Anatomy-based Inverse Planning for Brachytherapy

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HDR Brachytherapy

Define Target
Localize catheters

+

Dose Plan

+

Tx

Advanced 3D Planning

+

Cone Beam CT

Class solutions

IMRT

Define Target
Localize catheters

+

Dose Plan

+

Tx

CT / MR

Fluo + US

Cone Beam CT

Anatomy-based

Inverse planning (IPSA)

+

Class solutions

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

IMBT

Define Target Localize catheters	+	Dose Plan	+	Tx
CT / MR Fluo + US Cone Beam CT		Anatomy-based Inverse planning (IPSA) + Class solutions		

X Ray Image x 2

QuickTime™ and a Photo - JPEG decompressor are needed to see this picture.

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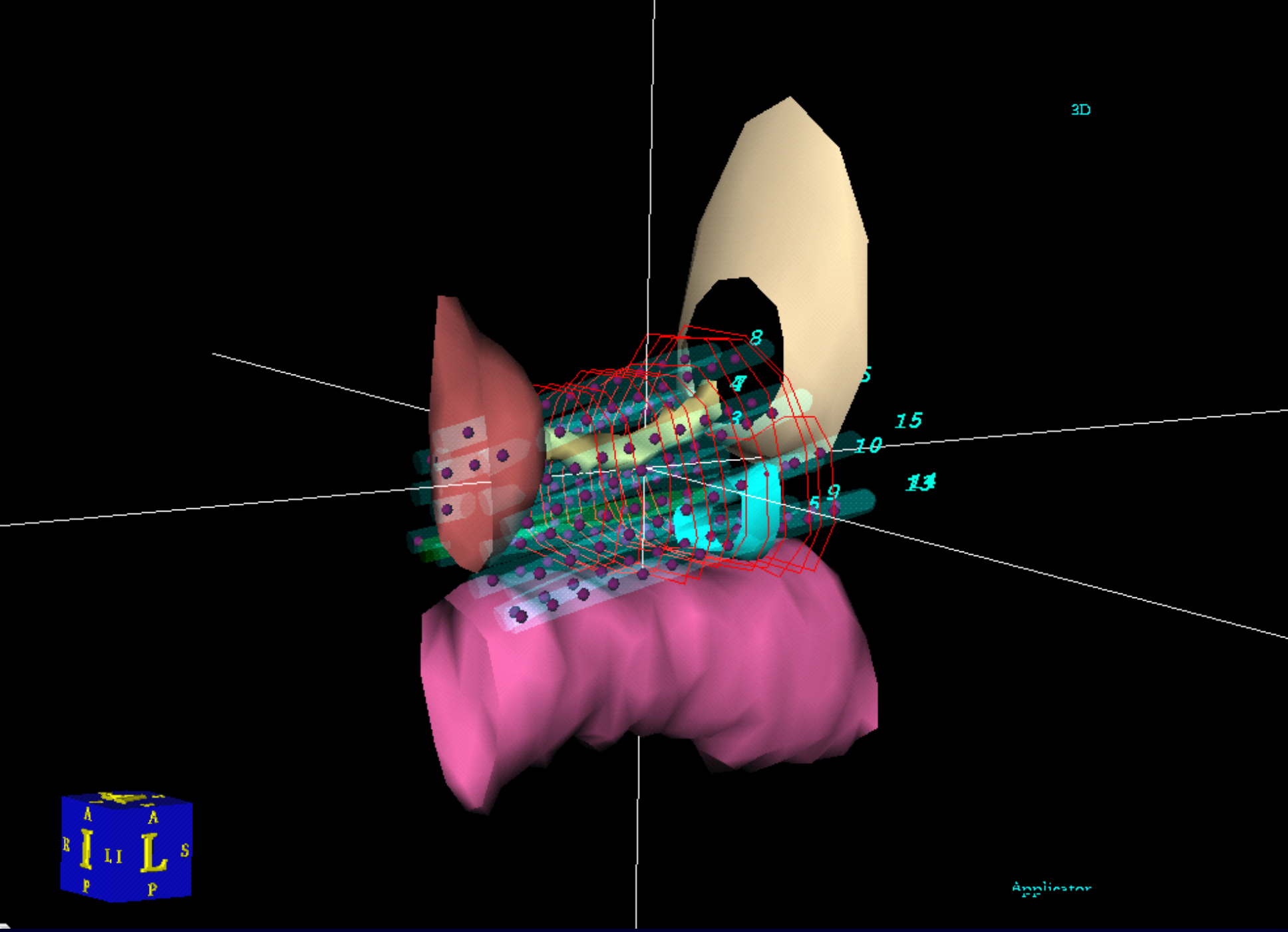
3D
8
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15
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A
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LI
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S
P
P
Applicator

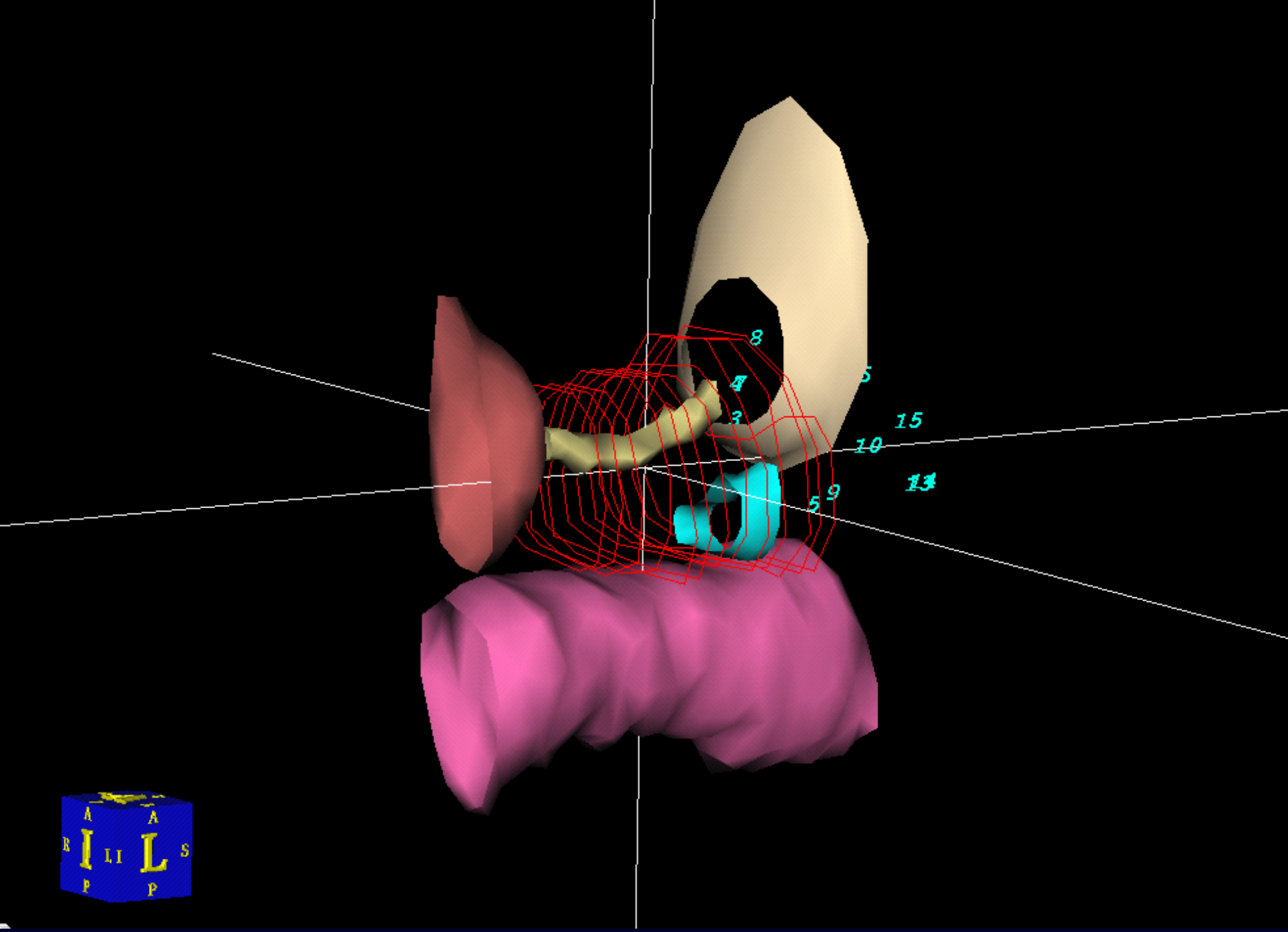
8
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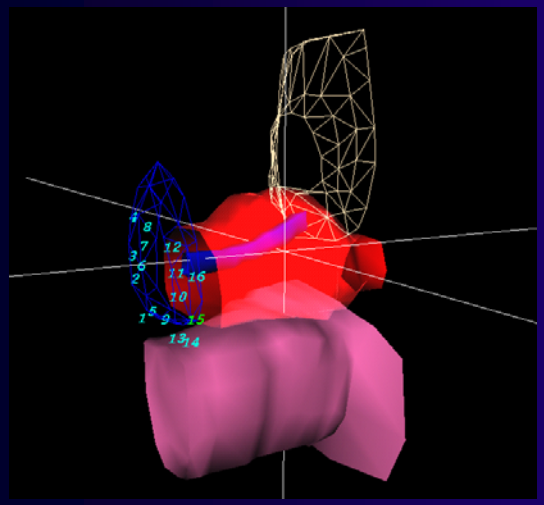
Image-based Inverse Planning HDR

- Introduction to IPSA
- Performance
- Clinical examples

Anatomy Conformal Dose Optimization

anatomical structures → treatment plan



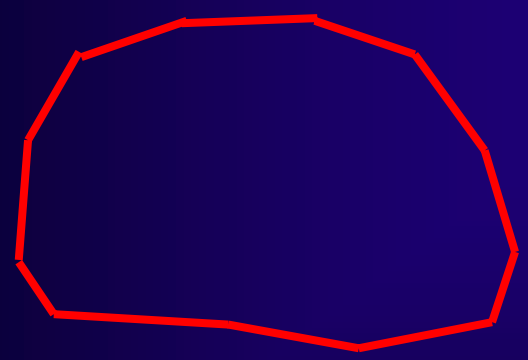
description of the Dose Constraints
Inverse **P**lanning

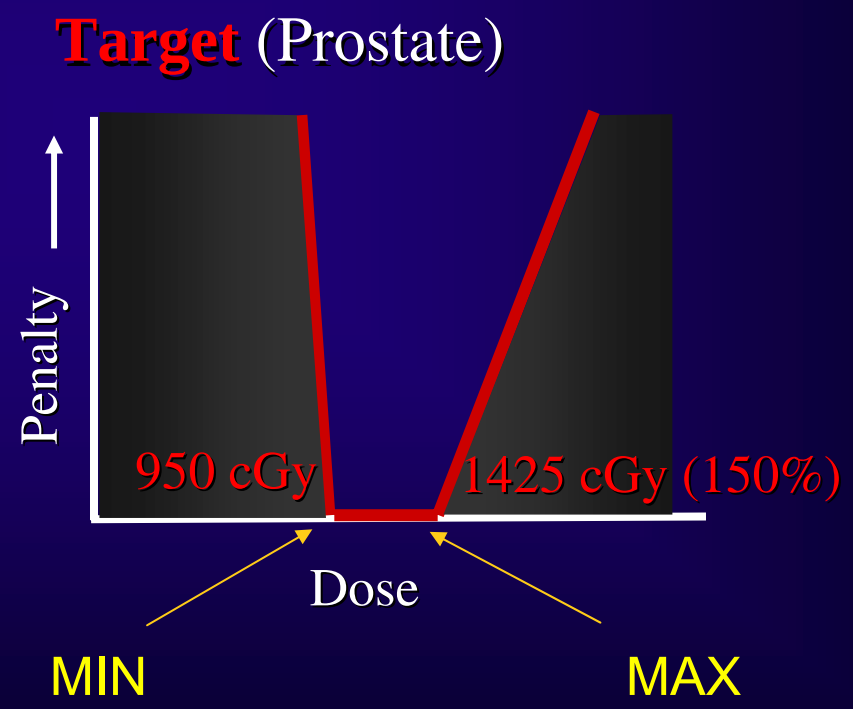
optimization engine
Simulated **A**nnealing

IPSA

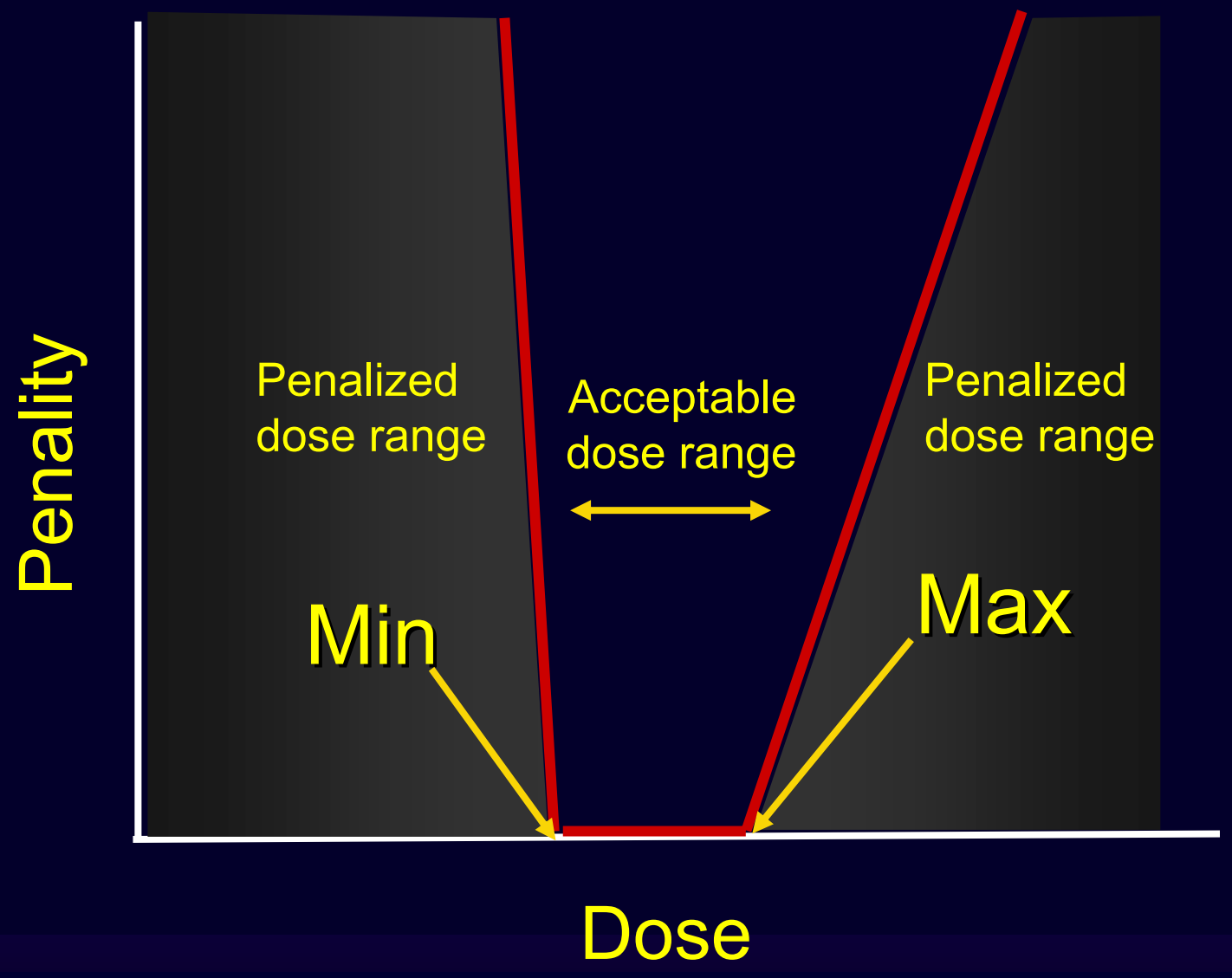
1 - Dose constraints

Physician's prescription =
- Target contours
- Organ at risk contours
- Dose constraints on each target and organs at risk

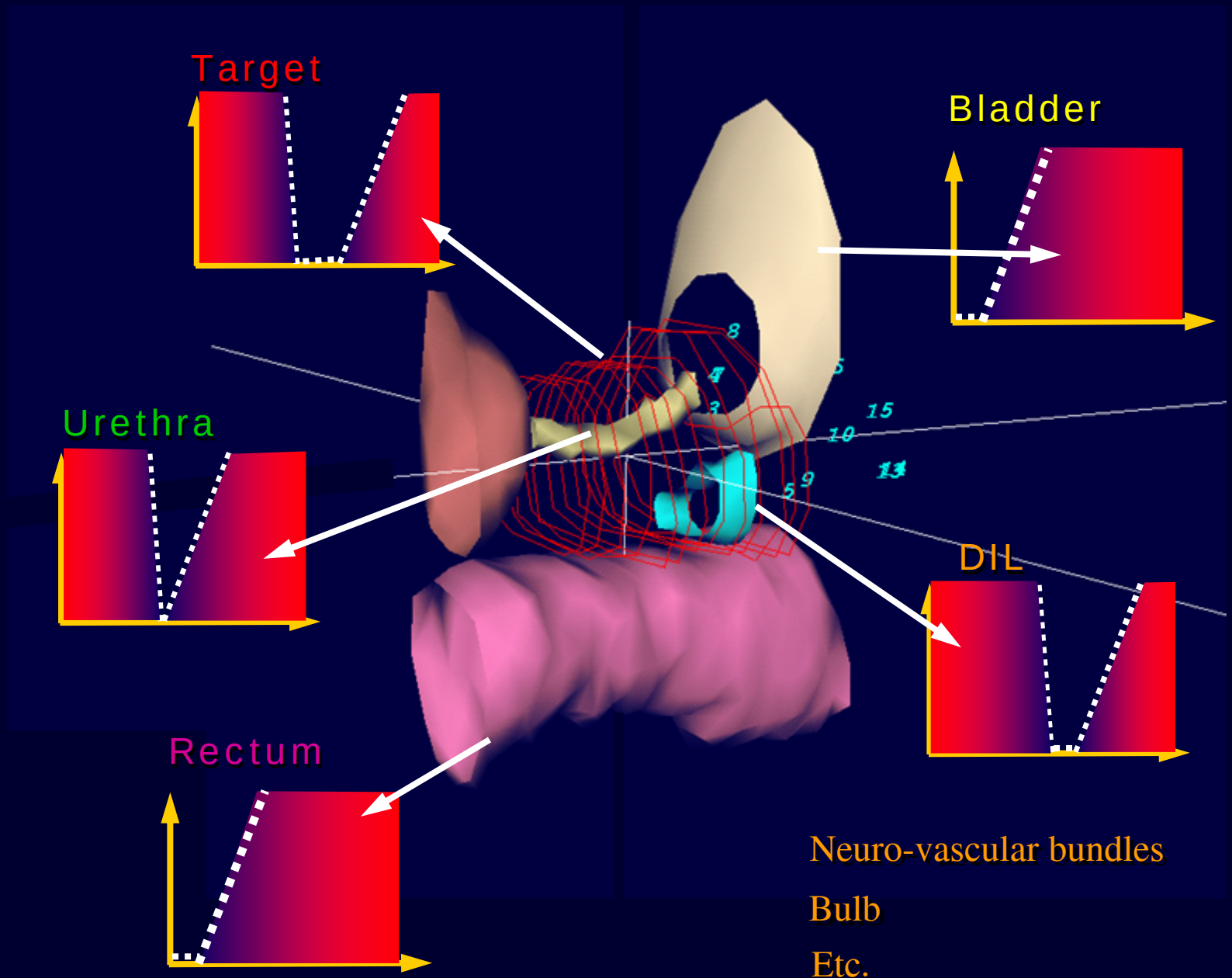




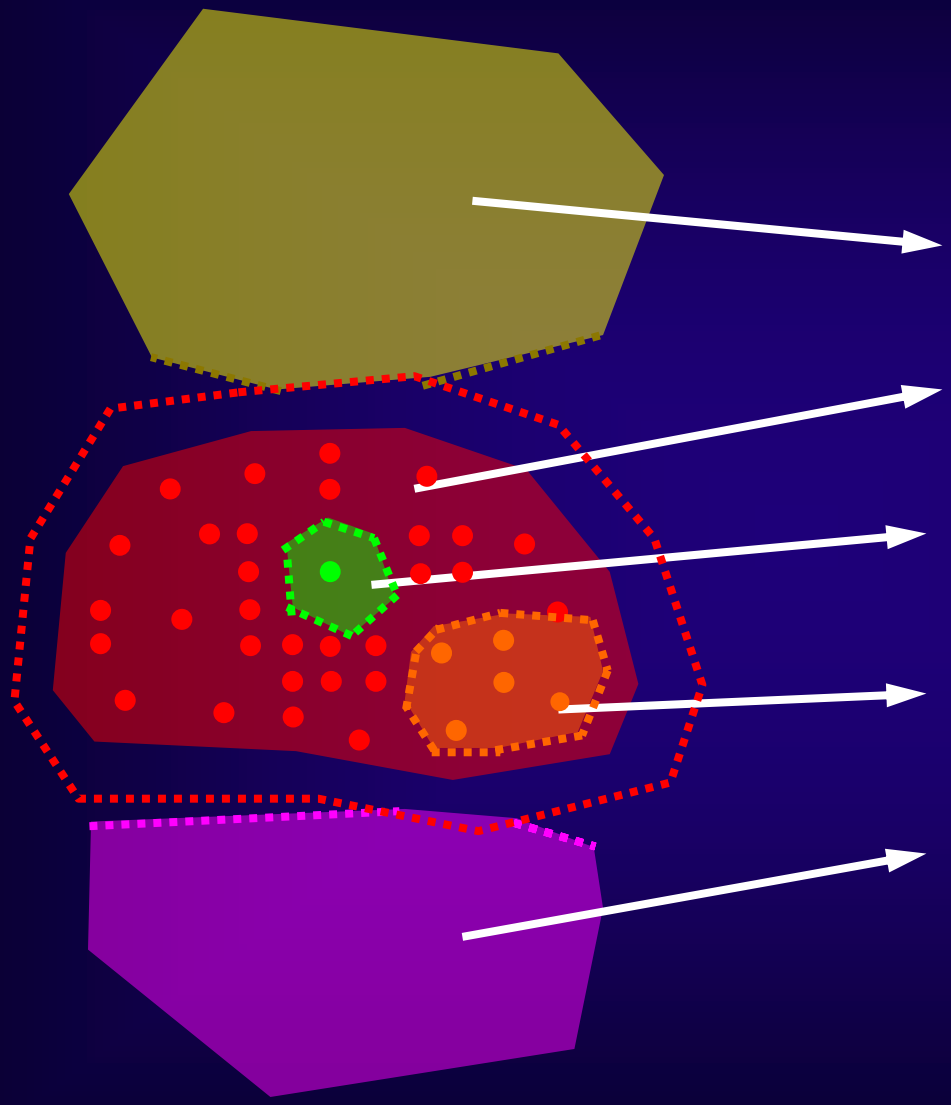
1 - Dose constraints



Anatomical Dose Prescription



Dose Constraints



potentials.txt

File Edit Search Preferences Help

```
GLOBAL DOSE PRESCRIPTION
------
TARGET
reference_target
ON        100 [ 950.0 1425.0 ] 100
IN        100 [ 950.0 1425.0 ] 30
dose      0.1
catheter  0.0
------
DIL
target
ON        0 [ 0.0 0.0 ] 0
IN        100 [ 1425.0 1425.0 ] 30
dose      0.0
catheter  0.0
------
URETHRA
organ_at_risk
ON        100 [ 950.0 1140.0 ] 30
IN        100 [ 950.0 1140.0 ] 30
dose      0.0
catheter  0.0
------
BULB
organ_at_risk
ON        0 [ 0.0 475.0 ] 20
IN        0 [ 0.0 475.0 ] 20
dose      0.0
catheter  0.0
------
RECTUM
organ_at_risk
ON        0 [ 0.0 475.0 ] 30
IN        0 [ 0.0 475.0 ] 30
dose      0.0
catheter  0.0
------
BLADDER
organ_at_risk
ON        0 [ 0.0 475.0 ] 20
IN        0 [ 0.0 475.0 ] 20
dose      0.0
catheter  0.0
------
```

Class Solution

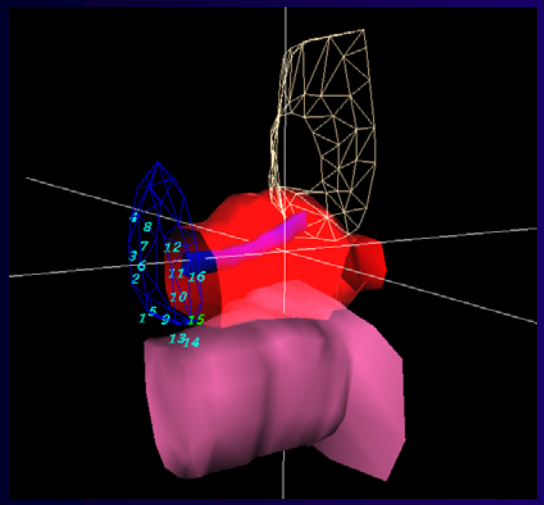
- Prostate
- GYN template
- T&O
- Vaginal Cylinder
- Base of tongue
- Naso-pharynx
- Rectum
- Sarcomas
- Breast
- etc.

Same set of dose constraints for all patients

Anatomy Conformal
Dose Optimization

Expert System

anatomical structures → treatment plan



description of the Dose Constraints
Inverse
Planning

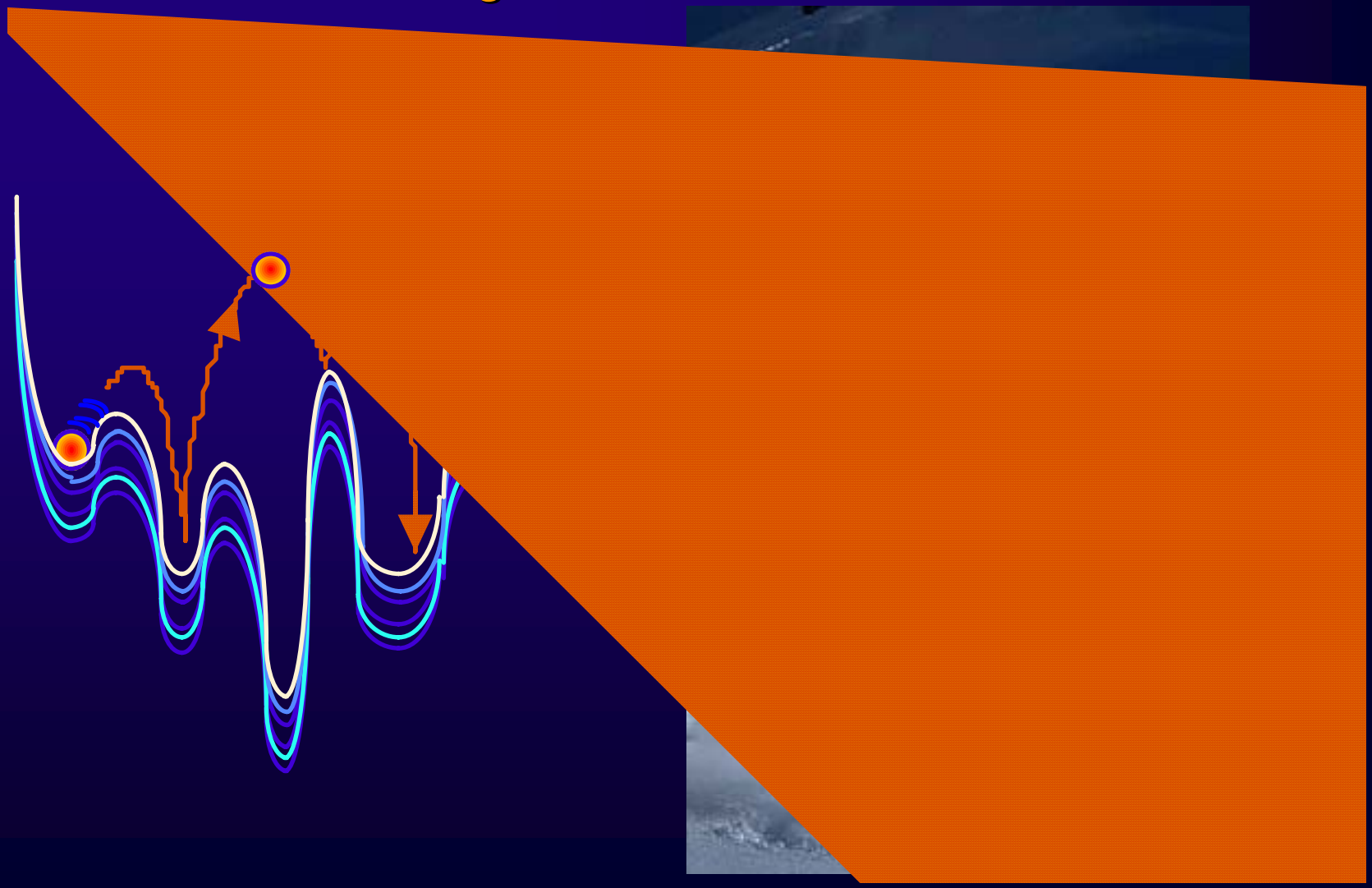
optimization engine

Simulated
Annealing

IPSA

2- Optimization Engine: Simulated Annealing

Search of minimum



Comparison

of

Inverse Planning

and

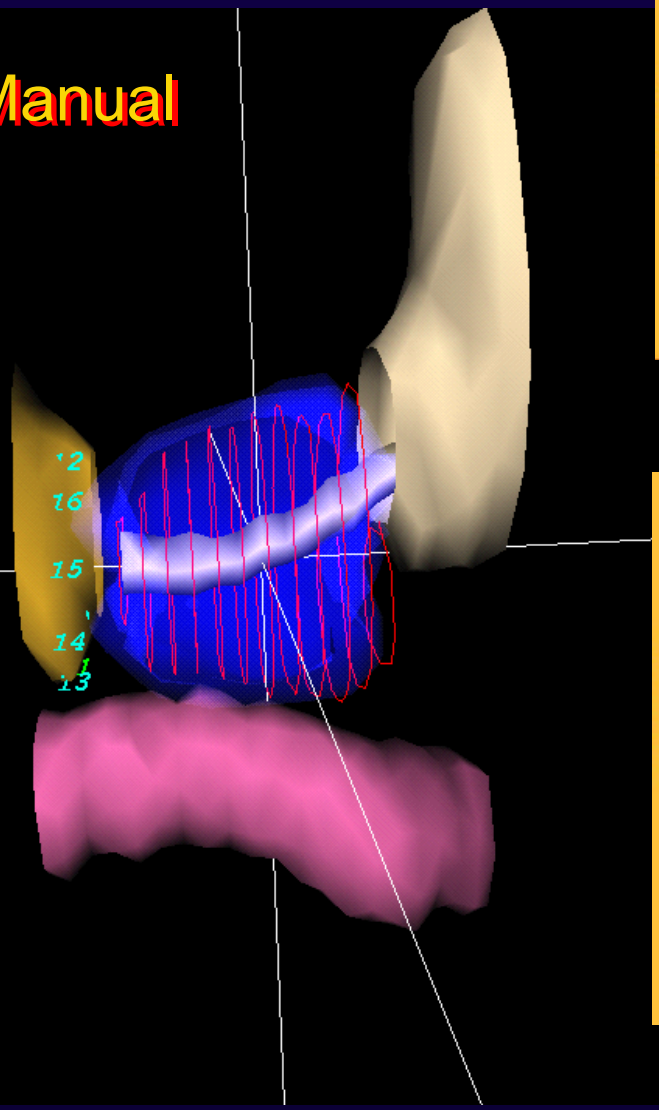
Geometrical Optimization

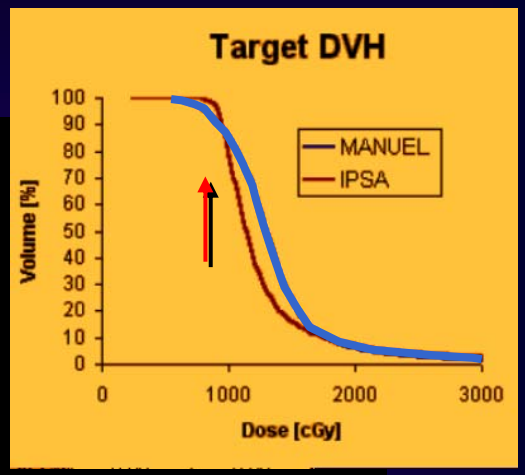
for

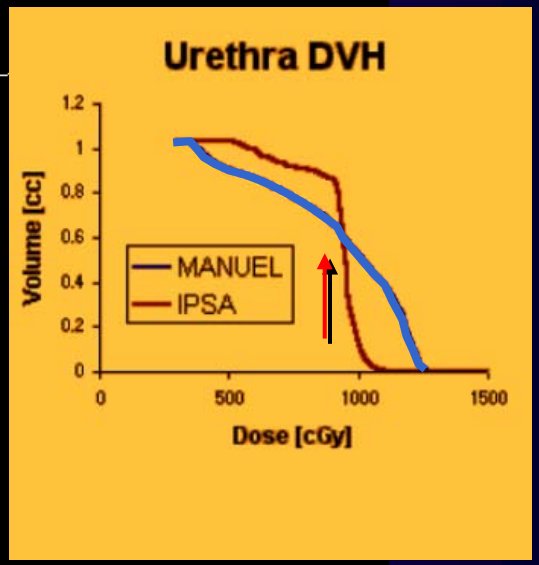
Prostate HDR Brachytherapy

G.O. + Manual

	MANUAL	IPSA
Target		
HI	**0.57**	**0.72**
V50 [%]	100.00	100.00
V75 [%]	98.31	100.00
V100 [%]	89.20	92.10
V120 [%]	70.07	51.05
V150 [%]	32.38	19.71
Rectum		
V50 [%]	17.05	11.54
V75 [%]	4.05	0.83
V100 [%]	0.44	0.00
V120 [%]	0.04	0.00
V150 [%]	0.00	0.00
Urethra		
V50 [%]	89.28	100.00
V75 [%]	78.14	90.74
V100 [%]	58.16	45.59
V120 [%]	30.85	0.09
V150 [%]	0.00	0.00







