2014 AAPM SUMMER SCHOOL
University of Vermont • Burlington, VT • June 22–26, 2014
SRS/SBRT/SABR:
Safely and Accurately Delivering
High-Precision, Hypofractionated Treatments

Stereotactic Body Radiotherapy (SBRT) for Prostate Cancer: Practical Considerations for Treatment Planning

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Outline of Presentation

- Introduction
- Simulation and immobilization
- Treatment planning process
  - Target and OAR contours
  - Beam design
  - Dose optimization/calculation
  - Plan evaluation
- Patient treatment setup and verification

Learning Objectives

- Summarize and discuss the clinical issues involved when planning prostate patient with SBRT treatment including target volume delineation, contouring critical structure, dose prescription strategies, and plan evaluation
- Summarize and discuss the clinical issues associated plan simulation, motion management and treatment verification for prostate SBRT

SBRT – Prostate

Study	Schedule	# of patients	Risk class	Medi F/U (mos)	Late grade 3 GU toxicity	Late grade 3 GI toxicity	FFBF
CyberKnife							
Katz et al. 2010 [5]	35 – 36.25 Gy in 5 fx	304	L-I-H	48	2%	-	97, 93, 75% at 4 year
Freeman, King, 2011. [6]	7-7.25 Gy in 5 fx	41	L	60	< 1%	-	93% at 5 year
McBride et al. 2012 [7]	36.25-37.5 Gy in 5 fx	45	L	44.5	< 1%	-	97.7% at 3 years
Fuller et al. [8]	38 Gy in 4 fx †	54	L-I	36	4%	-	96% at 3 years
Kang et al. [9]	32-36 Gy in 4 fx	44	L-I-H	40	-	-	100%, 100%, 90.9% at 5 years
King et al. 2012 [10]	36.25 Gy in 5 fx	67	L	32.4	3.5%	-	94% at 4 years
Gantry-based Systems							
Madsen et al. 2007 [11]	33.5 Gy in 5 fx	40	L	41	-	-	90% at 4 years
Boike et al. 2011 [12]	45-50 Gy in 5 fx	45	L-I	30, 18, 12	4%	2% plus 1 Grade 4	100% at 1–2.5 years

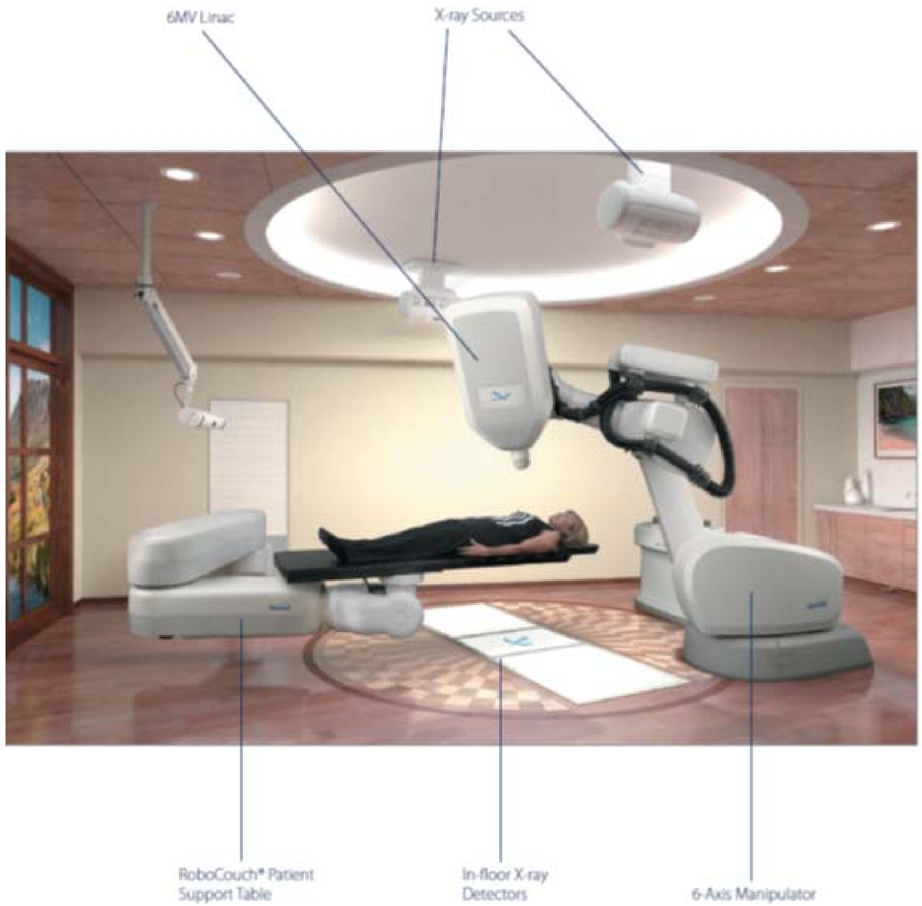
Abbreviations: L = low; I = intermediate; H = high.

Alongi et al. Radiation Oncology 2013, 8:171

Common treatment techniques

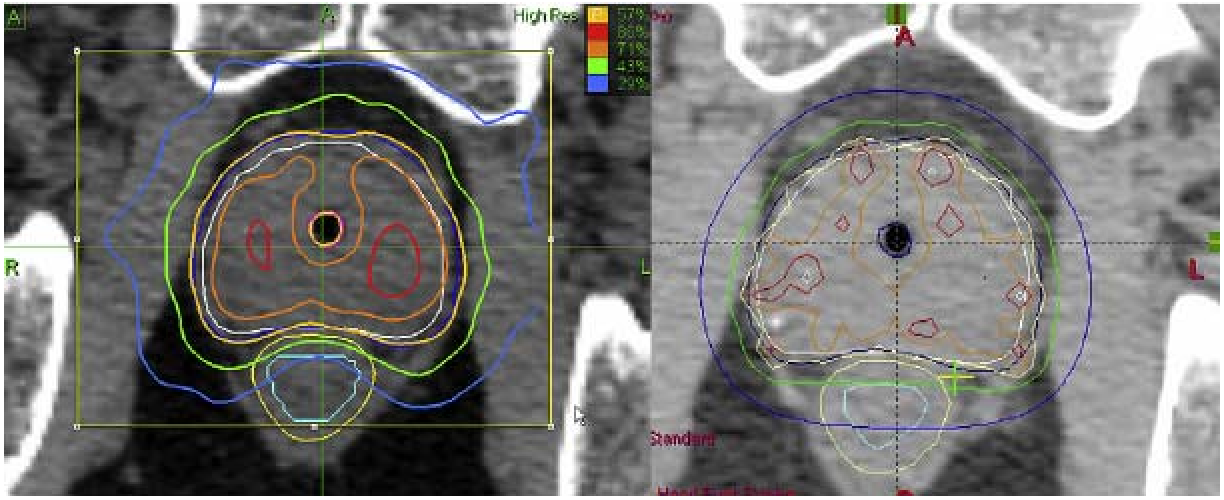
- Isocenter
  - Isocentric (Linac gantry based) vs. non-isocentric (Cyberknife)
- Beam arrangement
  - Coplanar vs. non-coplanar beams
  - Static gantry angle IMRT vs. Volumetric arc modulated treatment (VMAT)
- PTV dose distribution
  - Homogenous vs. Heterogeneous vs. Simultaneous boost

Isocentric vs. non-isocentric

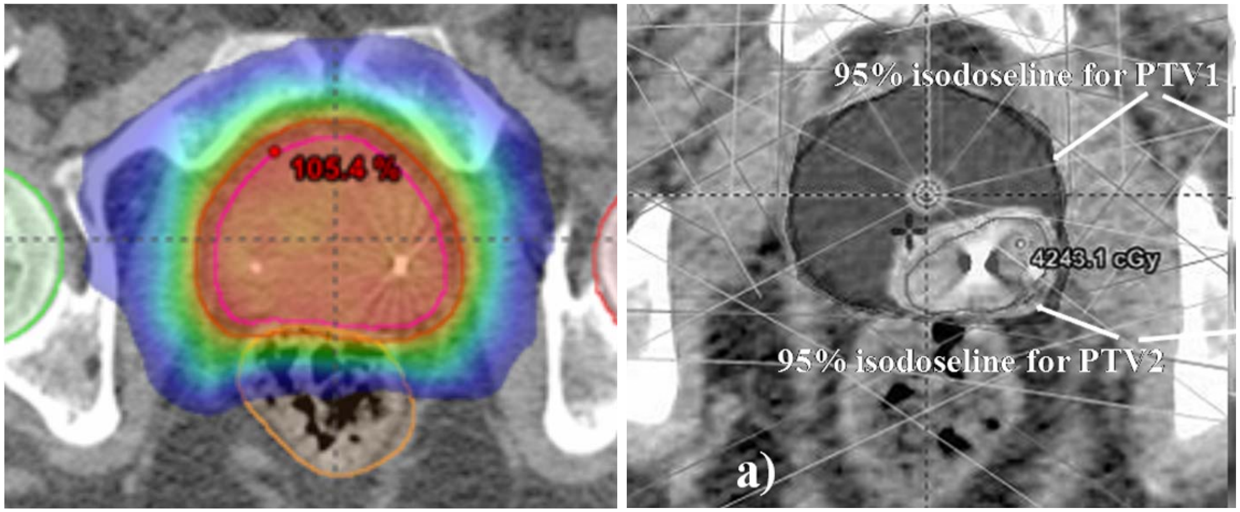


Courtesy of BrainLab®

Courtesy of Accuray®



D. B. FULLER et al., IJROBP. V70(5), 2008



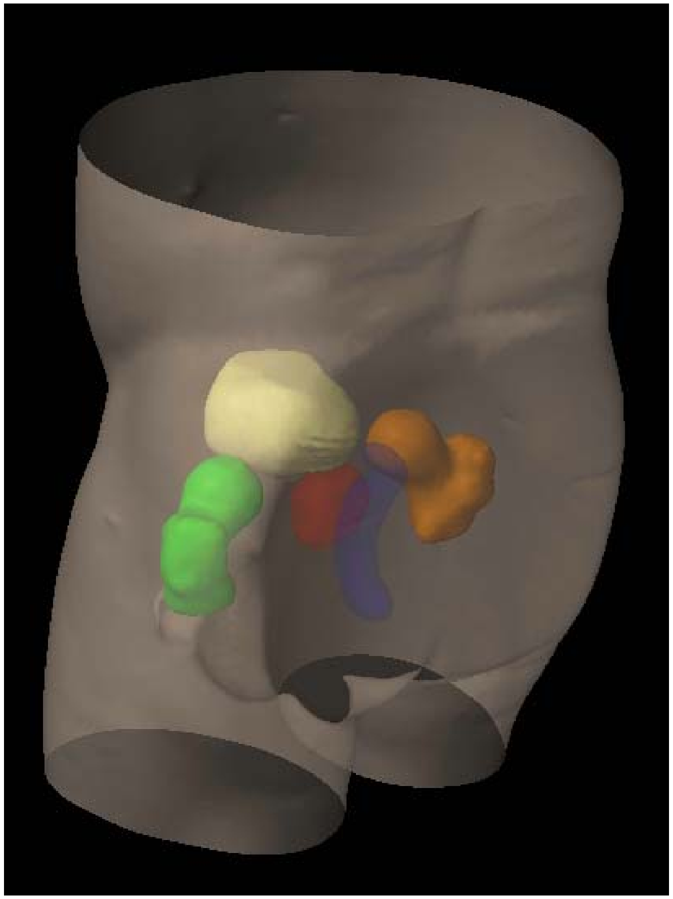
Udrescu et al. Physica Medica.2013(in press)

