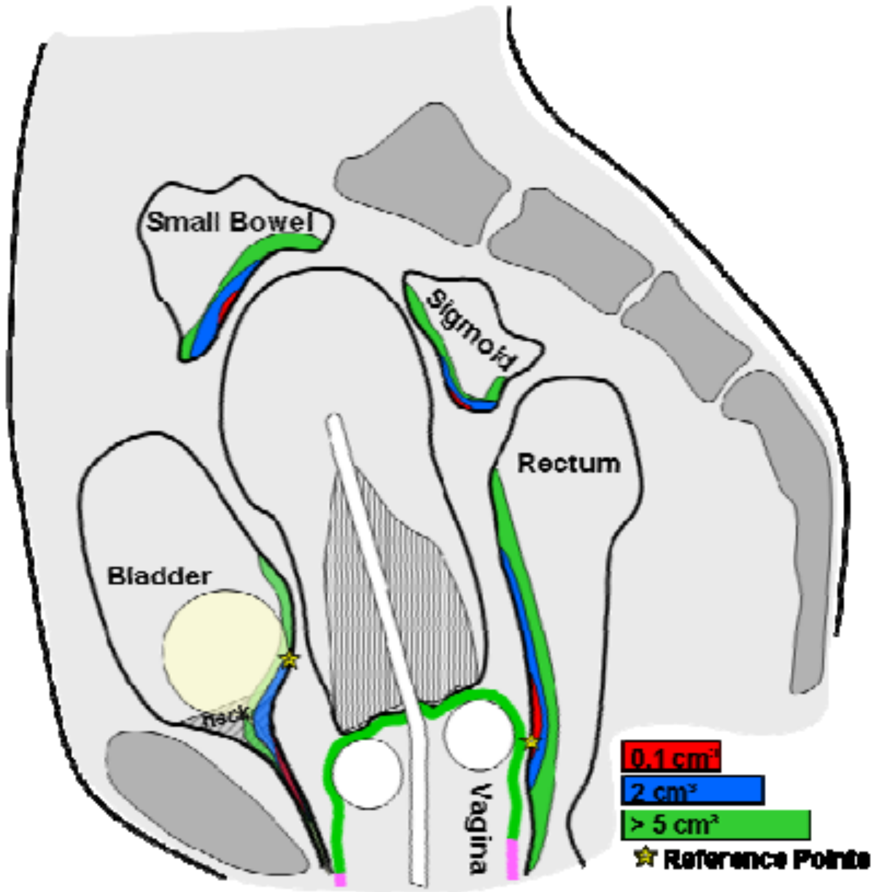
Brachytherapy applicator not fixed !



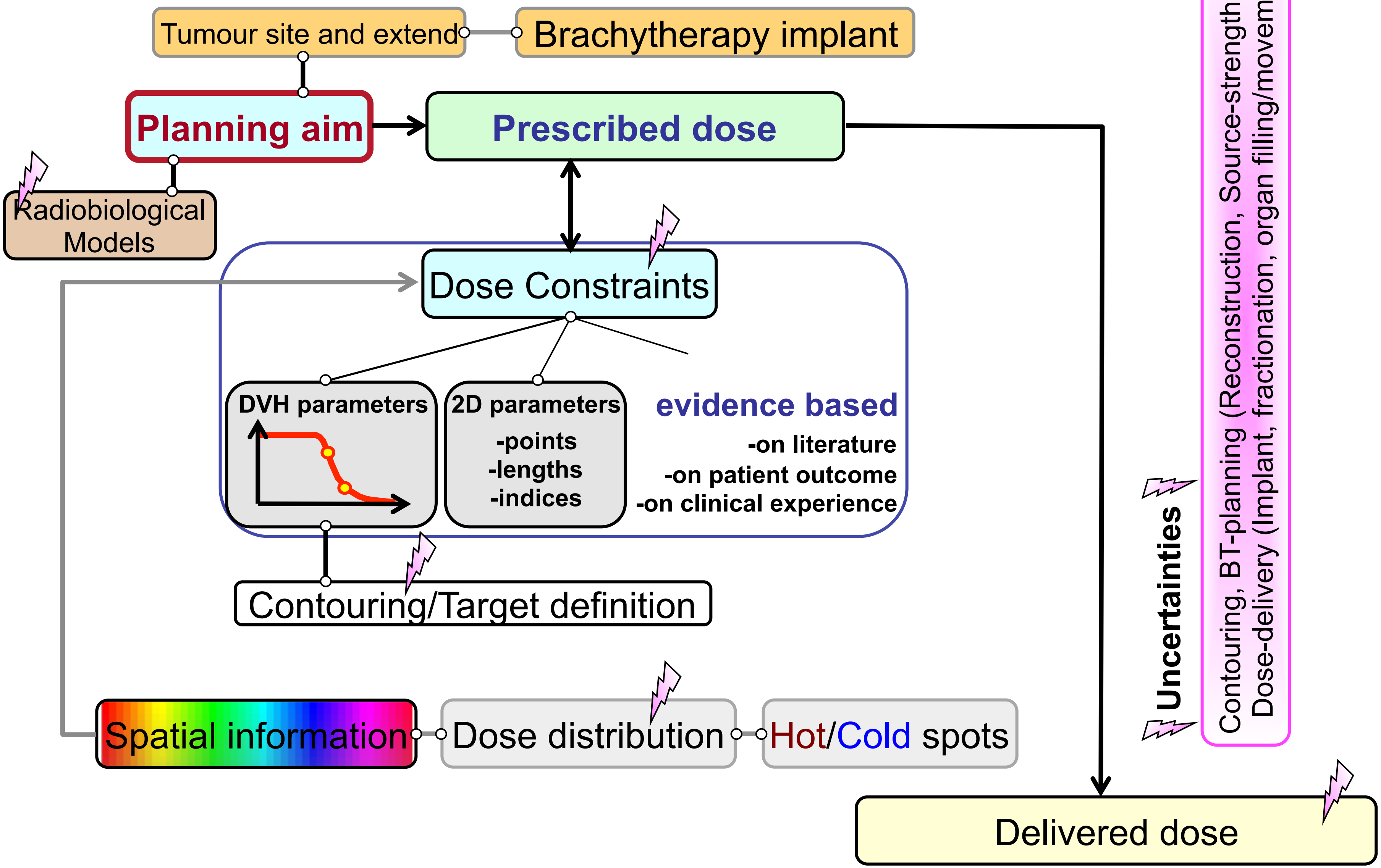
B_{icru} / D_{2cm3} ratio <1



B_{icru} / D_{2cm3} ratio ≥1



Individual Treatment Objectives



Thank You

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on behalf of

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

Department of Radiotherapy
Medical University of Vienna