Applicator

IPSA

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Target		
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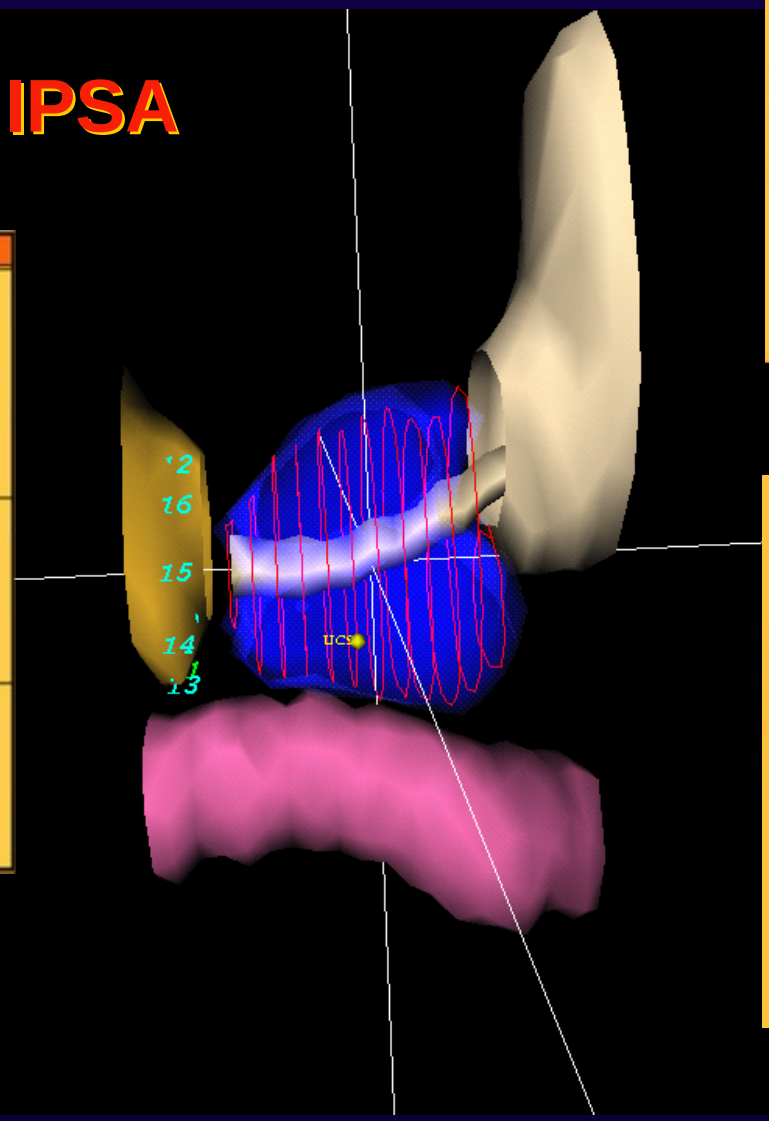
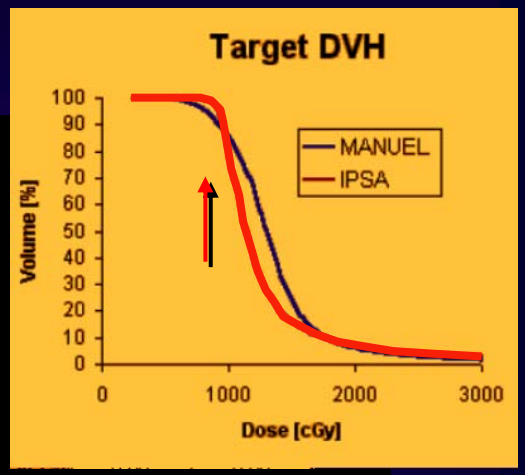
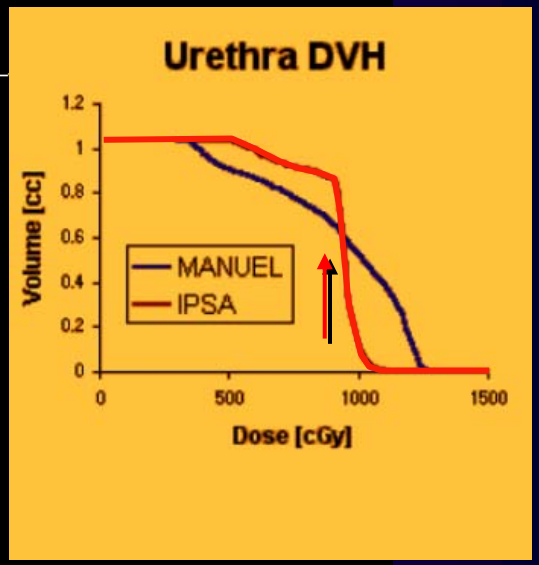
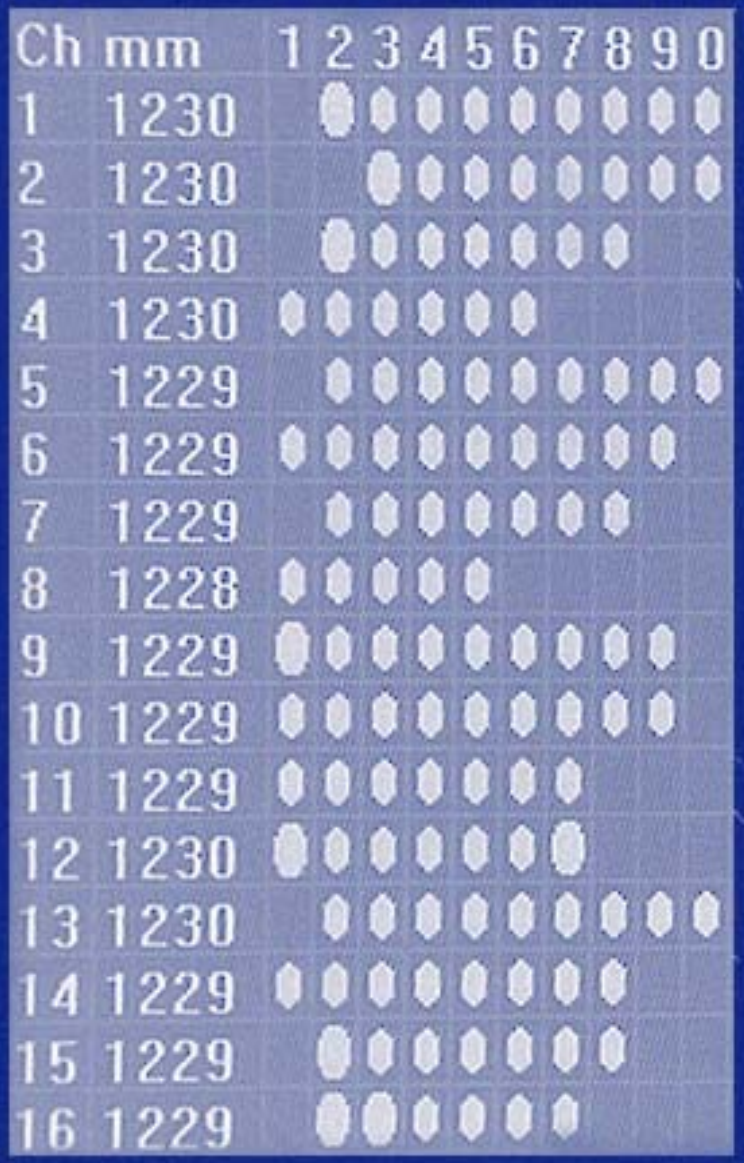




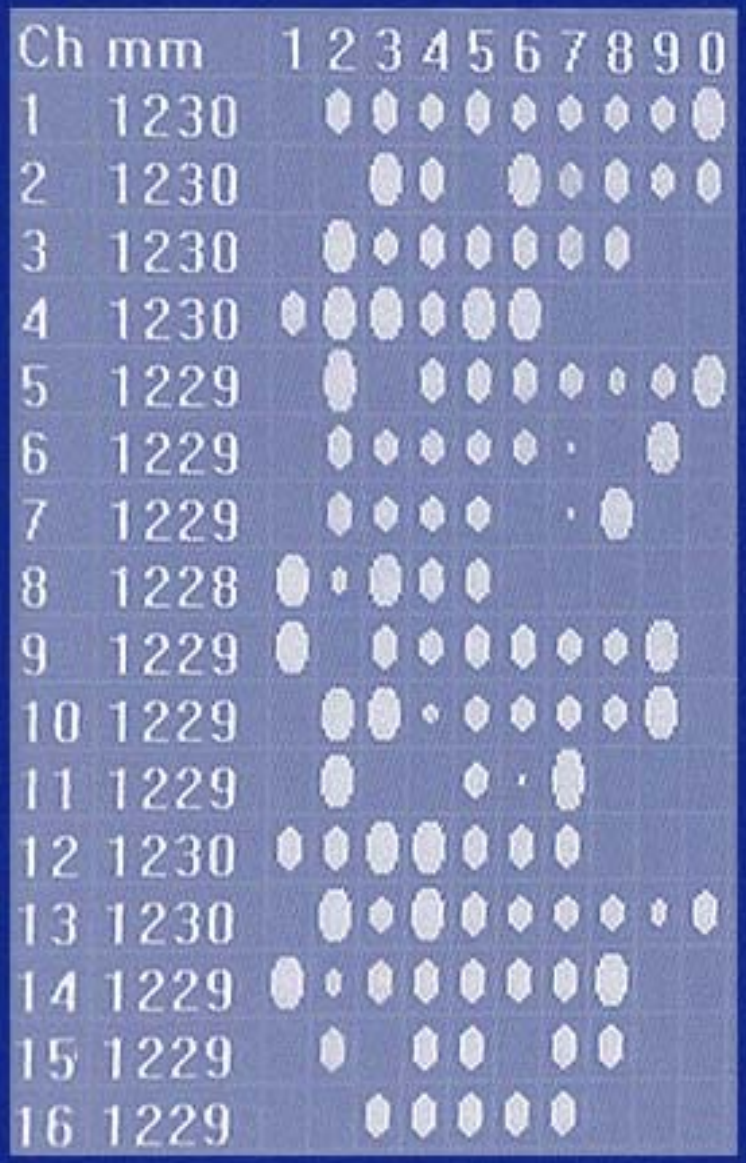


Applicator

GO


Ch mm 1 2 3 4 5 6 7 8 9 0
1 1230
2 1230
3 1230
4 1230
5 1229
6 1229
7 1229
8 1228
9 1229
10 1229
11 1229
12 1230
13 1230
14 1229
15 1229
16 1229

IPSA


Ch mm 1 2 3 4 5 6 7 8 9 0
1 1230
2 1230
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4 1230
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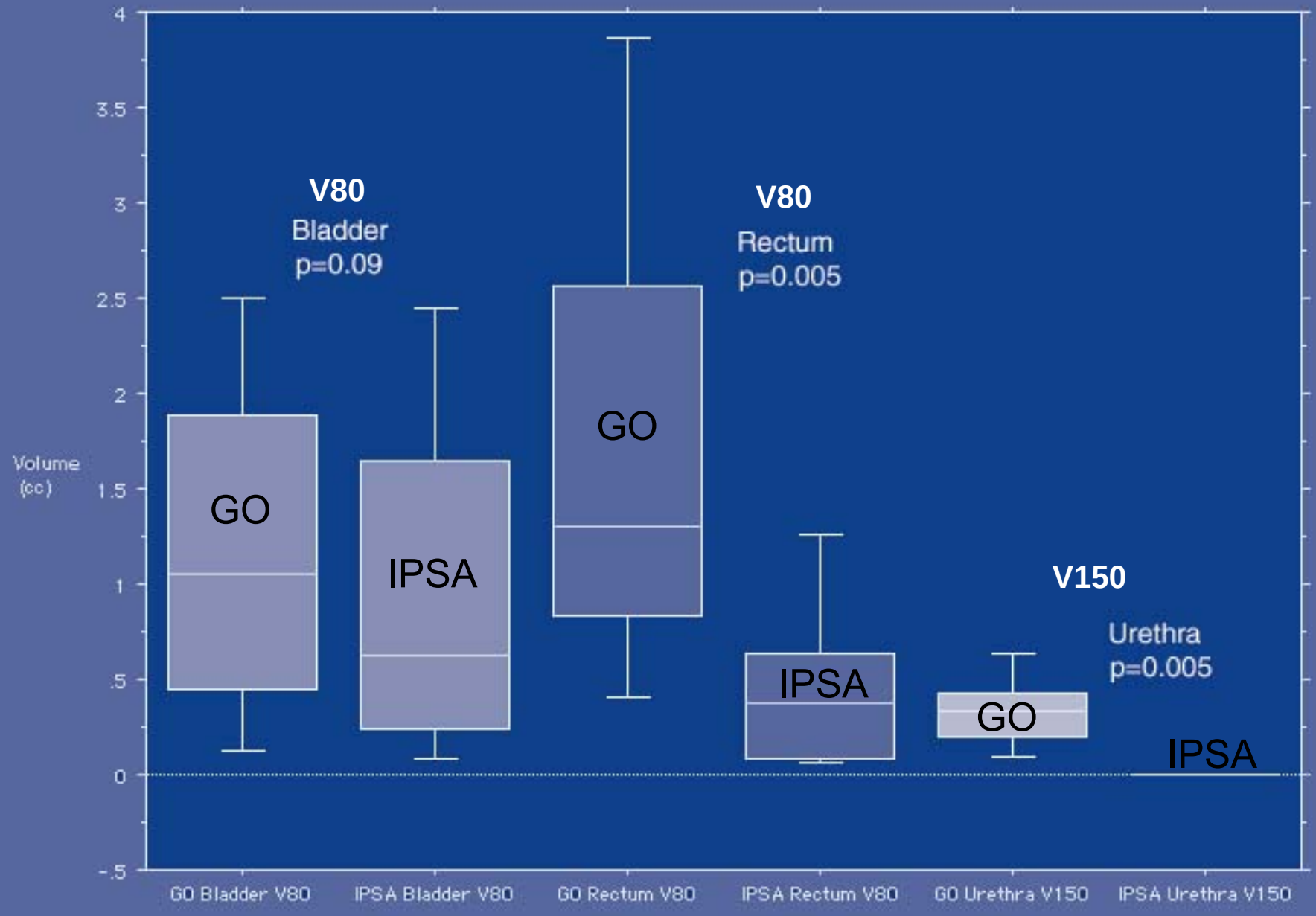
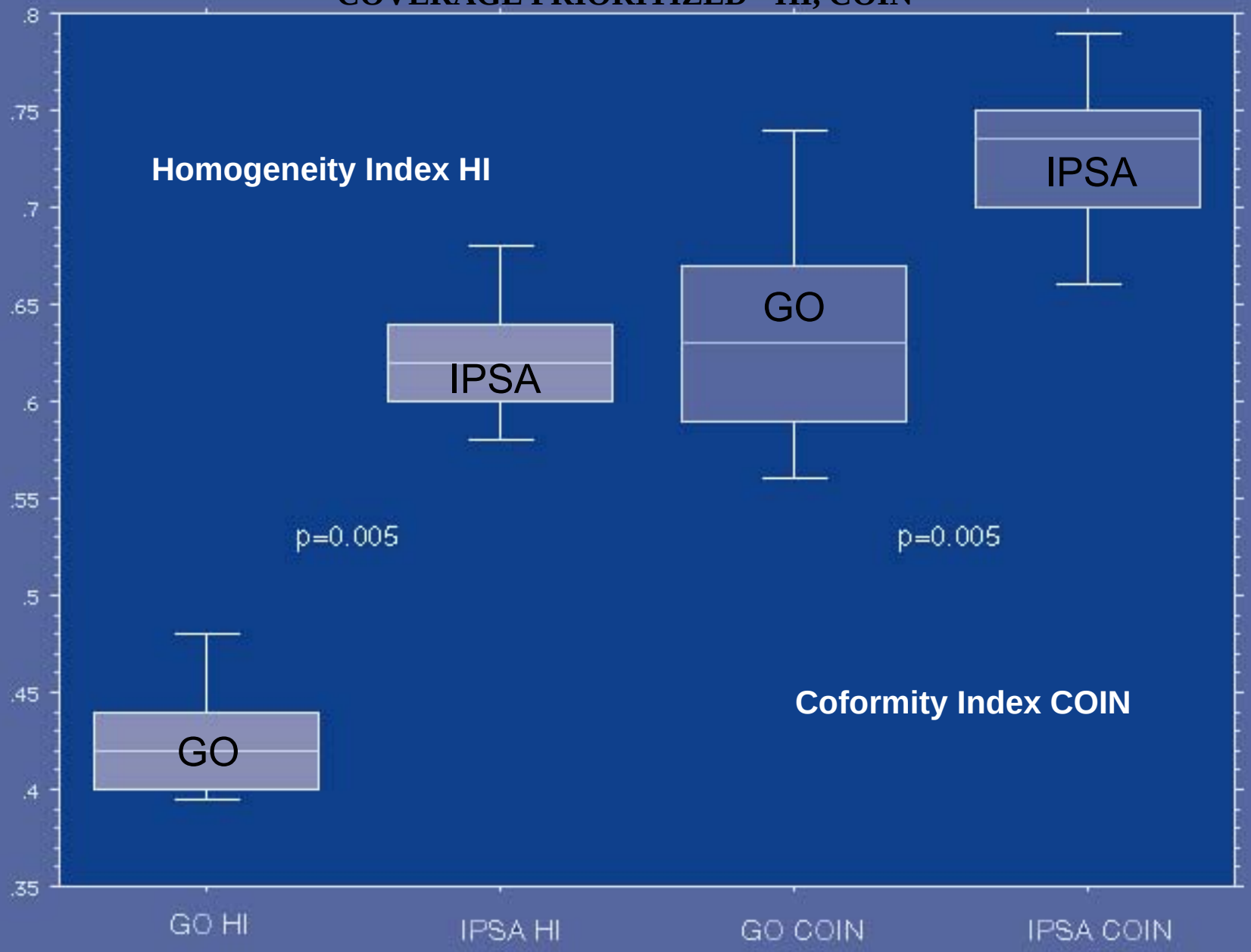
COVERAGE PRIORITIZED

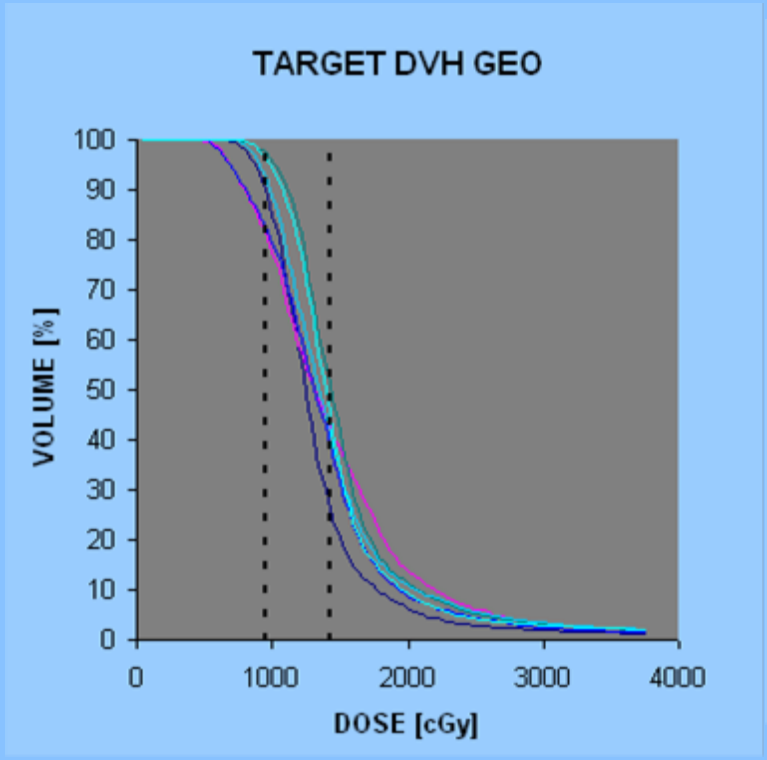


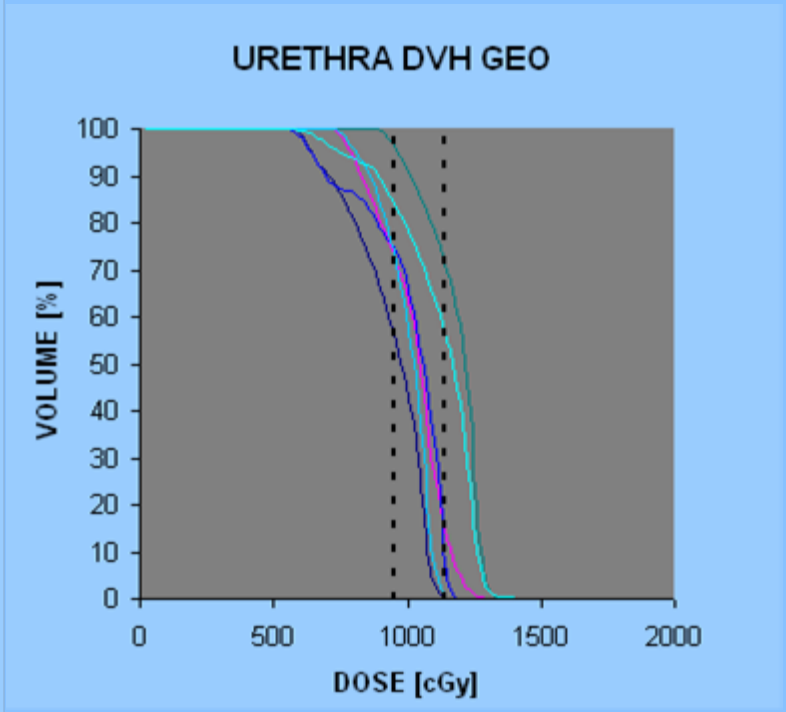
COVERAGE PRIORITIZED - HI, COIN



Geo + Manual : 6 patients

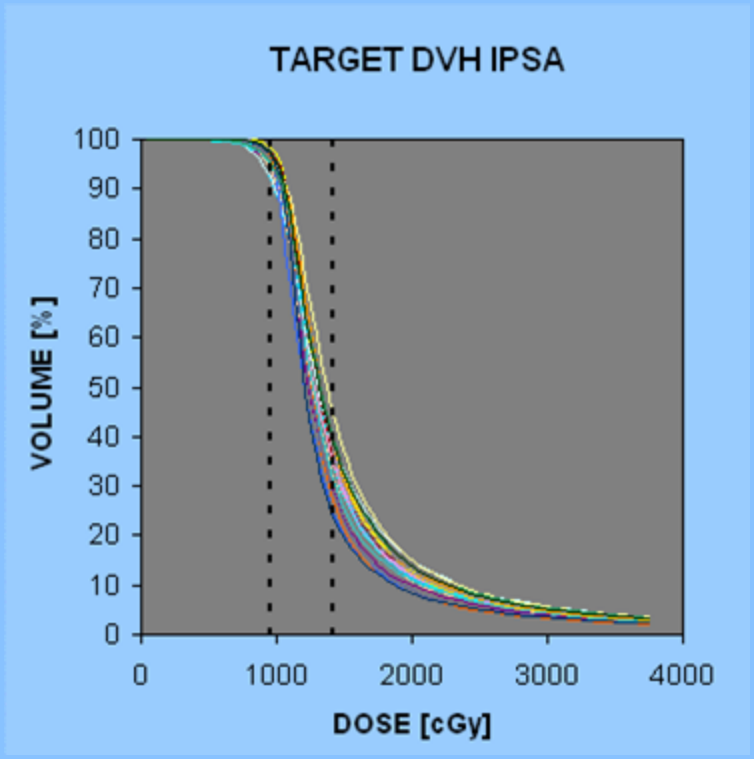
45 minutes

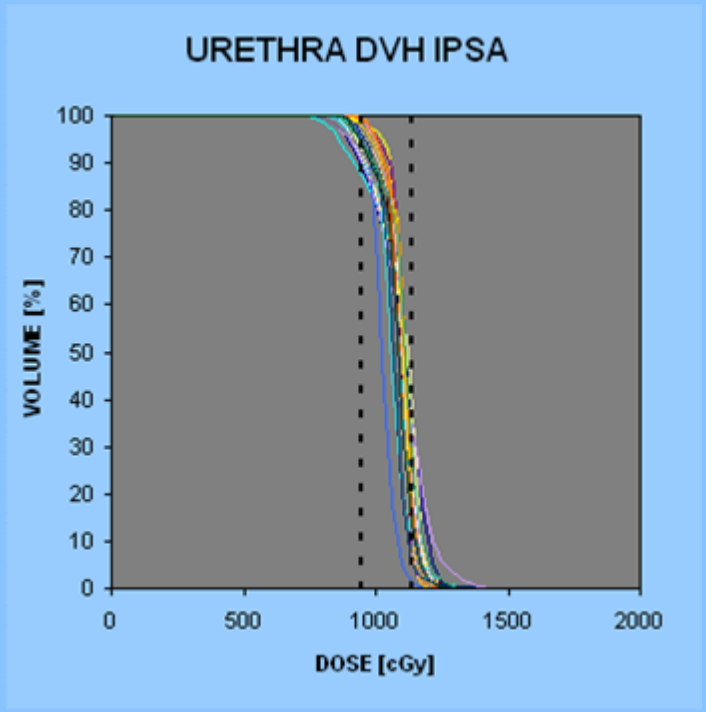




IPSA : 20 patients

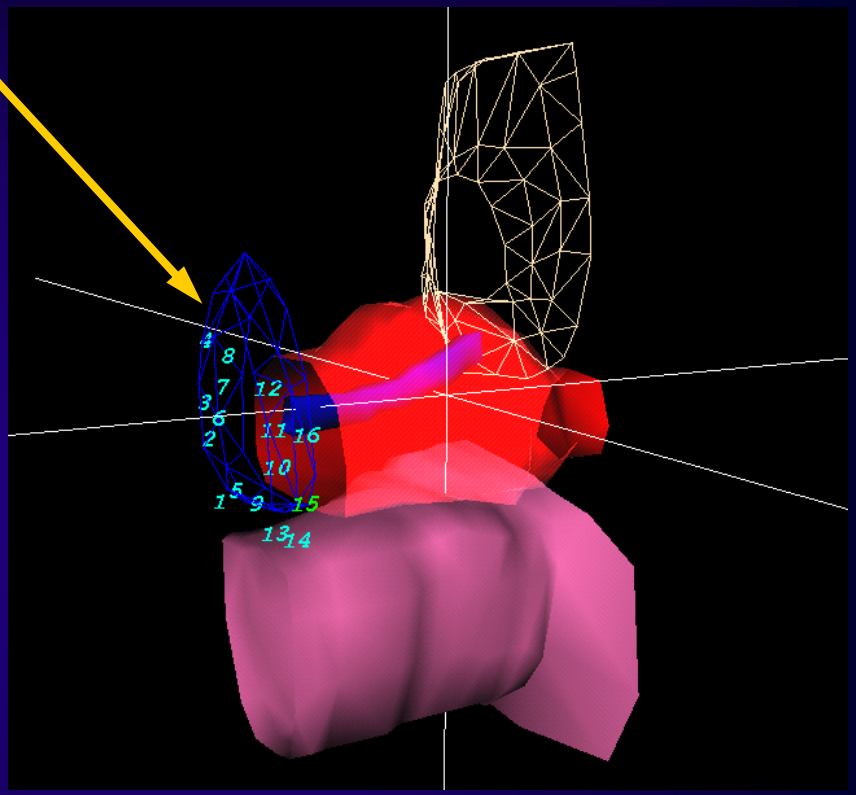
30 seconds



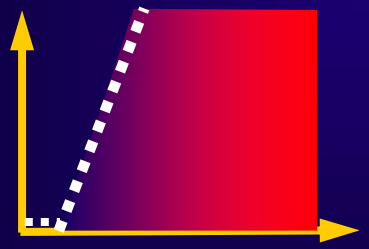


Protection of the bulb of the penis

Bulb CT contours from 17 patients

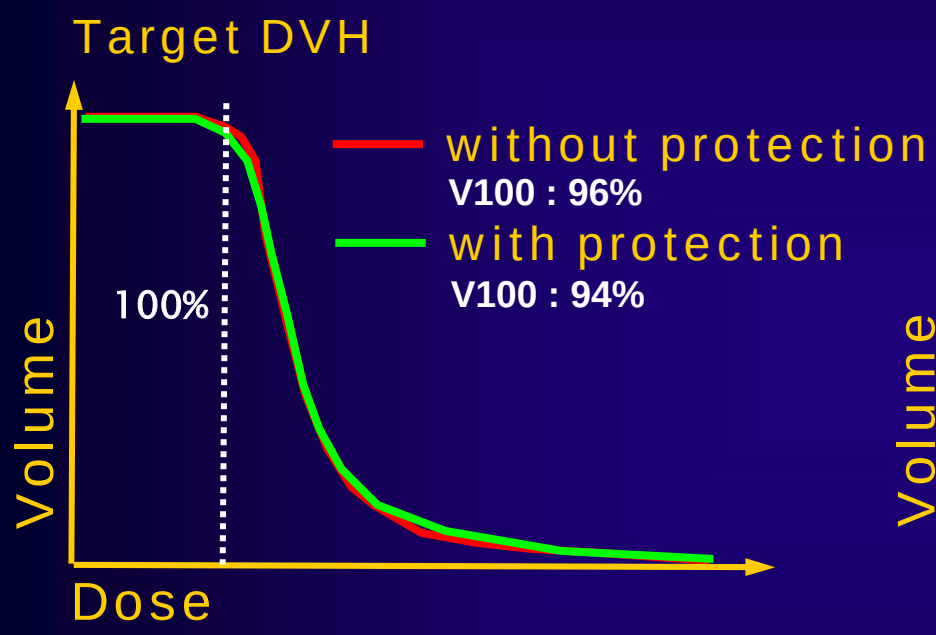


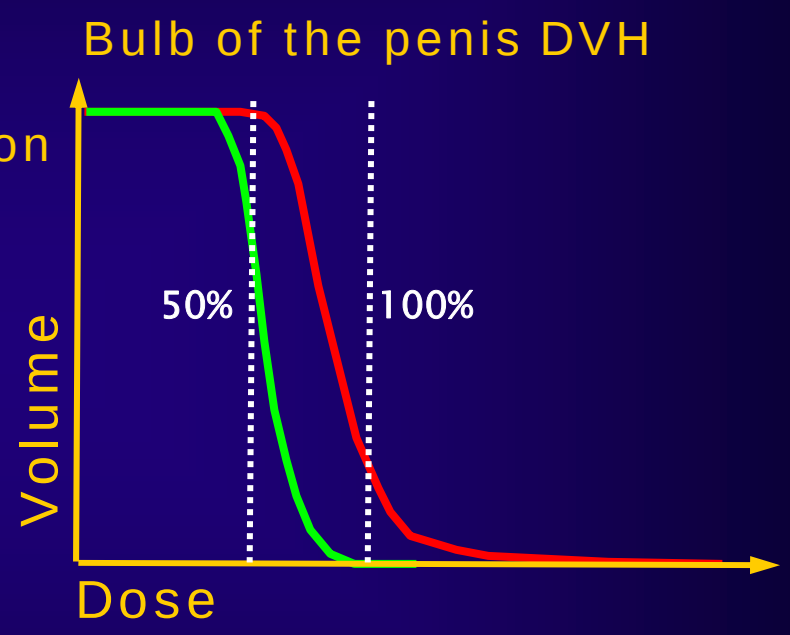
Bulb of the penis



50% = 475cGy

Protection of the bulb of the penis



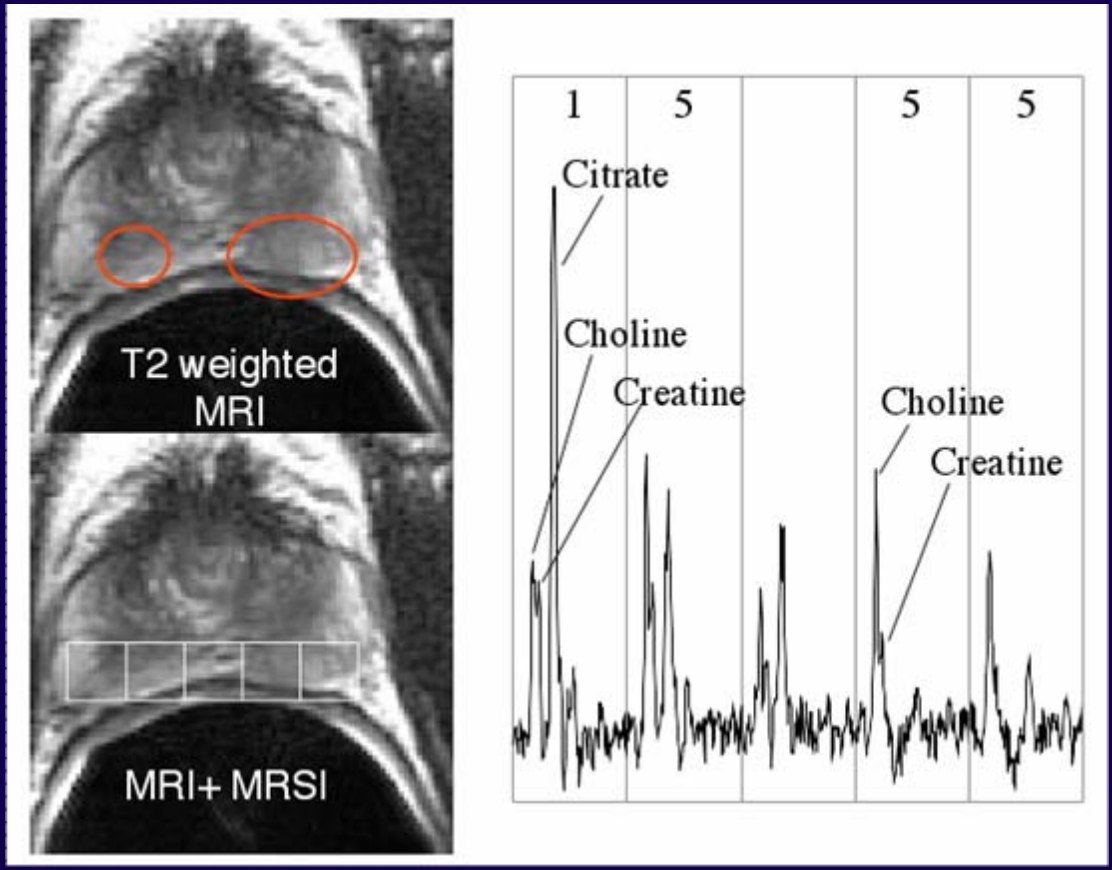


Average on 17 patients

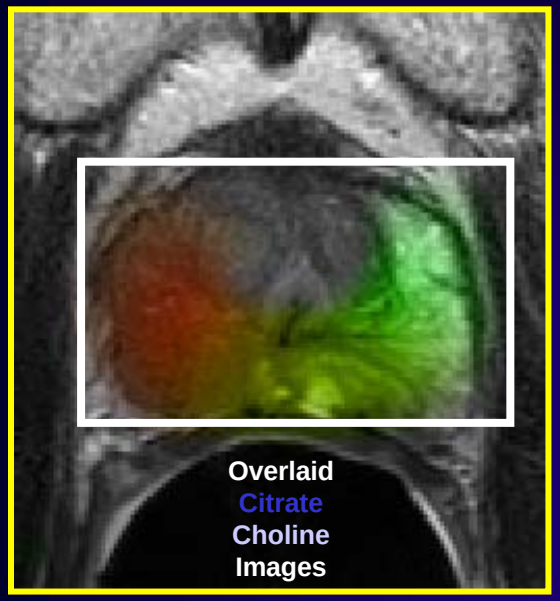
BULB: V75 ↓ 80%

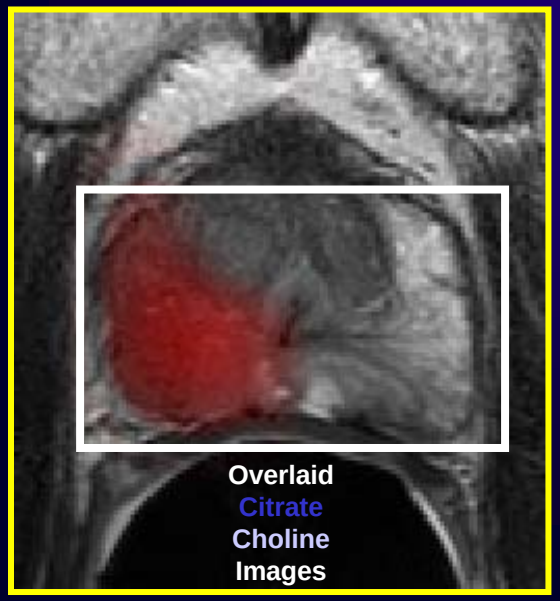
TGT: V100 ↓ 2% (98->96%)