Clinical Workflow

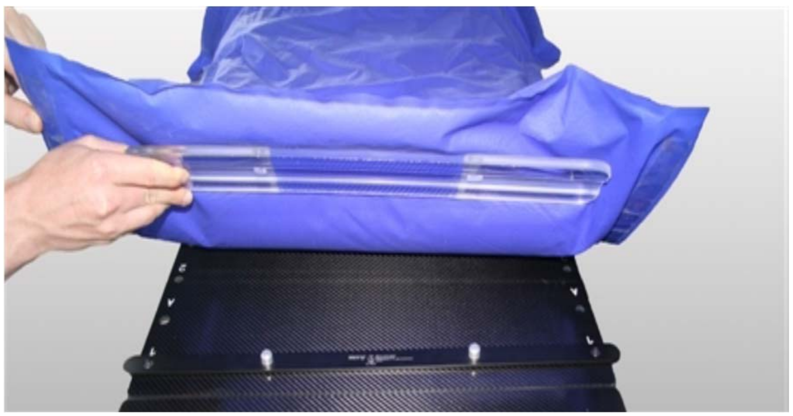
- Patient immobilization and simulation
- Target and organ at risk (OAR) delineation
- Isocenter placement and beam design
- Dose optimization and calculation
- Plan evaluation and quality assurance
- Patient setup and verification
- Treatment delivery

Special considerations - Challenges

- Close proximity of OARs
- High dose gradient / conformity
- Organ motion



Patient immobilization



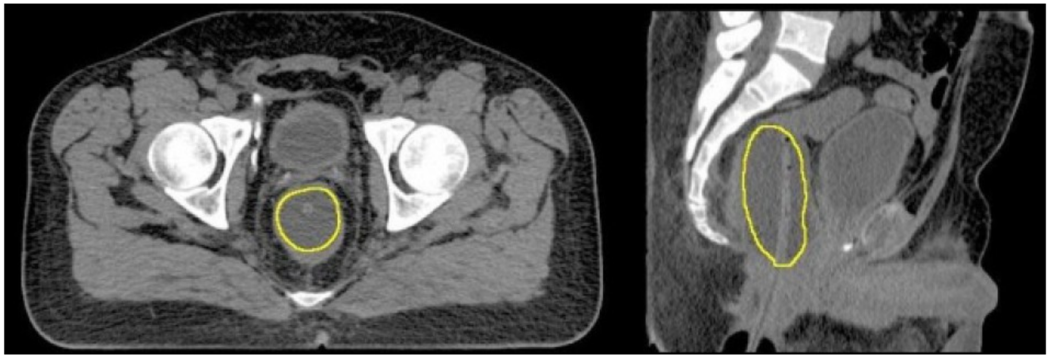
Vacuum bag

Body frame

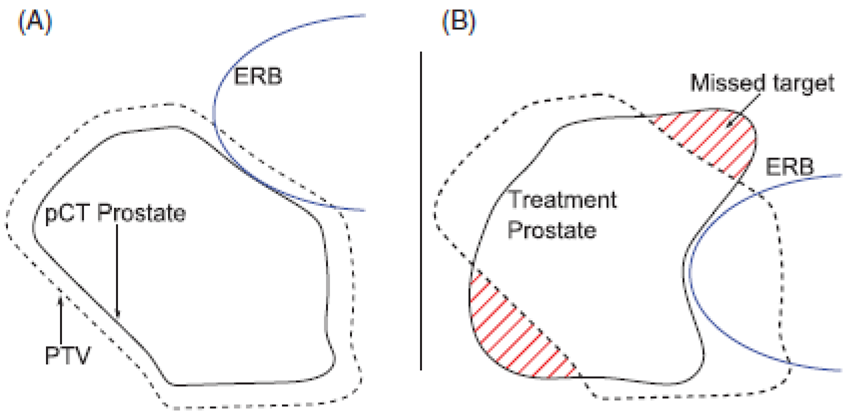
CT simulation

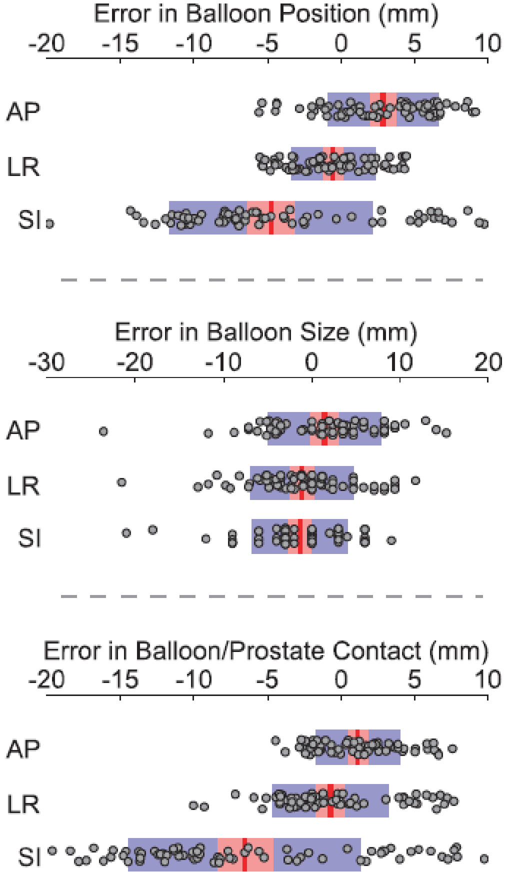
- Placement of 3 gold markers via trans-rectal ultrasound
- Patient instructed to have comfortably full bladder
- Patient in supine position in the immobilization device
- Non-contrast CT scan and MRI of the pelvis
  - from above the iliac crest to below the ischium
  - 1.5mm slice thickness

Rectal Balloon



Both S etc. TCR, Vol.1(3), 2012

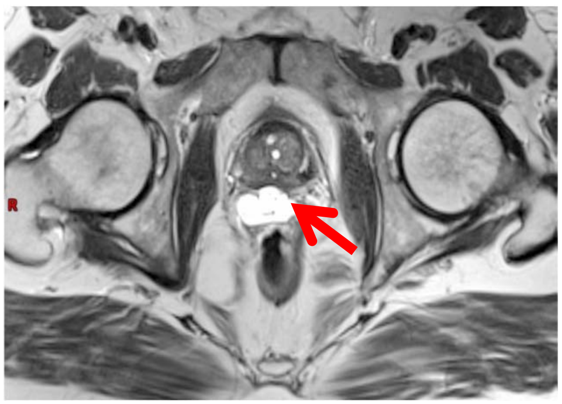


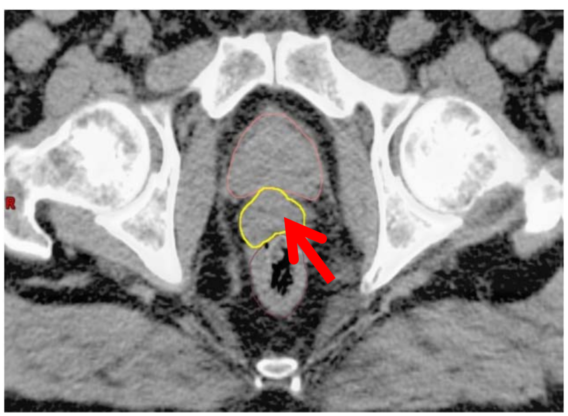


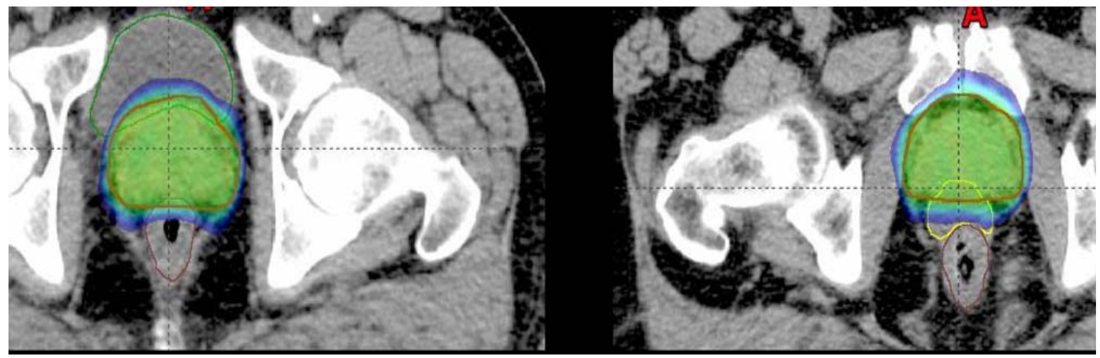
B L Jones *et al,* Phys. Med. Biol. **58** (2013)

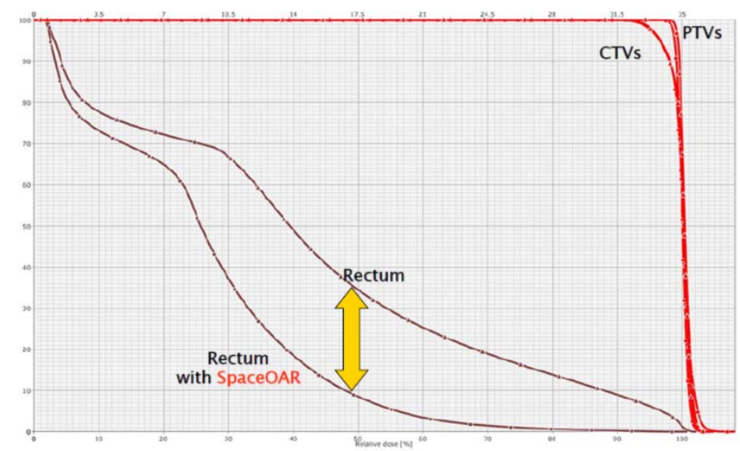
Spacer between Prostate and Rectum

- Biocompatible liquid gel injected between the prostate and rectum under ultrasound guidance