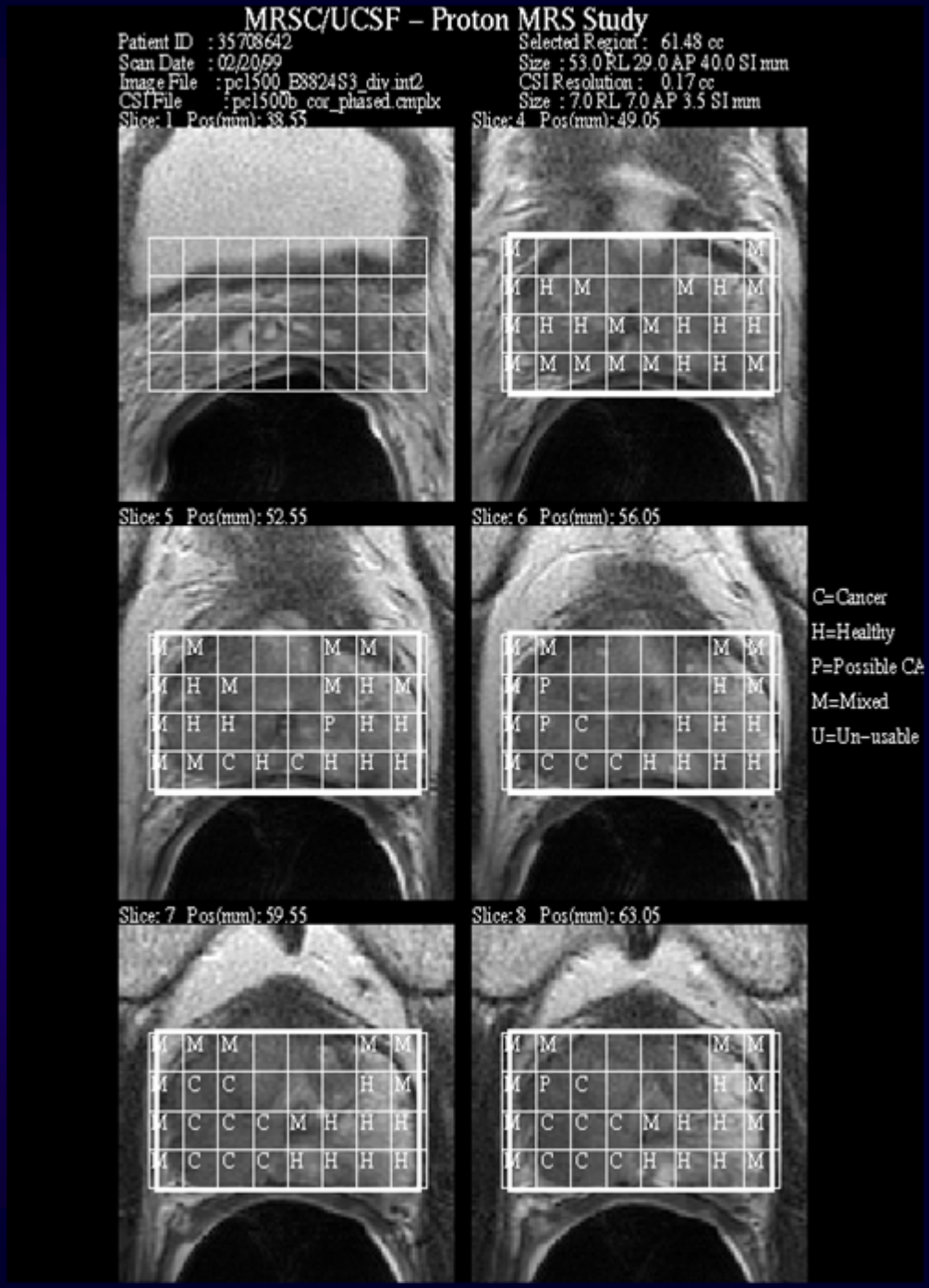
Functional Imaging: MR-Spectroscopy



Display And Interpretation of Combined MRI/MRSI Data

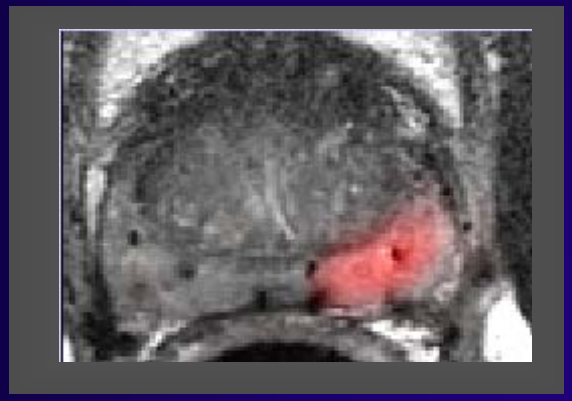






Additional constraint: Boost within the prostate

MR Spectroscopy



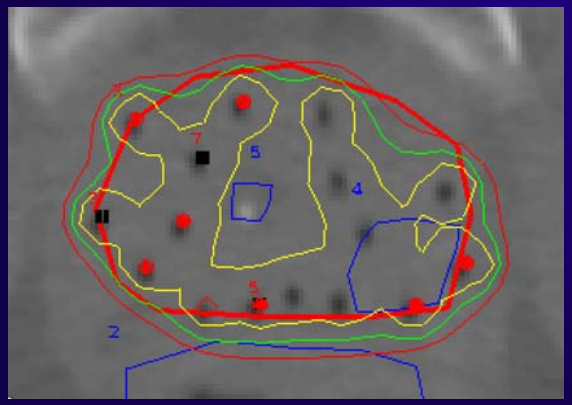
Inverse Planned

Target -> 100 %

D.I.L. -> 120 %

Standard plan

Geo + Manual



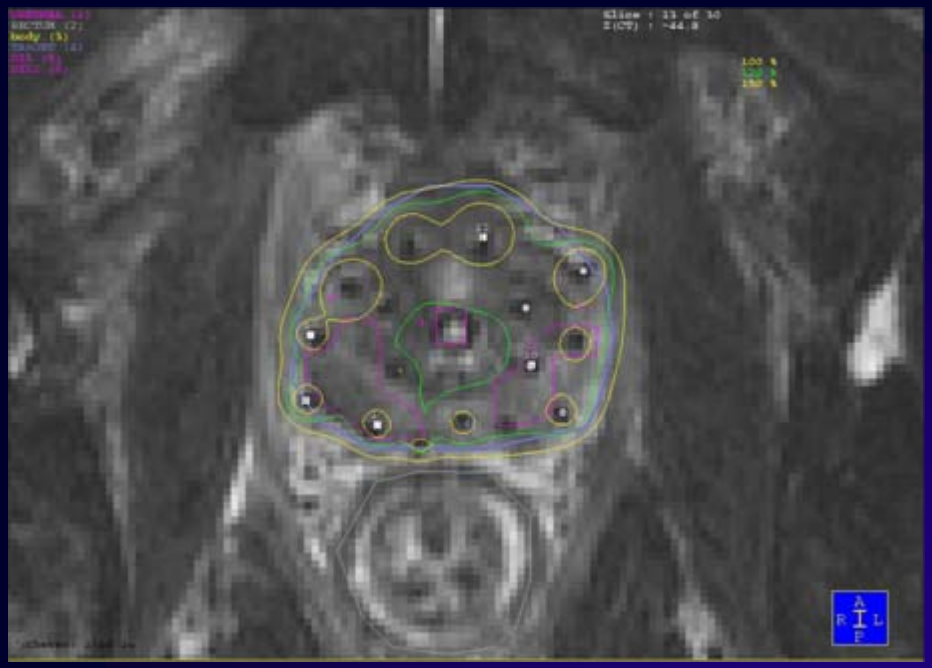
Target -> 100 %

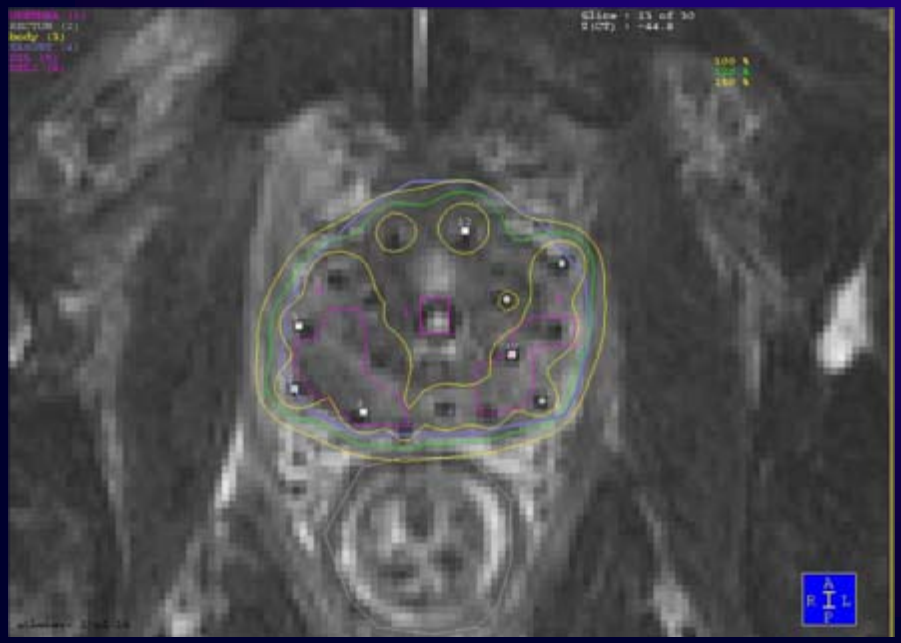
D.I.L. -> 150 %

------ 100 %

------ 120 %

------ 150 %

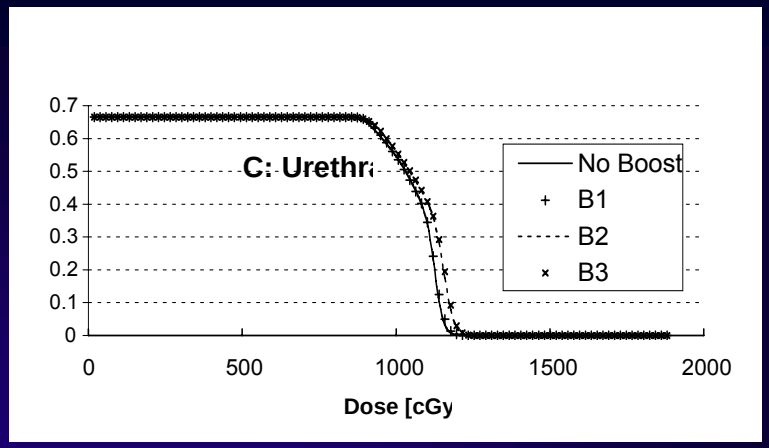


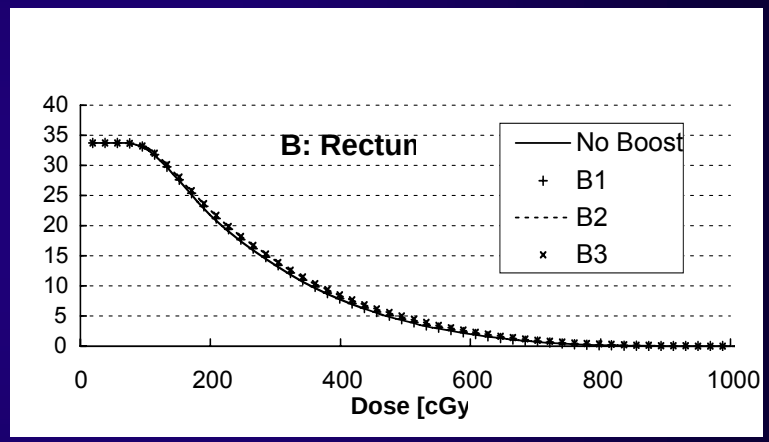


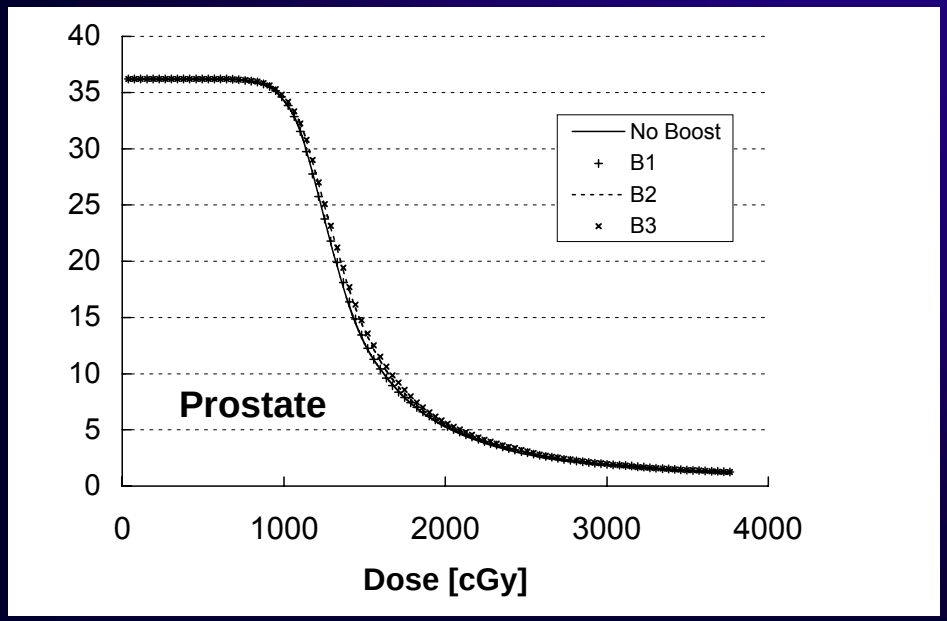
DIL_120_150	DIL_150_150
DIL_150_170	MR

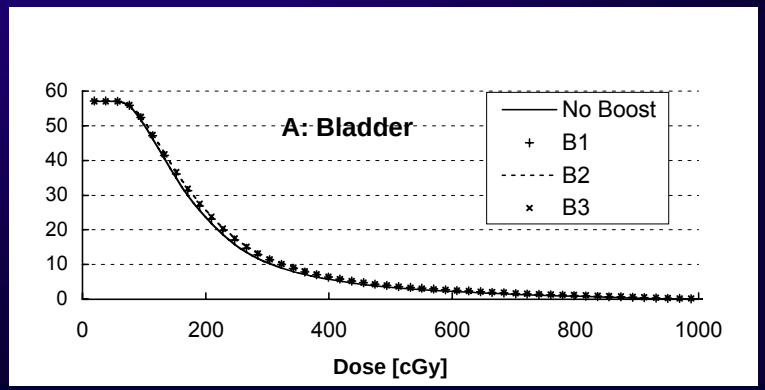
MRS-defined DIL Boost

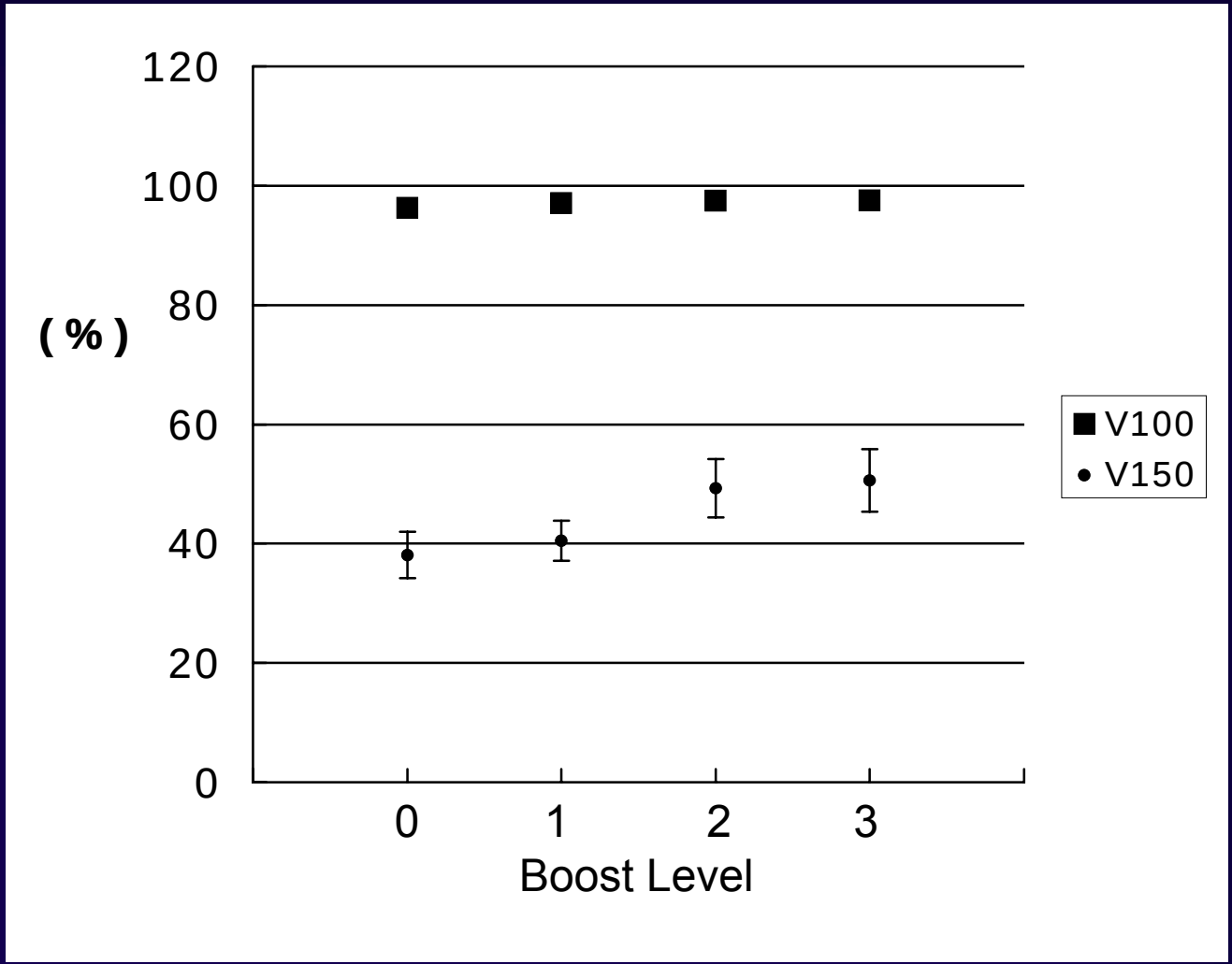
0	No Boost
B1	120 - 150%
B2	150 - 150%
B3	150 - 170%







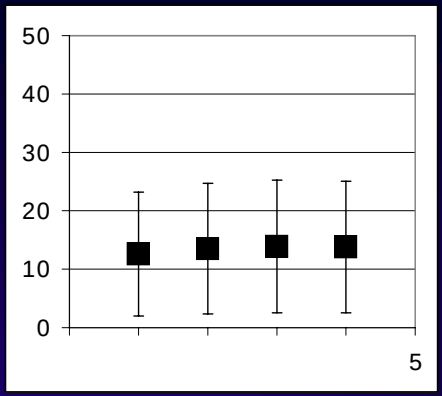



120
100
80
60
40
20
0
(%)
0
1
2
3
Boost Level
V100
V150

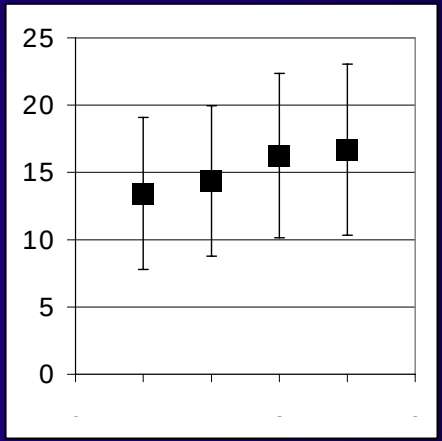
MRS-defined DIL Boost

0	No Boost
B1	120 - 150%
B2	150 - 150%
B3	150 - 170%

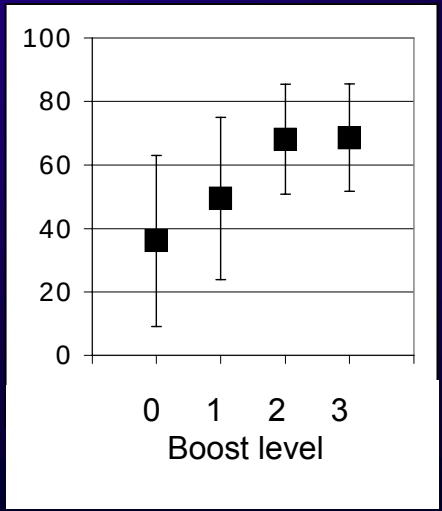
BLADDER: V50(%)

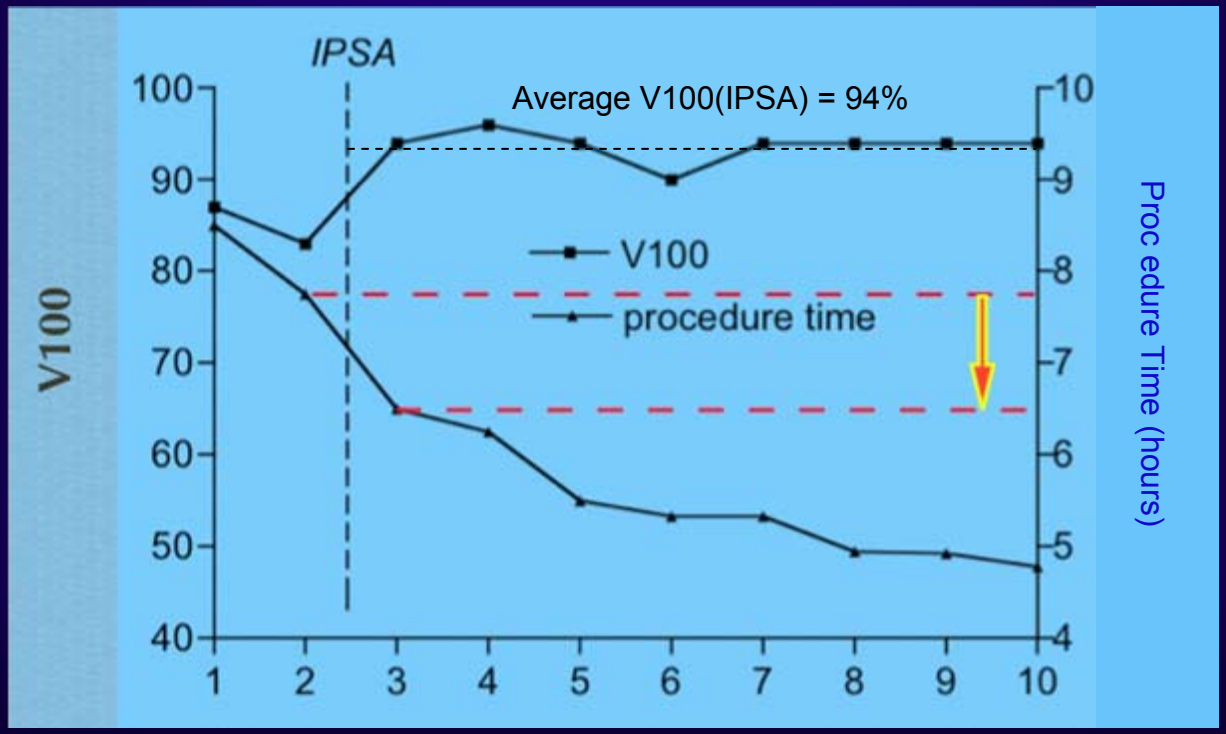


RECTUM: V50(%)



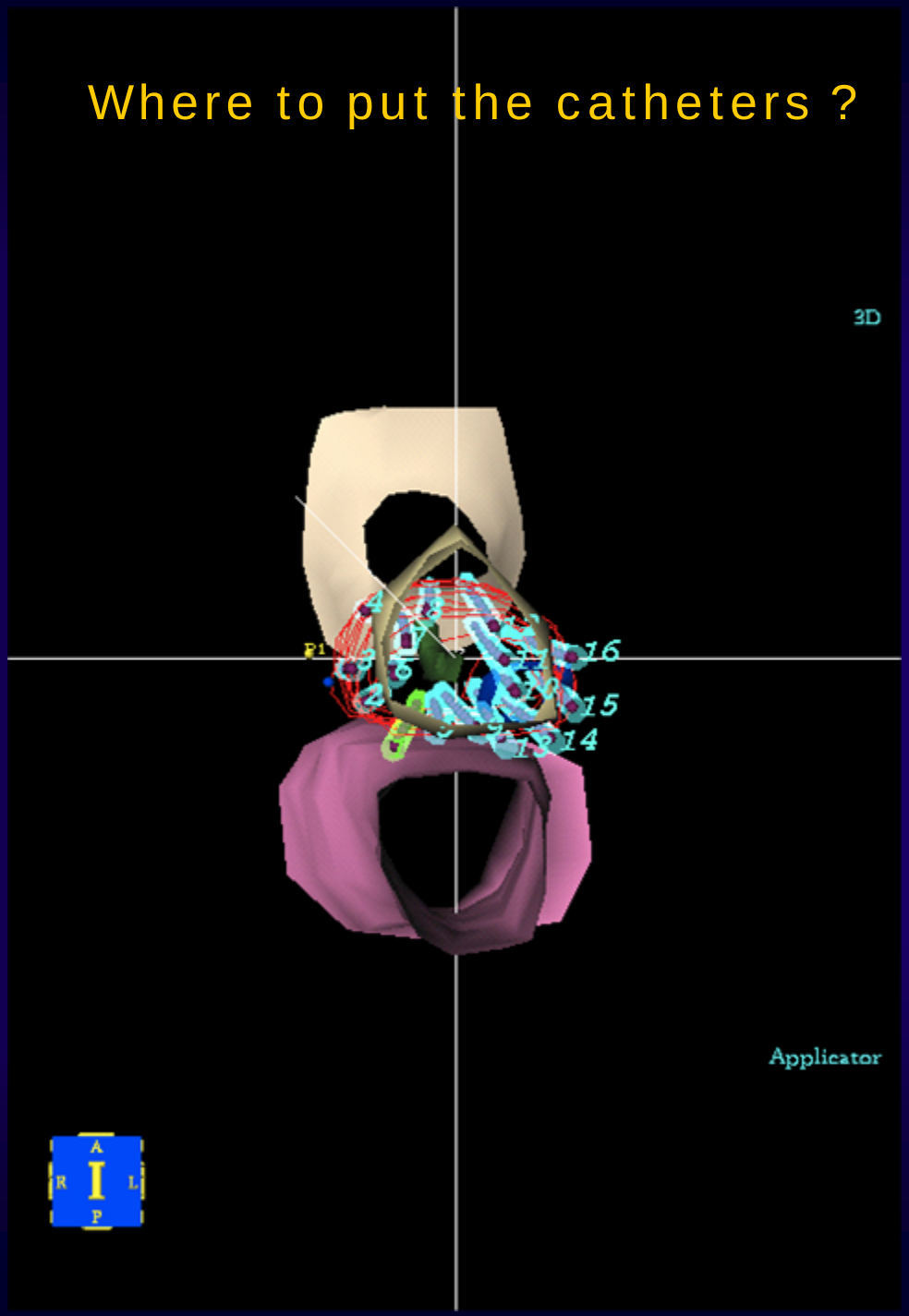
URETHRA: V120(%)

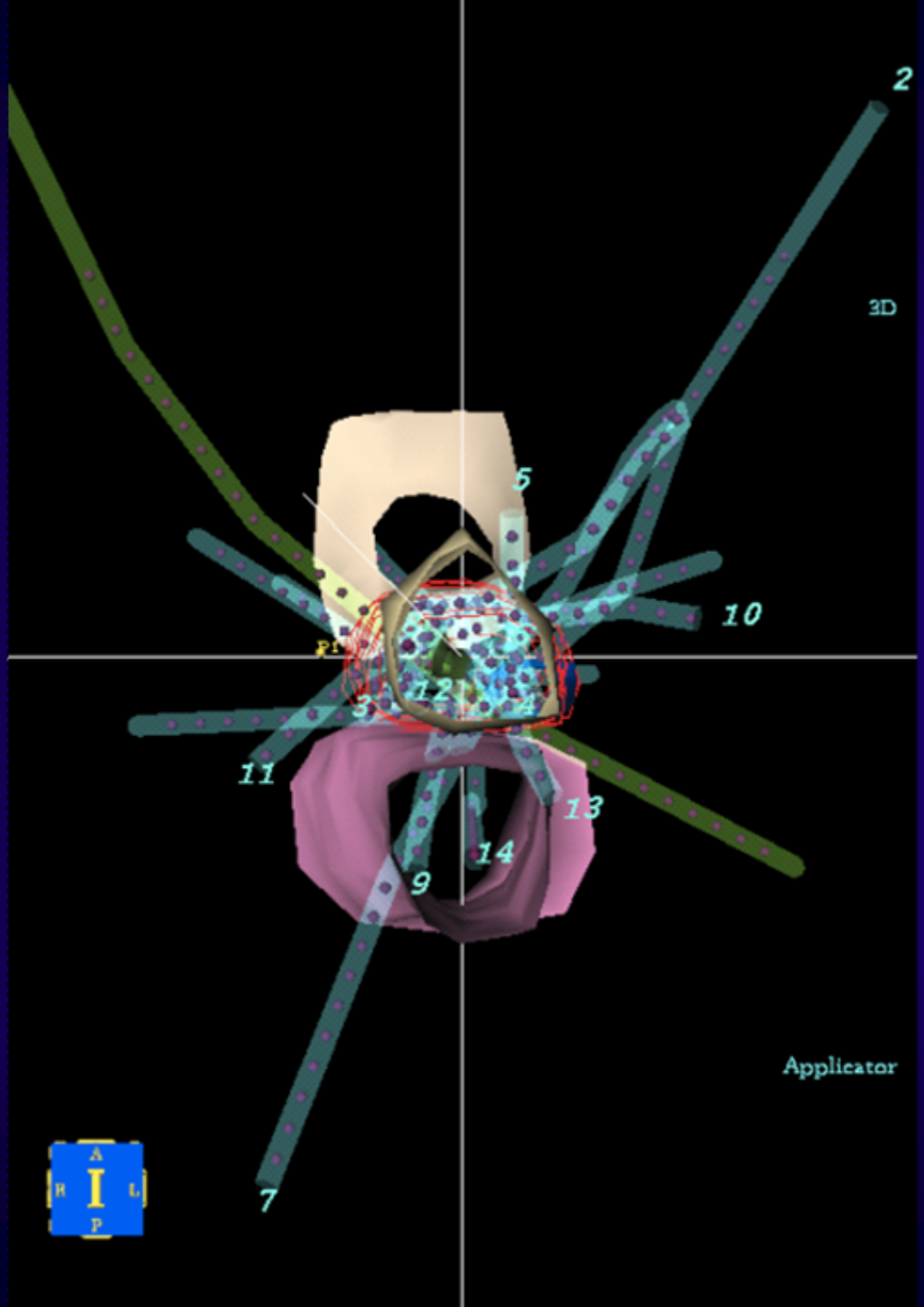




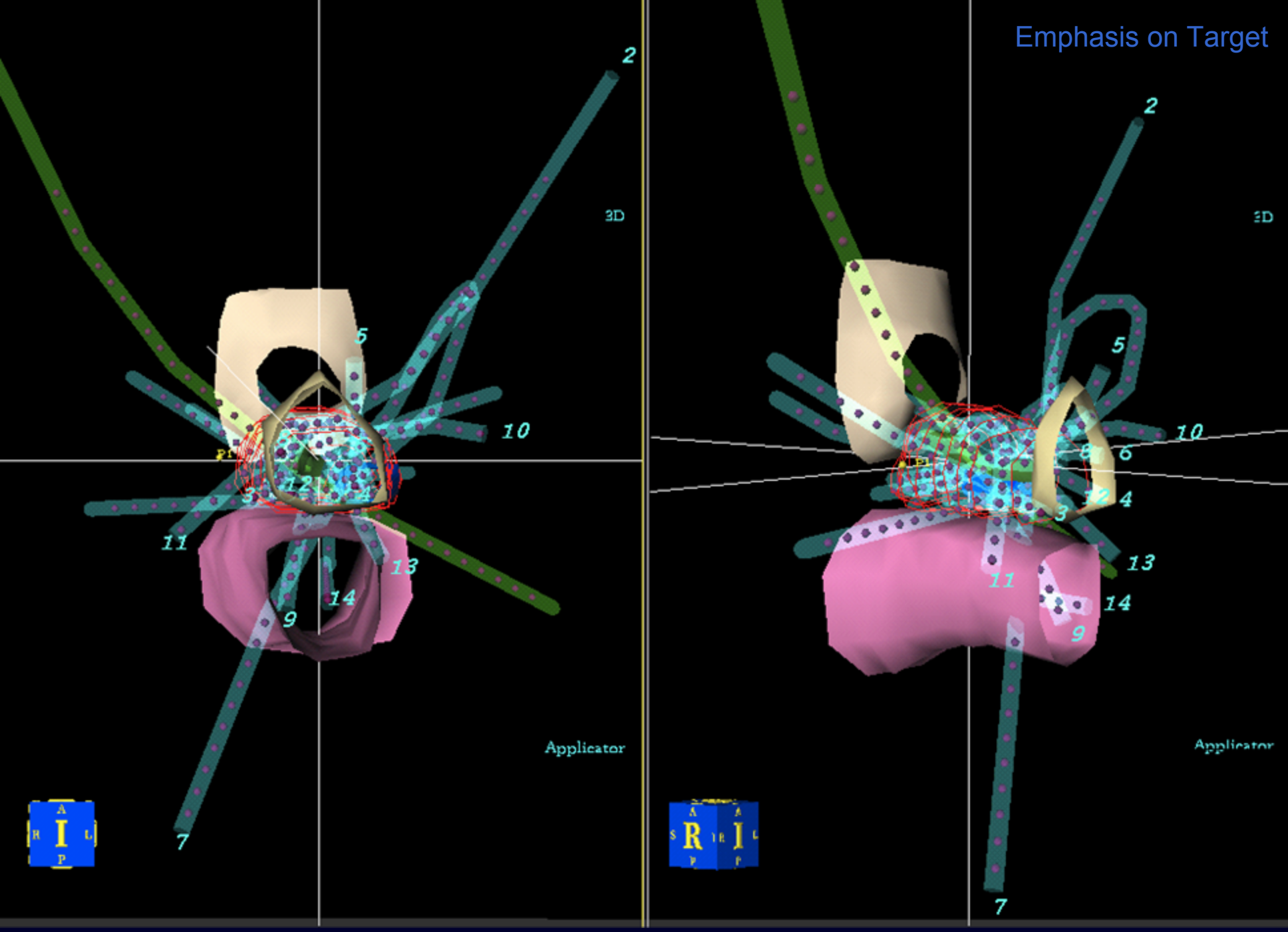
Dr Cynthia Menard

Where to put the catheters ?

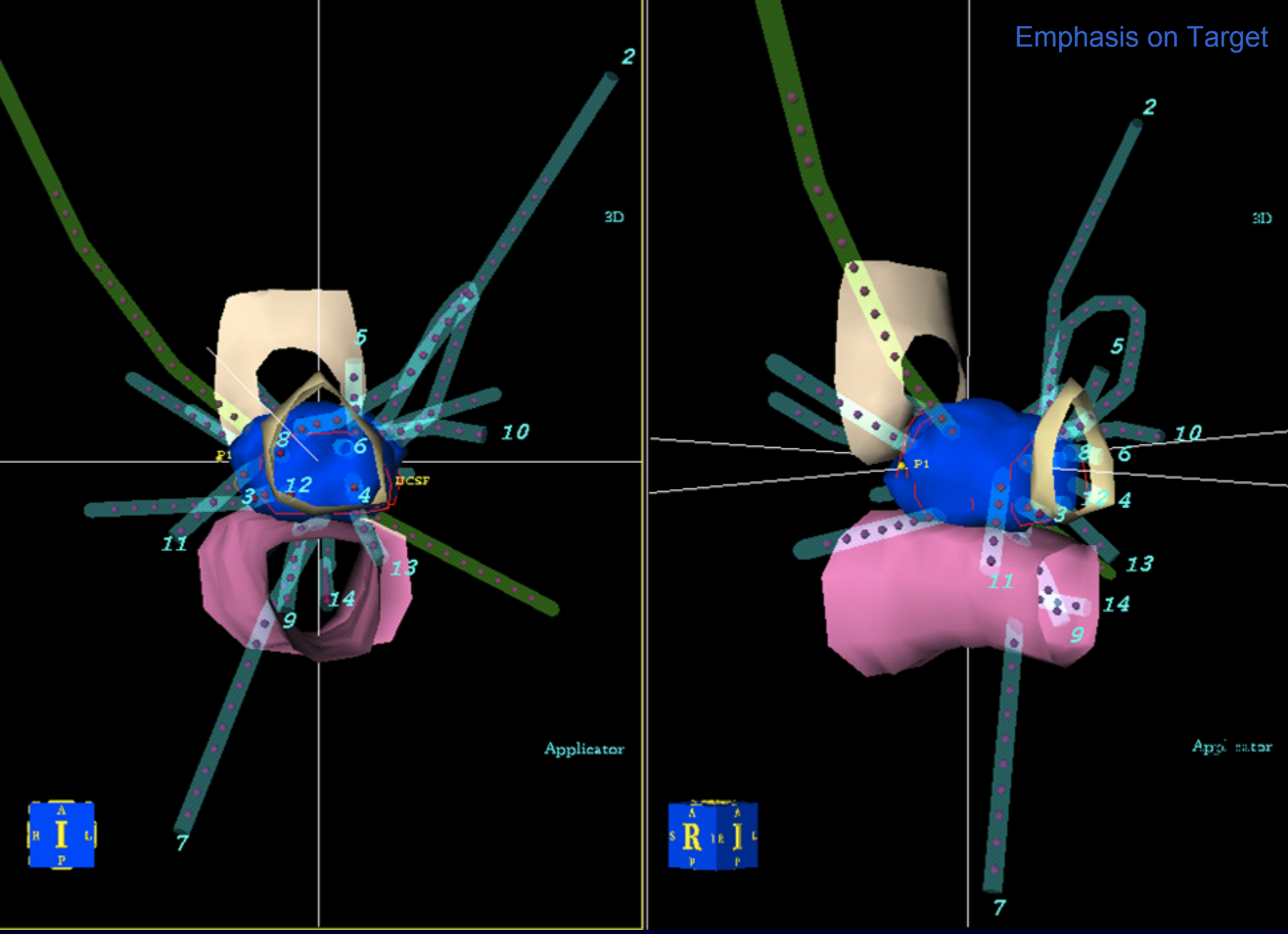


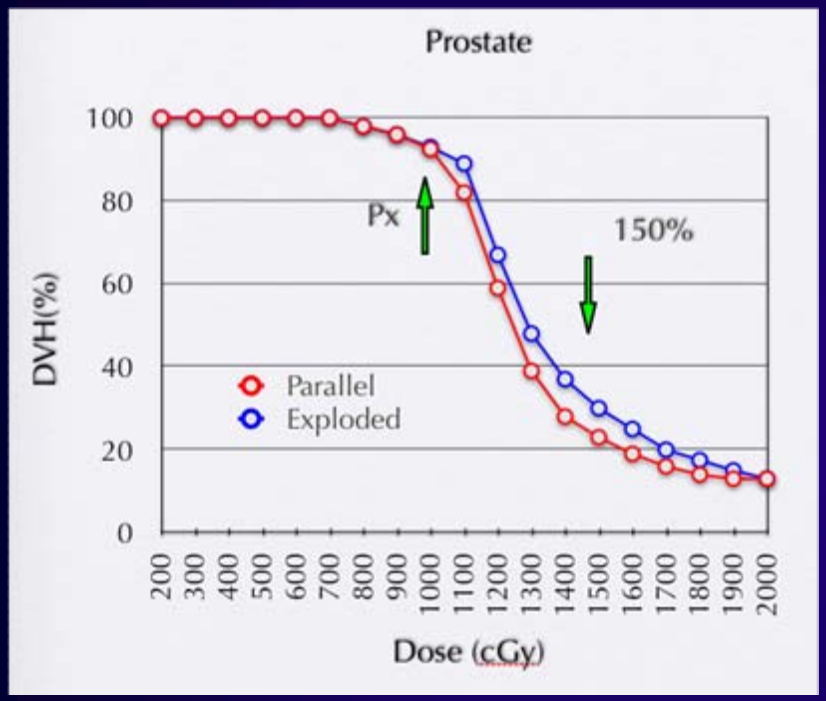

2
3D
5
10
12
3
4
11
13
14
9
Applicator
7
A
R
L
P

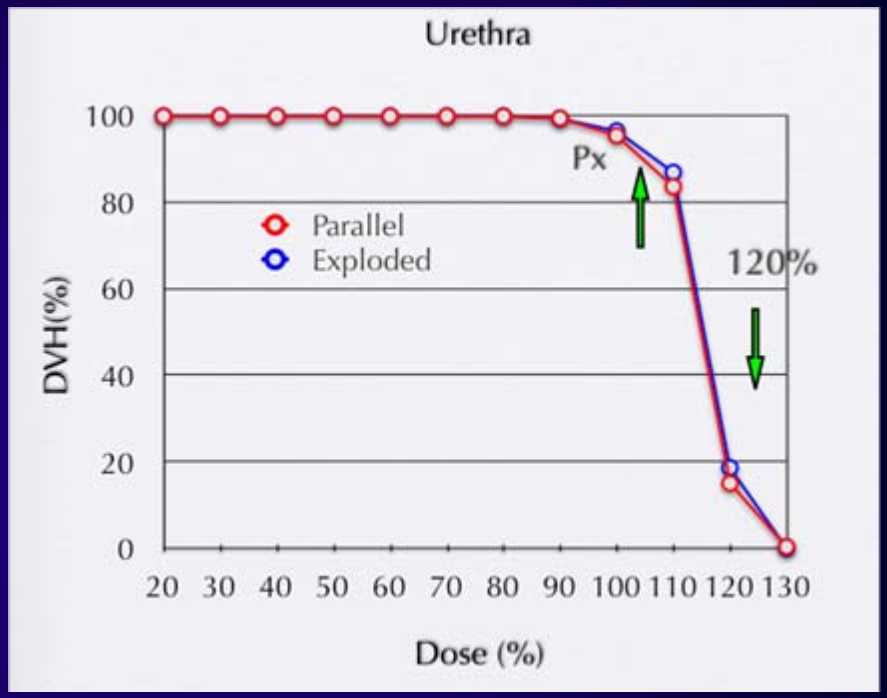
Emphasis on Target



Emphasis on Target

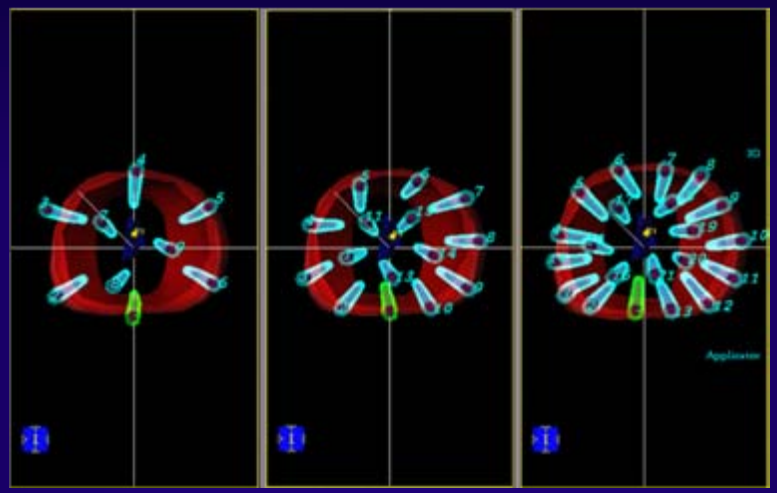


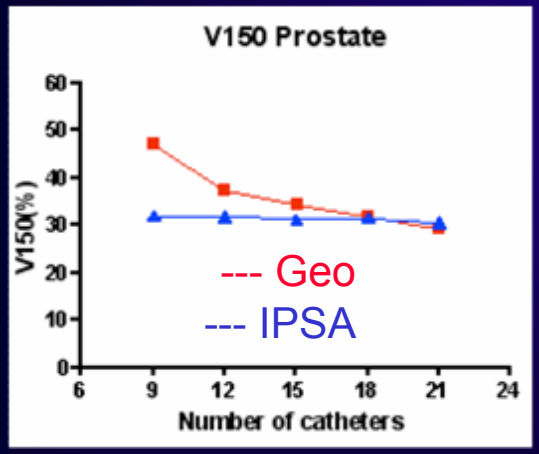


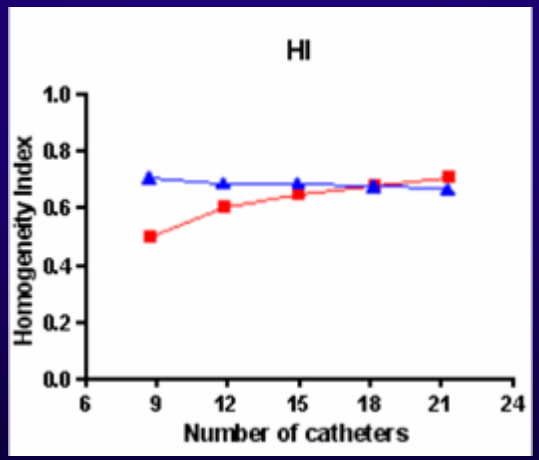


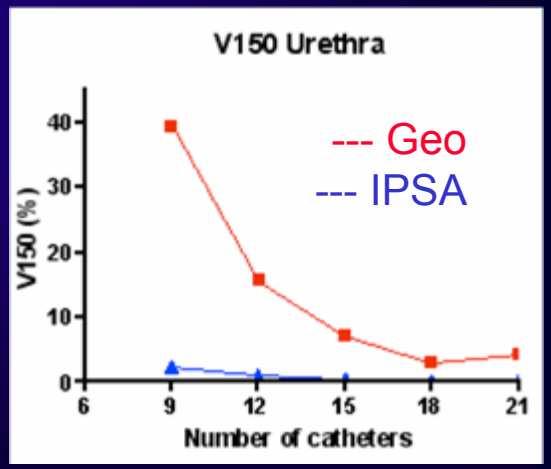
Bladder, Rectum, Bulb: Identical DVHs

How sensitive is the dosimetry of an implant to the number of catheters implanted ?

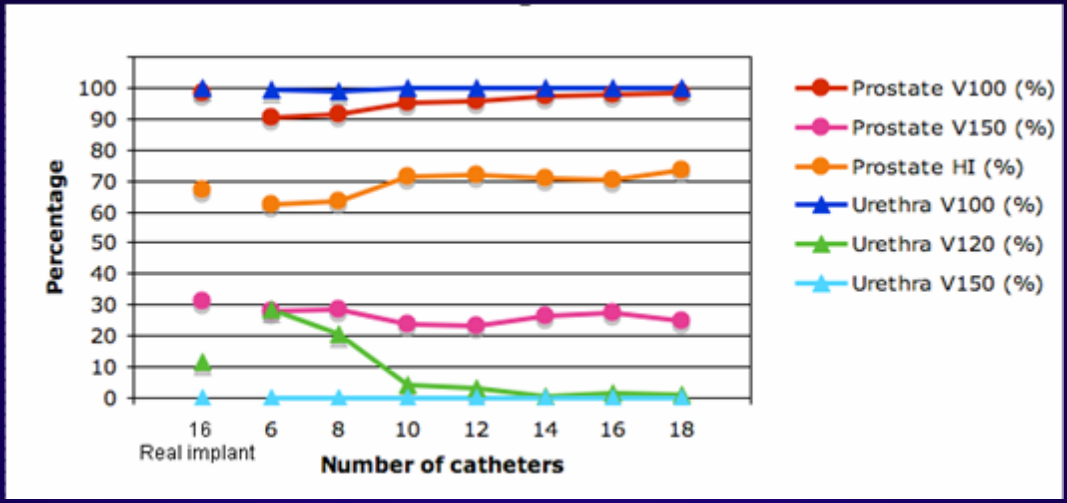


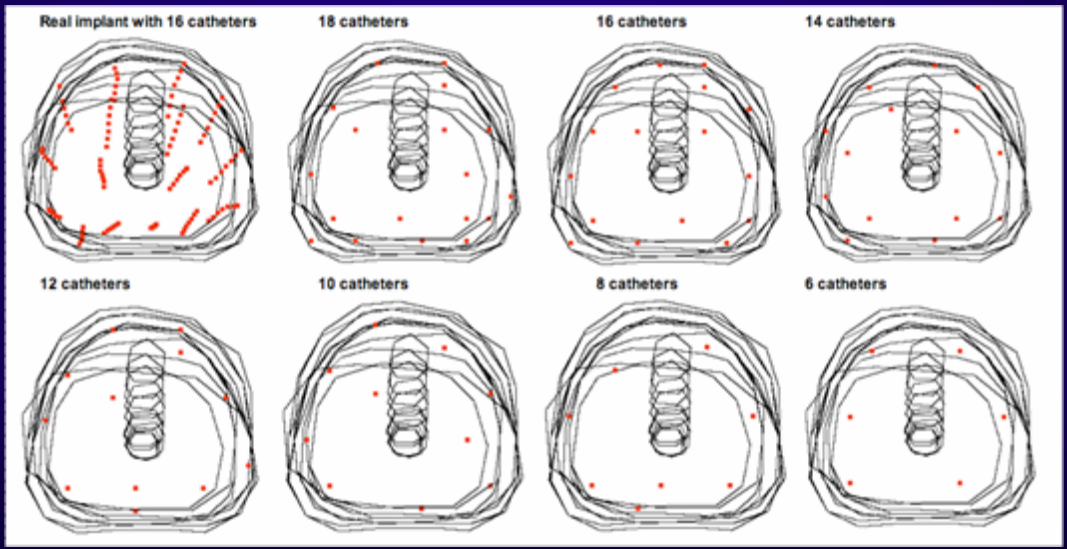






How sensitive is the dosimetry of an implant when the catheter positions are optimized ?





Lessard et al., AAPM 2005

Quickline PICT

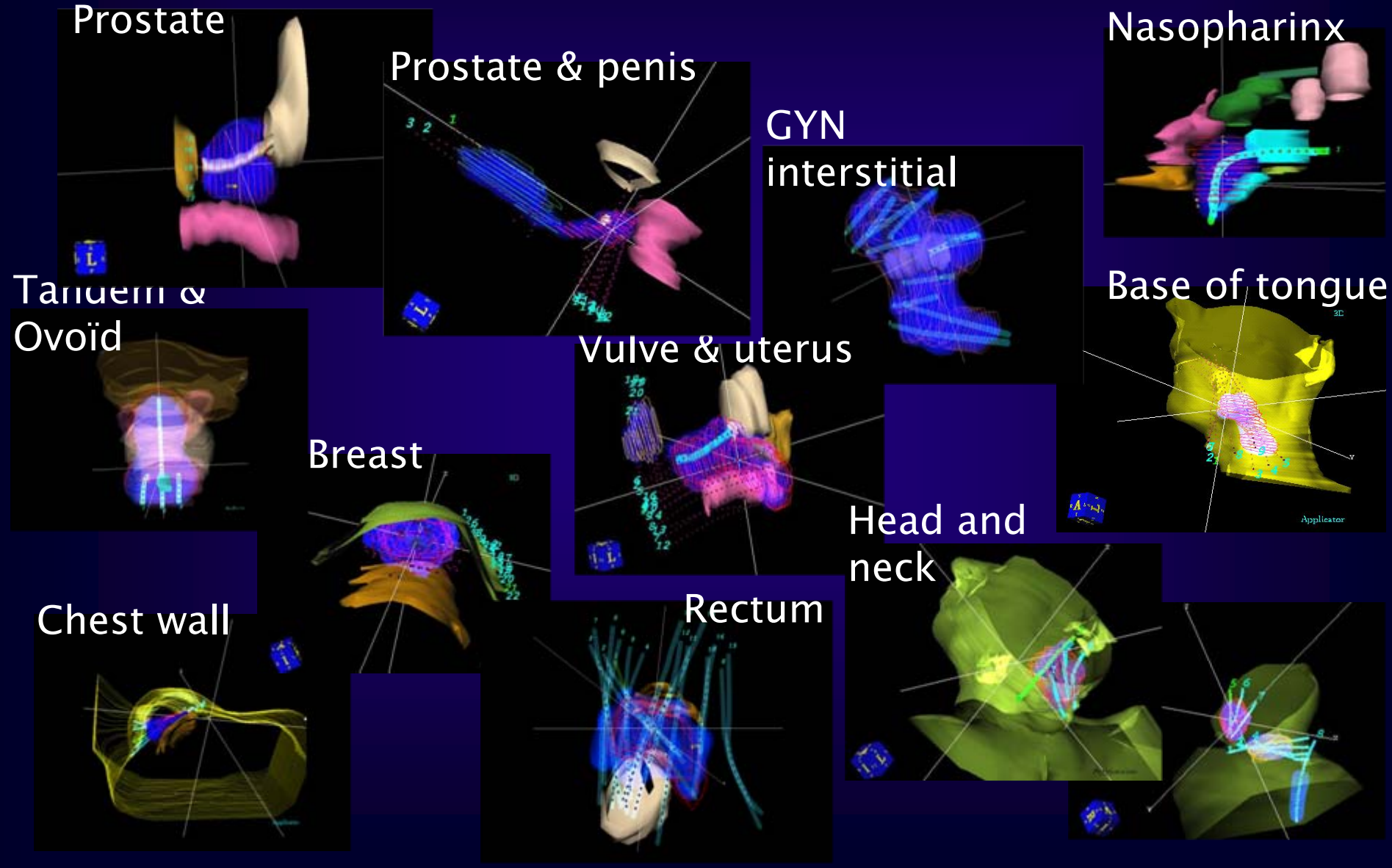
Quickline PICT

Quickline PICT

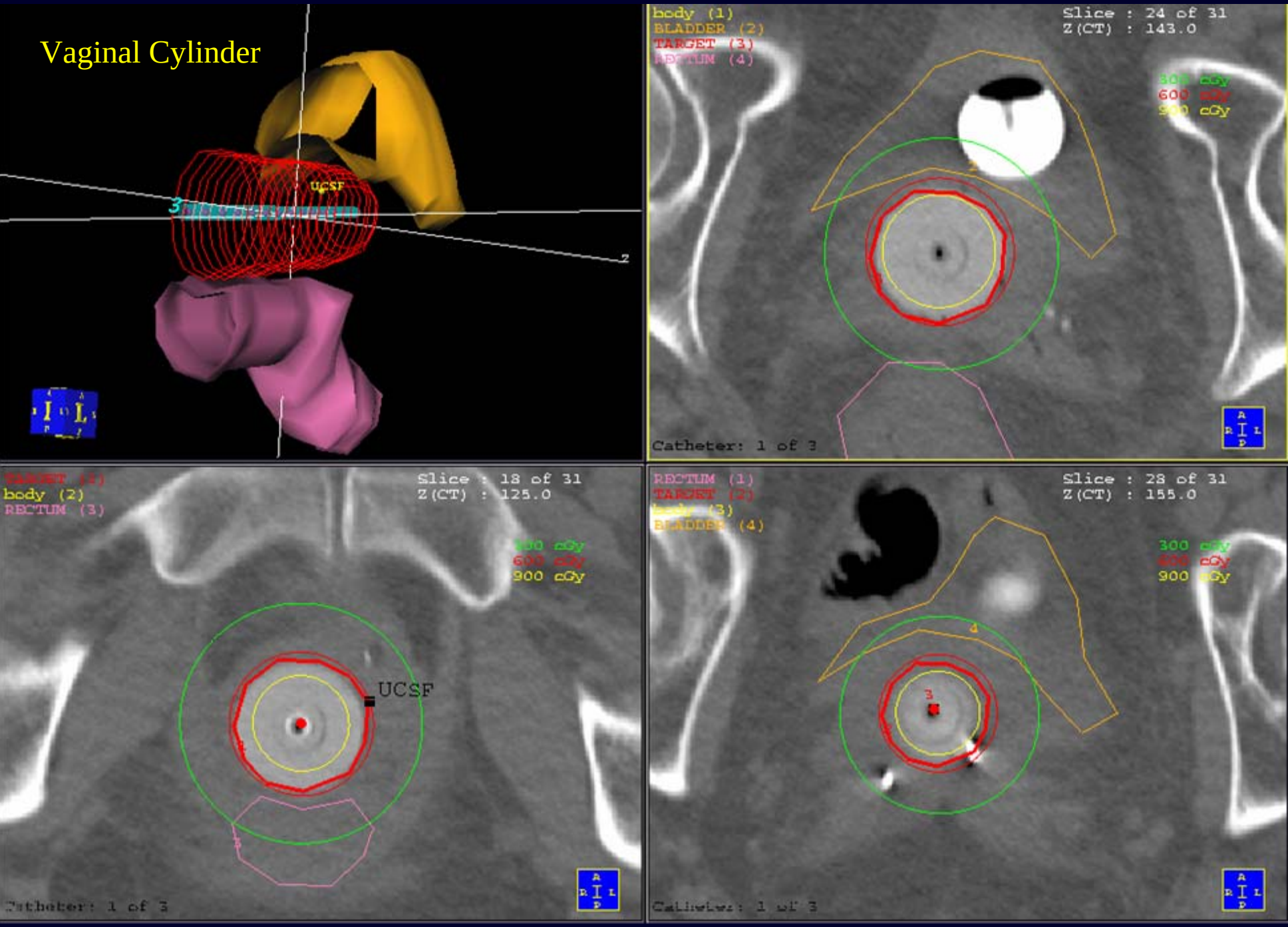
Quickline PICT

HDR Brachytherapy

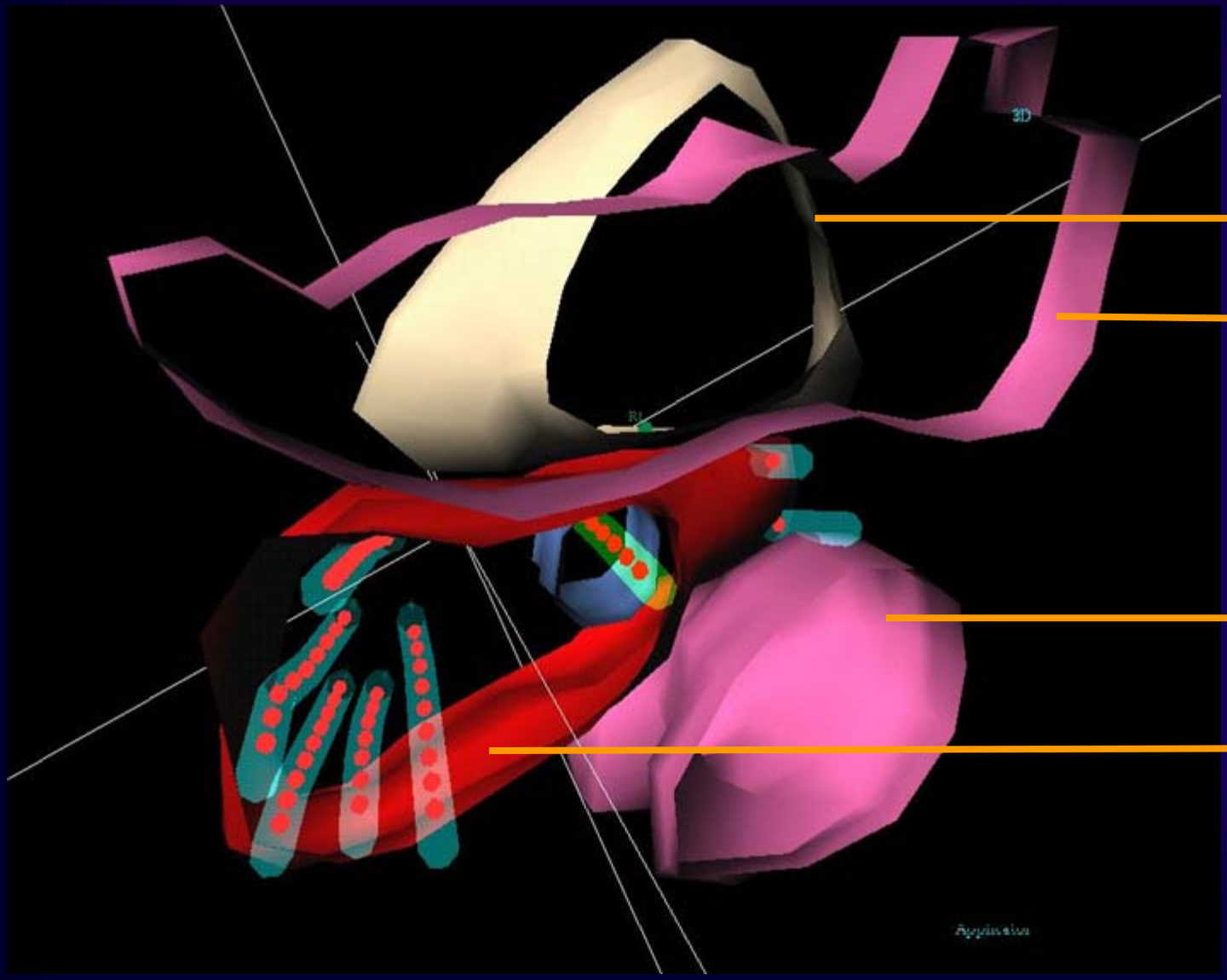
IPSA in Plato BPS



Vaginal Cylinder



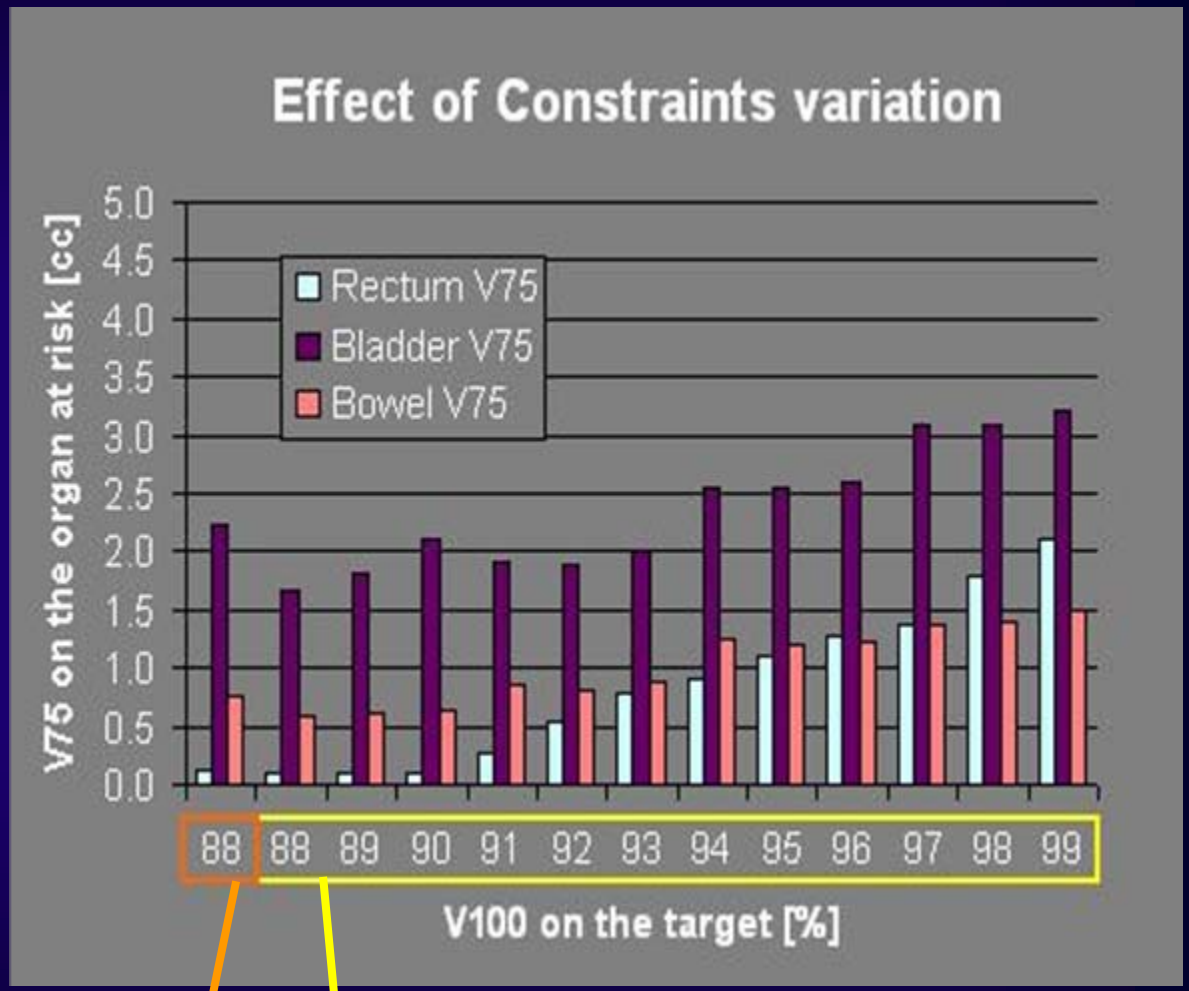
Effect of dose constraint variations on a GYN-template



Effect of dose constraint variations on a GYN-template

This graph shows the effect on the organ at risk protection when more emphasis is put on the coverage.

While the coverage approaches the 100% of the target volume, each organ at risk receives more dose.

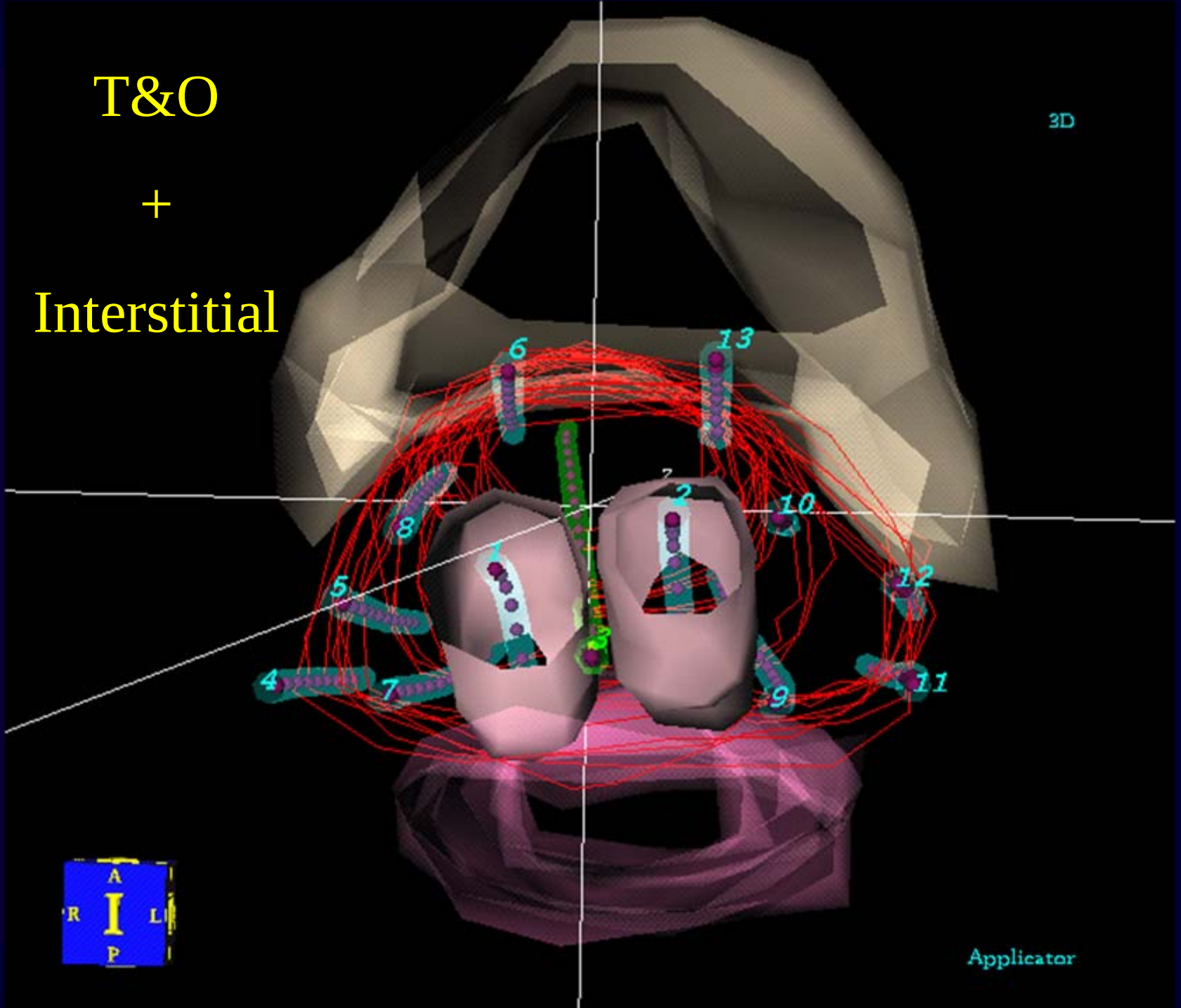


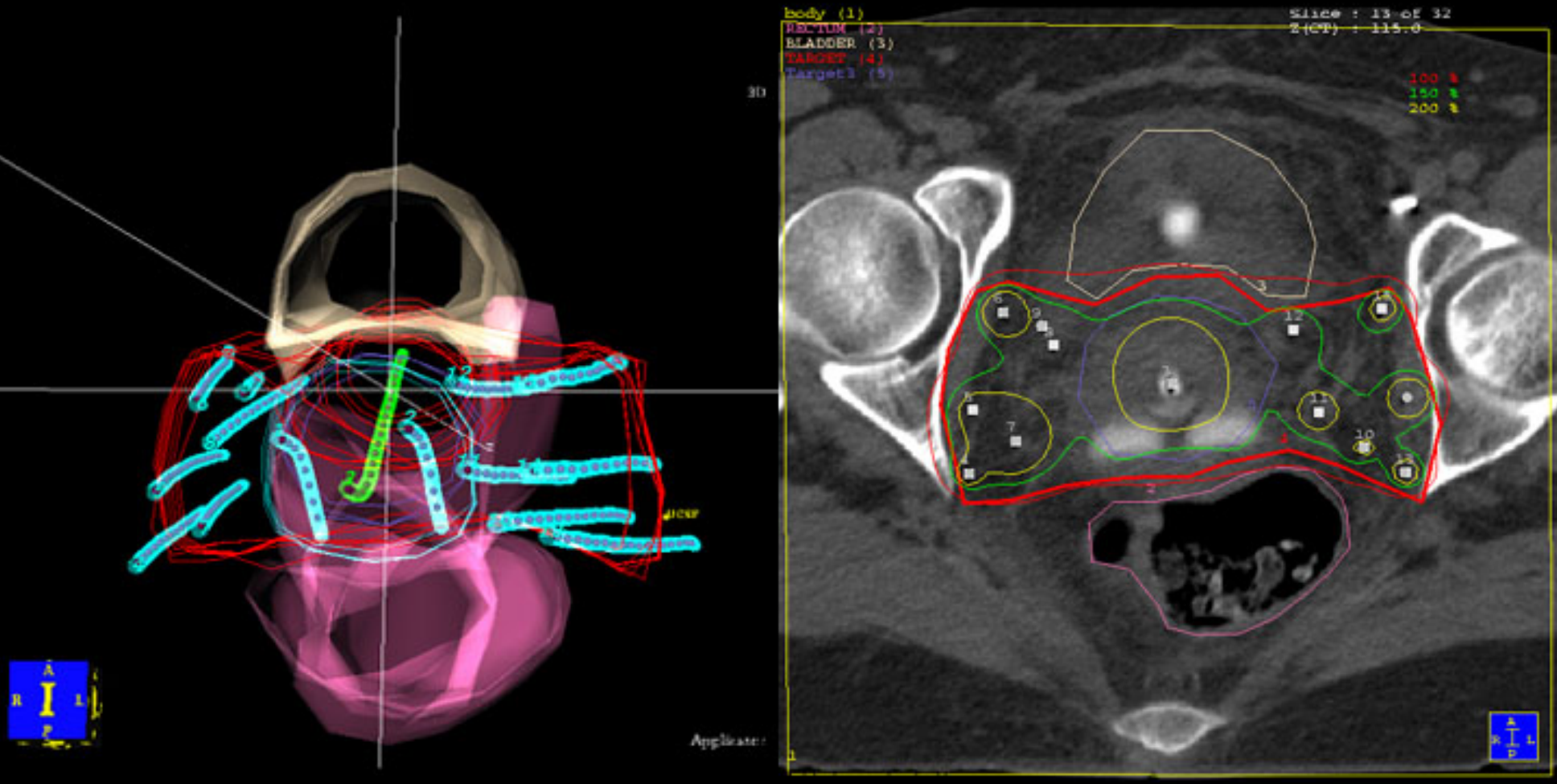
Manual IPSA

T&O

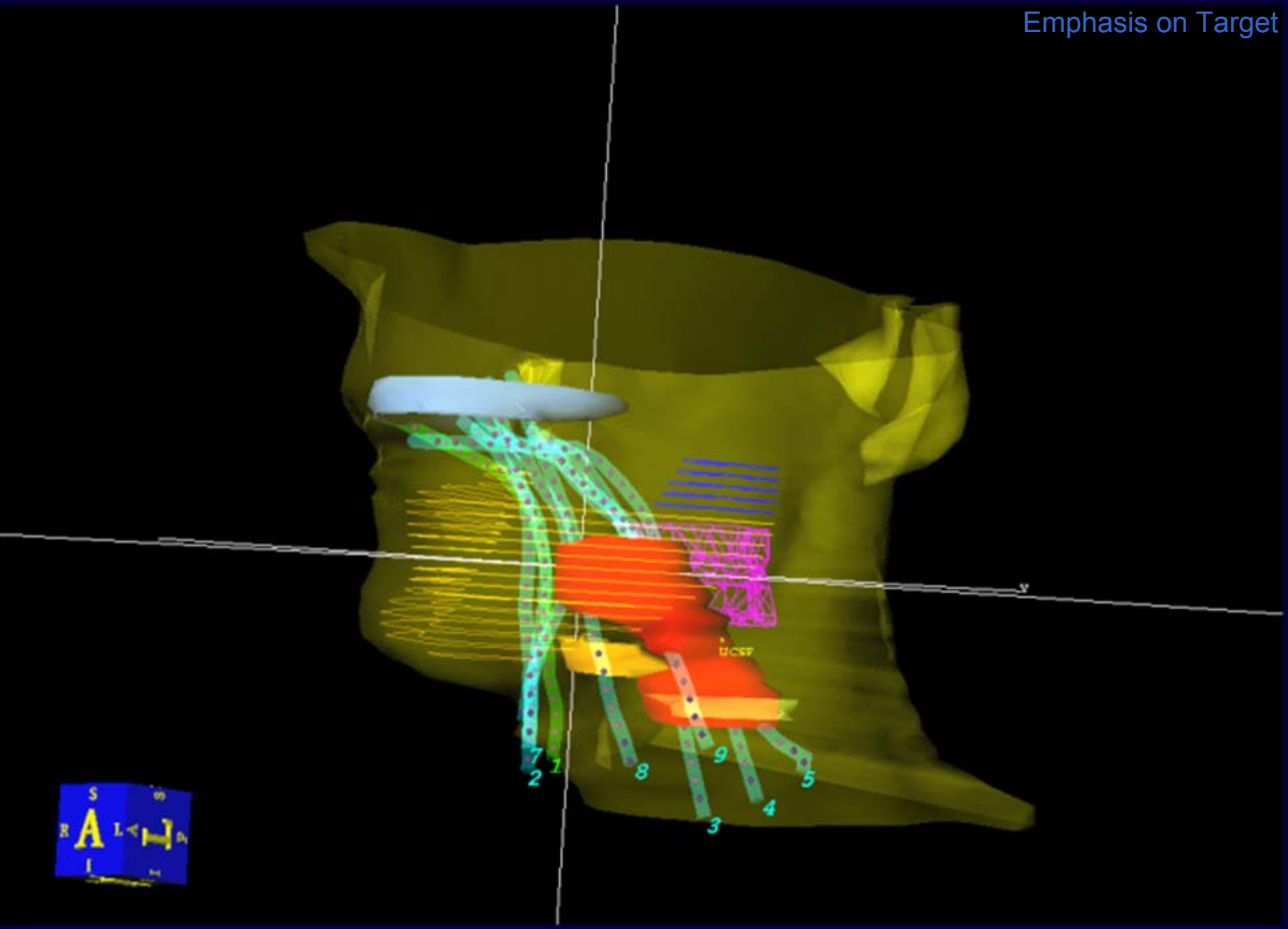
+

Interstitial

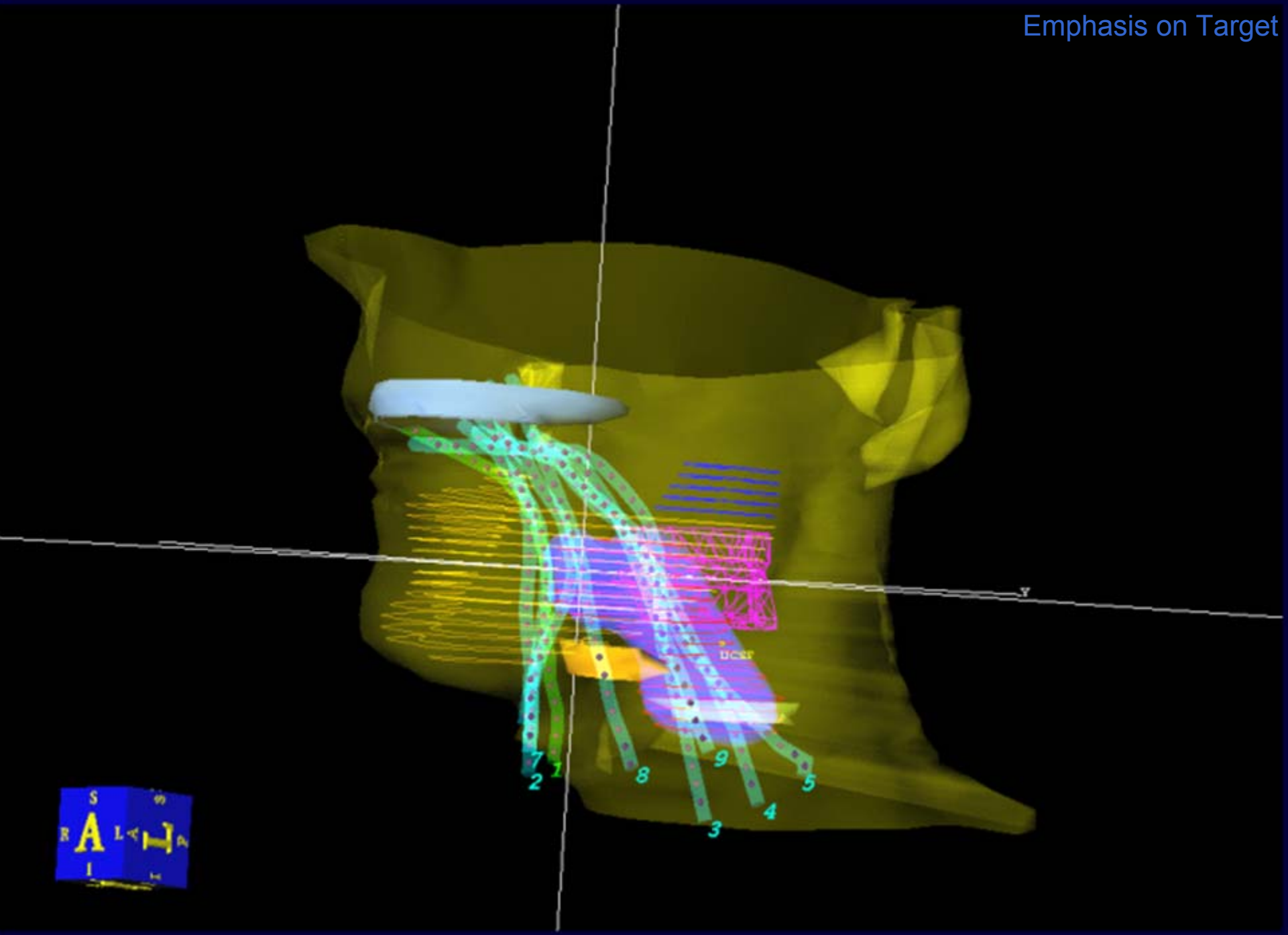



body (1)
RECTUM (2)
BLADDER (3)
TARGET (4)
Target3 (5)
Slice : 13 of 32
Z(CT) : 115.0
100 %
150 %
200 %
A
R
L
P