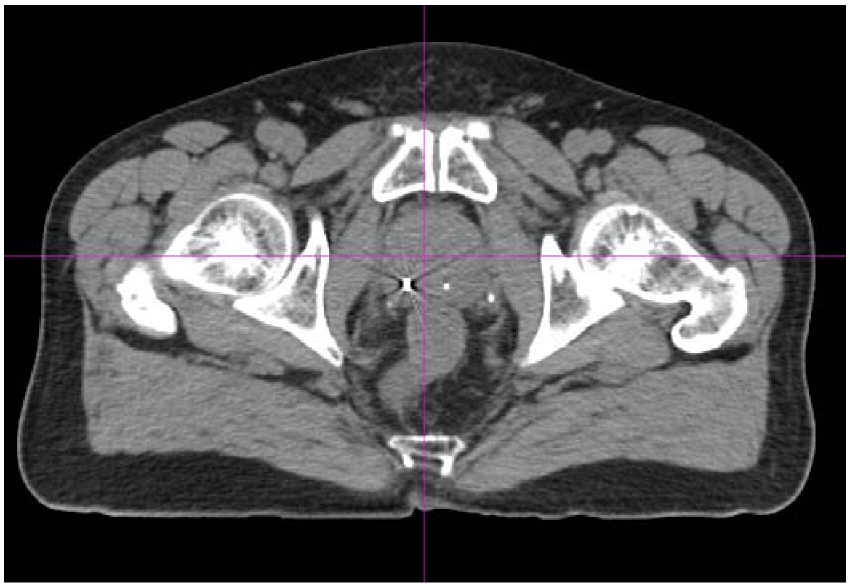


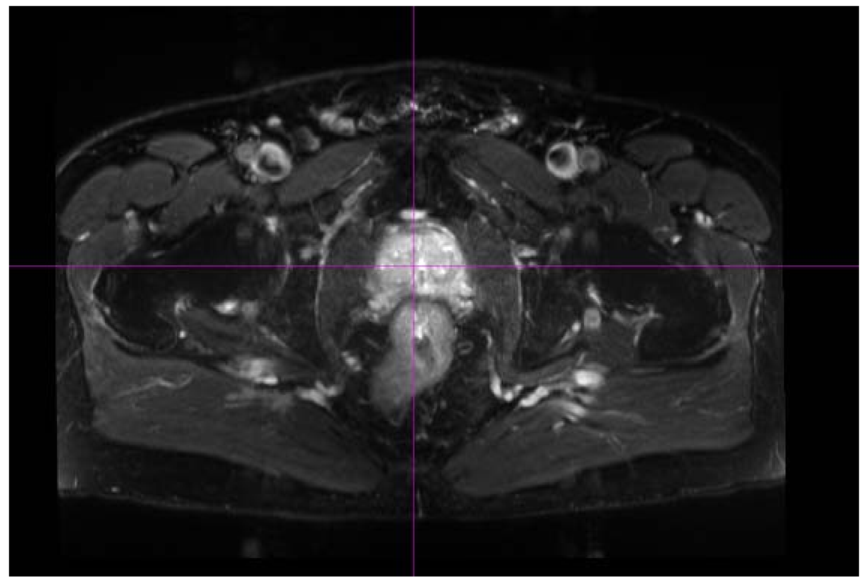




Alongi et al. Radiation Oncology 2013, 8:171

Target localization

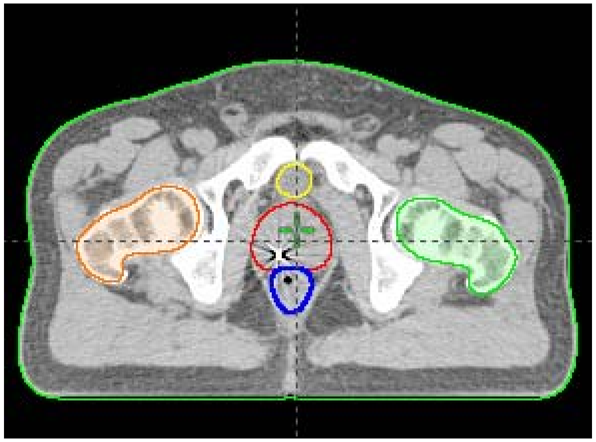


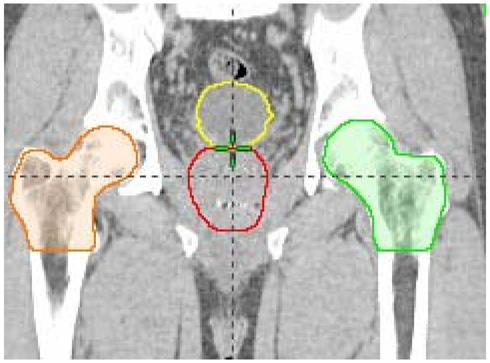


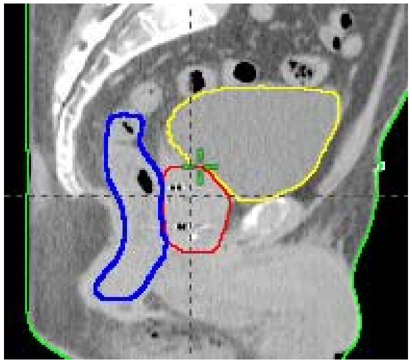
MRI Prostate Anatomy Atlas: http://www.prostadoodle.com/

OAR contours

- Bladder
- Rectum
- Penile bulb
- Femoral heads
- Urethra (optional)
- Bowel (optional)
- Testes (optional)







Planning dose constraints

TABLE 1. Literature-based treatment parameters for HDR and robotic SBRT protocols.

Parameter	*HDR*[(13)]	*San Diego*[(8)]	*UCSF*[(9)]	*Erasmus*[(7)]	*UCLA*[(10)]
Total dose	19 Gy	38 Gy	19 or 38 Gy	38 Gy	36.25 Gy
Fractions	2	4	2 or 4	4	5
Prescription		>50%	>60%	>67%	88%-92%
PTV margin	none	2-5 mm/0 post.	2 mm/0 post.	3 mm/0 post.	5 mm/3 mm post.
PTV	V100%[a] ≥90%	V100%[a] ≥95%	V100%[a] ≥95%	V100%[a] ≥95%	V100%[a] ≥95%
Rectum	V75%[a] <1 cc	Wall V100%[a] = 0 Mucosa[b] V75%[a] = 0	V75%[a] <2 cc	Wall V100%[a] = 0 Mucosa[b] V75%[a] = 0 V85%[a] <1 cc	V50%[a] <50% V80%[a] <20% V90%[a] <10% V100%[a] <5%
Bladder	V75%[a] <1 cc	V120%[a] = 0	V75%[a] <3 cc	V110%[a] = 0 V100%[a] <1 cc	V50%[a] <40% V100%[a] <10%
Urethra	V125%[a] <1 cc	V120%[a] = 0	V120%[a] <10%	V120%[a] = 0	

[a] Vxx: Volume of structure (PTV or organ at risk) receiving xx% of prescription dose.
[b] Mucosa: solid structure formed by a 3 mm contraction of the rectal wall.

Descovich et al. JACMP Vol. 14 (5), 2013

Dose conformity and Homogeneity

$$Conformity\ index_{RTOG} = \frac{V_{RI}}{TV}$$

$$Conformation\ number\ (CN) = \frac{TV_{RI}}{TV} \times \frac{TV_{RI}}{V_{RI}}$$

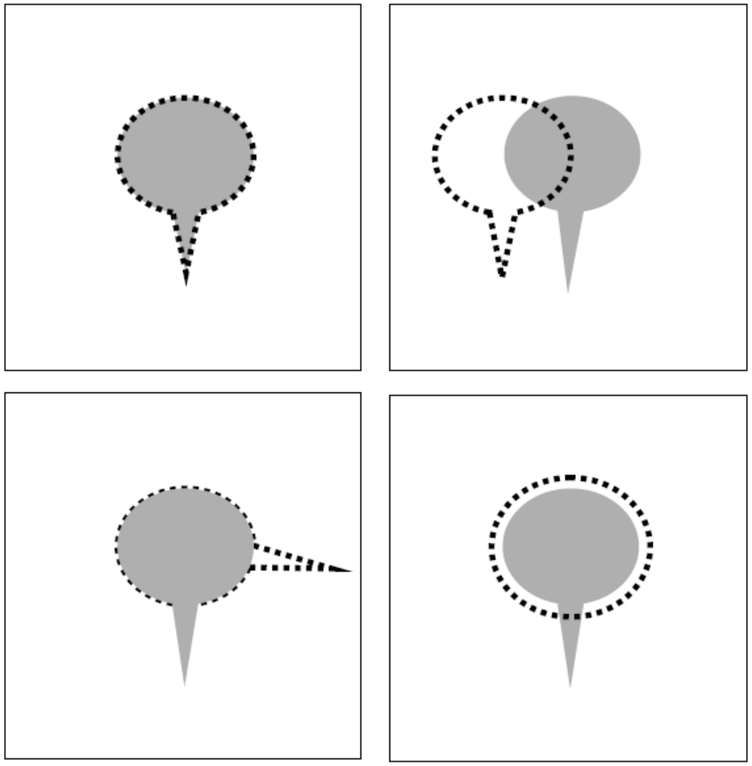
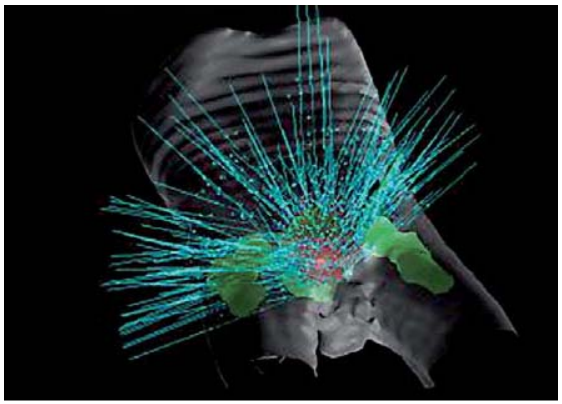


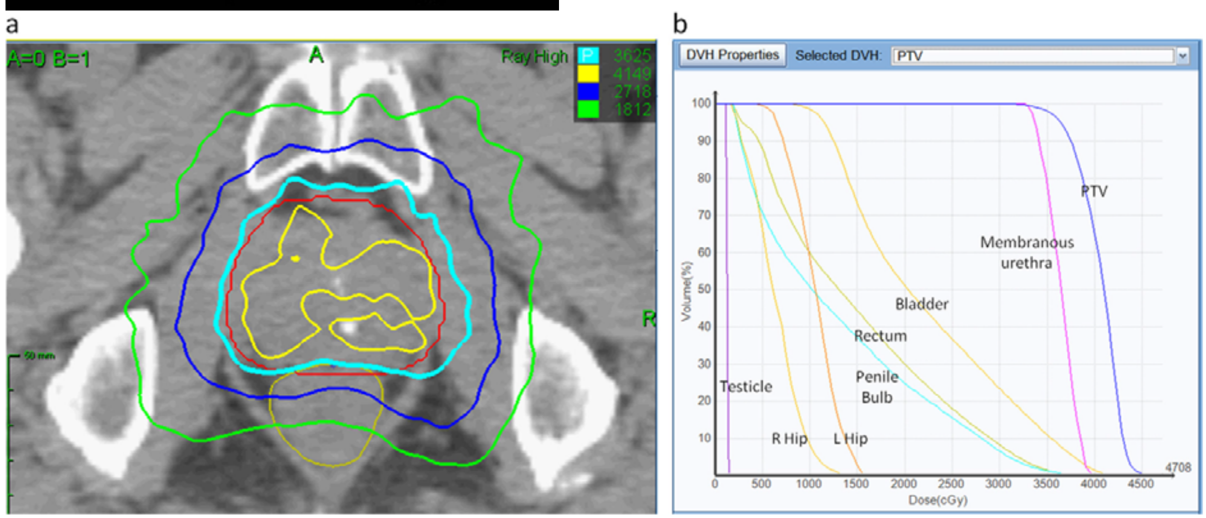
Fig. 1. Four possibilities for which the V_{RI}/TV ratio is equal to 1 (index proposed by the RTOG) (1) (target volume, shaded; volume of reference isodose, enclosed in black dashes).

Feuvret L. et. al., IJROBP, V64(2), 2006

Cyberknife plan

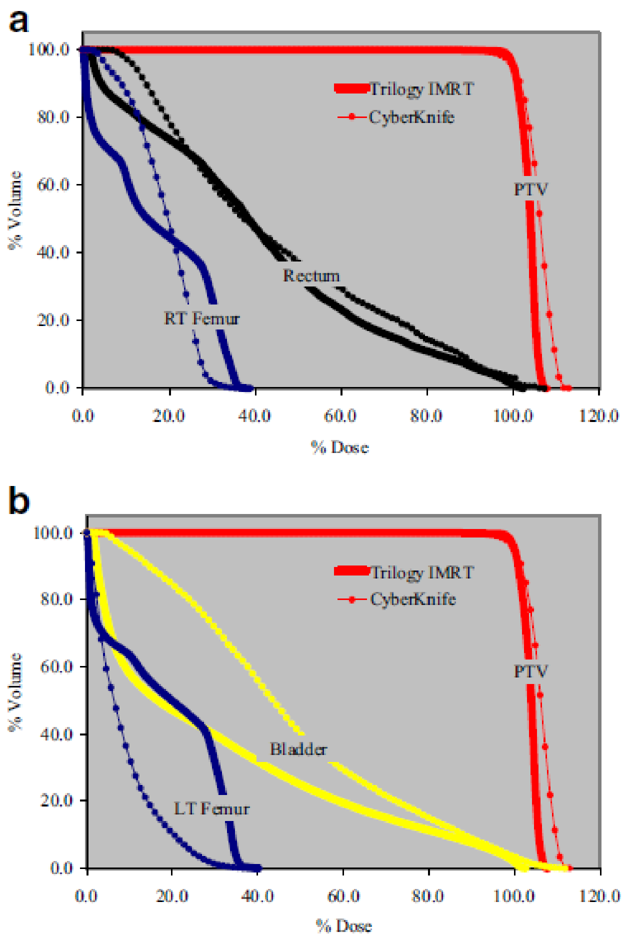


- Typical treatments consist of about 100-120 non-coplanar beams
- Total treatment 40-60 minutes
- Imaging correction every 5–7 beams (about every 30–90s)



Chen et al. Radiation Oncology 2013, 8:58

Cyberknife vs. Linac IMRT



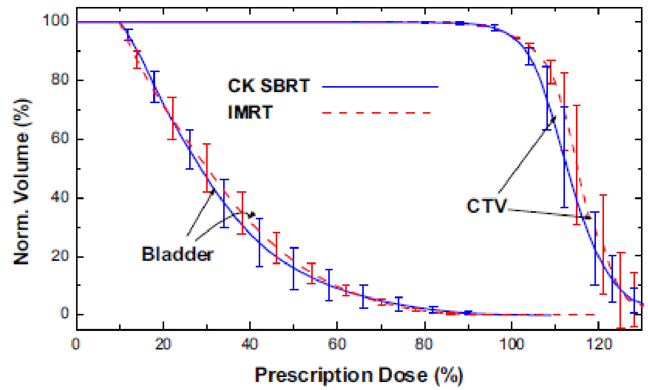
Pawlicki et al. Med Dosi 32(2), 2007

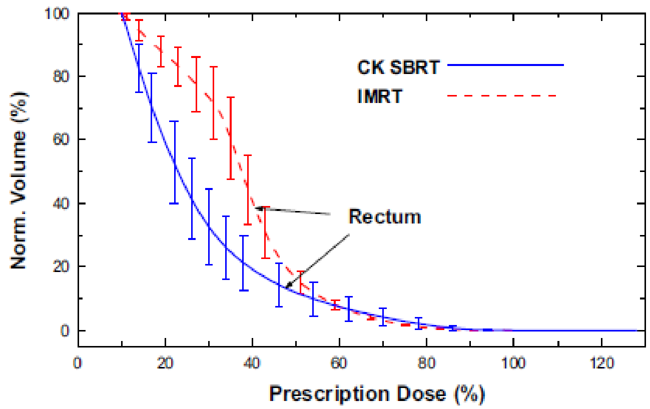
- No posterior beams in cyberknife plan. More anterior beams transvers the bladder
  - ➢ Higher bladder dose
- Fewer beams to enter from the left side of patient due to the robotic kinematic constraints
  - ➢ Higher dose to right femur compared with left femur

Cyberknife vs. Linac IMRT

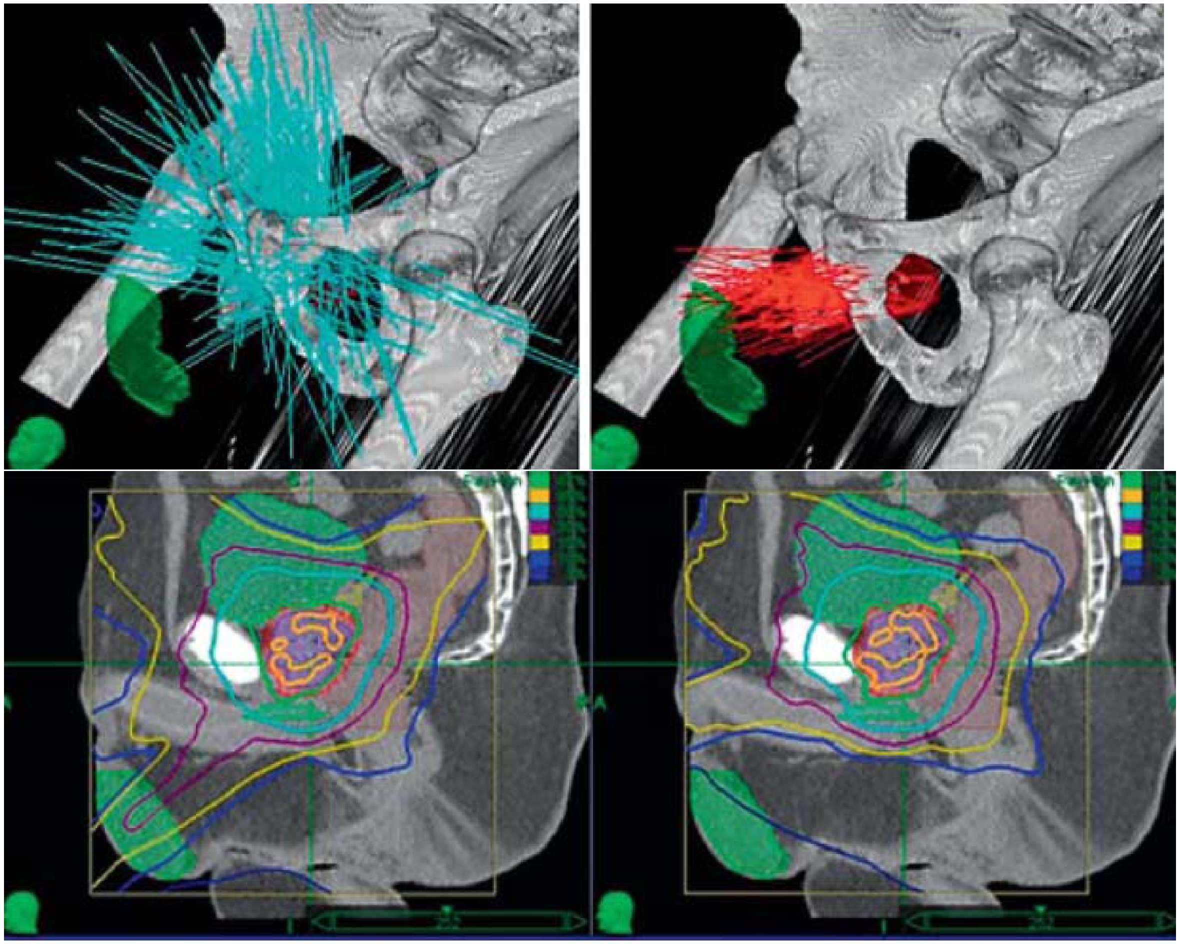
Table 1. Conformity index and homogeneity index values for each patient for CK SBRT and simulated IMRT plans