Emphasis on Target

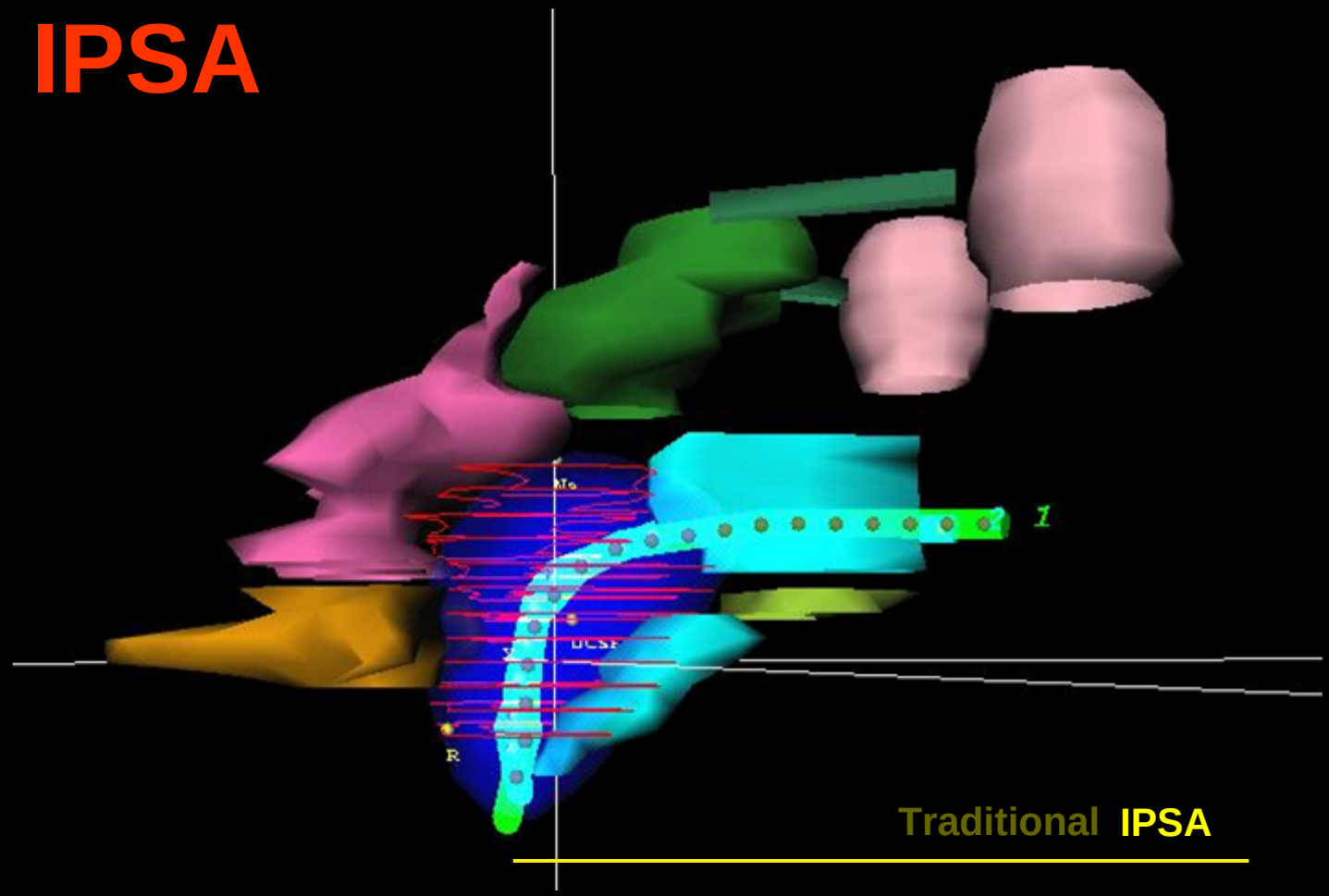


Emphasis on Target

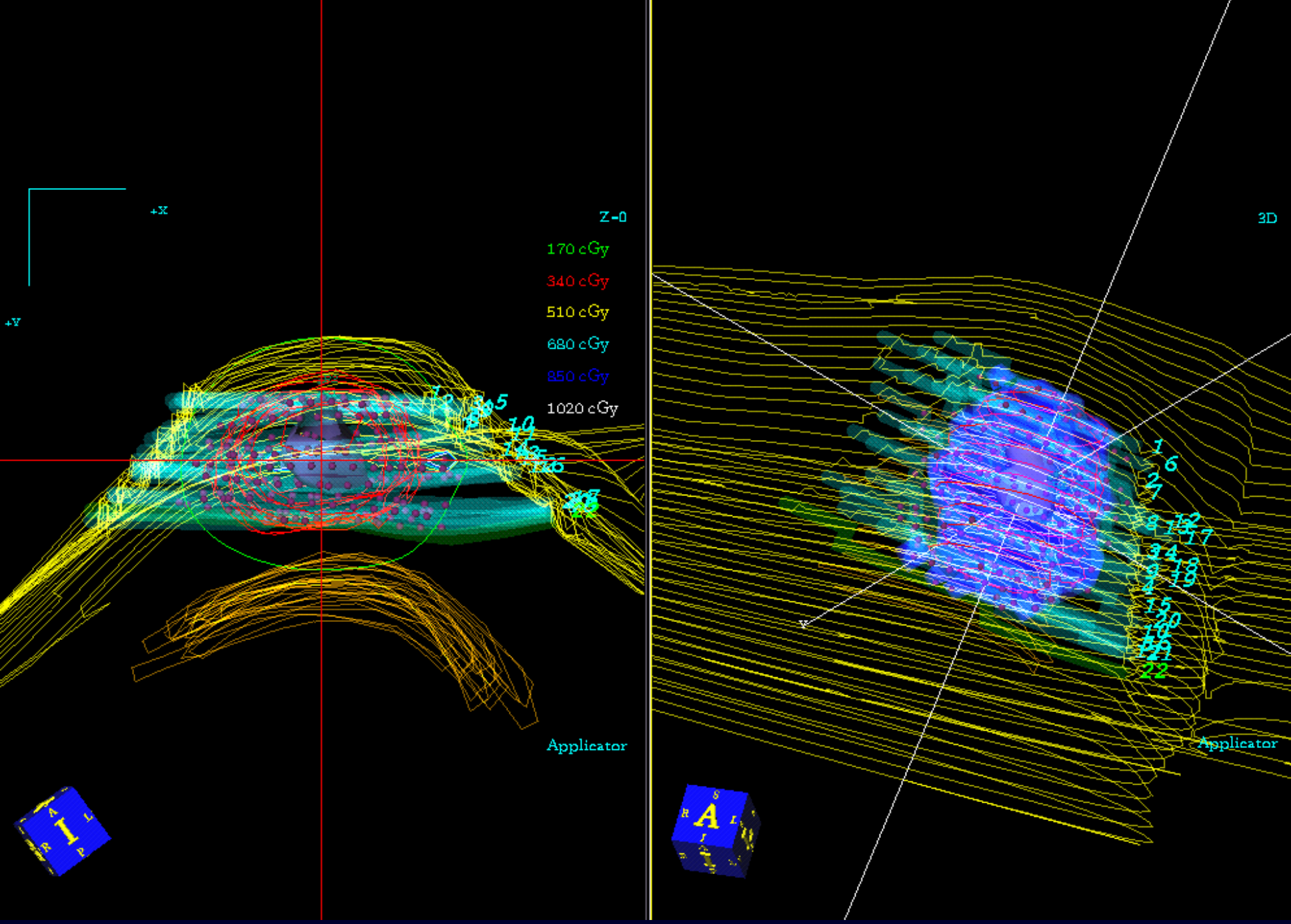


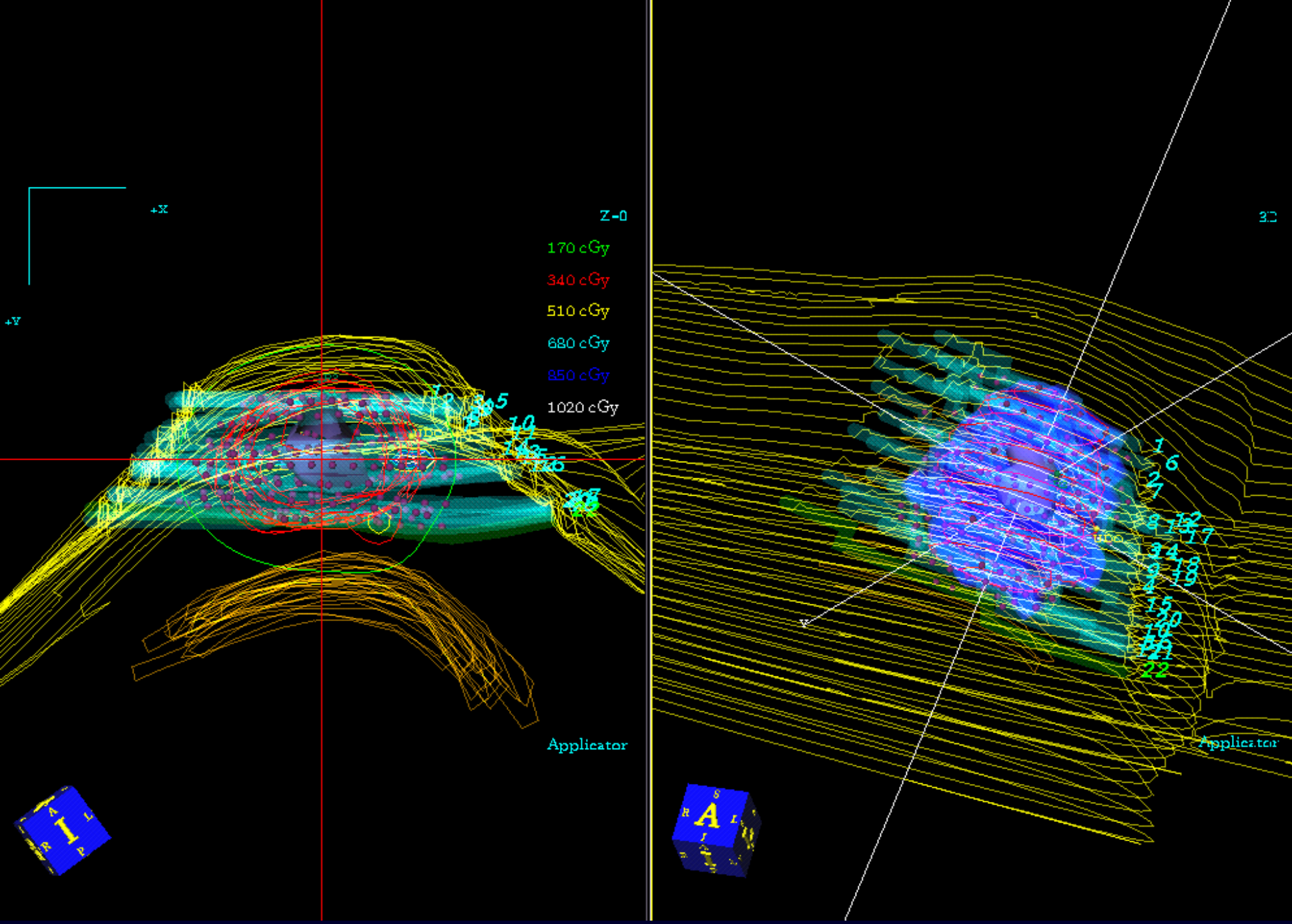
Emphasis on Target

IPSA



	Traditional	IPSA
CTV V100	56 %	**77 %**
Soft palate	3.08 cc	**3.55 cc**
Nasa septum V100	1.65 cc	**0.25 cc**

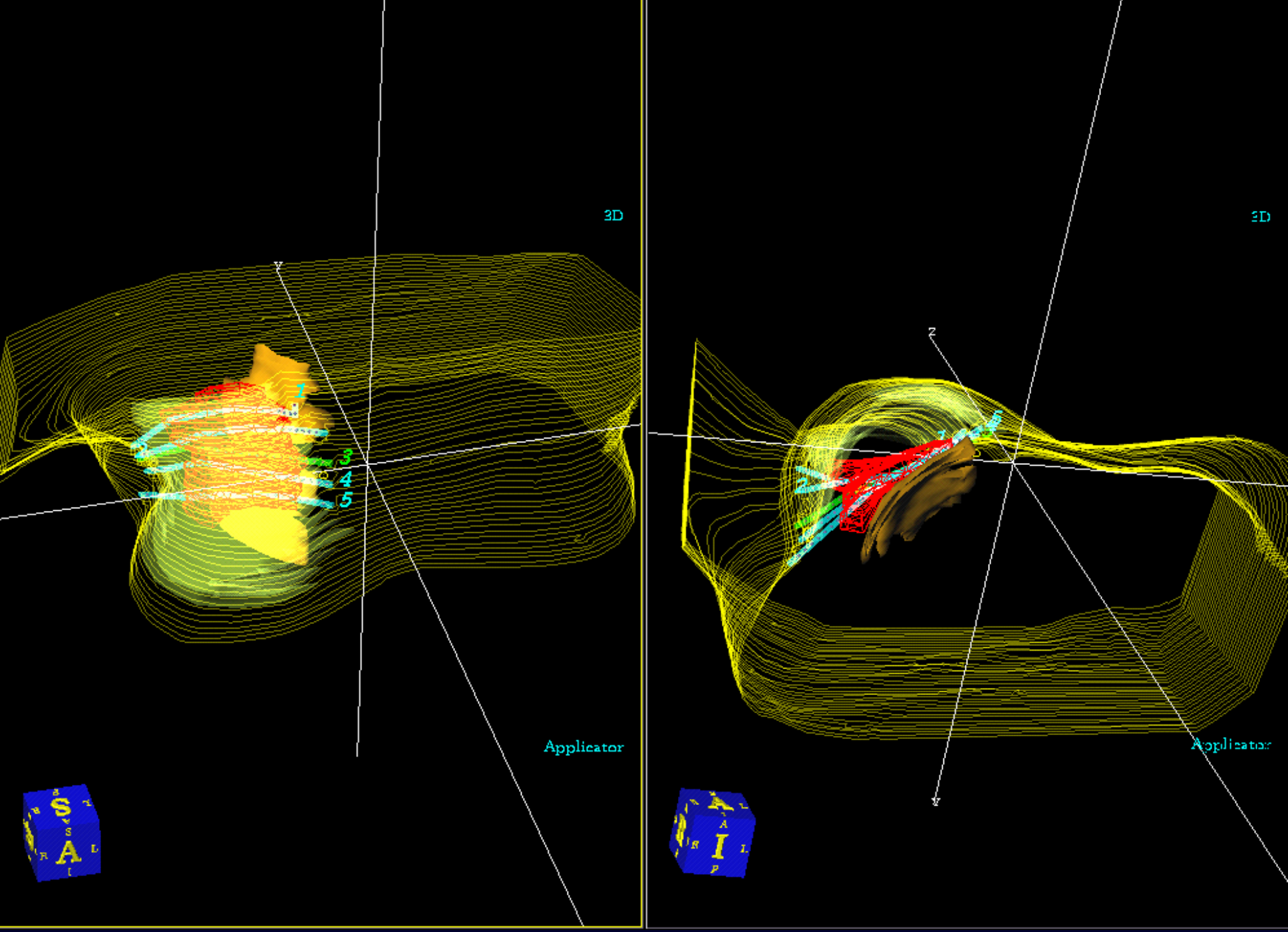

+X
+Y
Z-0
170 cGy
340 cGy
510 cGy
680 cGy
850 cGy
1020 cGy
Applicator
3D
Applicator

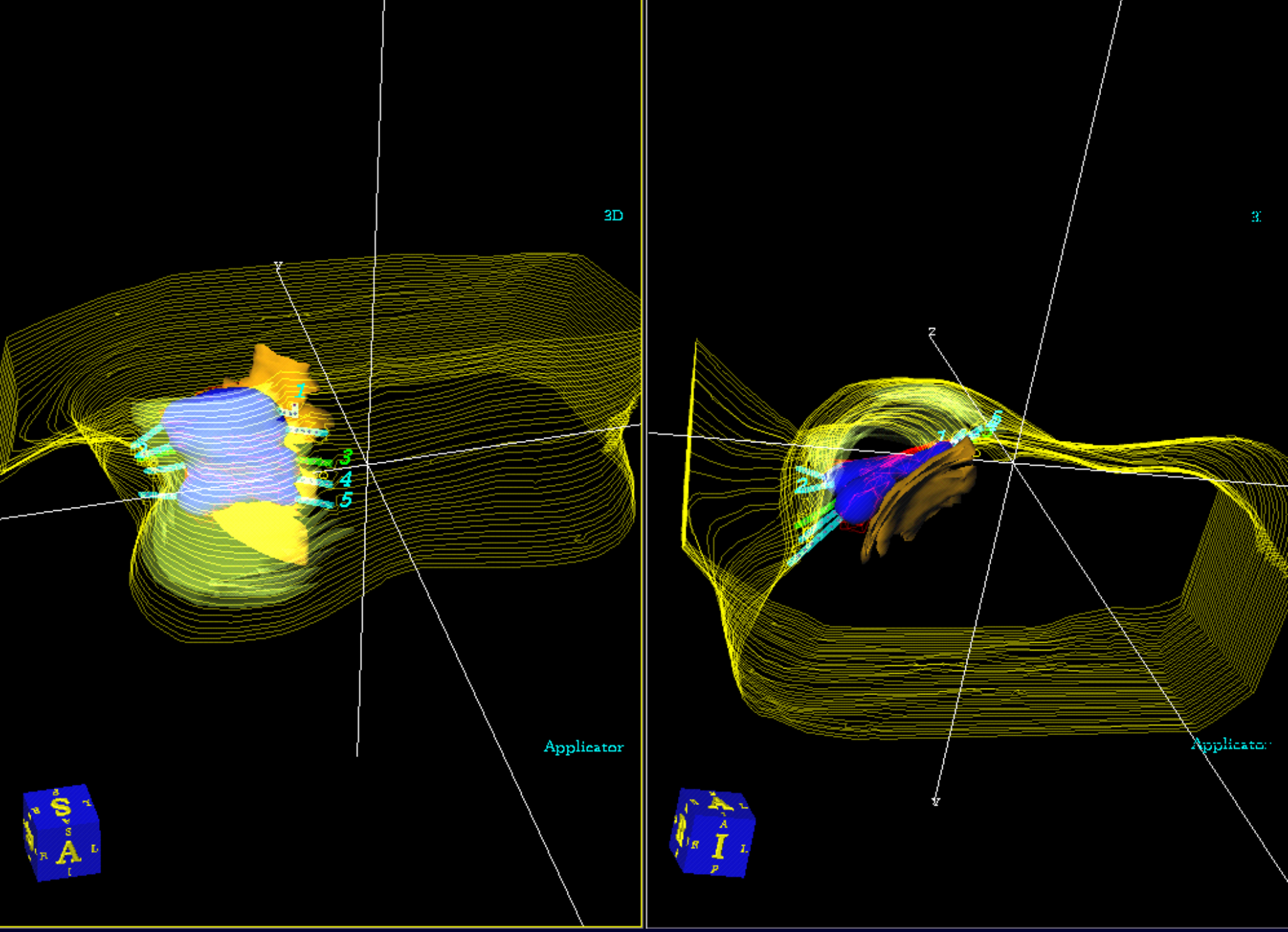

+X
+Y
Z-0
170 cGy
340 cGy
510 cGy
680 cGy
850 cGy
1020 cGy
Applicator
Applicator

Breast Implant

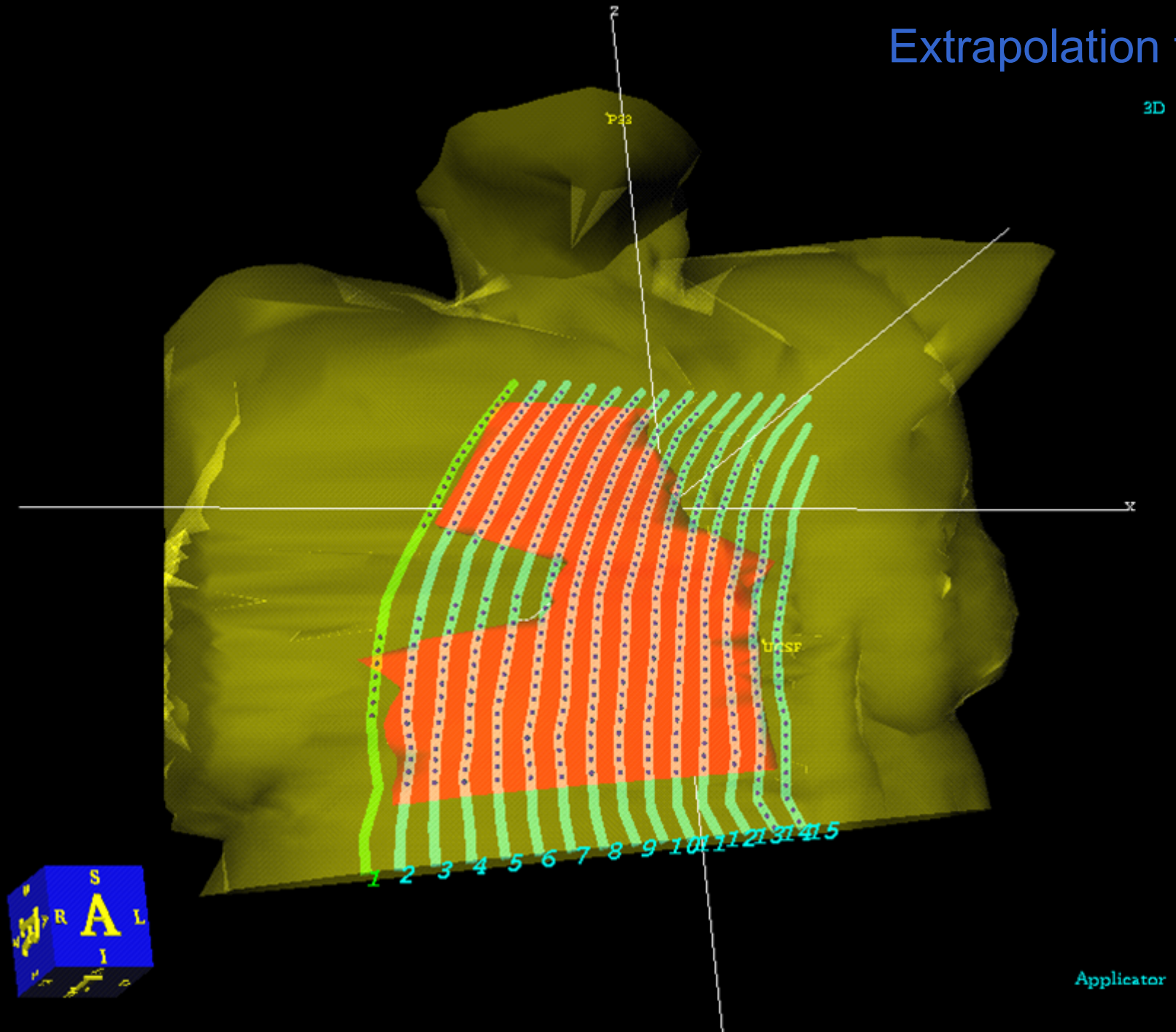
	Traditional*	IPSA	IPSA
CTV V100	**93.8 %**	**93.8 %**	**90.0 %**
CTV V150	**18.4 %**	**14.7 %**	**12.0 %**
Skin		**-5 %**	**-8 %**
Ribs		**-5 %**	**-8 %**

* Wierocik, Djay, Florida

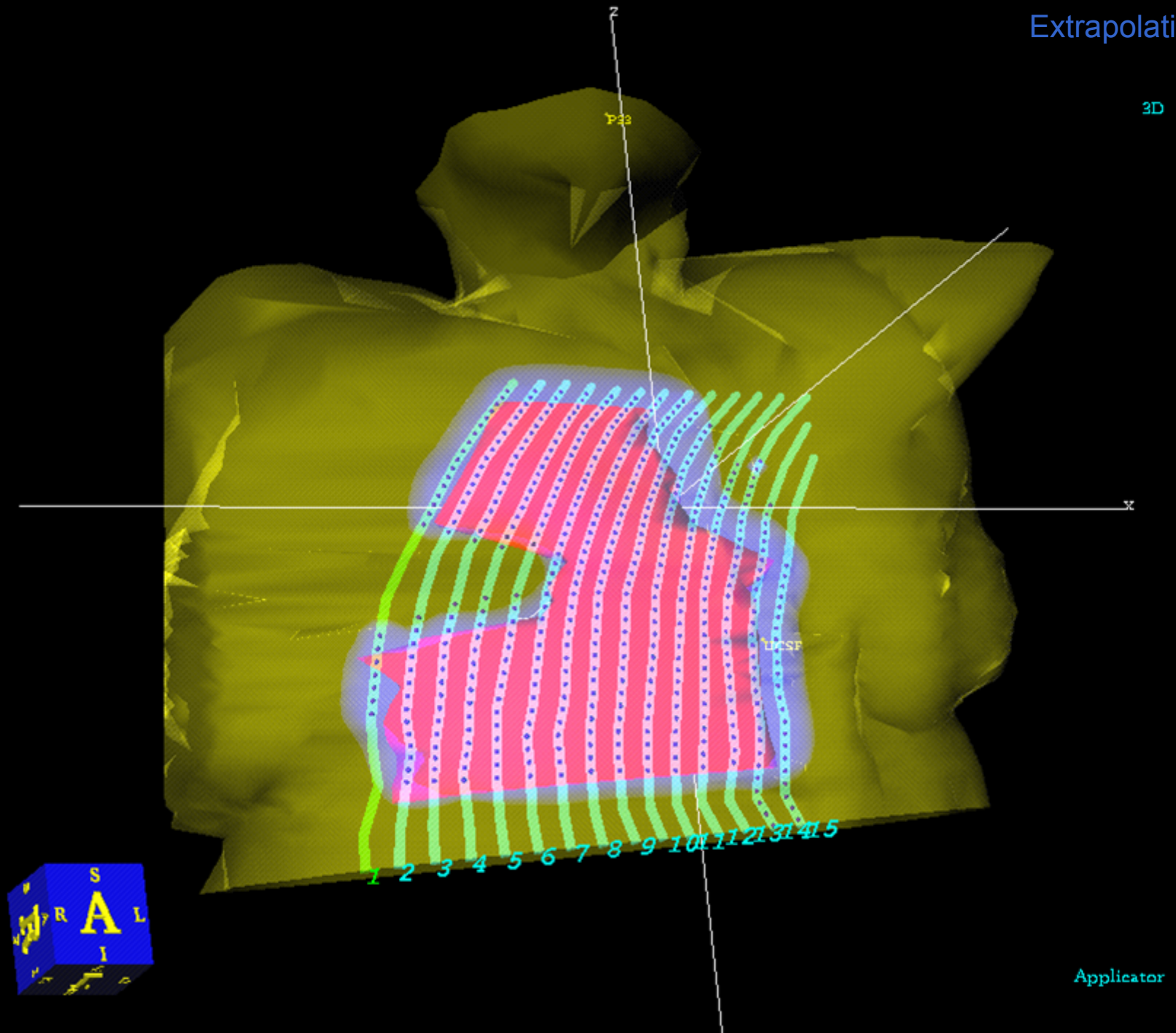

3D
Y
1
2
3
4
5
Applicator
S
A
3D
Z
Y
Applicator
A
I


3D
Applicator
1
2
3
4
5
S
A
3D
Applicator
Z
Y
A
I
P

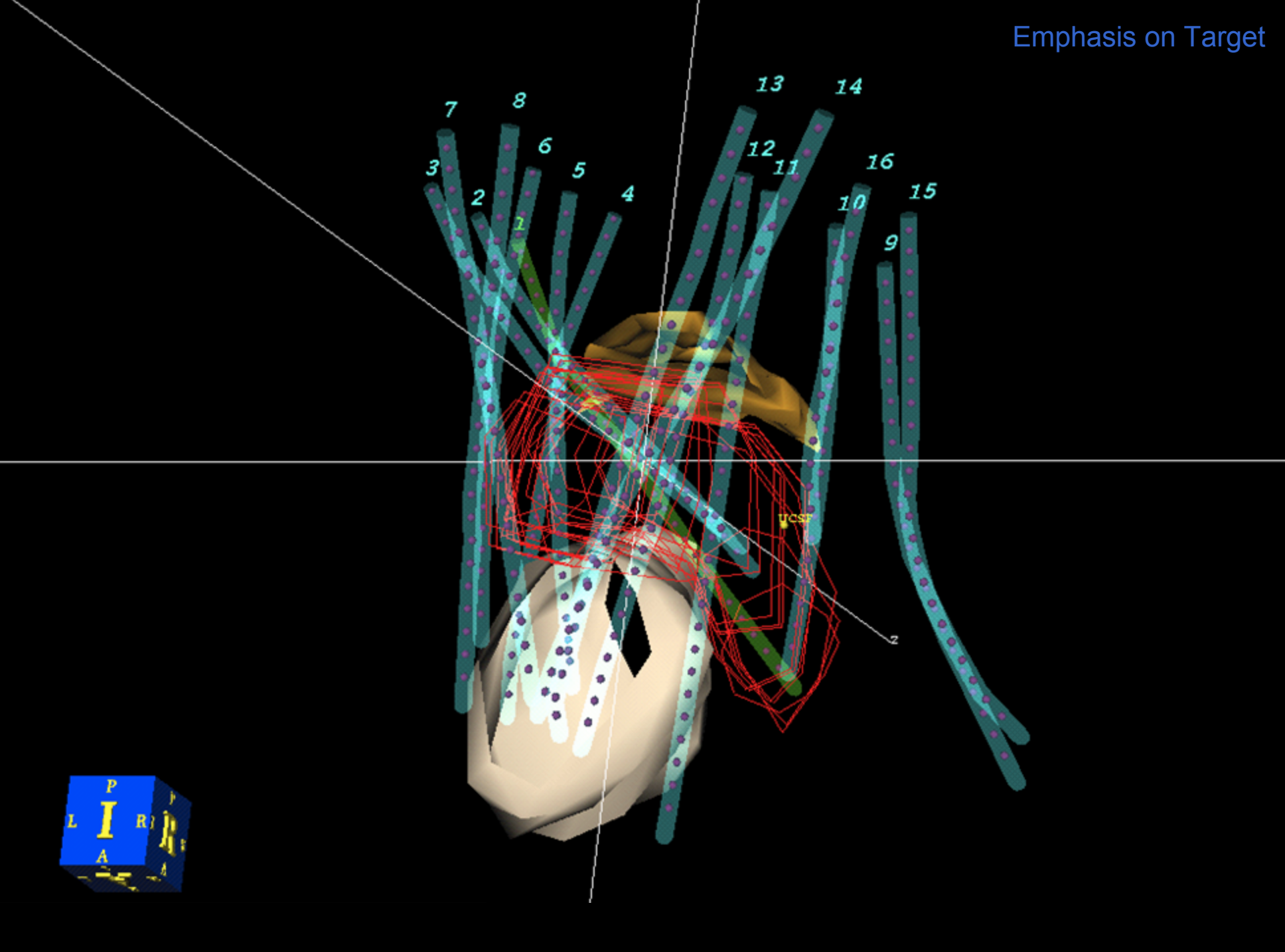
Extrapolation to IORT



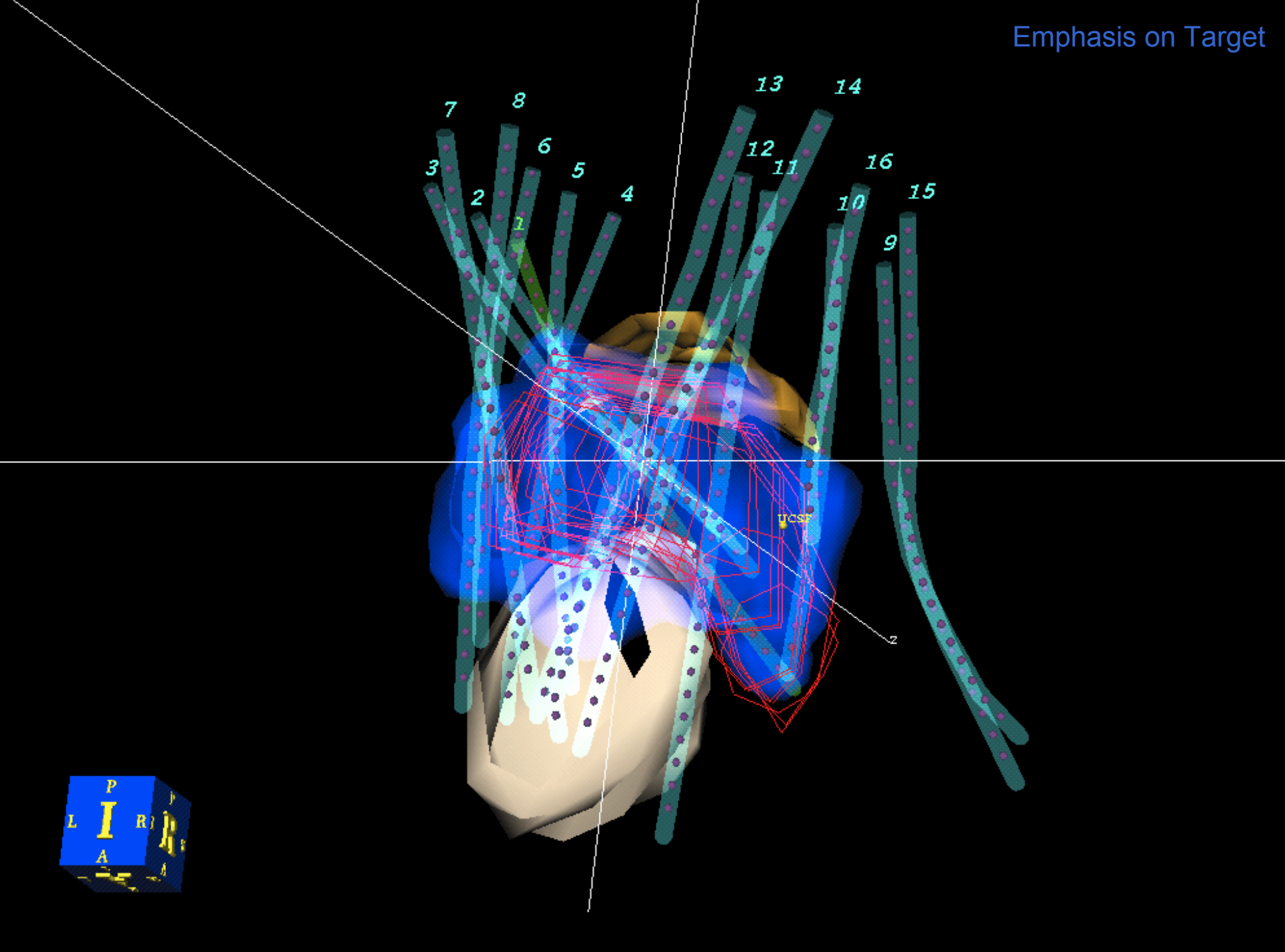
Extrapolation to IORT



Emphasis on Target



Emphasis on Target



HDR Brachytherapy

IPSA

7 institutions
and more than 600 patients
treated since 2000

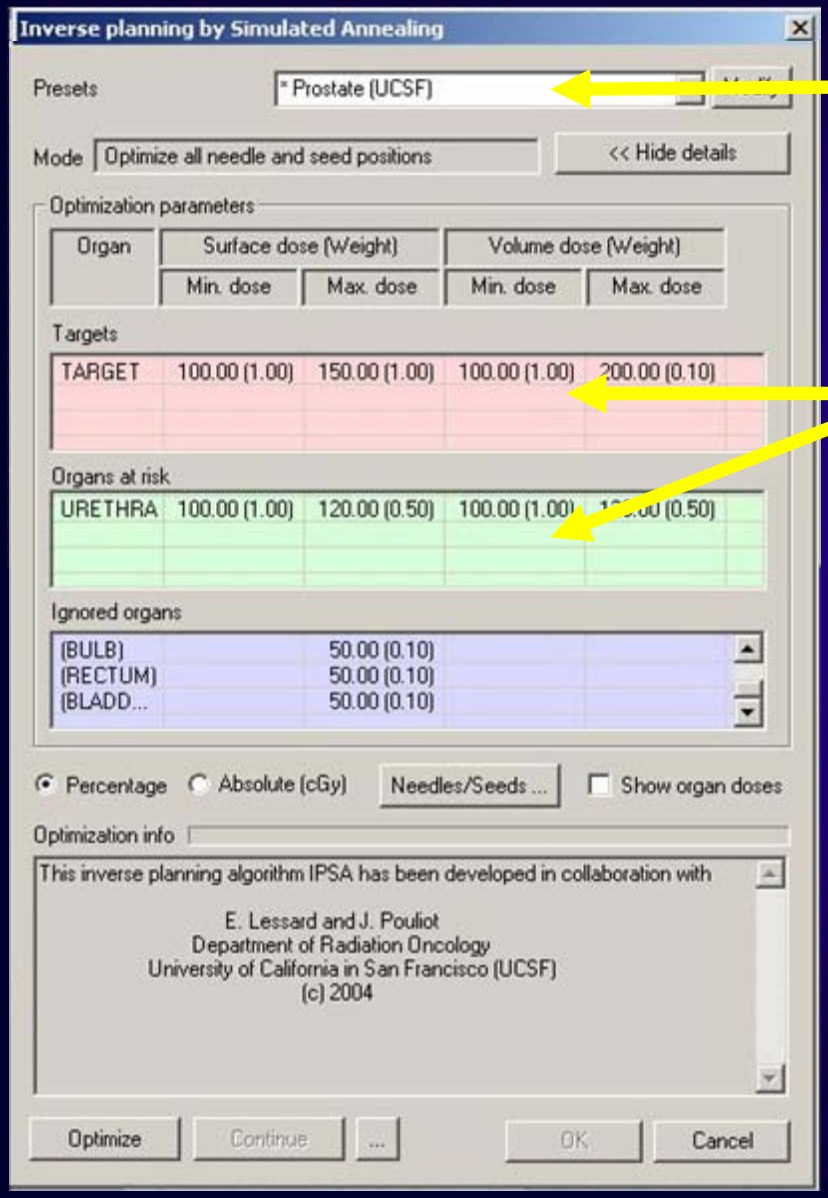
UCSF Comprehensive Cancer Center, San Francisco, USA
CHUQ Hôtel Dieu de Québec, Canada
National Institute of Health, Bethesda, USA
Centre Alexis Vautrin, Nancy, France
Toronto Sunnybrook Regional Cancer Center, Canada
CHUM Hôpital Notre-Dame, Montreal, Canada
Christiana Health Care, Newark, USA

Institut Gustave Roussy, Paris, France

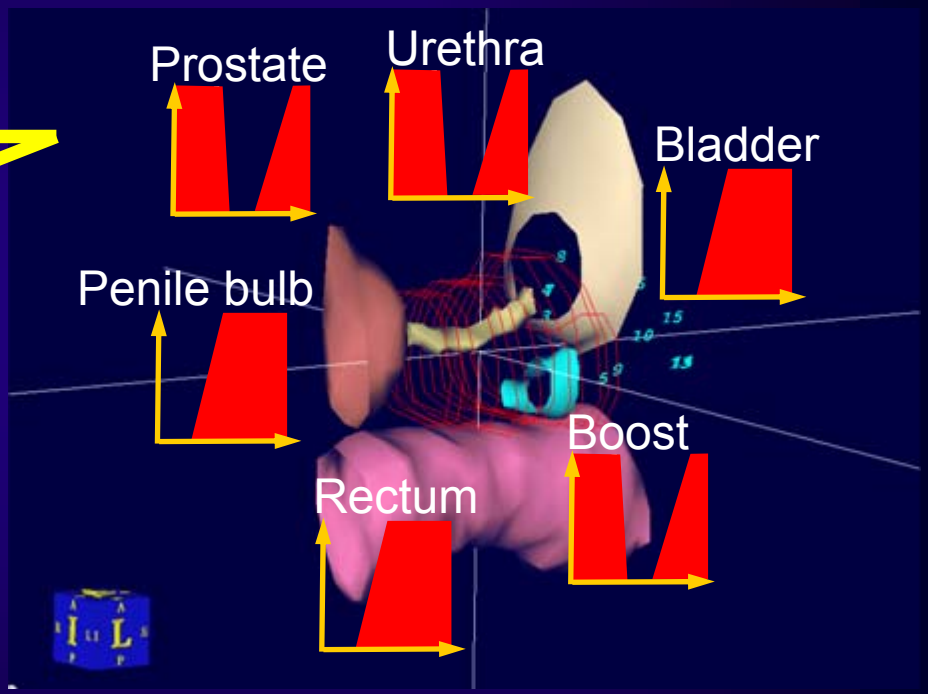
...

Permanent Prostate Implant

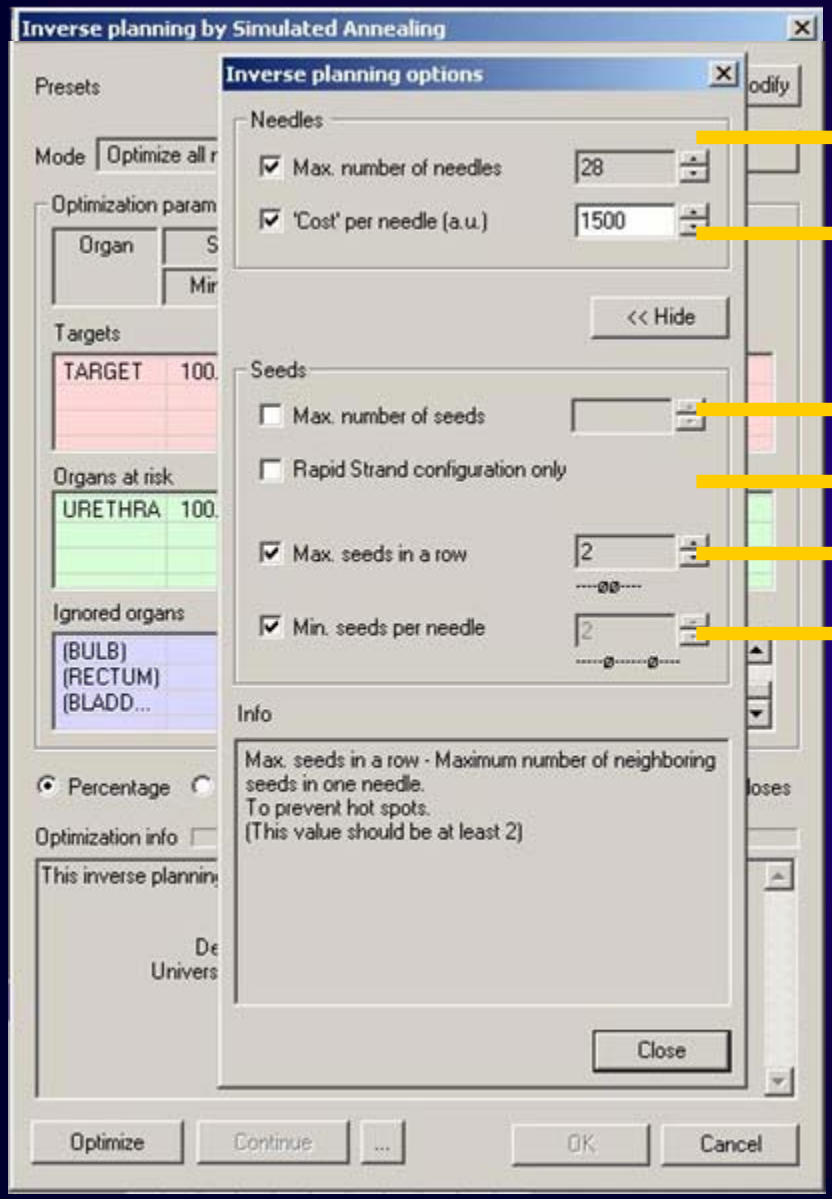
User interface in SPOTpro 3.0



Class Solution



Additional options



Max number of needles

Penalty per needle

Max number of seeds

Rapid Strand pattern only

Max number of seeds in a row

Min number of seeds per needle

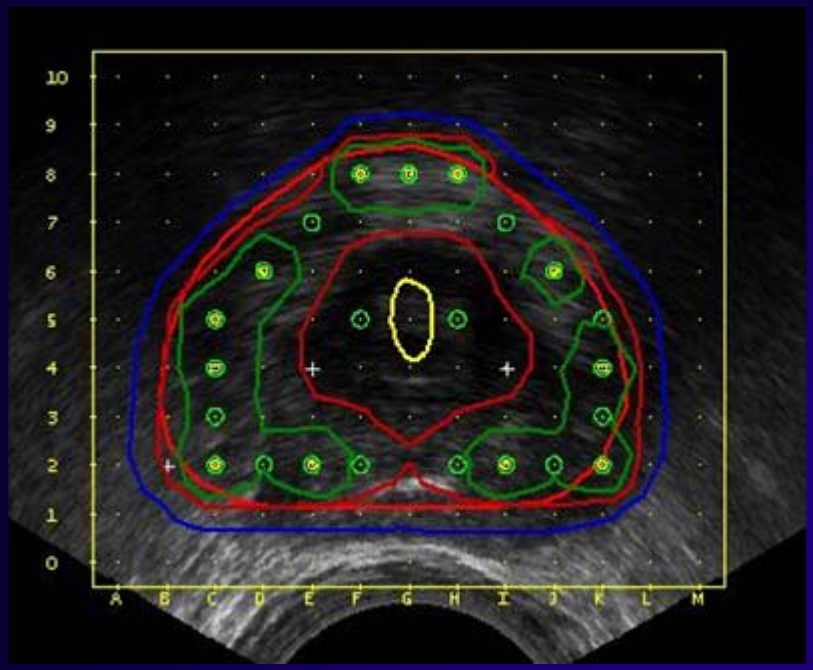
Goal of the study:

- Define a Class solution
- that mimic an experienced dosimetrist

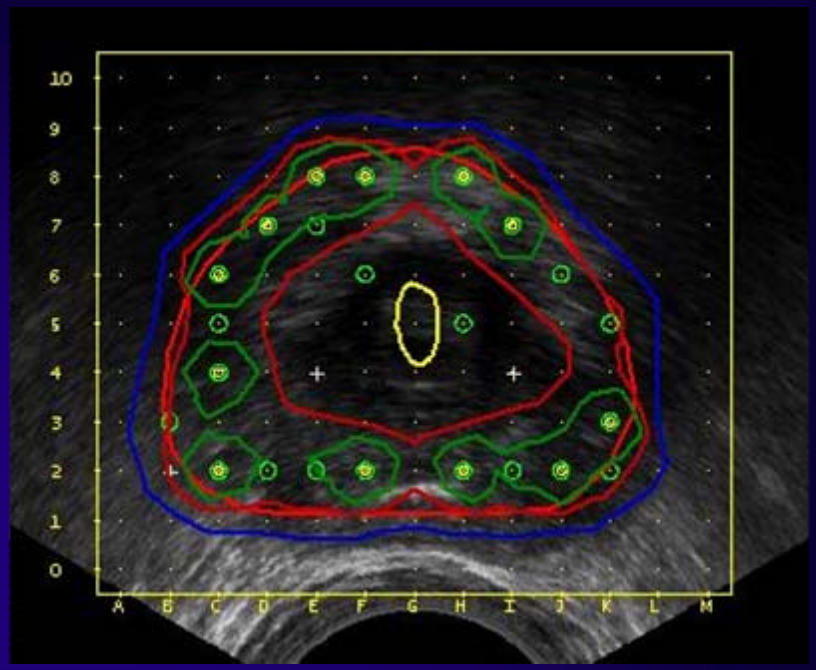
UCSF experience:

- More than 750 patients since 1996
- 95% biochemical desease-free survival (BDFS) after 5 years
- 1 dosimetrist
- Establishment of rules for manual pre-planning

DOSIMETRIST



IPSA

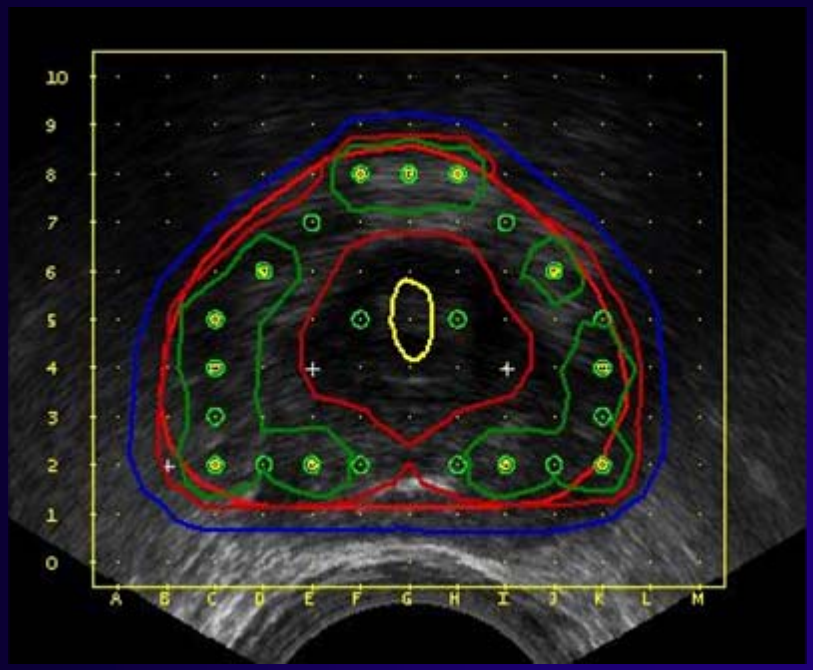


46 cc

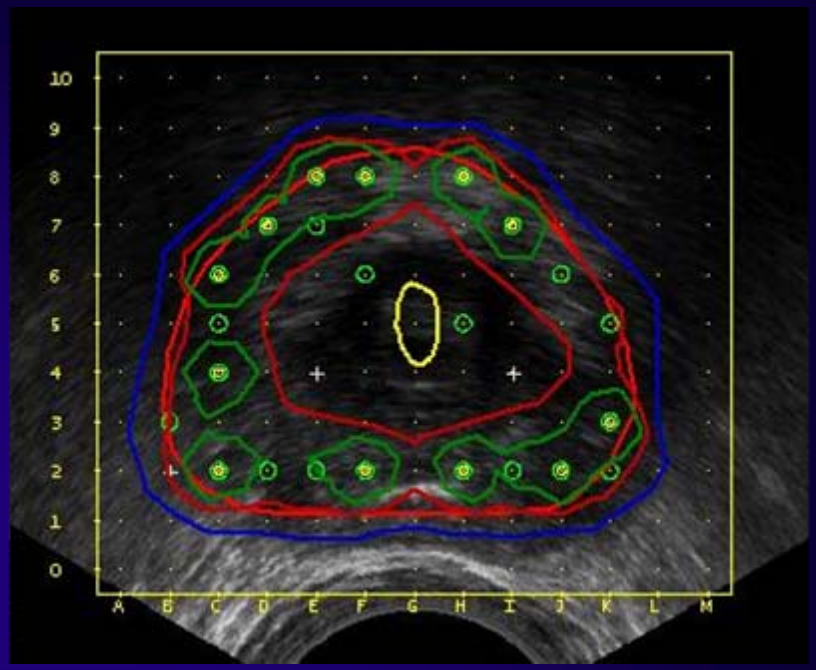
91 seeds
26 needles

90 seeds
23 needles

DOSIMETRIST



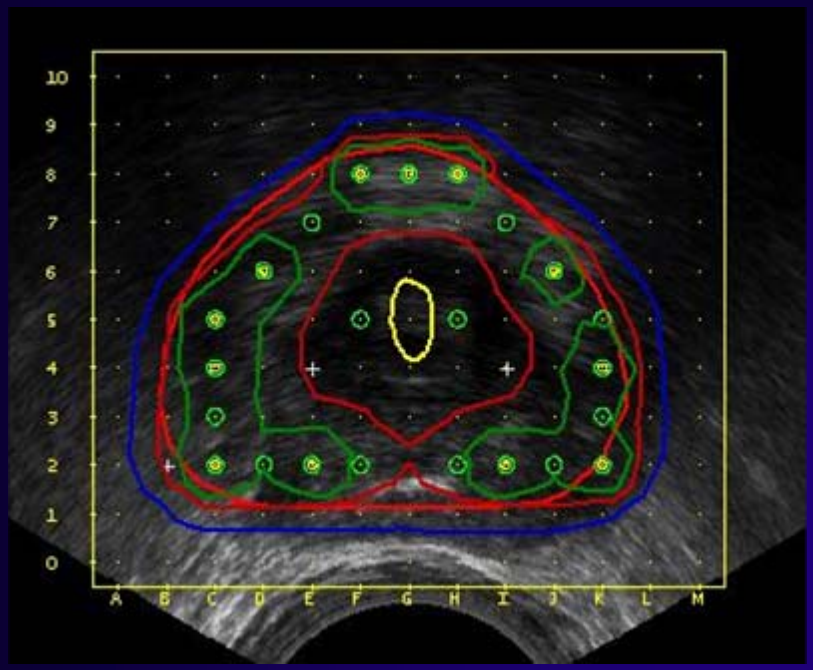
IPSA



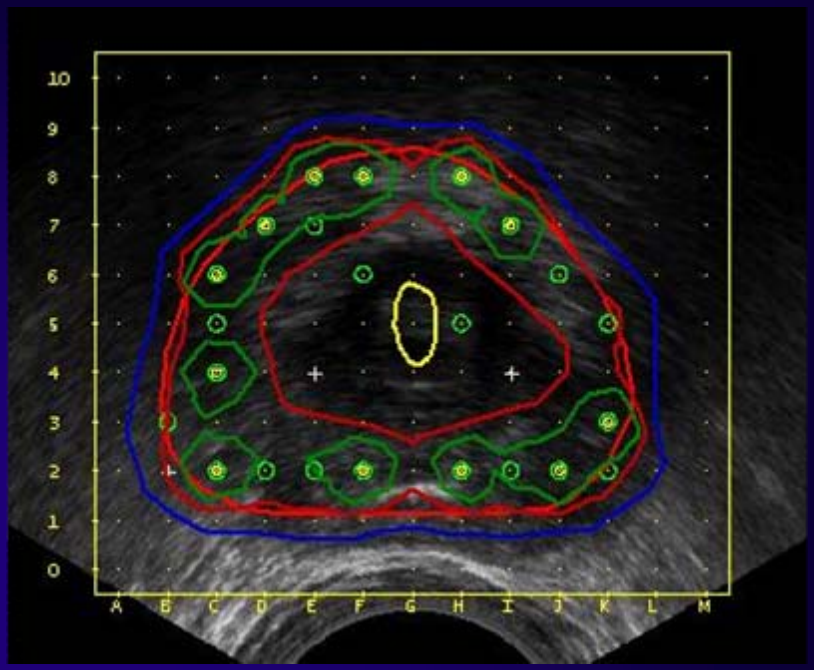
Prostate dosimetric indices

V100 = 99.6%	V100 = 99.7%
V150 = 61.4%	V150 = 61.4%
V200 = 26.1%	V200 = 25.5%
D90 = 177 cGy	D90 = 173 cGy

DOSIMETRIST



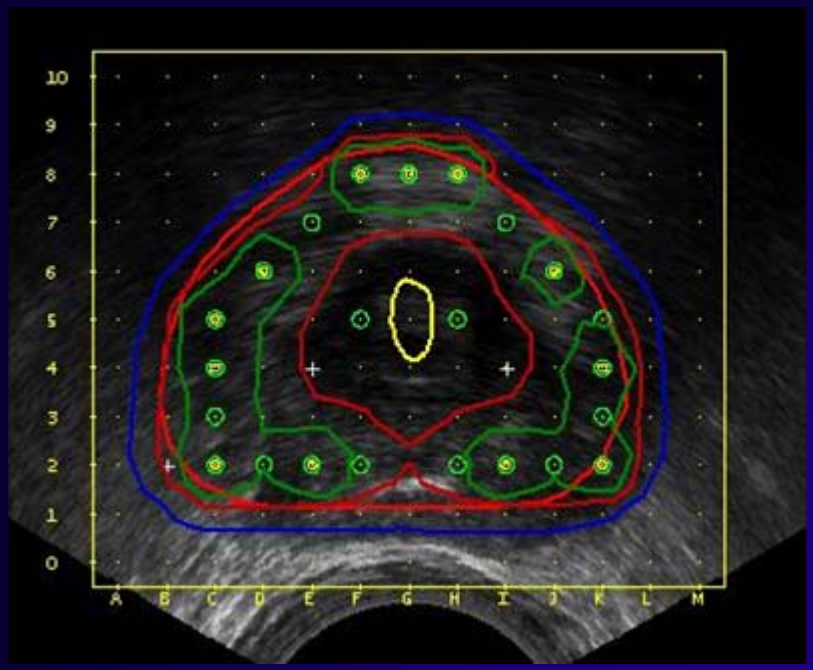
IPSA



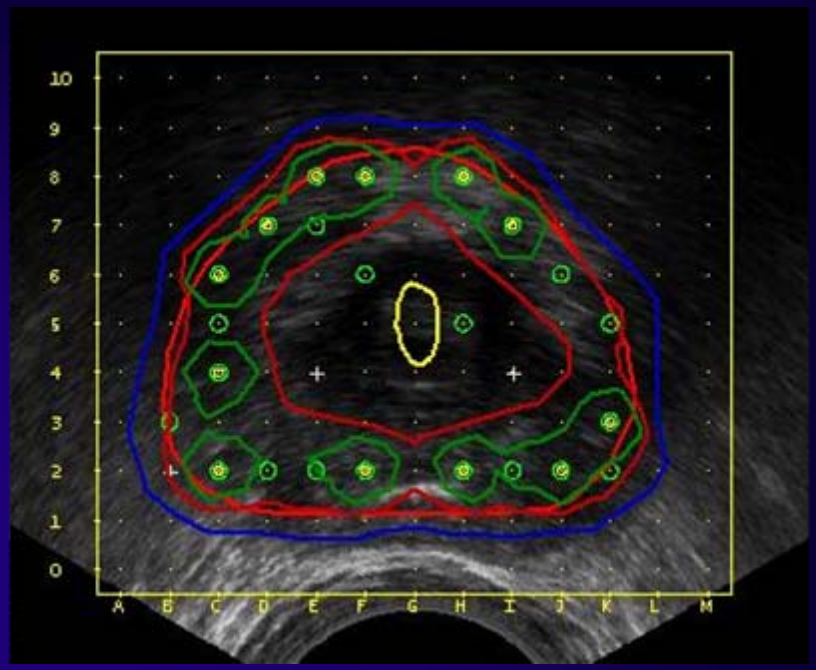
Urethra dosimetric indices

V100 = 94.2%	V100 = 97.6%
V150 = 0.0%	V150 = 0.0%
D10 = 192 Gy	D10 = 174 Gy

DOSIMETRIST



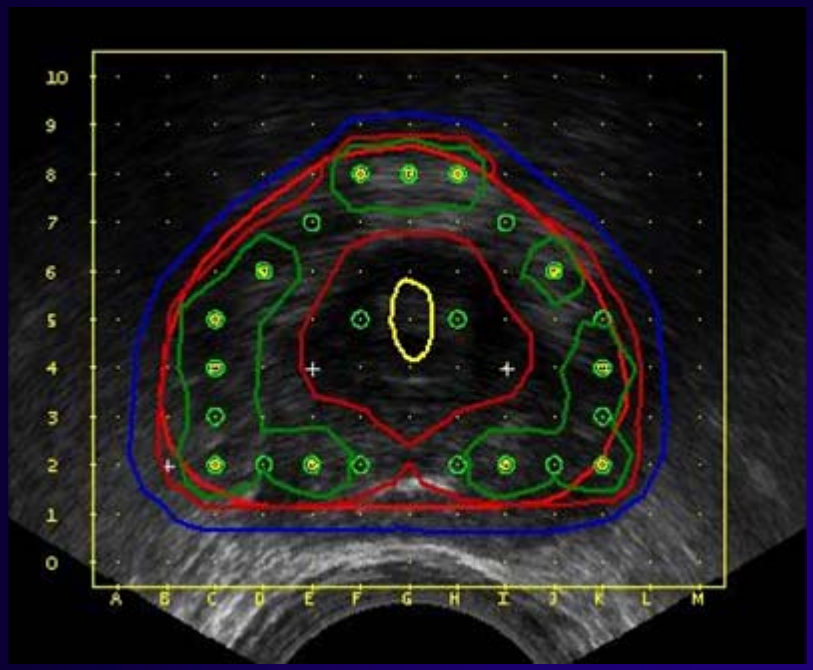
IPSA



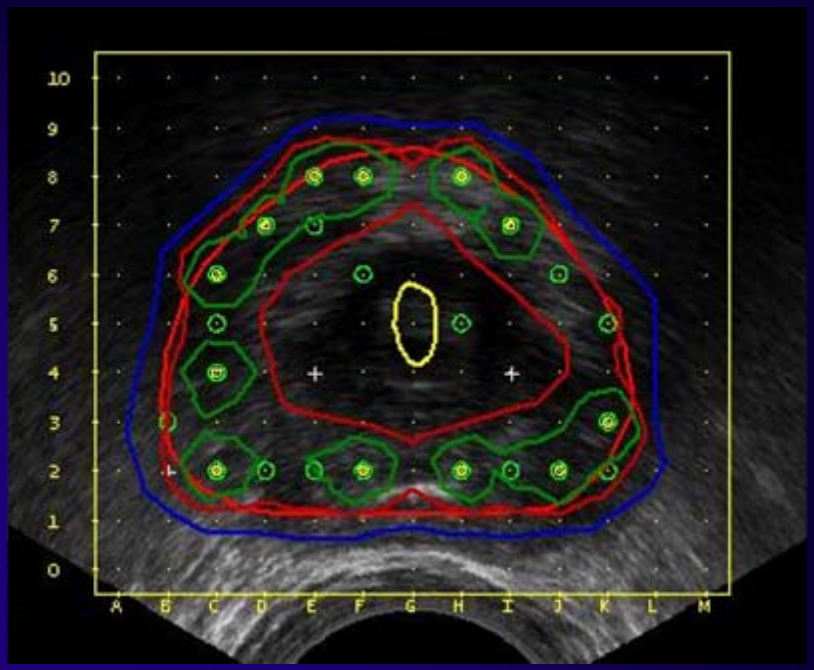
Seed loading pattern

2 seed outside the prostate	0 seed outside the prostate
1 needle with ---------o-	0 needle with ---------o-
4 needle with --ooo----	0 needle with --ooo----

DOSIMETRIST



IPSA

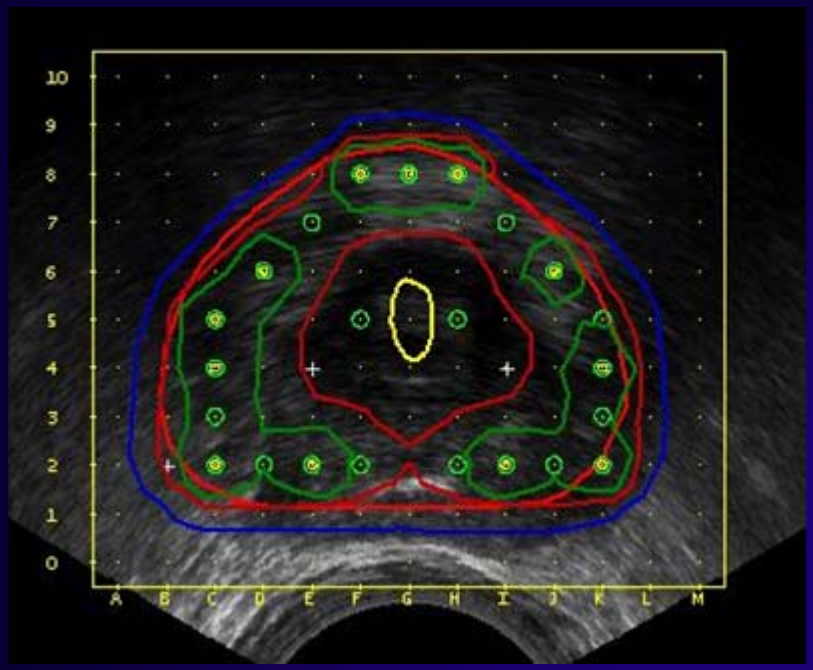


Planning time

20 minutes
for 1 dosimetrist

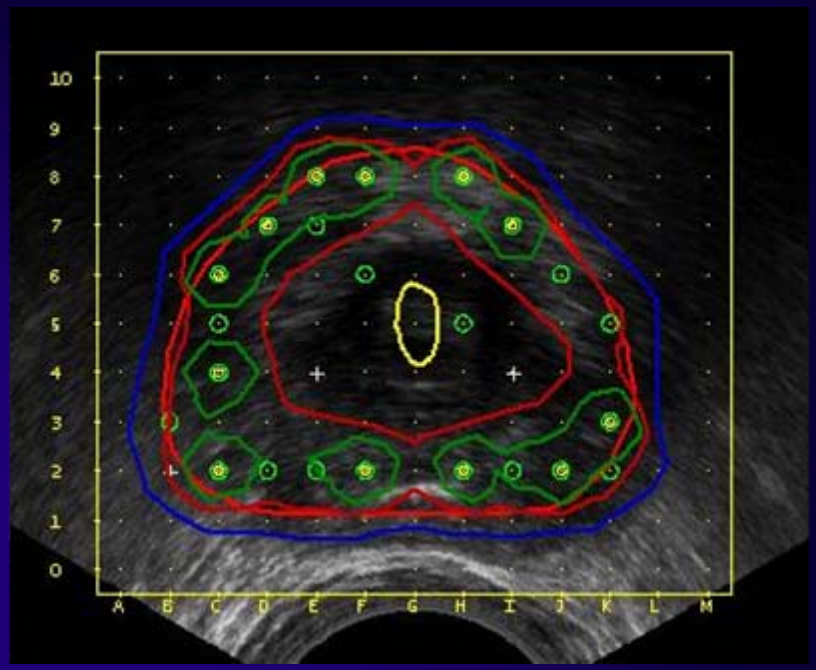
15 sec
for 400,000 iterations
(2.5 GHz PC)

DOSIMETRIST



Pre-planning

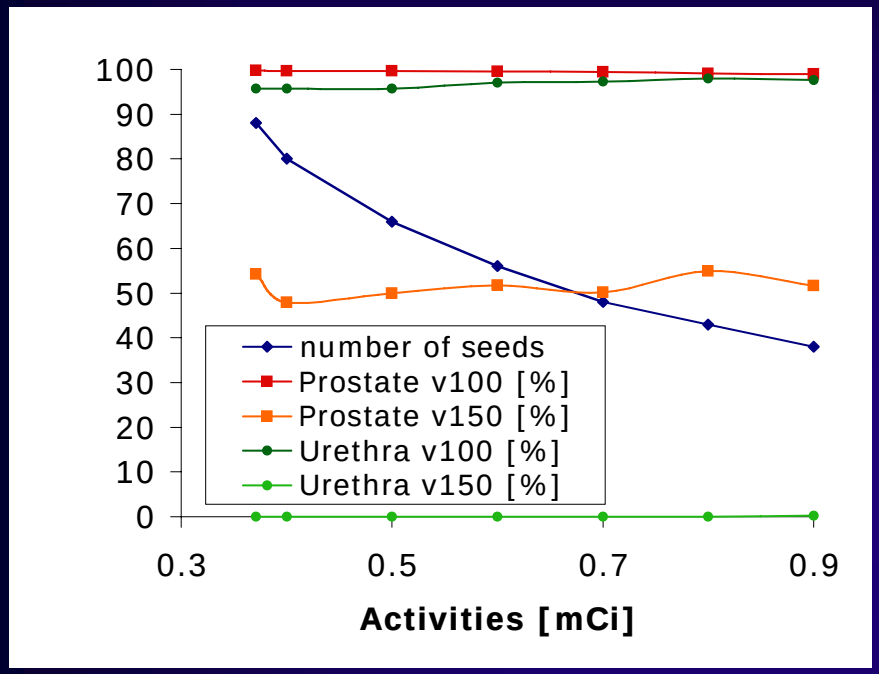
IPSA

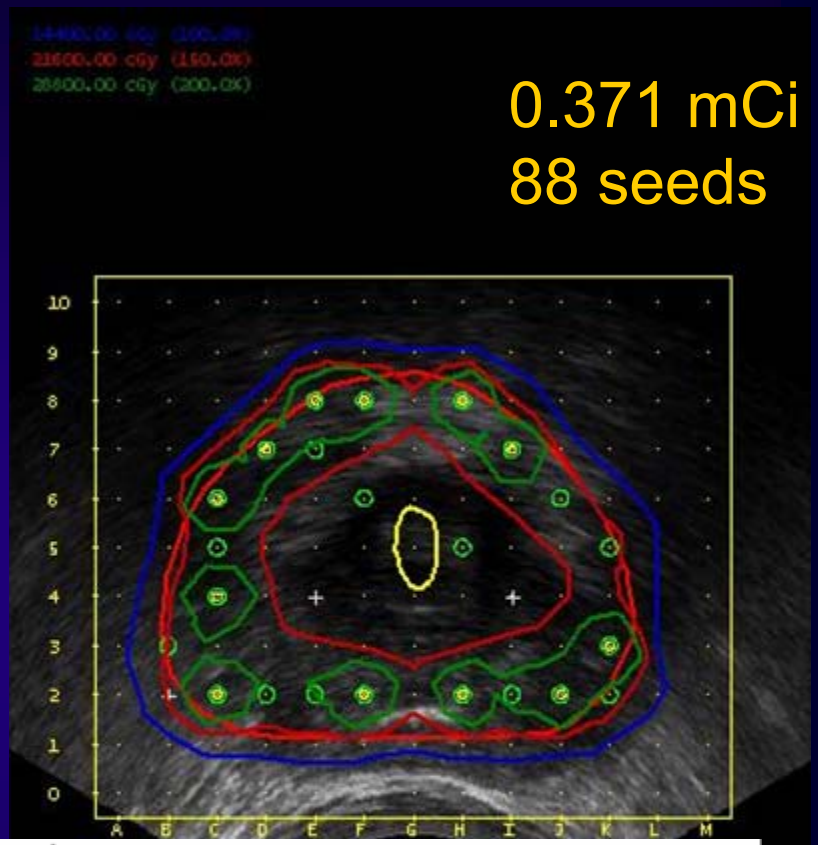


Fast enough for
Intra-operative pre-planning

Also designed for
Live-planning

Dosimetric indices vs source activity

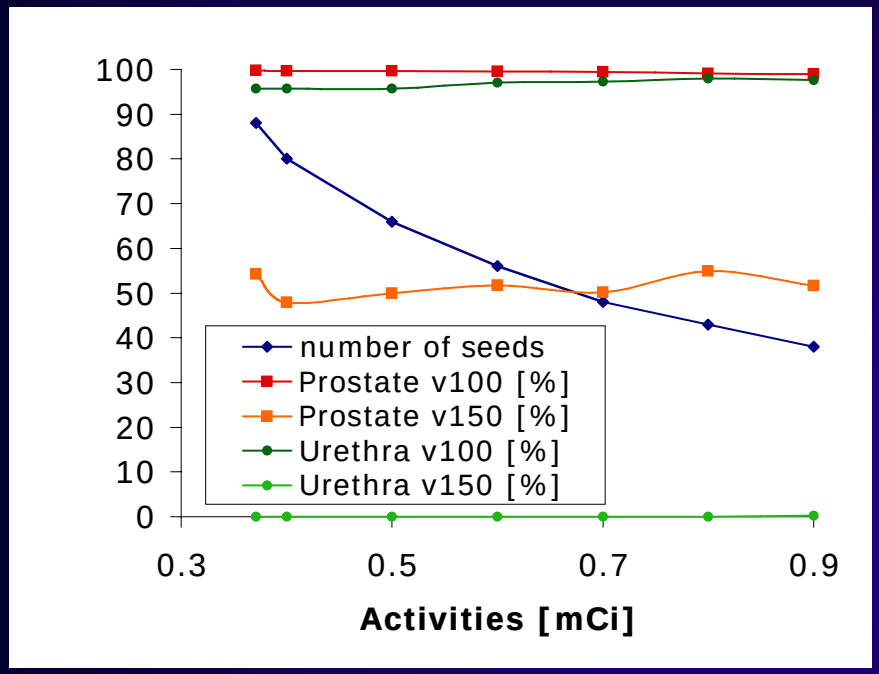


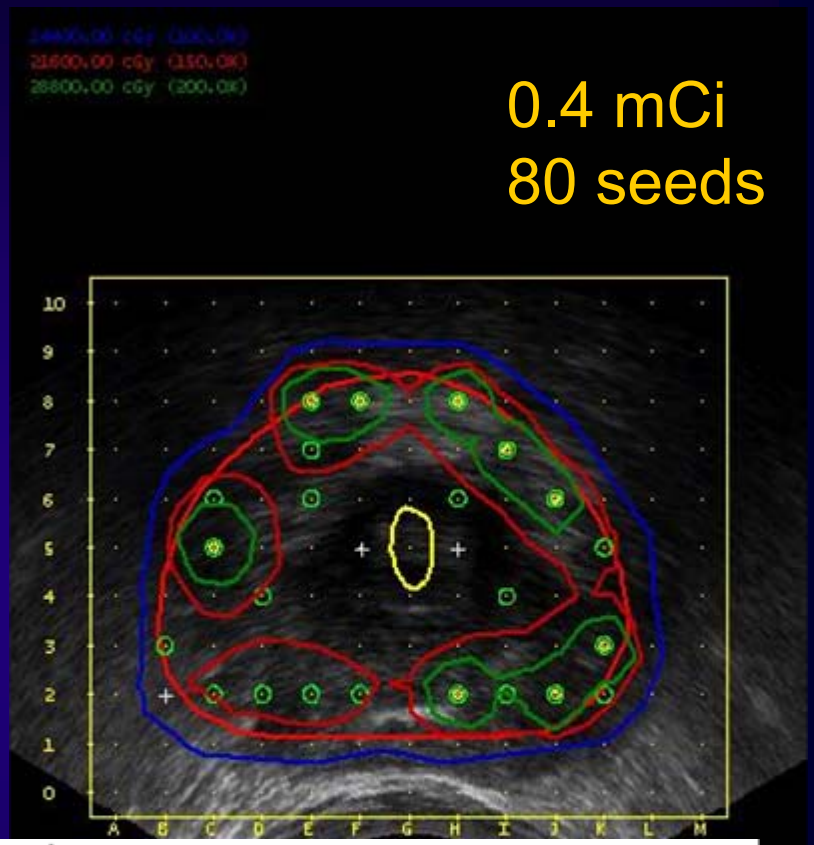


Dosimetric indices vs source activity with IPSA optimization

Activity [mci]	number of seeds	number of needles	Prostate v100 [%]	v150 [%]	Urethra v100 [%]	v150 [%]
► 0.371	88	26	99.77	54.27	95.70	0.02
0.4	80	26	99.69	47.91	95.73	0.02
0.5	66	26	99.65	49.98	95.72	0.01
0.6	56	26	99.60	51.75	97.10	0.00
0.7	48	24	99.42	50.21	97.31	0.00
0.8	43	23	99.15	54.93	98.01	0.00
0.9	38	19	99.00	51.68	97.59	0.21