		CI			HI		
Pt. No.	Volume (cm^3)	CK SBRT	IMRT	ΔCI%	CK SBRT	IMRT	ΔHI%
1	138.0	1.13	1.24	−8.87	1.33	1.18	12.71
2	95.6	1.31	1.41	−7.09	1.35	1.31	3.05
3	67.3	1.11	1.58	−29.75	1.39	1.38	0.72
4	64.0	1.11	1.52	−26.97	1.67	1.30	28.46
5	41.7	1.13	1.41	−19.86	1.39	1.27	9.45
6	40.0	1.16	1.54	−24.68	1.41	1.30	8.46
7	36.2	1.20	1.35	−11.11	1.49	1.20	24.17
8	28.0	1.30	1.45	−10.34	1.56	1.27	22.83
Mean	60.9	1.18	1.44	−17.33	1.45	1.28	13.73
SD	37.1	0.08	0.11	9.03	0.12	0.06	10.28
p		<.01		.01			





S. Hossain et al. IJROBP.78(1), 2010



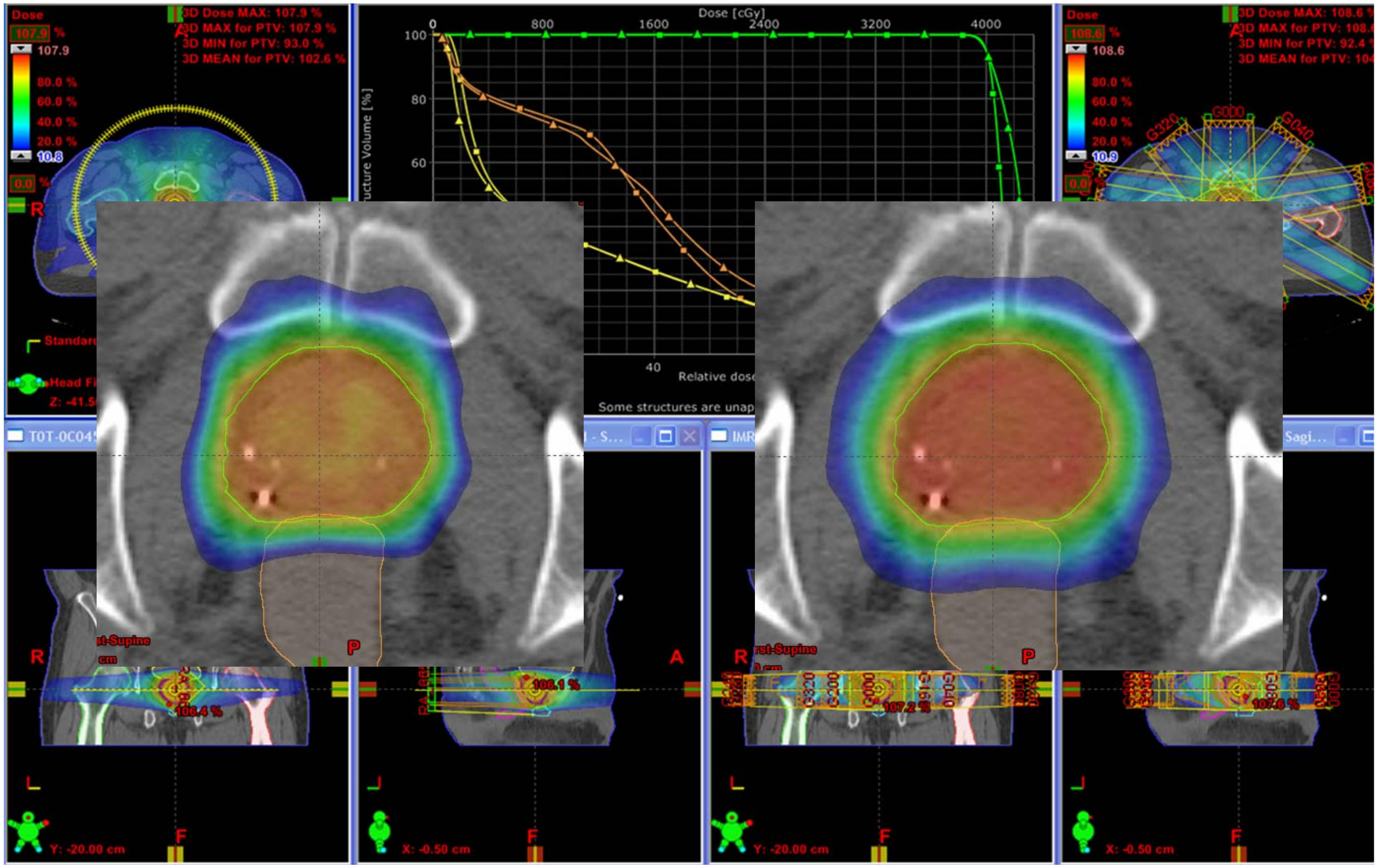
All beams:	Excluding direct beams:
10–30% isodose through testes	3% isodose skims testes
Testicular mean dose: approx. 6.6 Gy	Testicular mean dose: approx. 1.3 Gy

King. Front Radiat Ther Oncol. V43. 2011

Volumetric Modulated Arc for SBRT

- Volumetric arc modulated therapy that simultaneously changes:
  - Gantry rotation speed
  - Treatment aperture shape (MLC)
  - Delivery dose rate
- Improved conformity
- Fast plan delivery

Linac VMAT and IMRT plan



Beam parameter selection

- Prostate SBRT plans developed for different number of arcs collimator angels, beam energies and couch rotations for ten patients
  - Plans with ±45º collimator angles required 38% less MU with no collimator rotations and 20% less than ±22.5º
  - Plans with ±45º collimator angles provided more homogeneous dose distribution
  - Plans with two arcs provided improved conformity and homogeneity compared with single arc

Agazaryan N. et. al. ASTRO 2010

Beam parameter selection

- Increasing the number of arcs to 3 did not provide significant improvement
- ±5º couch rotations between arcs did not improve the plan dosimetry significantly
- Selection of beam energy between 6MV and 10MV did not show notable dosimetric difference

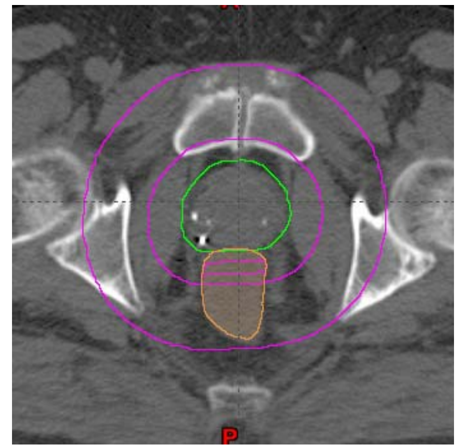
Agazaryan N. et. al. ASTRO 2010

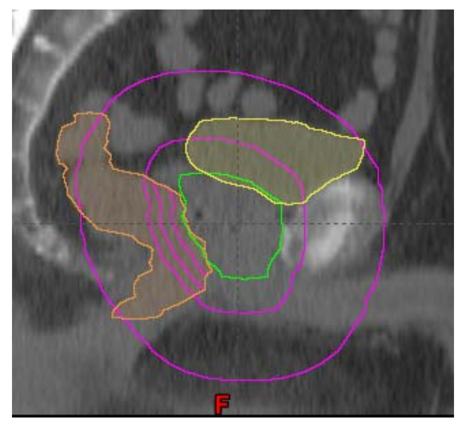
Current planning protocol

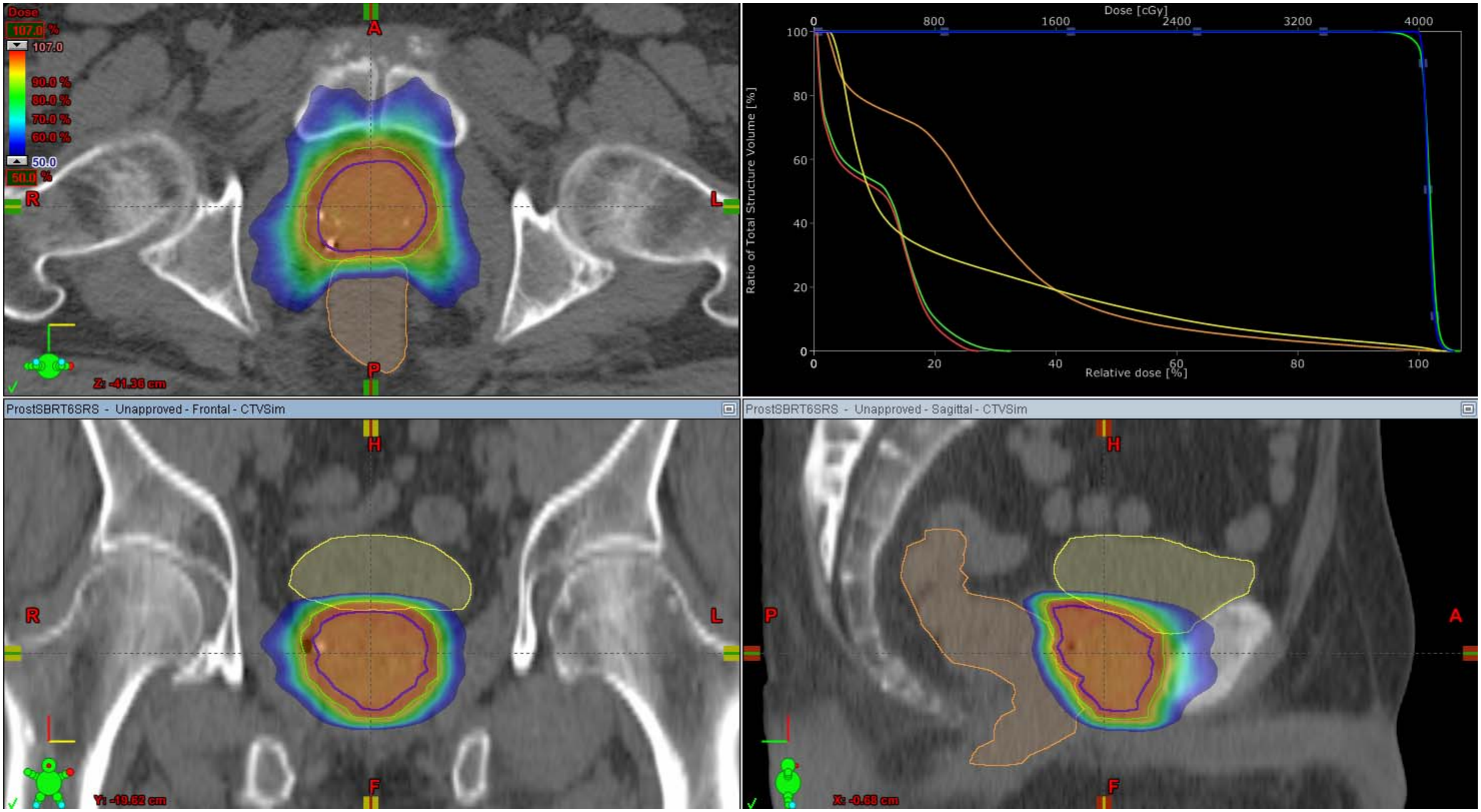
- Prescription: 8Gy x 5 fractions
- Beam energy: 6MV SRS (1000MU/Minute)
- Arc: 2 full arcs split to 4 half arcs
- Collimator rotation: $\pm 45^{\circ}$
- No couch rotation