Dosimetric indices vs source activity

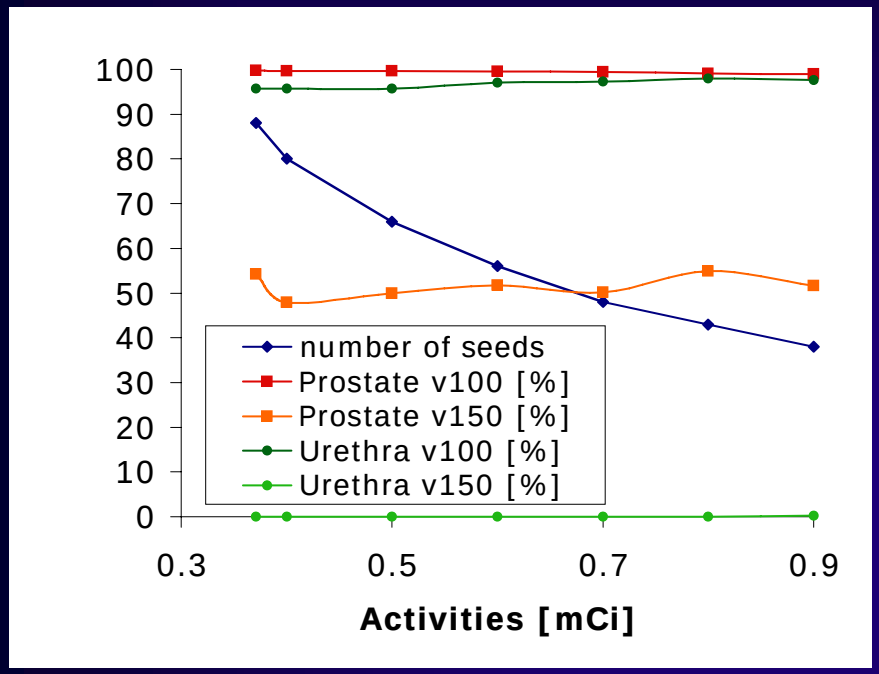


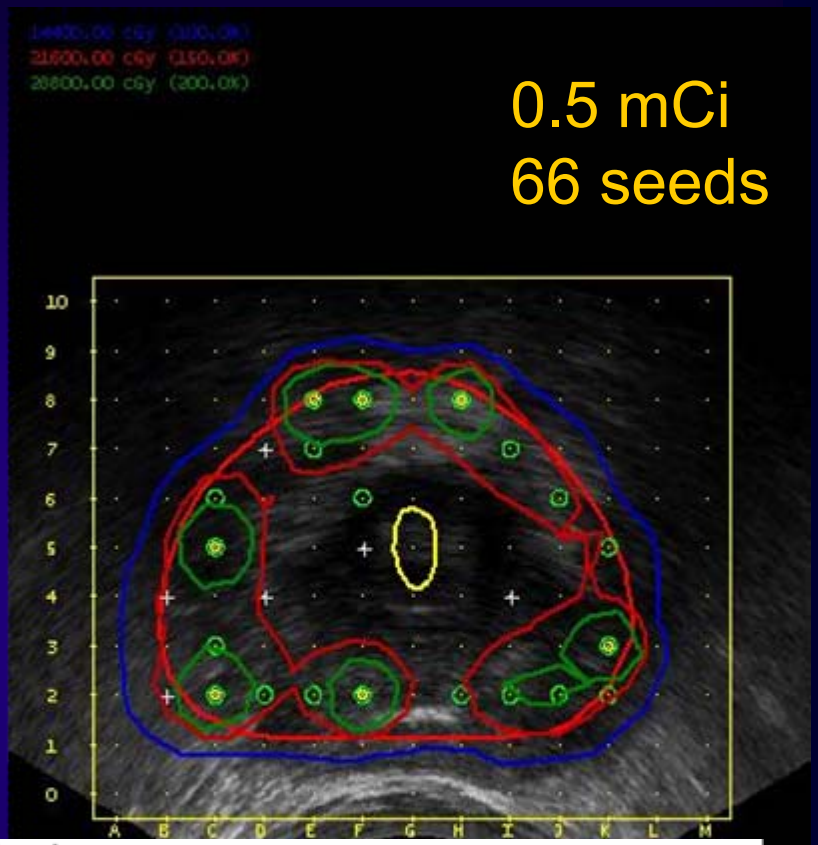


Dosimetric indices vs source activity with IPSA optimization

Activity [mci]	number of seeds	number of needles	Prostate v100 [%]	v150 [%]	Urethra v100 [%]	v150 [%]
0.371	88	26	99.77	54.27	95.70	0.02
► 0.4	80	26	99.69	47.91	95.73	0.02
0.5	66	26	99.65	49.98	95.72	0.01
0.6	56	26	99.60	51.75	97.10	0.00
0.7	48	24	99.42	50.21	97.31	0.00
0.8	43	23	99.15	54.93	98.01	0.00
0.9	38	19	99.00	51.68	97.59	0.21

Dosimetric indices vs source activity





Dosimetric indices vs source activity with IPSA optimization

Activity [mci]	number of seeds	number of needles	Prostate v100 [%]	v150 [%]	Urethra v100 [%]	v150 [%]
0.371	88	26	99.77	54.27	95.70	0.02
0.4	80	26	99.69	47.91	95.73	0.02
► 0.5	66	26	99.65	49.98	95.72	0.01
0.6	56	26	99.60	51.75	97.10	0.00
0.7	48	24	99.42	50.21	97.31	0.00
0.8	43	23	99.15	54.93	98.01	0.00
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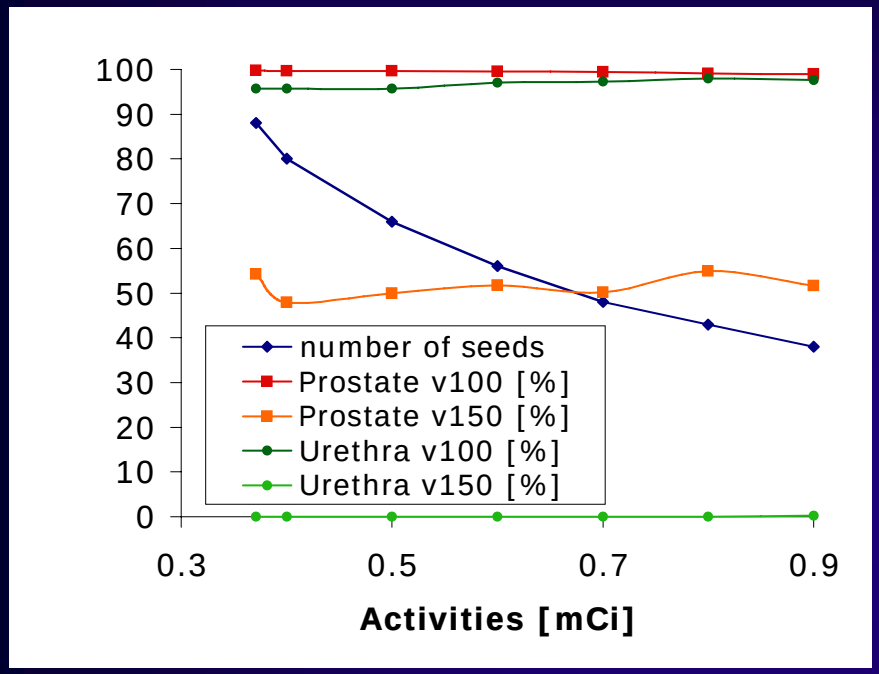

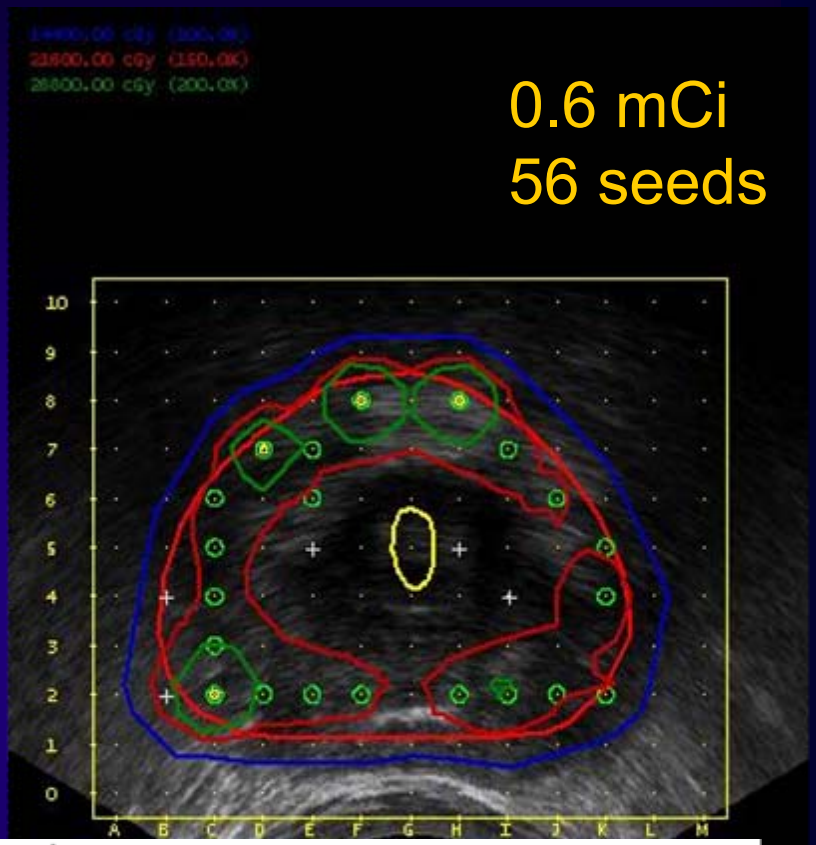

Dosimetric indices vs source activity with IPSA optimization

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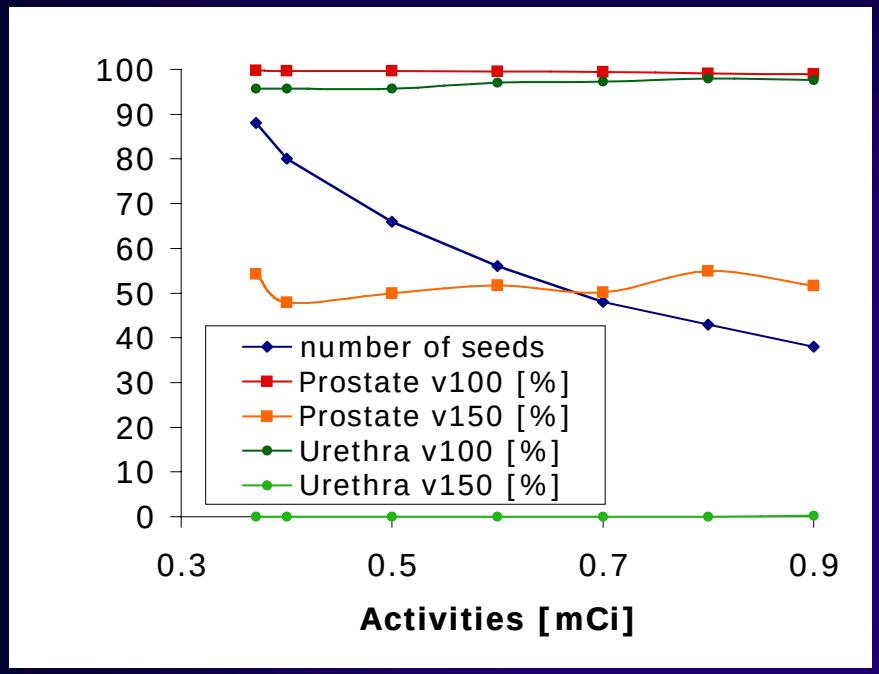

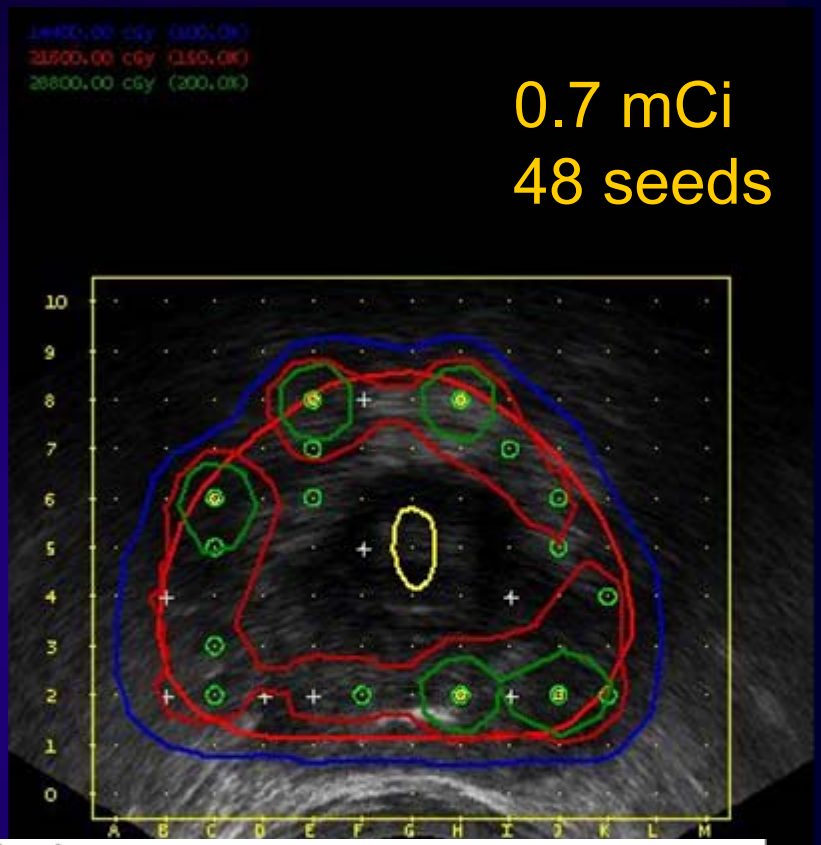

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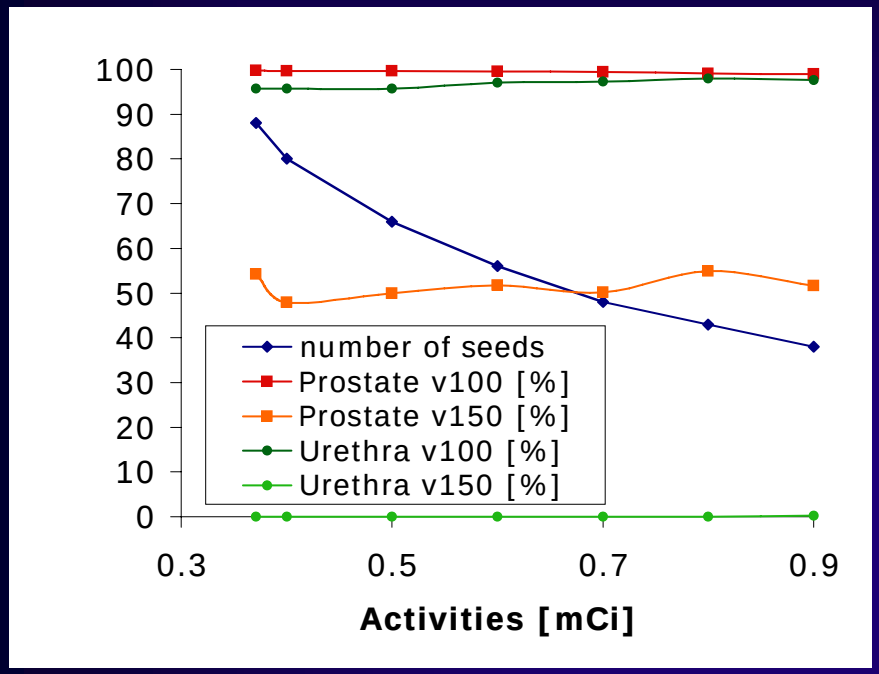

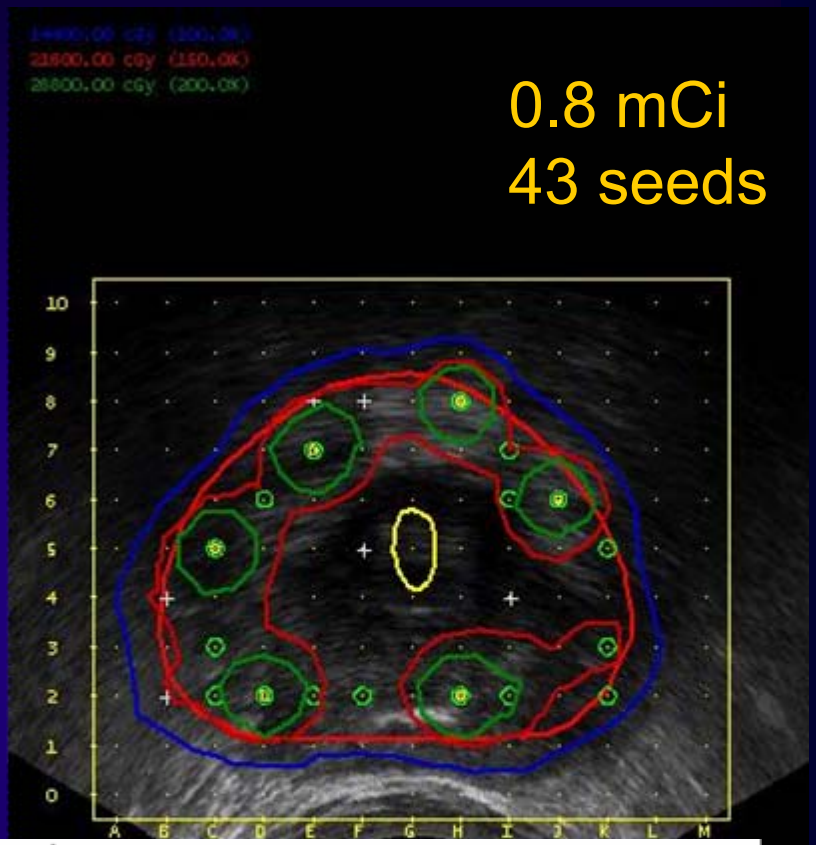

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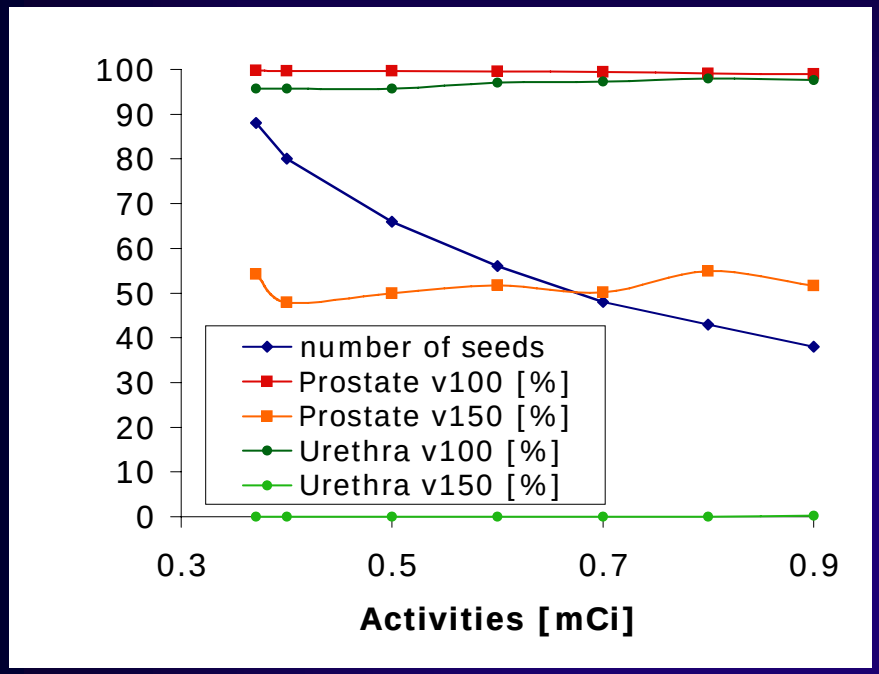

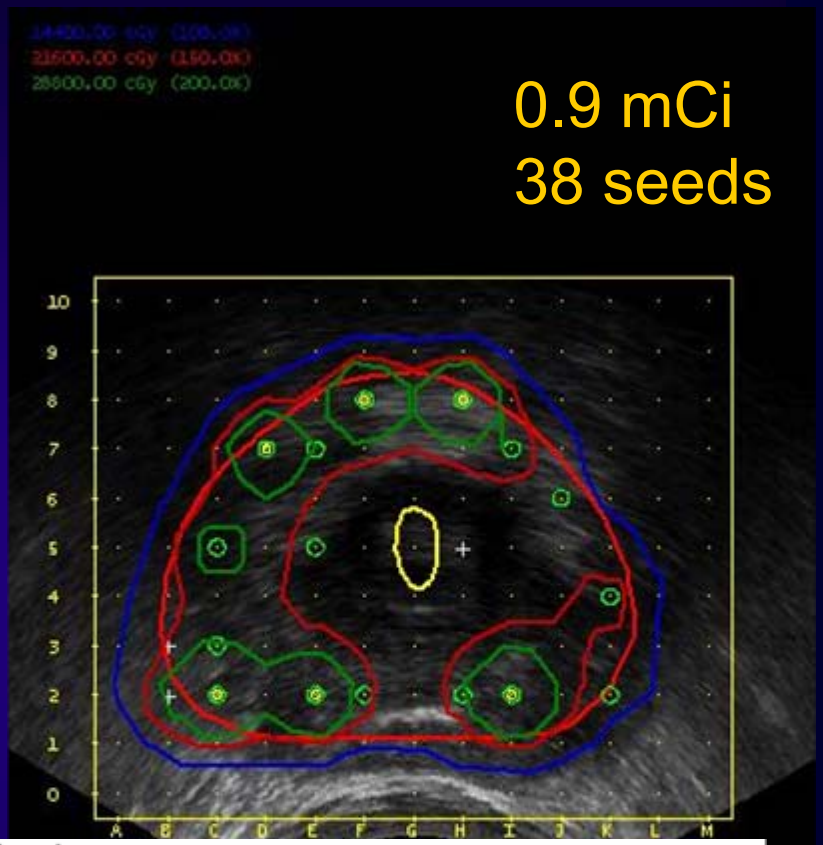

Dosimetric indices vs source activity with IPSA optimization

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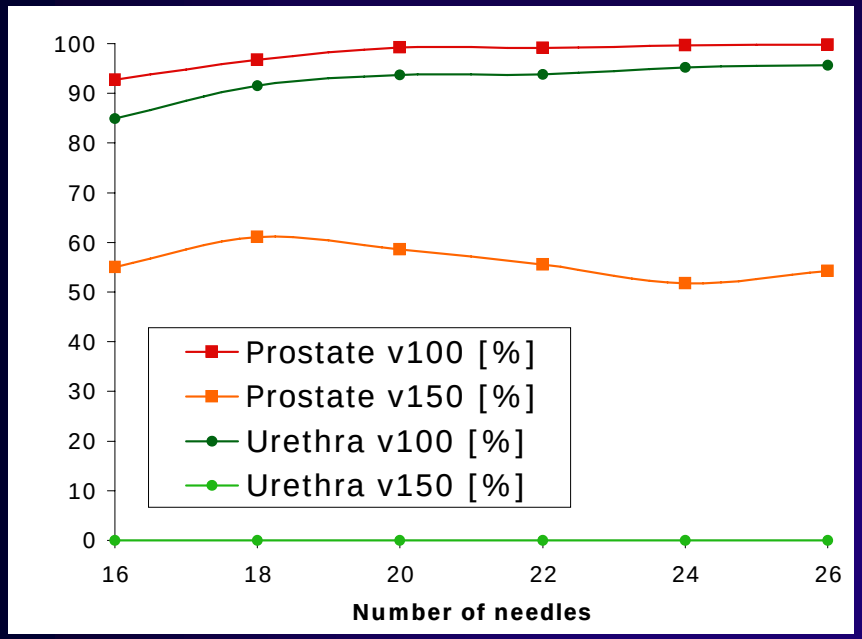
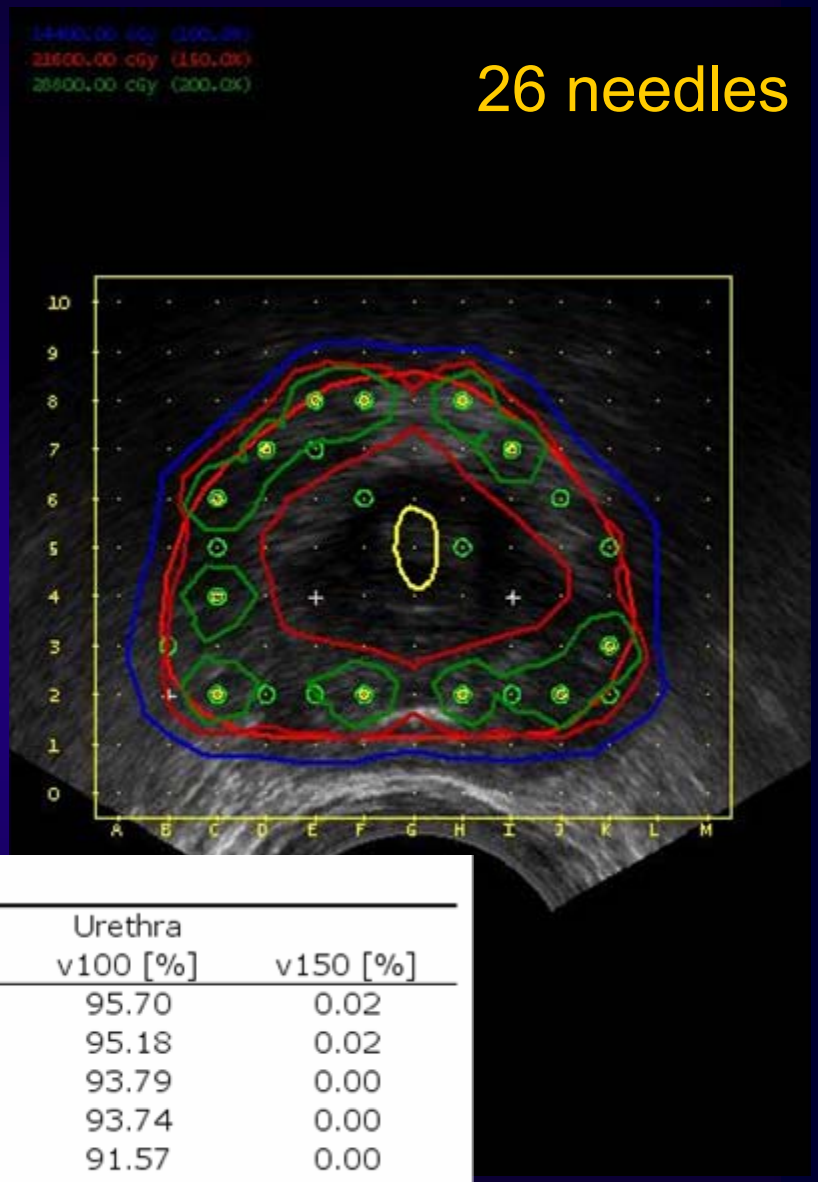
Dosimetric indices vs number of needles

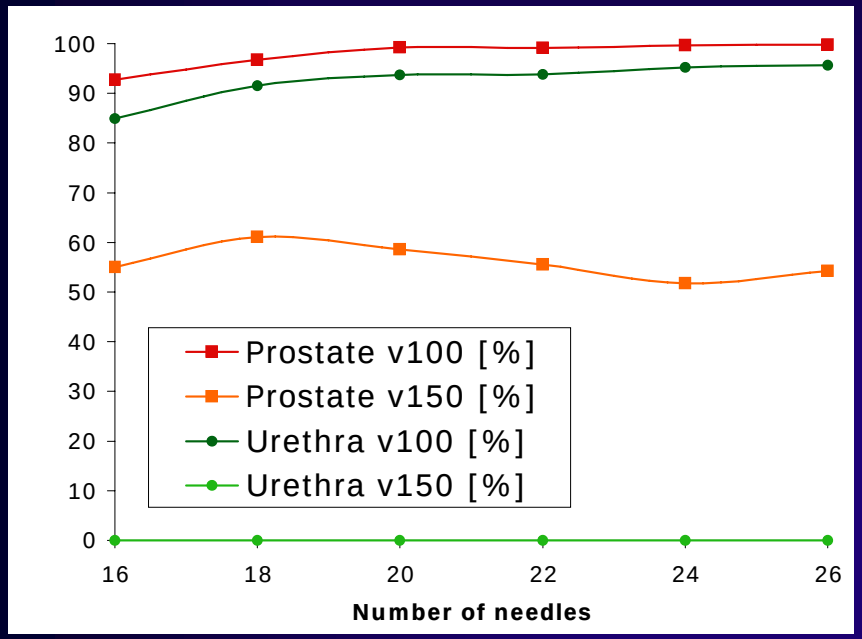


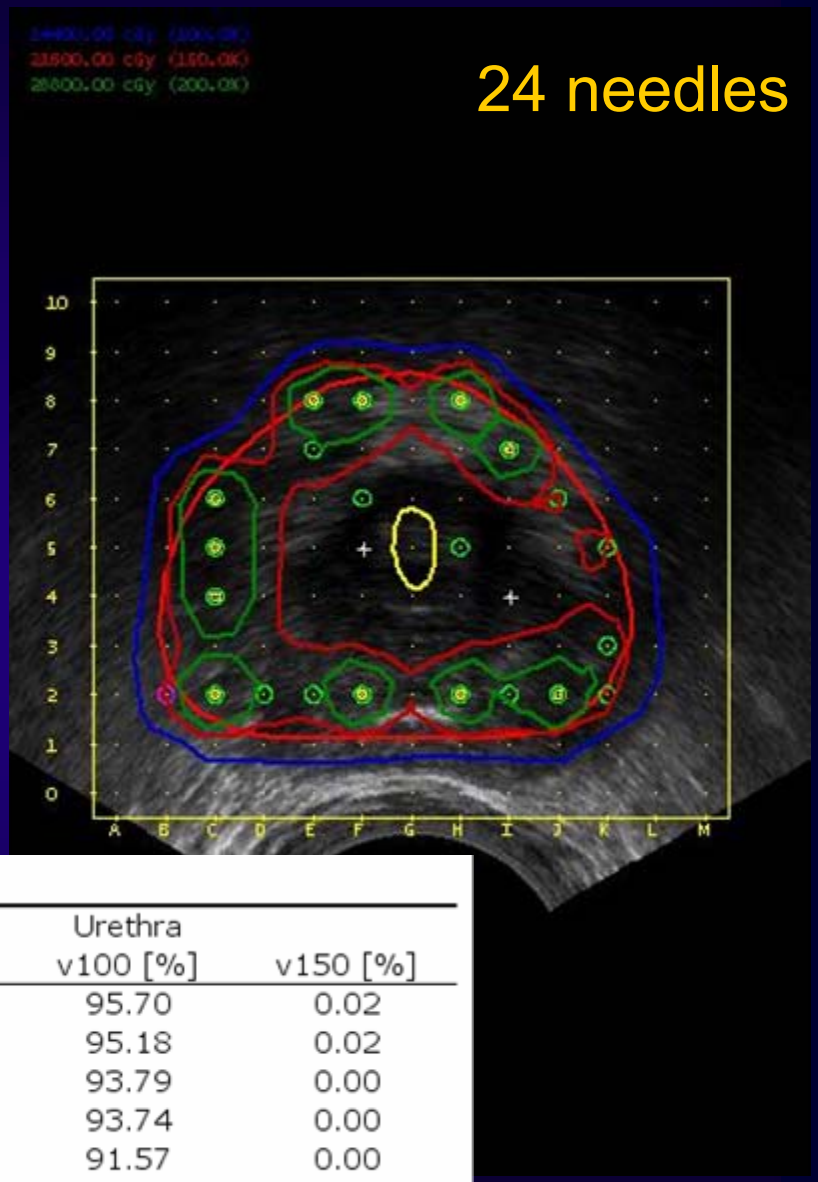


Dosimetric indices vs number of needles

number of needles	number of seeds	Prostate v100 [%]	Prostate v150 [%]	Urethra v100 [%]	Urethra v150 [%]
26	88	99.77	54.27	95.70	0.02
24	87	99.68	51.73	95.18	0.02
22	88	99.17	55.55	93.79	0.00
20	88	99.20	58.57	93.74	0.00
18	87	96.73	61.04	91.57	0.00
16	85	92.75	55.03	84.88	0.01

Dosimetric indices vs number of needles





Dosimetric indices vs number of needles

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26	88	99.77	54.27	95.70	0.02
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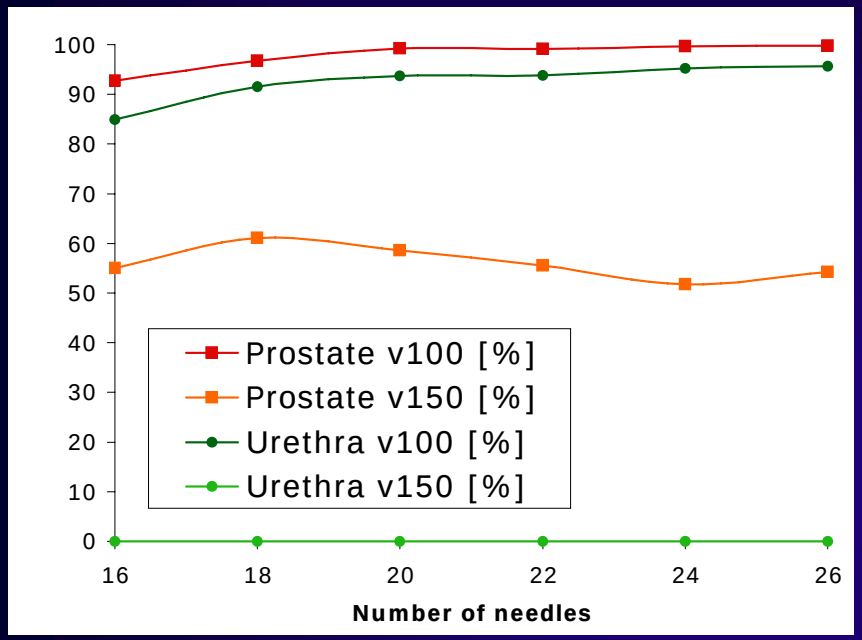