Plan optimization

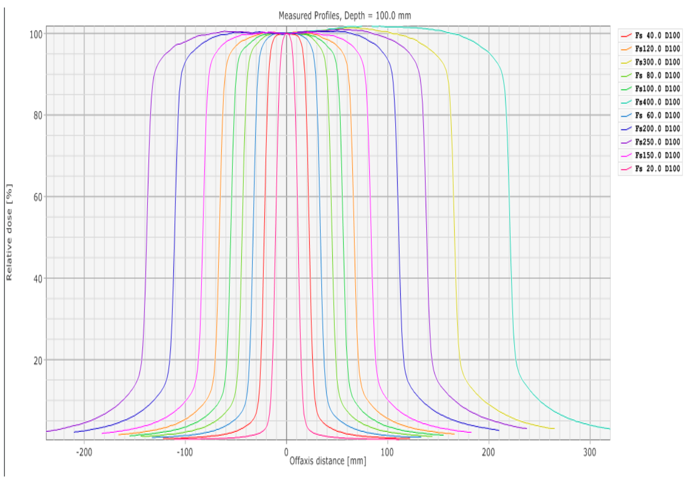
- Goals:
  - PTV:
    - V100≥95%   R50 < 4.0
  - Rectum:
    - V20Gy < 50%   V32Gy < 20%
    - V36Gy < 10%   V40Gy < 5%
  - Bladder:
    - V20Gy < 40%   V40Gy<10%
  - Femur header:
    - V16Gy < 5%

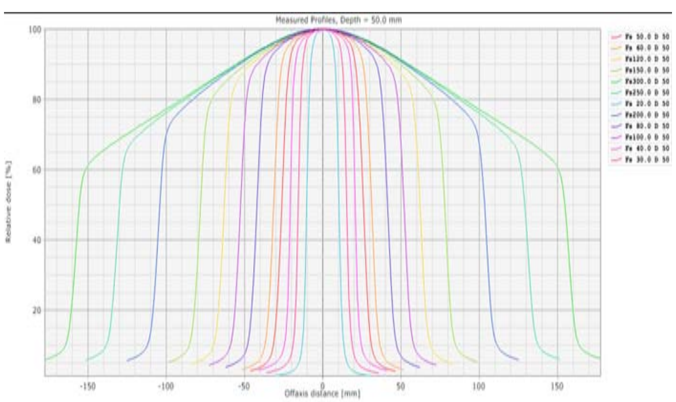


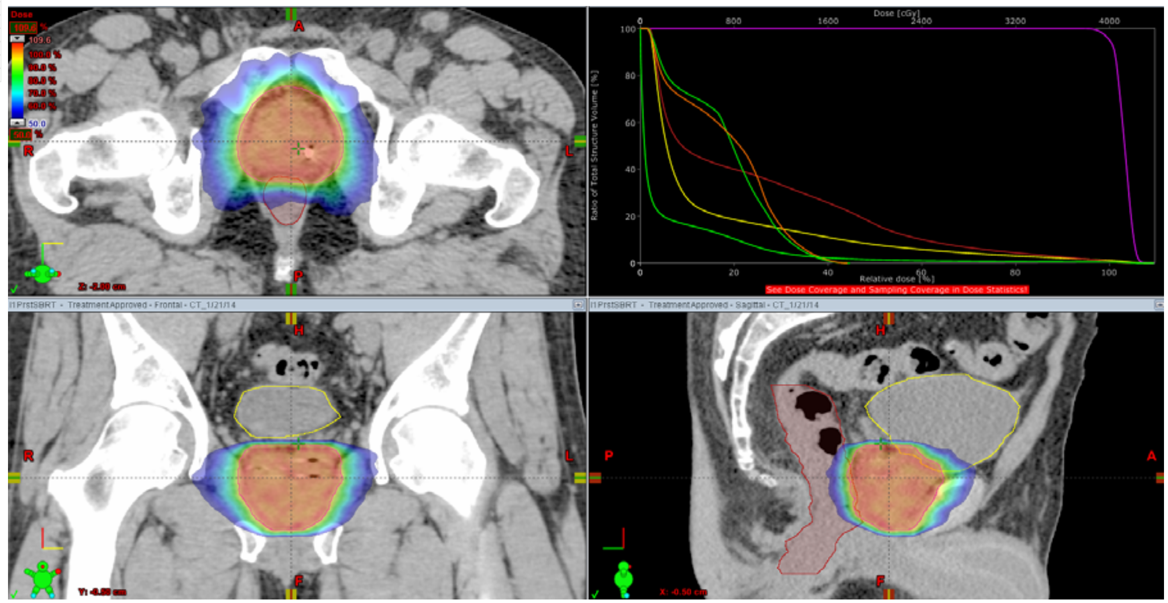



Dose
107.0 %
107.0
90.0 %
80.0 %
70.0 %
60.0 %
50.0
50.0 %
A
P
R
L
Z: -41.36 cm
Dose [cGy]
0
800
1600
2400
3200
4000
Ratio of Total Structure Volume [%]
100
80
60
40
20
0
Relative dose [%]
0
20
40
60
80
100
ProstSBRT6SRS - Unapproved - Frontal - CTVSim
H
F
R
L
Y: -10.62 cm
ProstSBRT6SRS - Unapproved - Sagittal - CTVSim
H
F
P
A
X: -0.68 cm

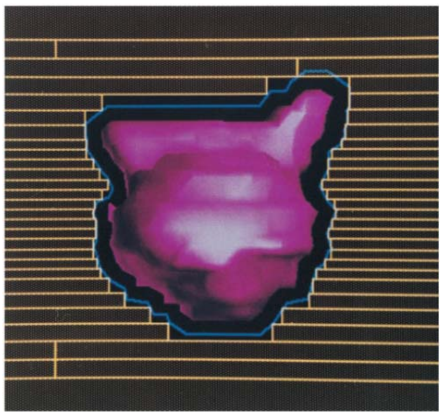
Flattering Filter Free (FFF)

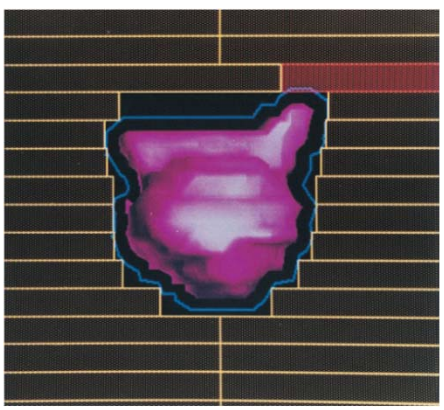


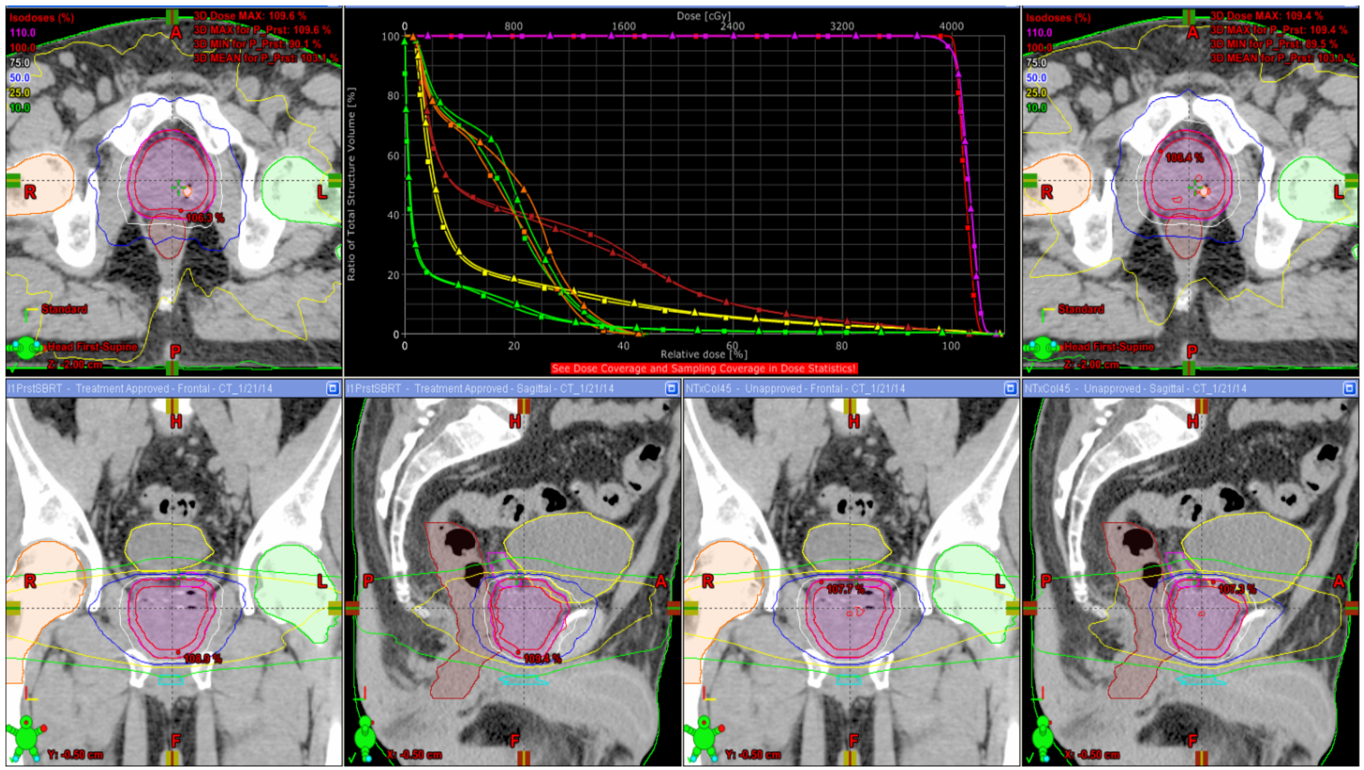




MLC Size







Standard MLC

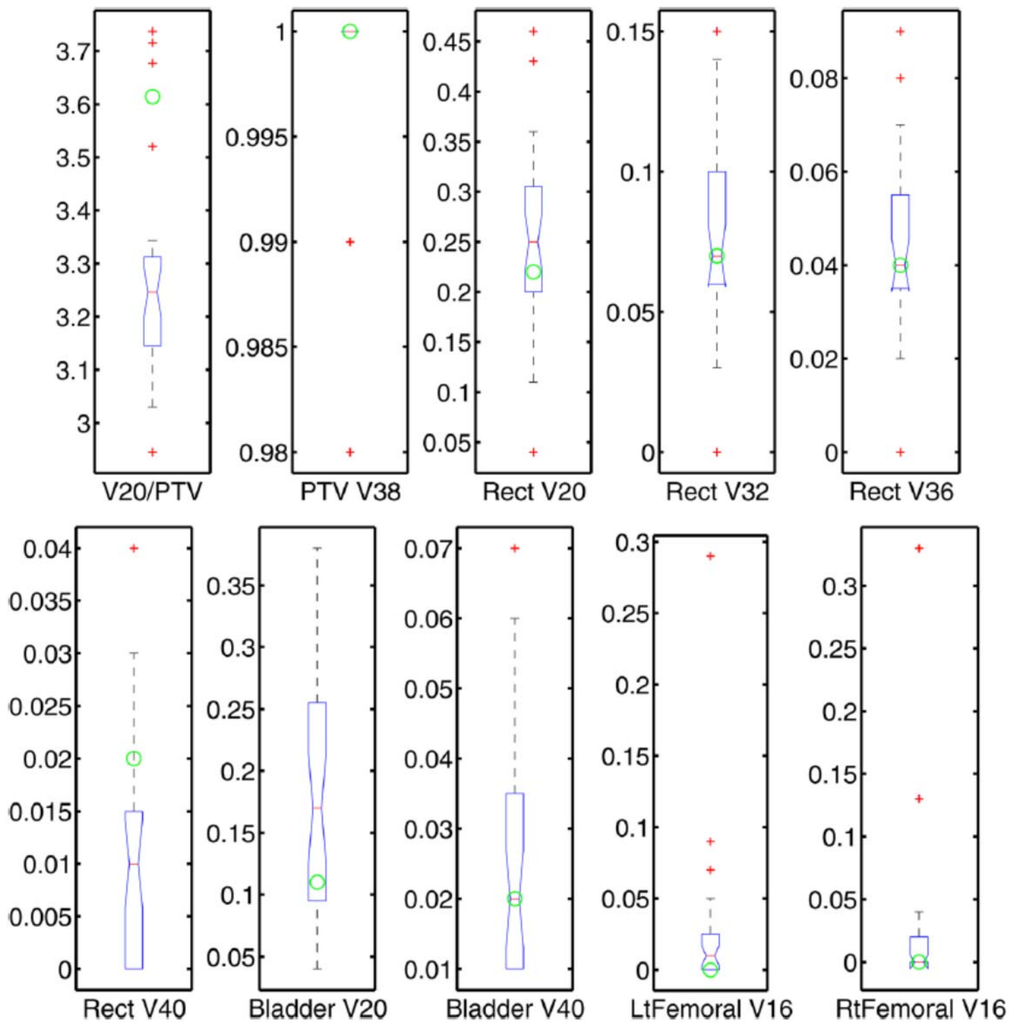
HD120 MLC

Plan evaluation – where you stand?

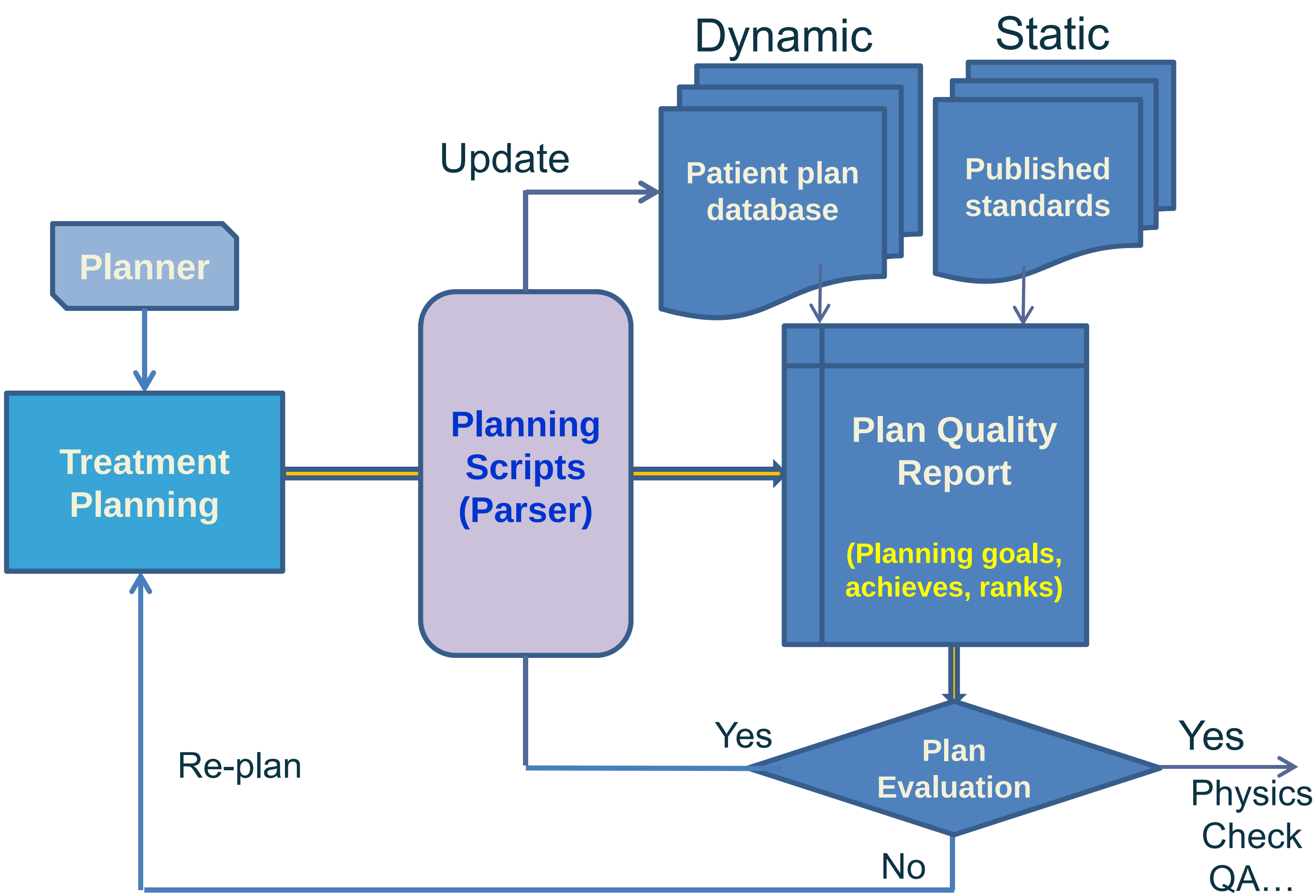
TABLE II. Plan quality statistics pre- and postincorporation of the new plan into the cohort of 32 existing plans.

	Stat. based on existing plans			Stat. upon new plan incorporation		
Clinical variable	25% quantile	Median	75% quantile	25% quantile	Median	75% quantile
PTV						
V38	100%	100%	100%	100%	100%	100%
V20/VPTV	3.15	3.25	3.3	3.15	3.25	3.3
Rectum						
V520	20%	25%	31%	20%	25%	30%
V32	6%	7%	10%	6%	7%	10%
V36	3.5%	4%	6%	3.8%	4%	5%
V40	0	1%	1.5%	0	1%	1.5%
Bladder						
V20	9.5%	17%	25.5%	9.8%	17%	25.5%
V40	1%	2%	3.5%	1%	2%	3.3%
Left femoral						
V16	0	1%	2.5%	0	1%	2.3%
Right femoral head						
V16	0	0	2%	0	0	2%

Ruan et. al. Medical Physics, Vol. 39(5), 2012



Ruan et. al. Medical Physics, Vol. 39(5), 2012



Cao et. al. AAPM 2013

Dosimetry Report Portal

Disease Site: ProstateSbrt
Sort By: Time Stamp of Entry
Sort Direction: Descending
Update

MRN	Patient Name	Disease Site	Plan Label	Presc. Dose	Study Date	Entry Time Stamp
[redacted]		ProstateSbrt	i1PrstSBRT	40	2014-05-09	2014-05-28 09:53:36
		rt	I1PrstSBRT	40	2014-05-09	2014-05-28 09:52:36
		rt	i1PrstSBRT	40	2014-04-21	2014-05-28 09:48:01
		rt	I1PrstSBRT	40	2014-03-26	2014-05-28 09:46:45
		rt	I1PrstSBRT	40	2014-03-26	2014-05-28 09:45:35
		rt	I1PrstSBRT	40	2014-03-24	2014-05-28 09:44:21
		rt	I1PrstSBRT	40	2014-03-19	2014-05-28 09:35:51
		rt	I1PrstSBRT	40	2014-03-18	2014-05-28 09:35:12
		rt	I1PrstSBRT	40	2014-03-17	2014-05-28 09:32:40
		rt	I1PrstSBRT	40	2014-03-14	2014-05-28 09:31:44
		rt	I1PrstSBRT	40	2014-03-12	2014-05-28 09:30:58
		rt	I1PrstSBRT	40	2014-02-28	2014-05-28 09:27:56
		rt	I1PrstSBRT	40	2014-02-11	2014-05-28 09:18:46
		rt	I1PrstSBRT	40	2014-02-10	2014-05-28 09:17:55
		rt	I1PrstSBRT	40	2014-02-07	2014-05-28 09:16:56
		rt	I1PrstSBRT	40	2014-01-31	2014-05-28 09:15:41
		rt	I1PrstSBRT	40	2014-01-30	2014-05-28 09:11:47