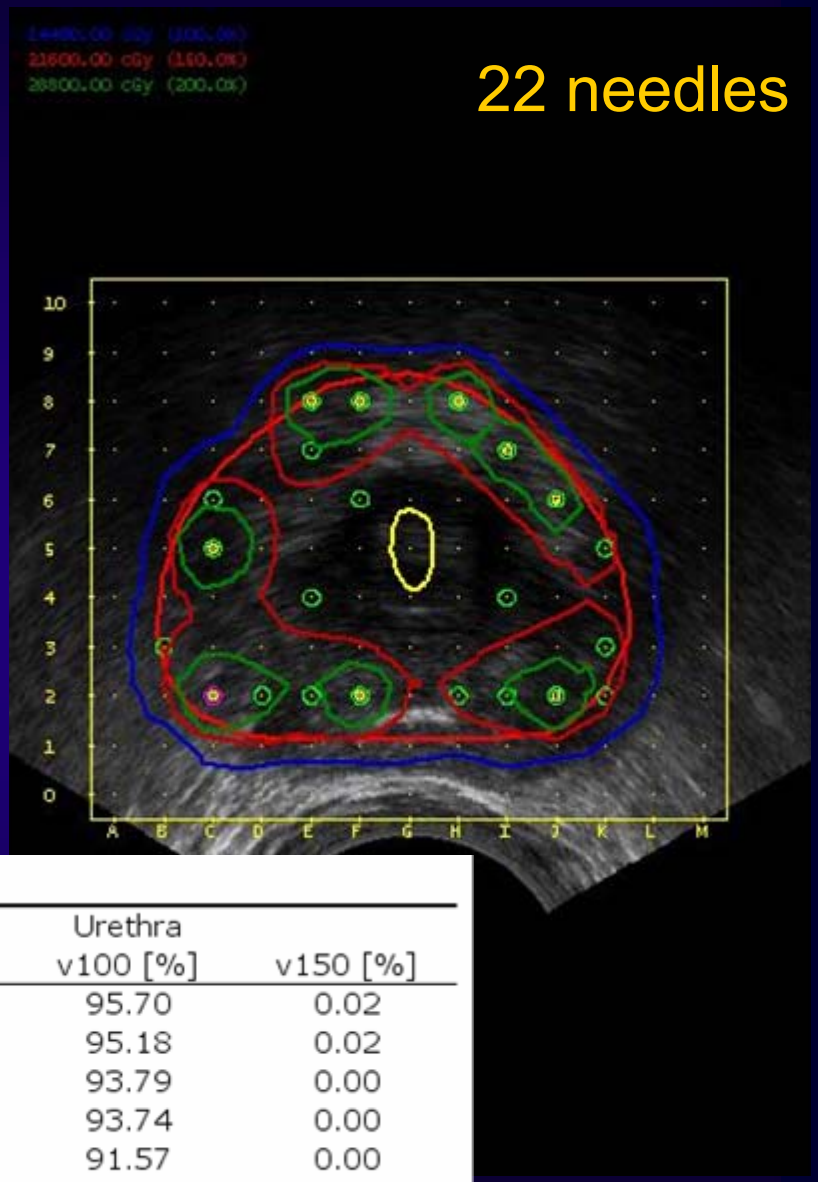

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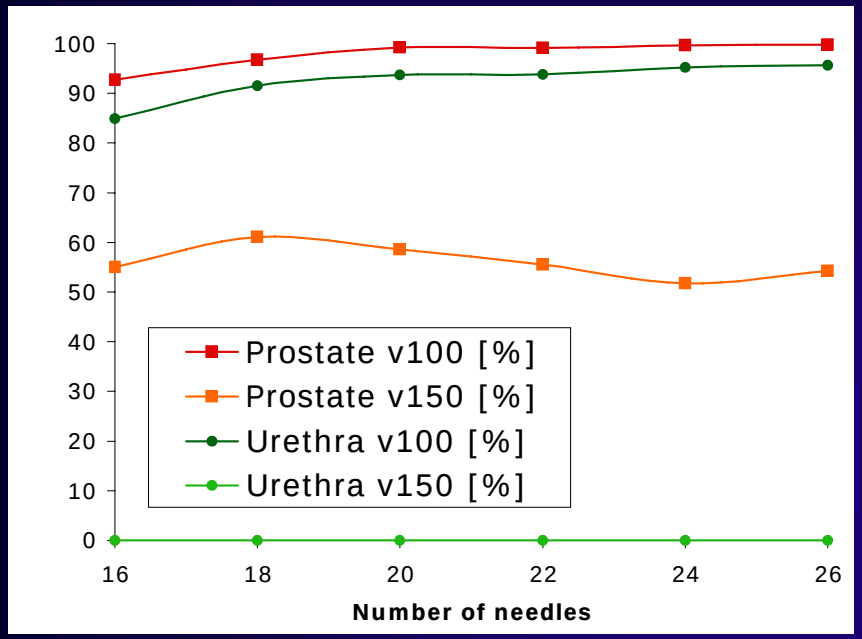

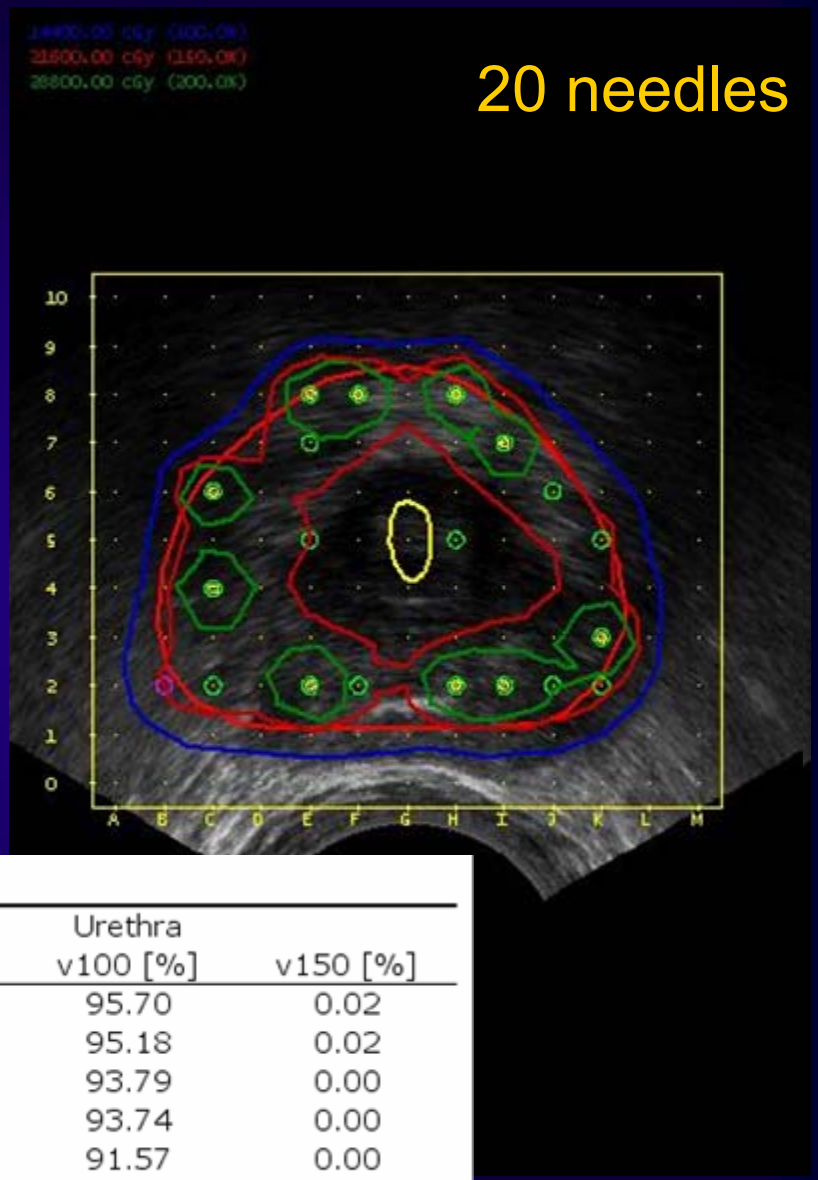

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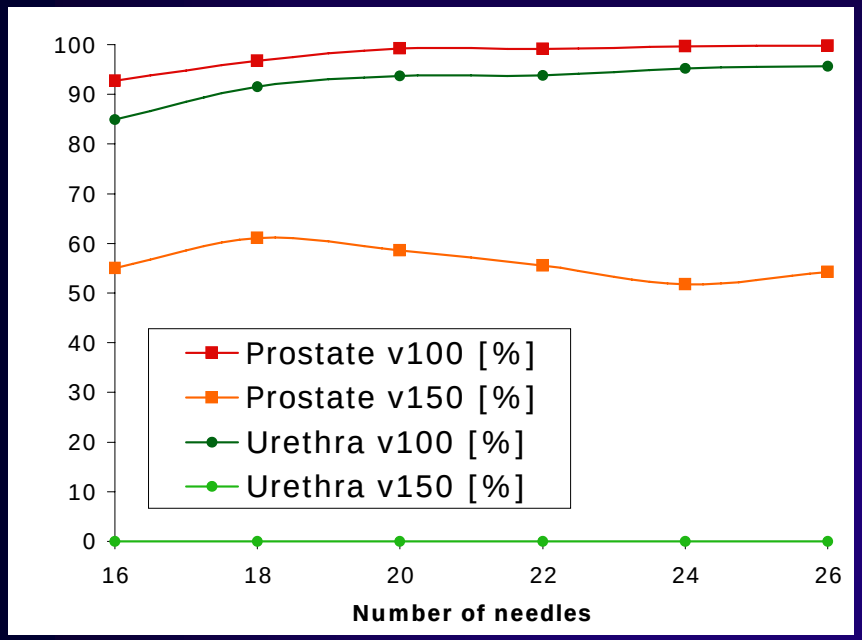

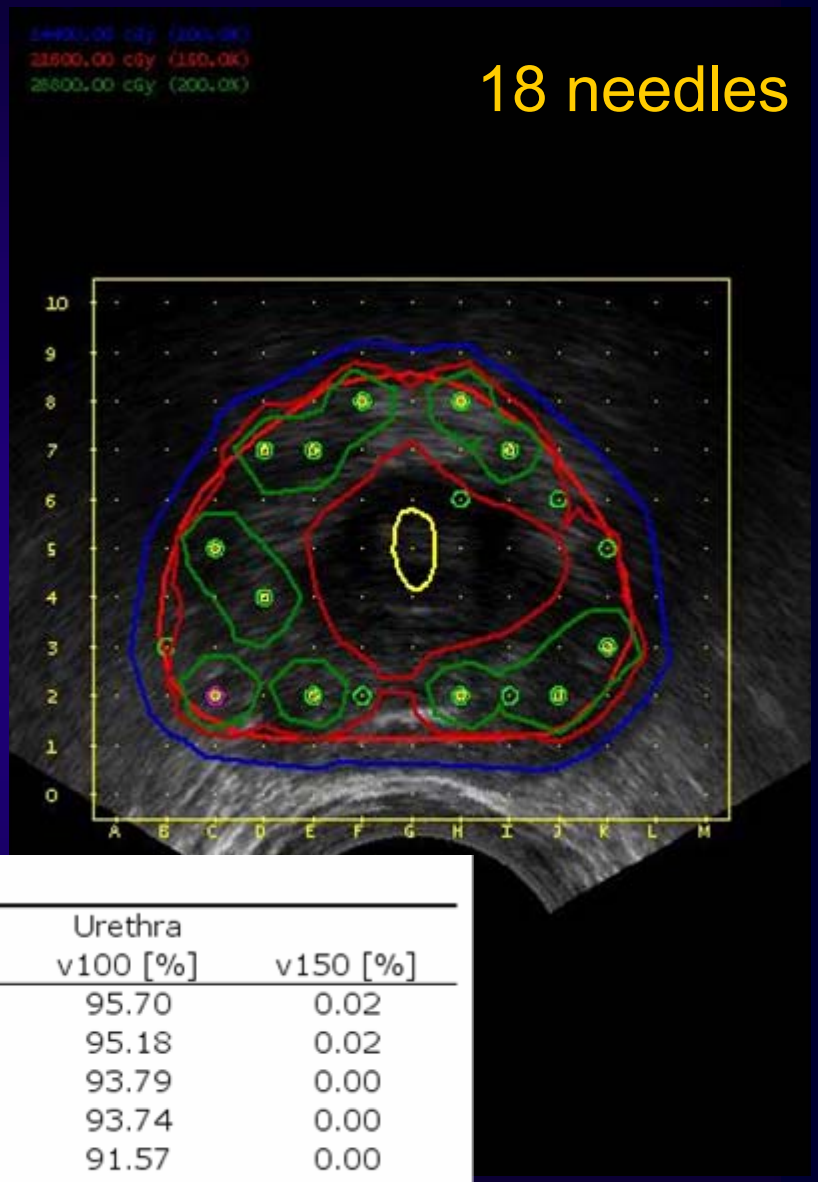

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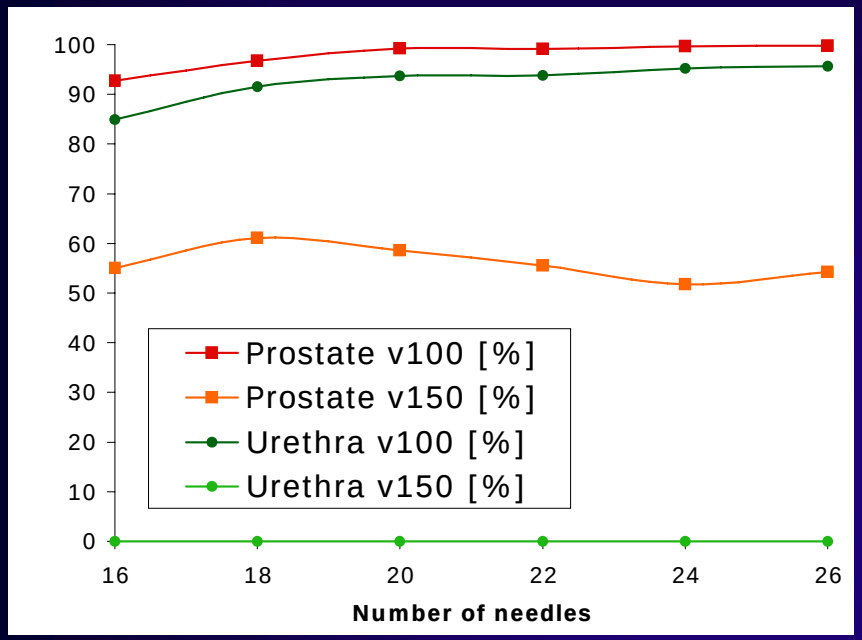

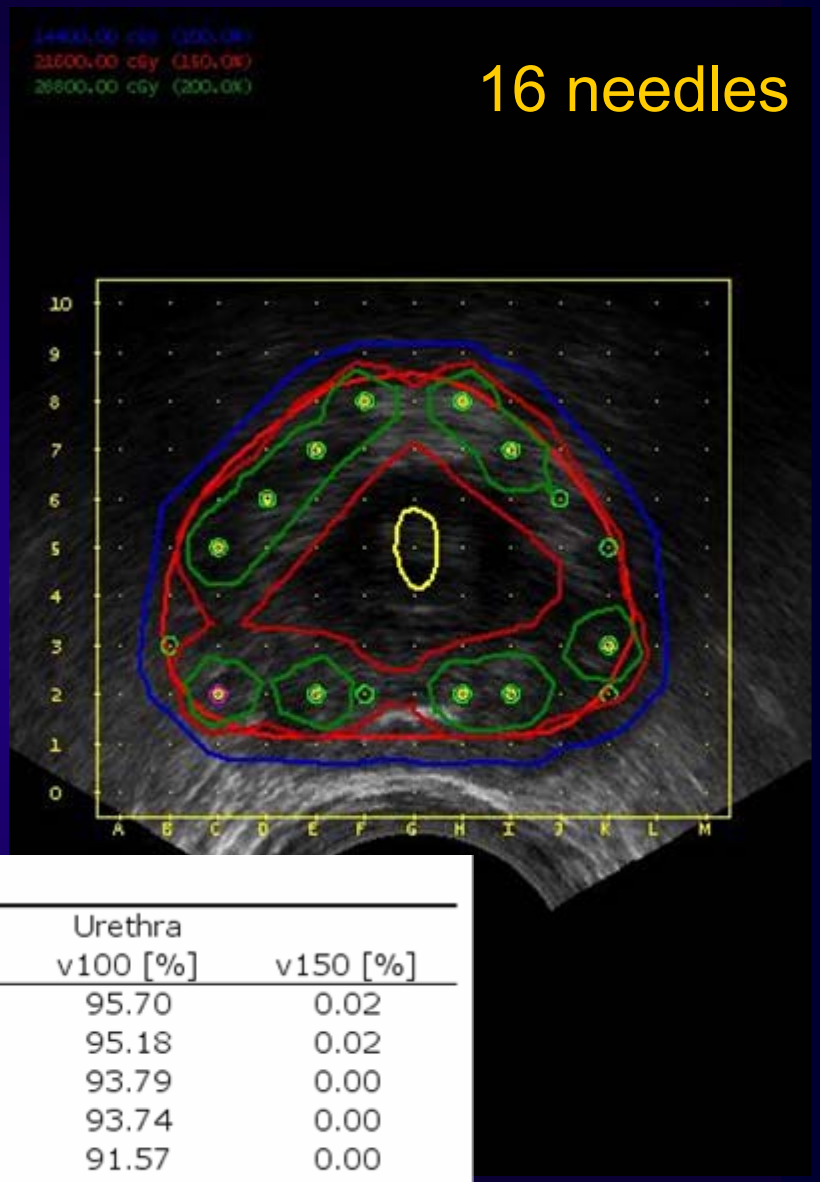

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IPSA gives the ability to boost positive biopsies

Inverse planning by Simulated Annealing

Presets: Prostate (UCSF) (*) — Save

Mode: Optimize all needle and seed positions — << Hide details

Optimization parameters

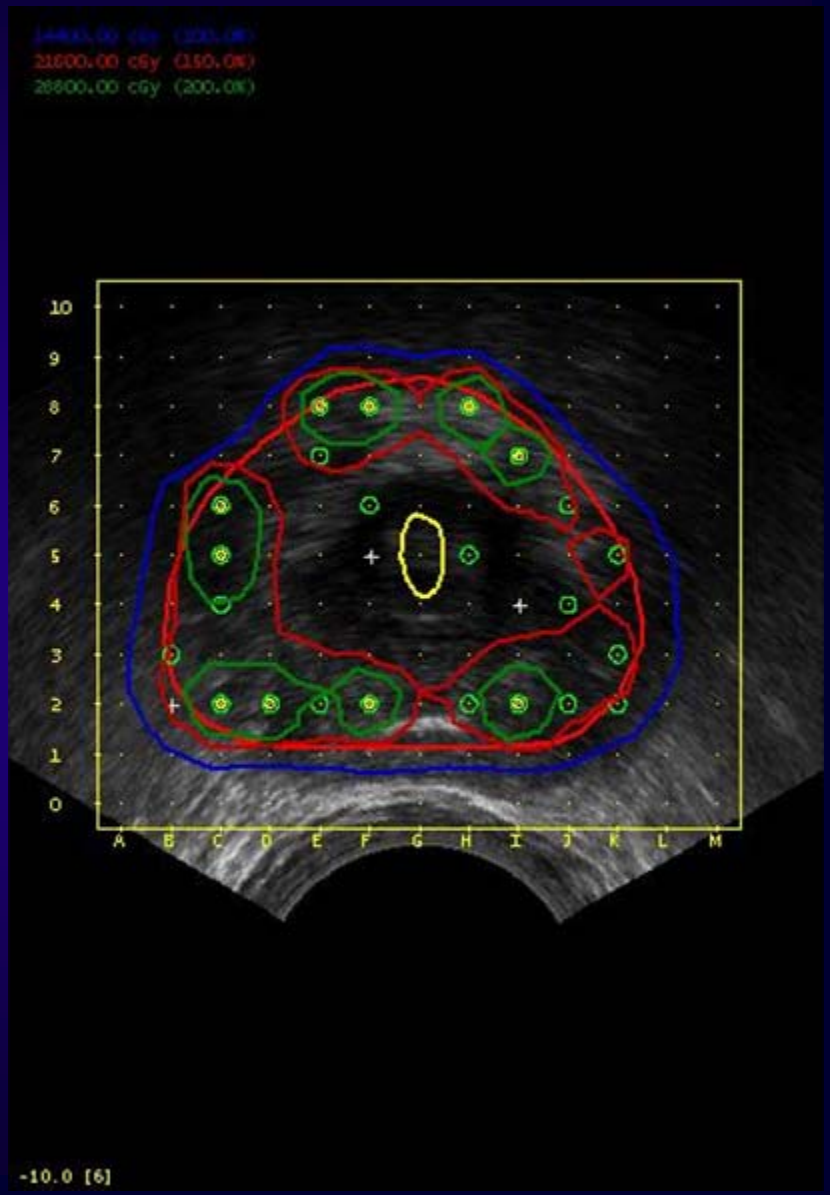
Organ	Surface dose (Weight)		Volume dose (Weight)	
	Min. dose	Max. dose	Min. dose	Max. dose
Targets				
TARGET	14400 (1.00)	21600 (1.00)	14400 (1.00)	28800 (0.30)
Organs at risk				
URETHRA	14400 (1.00)	17280 (0.50)	14400 (1.00)	17280 (0.50)
Ignored organs				
Rectal wall		0 (0.00)		
biopsy1		7200 (1.00)		
biopsy3		7200 (1.00)		
biopsy2		7200 (1.00)		

Percentage / Absolute (cGy) — Show organ doses

Optimization info

Number of seeds: 87, Cost-function: 42445.3 (iteration 140000)

Optimize | Stop | ... | OK | Cancel



IPSA gives the ability to boost positive biopsies

Inverse planning by Simulated Annealing

Presets: Positive Biopsies (UCSF) (*) — Save

Mode: Optimize all needle and seed positions — << Hide details

Optimization parameters

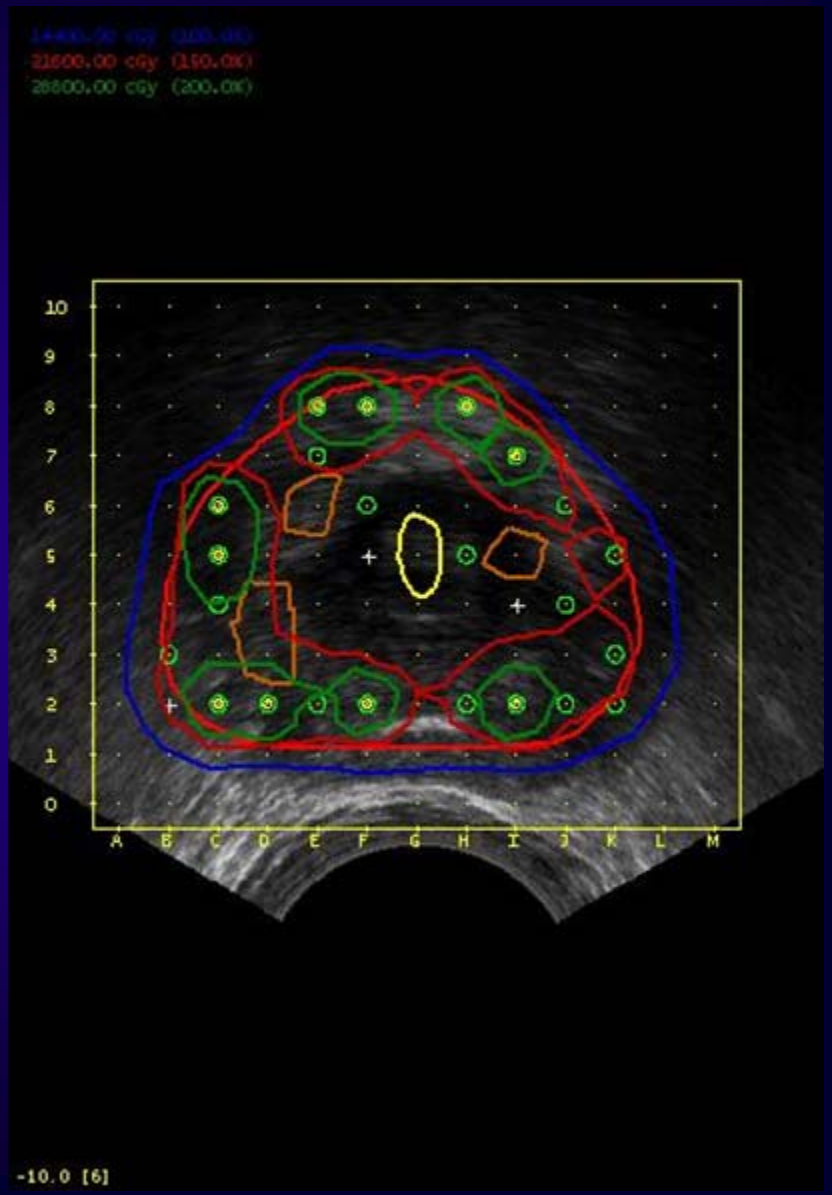
Organ	Surface dose (Weight)		Volume dose (Weight)	
	Min. dose	Max. dose	Min. dose	Max. dose
Targets				
biopsy1	21600 (1.00)	28800 (0.30)	21600 (1.00)	28800 (0.30)
biopsy2	21600 (1.00)	28800 (0.30)	21600 (1.00)	28800 (0.30)
biopsy3	21600 (1.00)	28800 (0.30)	21600 (1.00)	28800 (0.30)
Organs at risk				
URETHRA	14400 (1.00)	17280 (0.50)	14400 (1.00)	17280 (0.50)
Ignored organs				
Rectal wall		0 (0.00)		
(DIL)	21600 (1.00)	28800 (0.30)	21600 (1.00)	28800 (0.30)
(BULB)		7200 (0.10)		
(RECTUM)		7200 (0.10)		

Percentage / Absolute (cGy) — Show organ doses

Optimization info

Number of seeds: 89, Cost-function: 25165.7 (iteration 140000)

Optimize | Stop | ... | OK | Cancel



IPSA gives the ability to boost positive biopsies

Inverse planning by Simulated Annealing

Presets: Positive Biopsies (UCSF) (*) — Save

Mode: Optimize all needle and seed positions — << Hide details

Optimization parameters

Organ	Surface dose (Weight)		Volume dose (Weight)	
	Min. dose	Max. dose	Min. dose	Max. dose

Targets

biopsy1	21600 (1.00)	28800 (0.30)	21600 (1.00)	28800 (0.30)
biopsy2				
biopsy3				

150% ≤ dose ≤ 200%

Organs at risk

URETHRA	14400 (1.00)	17280 (0.50)	14400 (1.00)	17280 (0.50)

Ignored organs

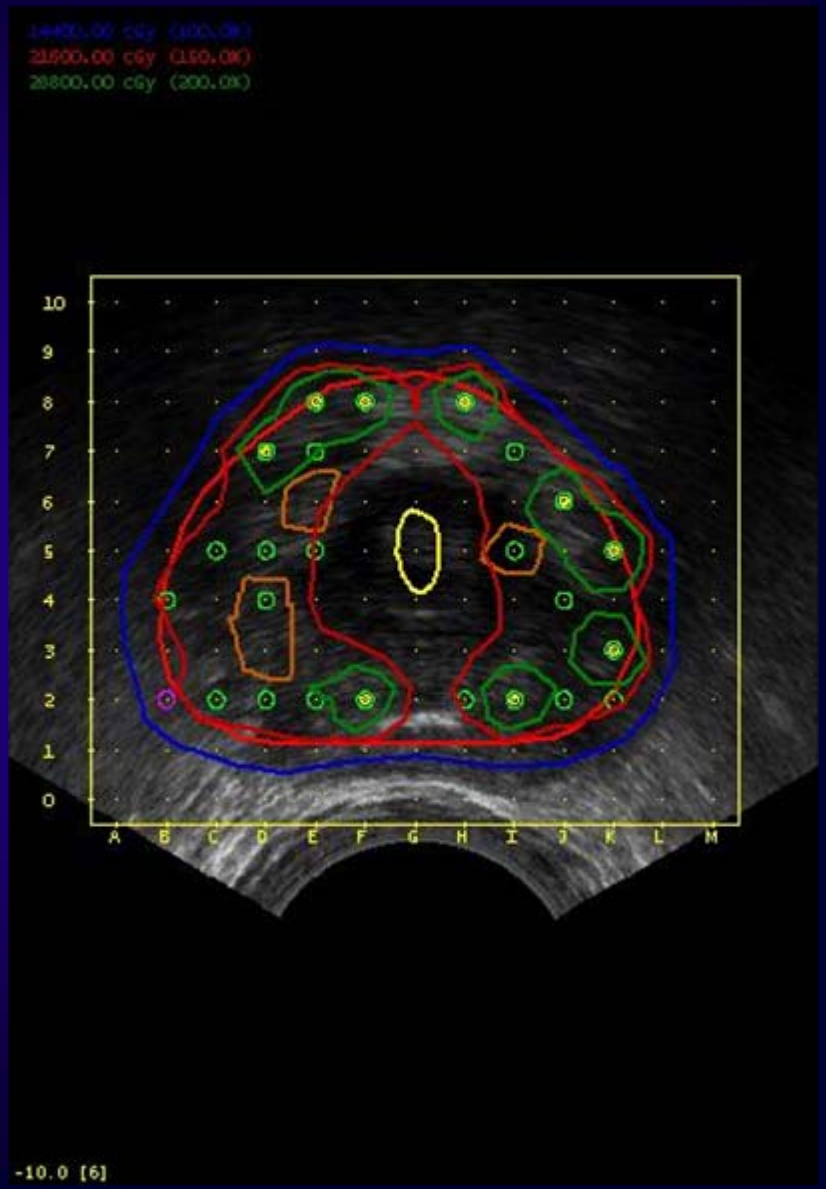
Rectal wall		0 (0.00)		
(DIL)	21600 (1.00)	28800 (0.30)	21600 (1.00)	28800 (0.30)
(BULB)		7200 (0.10)		
(RECTUM)		7200 (0.10)		

Percentage — Absolute (cGy) — Show organ doses

Optimization info

Number of seeds: 89, Cost-function: 25165.7 (iteration 140000)

Optimize — Stop — ... — OK — Cancel



IPSA gives the ability to boost positive biopsies

Inverse planning by Simulated Annealing

Presets: Positive Biopsies (UCSF) (*) | Save

Mode: Optimize all needle and seed positions | << Hide details

Optimization parameters

Organ	Surface dose (Weight)		Volume dose (Weight)	
	Min. dose	Max. dose	Min. dose	Max. dose

Targets

biopsy1	21600 (1.00)	0 (0.00)	21600 (1.00)	0 (0.00)
biopsy2				0 (0.00)
biopsy3				0 (0.00)

150% ≤ dose

Organs at risk

URETHRA	14400 (1.00)	17280 (0.50)	14400 (1.00)	17280 (0.50)

Ignored organs

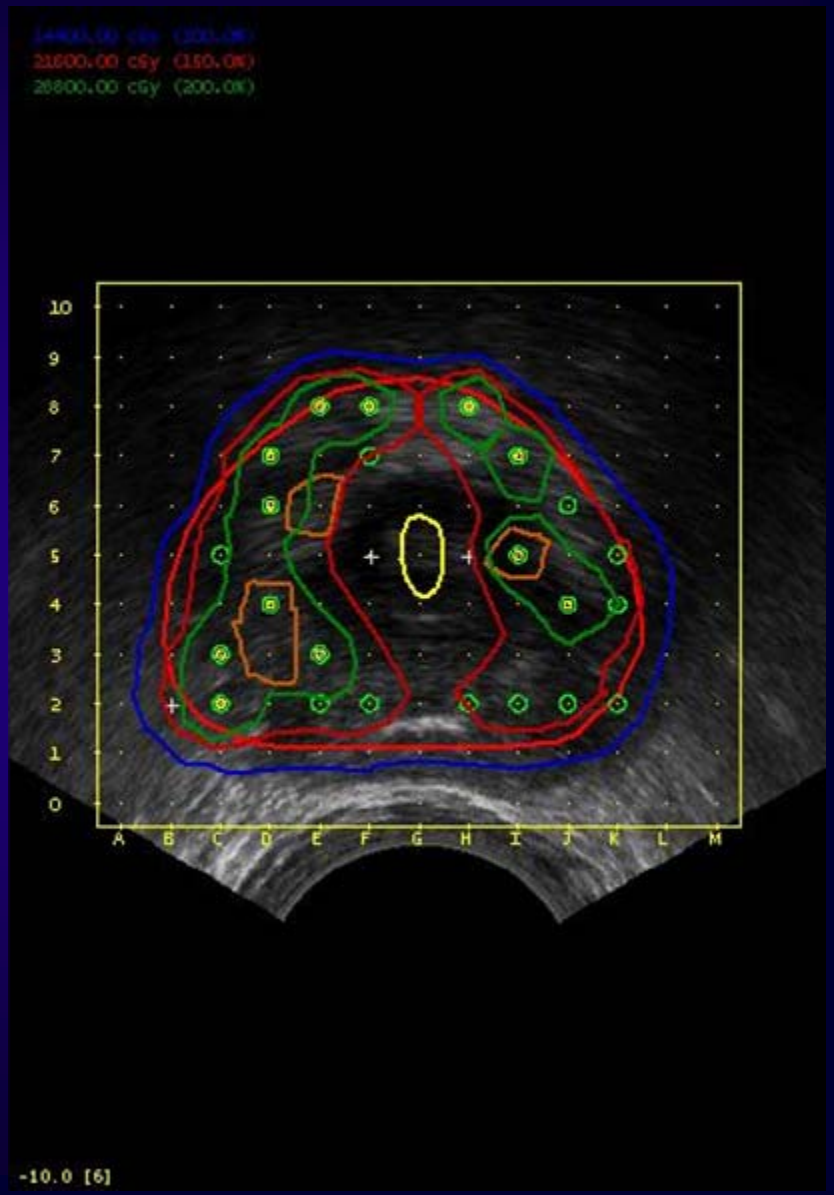
Rectal wall		0 (0.00)		
(DIL)	21600 (1.00)	28800 (0.30)	21600 (1.00)	28800 (0.30)
(BULB)		7200 (0.10)		
(RECTUM)		7200 (0.10)		

Percentage | Absolute (cGy) | Show organ doses

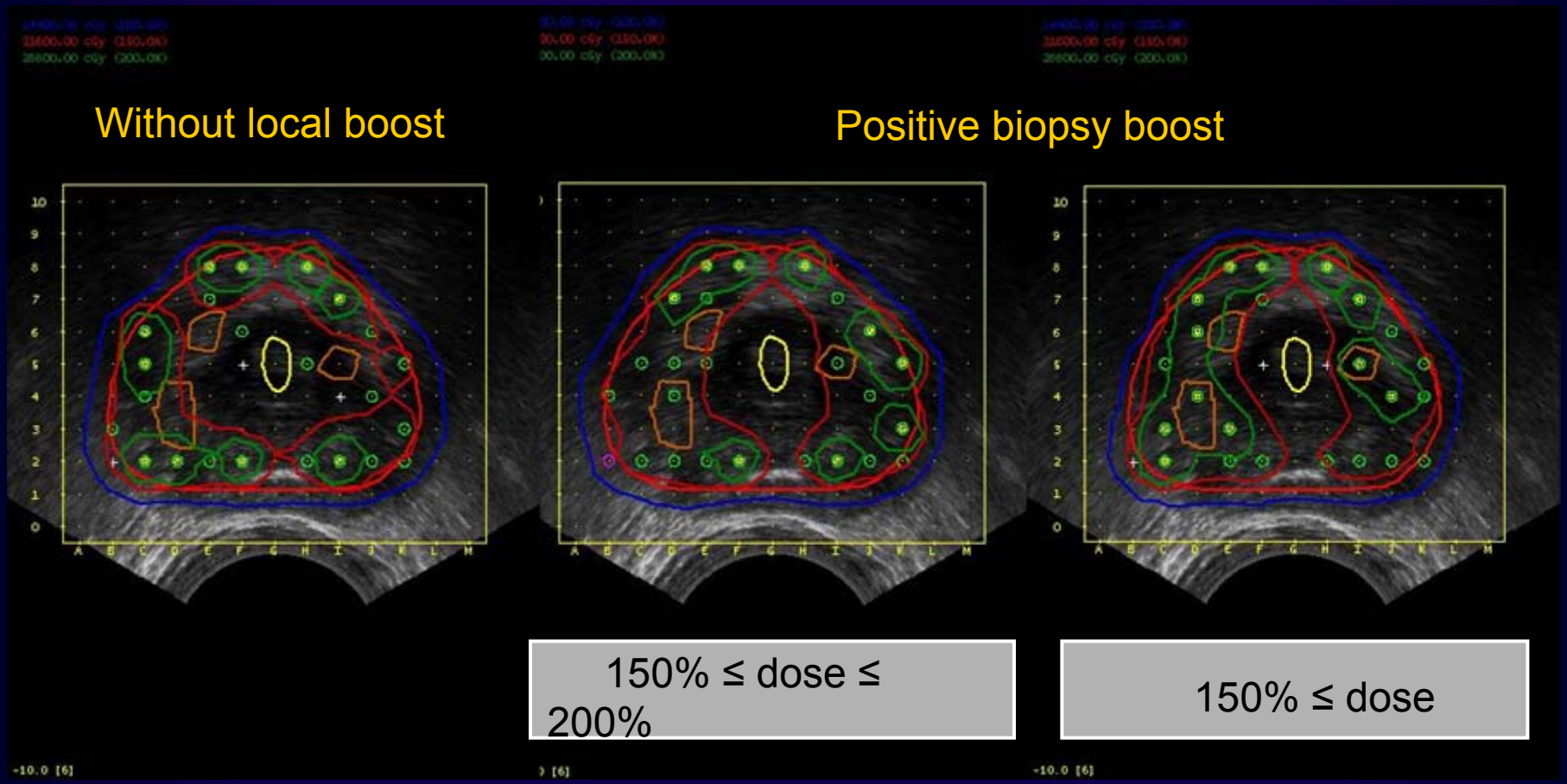
Optimization info

Number of seeds: 88, Cost-function: 23182.8 (iteration 140000)

Optimize | Stop | ... | OK | Cancel



IPSA gives the ability to boost positive biopsies



Workload Shift

- Contour of anatomy
  - Reference target
  - Other Targets
  - Organs to protect
- Specification of Dose Contraints
  - No patient to patient adjustment needed
  - Library (class solution)

- Manual determination of active source positions
- Further dwell times adjustment

Dosimetric Advantages

- Better dose coverage on the target
- Better homogeneity index
- Takes into account all contoured targets and organs at risk
- Allows several targets, each with specific dose prescription
- Delivers dose distributions not considered before

Technical Advantages

- Optimization is achieved in a short time (20 to 50 s.)
- Automatically switches off the undesirable dwell-positions.
- No manual adjustment of dwell-times is required.
- Quality of planning is independent of the dosimetrist experience.
- Minimize the impact of misplaced catheters.

Summary

- If you can:
  - Define a Target
  - Insert enough catheters
- You can:
  - Obtain a conformal dose
  - Protect OAR
  - Be ready to treat in a short time

Thanks to

YongBok Kim, Ph.D.
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