ProstateSbrt Plan Quality Report

MRN: [redacted] **Patient Name:** [redacted] **Plan Label:** i1PrstSBRT
Prsc. Dose: 40 Gy **Num. of Fractions:** 5 **Dose/Fraction:** 8 Gy
Study Date: 2014-05-09 **Entry Time Stamp:** 2014-05-28 09:53:36.310379

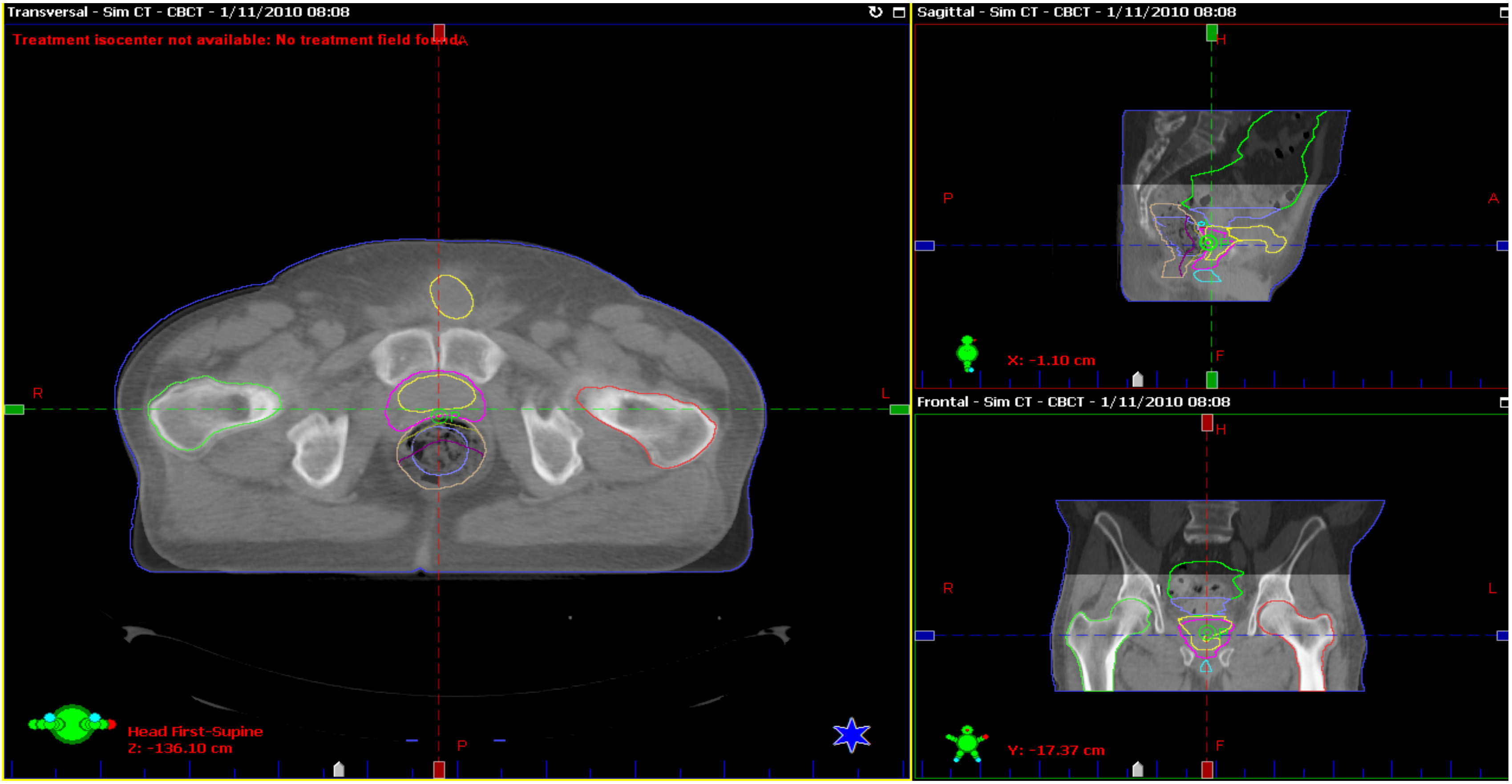
Structure	End Point	Ideal	Acceptable	Output	Mean	StdDev	25 Pctl	Median	75 Pctl	Suggestion	Distribution
P_Prst	V100%		≥ 95 %	**95.13** %	95.12 %	0.20 %	95.00 %	95.14 %	95.28 %	Acceptable	
P_Prst	V50%/Vol		≤ 4	**3.50**	3.37	0.13	3.28	3.35	3.43	Acceptable	
O_Rctm	V50%		≤ 50 %	**20.98** %	20.89 %	5.78 %	17.80 %	20.24 %	24.29 %	Acceptable	
O_Rctm	V80%		≤ 20 %	**8.96** %	6.67 %	2.65 %	4.78 %	5.56 %	8.96 %	Acceptable	
O_Rctm	V90%		≤ 10 %	**5.73** %	4.09 %	1.92 %	2.58 %	3.23 %	5.73 %	Acceptable	
O_Rctm	V100%		≤ 5 %	**2.23** %	1.37 %	1.02 %	0.65 %	0.86 %	2.23 %	Acceptable	
O_Bldr	V50%		≤ 40 %	**19.52** %	14.87 %	8.81 %	8.69 %	14.35 %	17.11 %	Acceptable	
O_Bldr	V100%		≤ 10 %	**2.99** %	3.06 %	1.98 %	1.78 %	2.59 %	3.23 %	Acceptable	
O_Femr_Lt	V40%		≤ 5 %	**0.26** %	0.52 %	0.94 %	0.00 %	0.00 %	0.52 %	Acceptable	
O_Femr_Rt	V40%		≤ 5 %	**0.63** %	1.53 %	3.89 %	0.00 %	0.00 %	0.31 %	Acceptable	

Export to PDF | Return to Repository Home | Remove Case Report

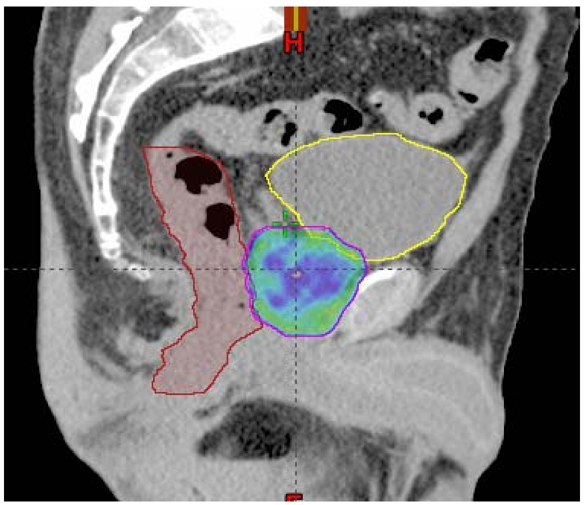
Patient Treatment Setup and Verification

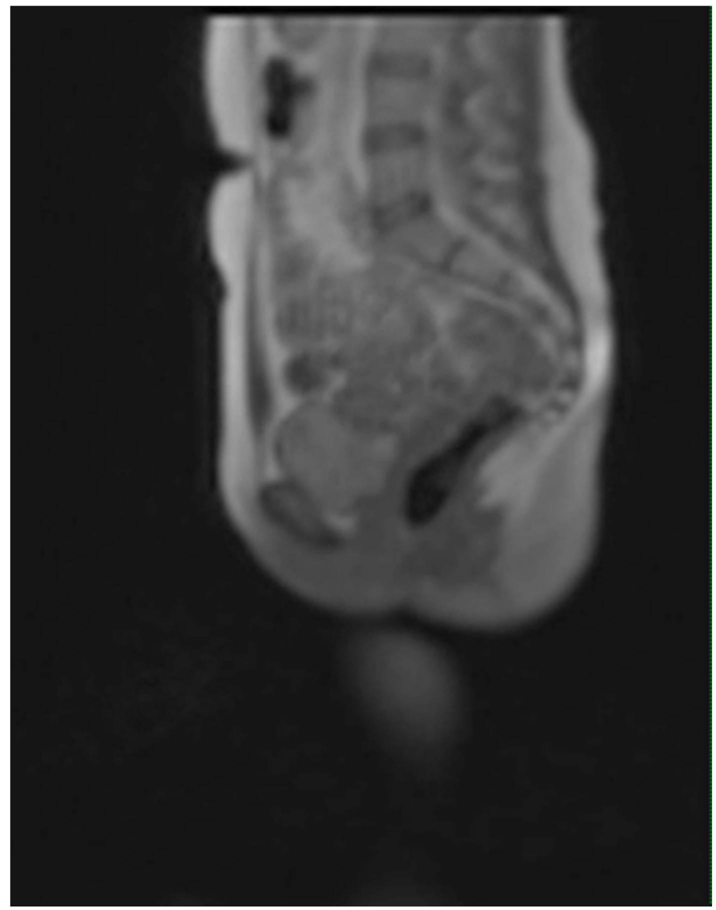
- Patient inter-fractional positioning correction:
  - 2D image pairs (OBI, ExacTrac …)
  - 3D volumetric image (CBCT)
- Patient intra-fractional motion tracking:
  - Electromagnetic tracking (Calypso)
  - Stereoscopic imaging (ExacTrac)


ExacTrac 5.5.2 Copyright ©2008 BrainLAB AG
File Options Advanced Settings Info Test Modules
Replay: Fusion & Shift Detection
Calibrate
Open Patient
Select Isocenter
Positioning
X-ray Correction
Video
Gating
Manual Tilt
Exit
M1
M2
M3
Overlay Mode
X-Ray
DRR
Add
Amber/Blue
Subtract
Spyglass
Shift
Vertical 5.06 0.07 °
Longitudinal -0.15 -0.27 °
Lateral -0.62 -2.83 °
Marker Detection
Automatic
Fusion
Reset Fusion
Marker
1 / 3
Delete
Define
Shift pattern
Reset
Please detect and fuse implanted markers.
Bony
Implants
Patient Settings
< Back
Next >
Cancel
Loading case done.


Transversal - Sim CT - CBCT - 1/11/2010 08:08
Treatment isocenter not available: No treatment field found
A
R
L
P
Head First-Supine
Z: -136.10 cm
Sagittal - Sim CT - CBCT - 1/11/2010 08:08
H
P
A
F
X: -1.10 cm
Frontal - Sim CT - CBCT - 1/11/2010 08:08
H
R
L
F
Y: -17.37 cm

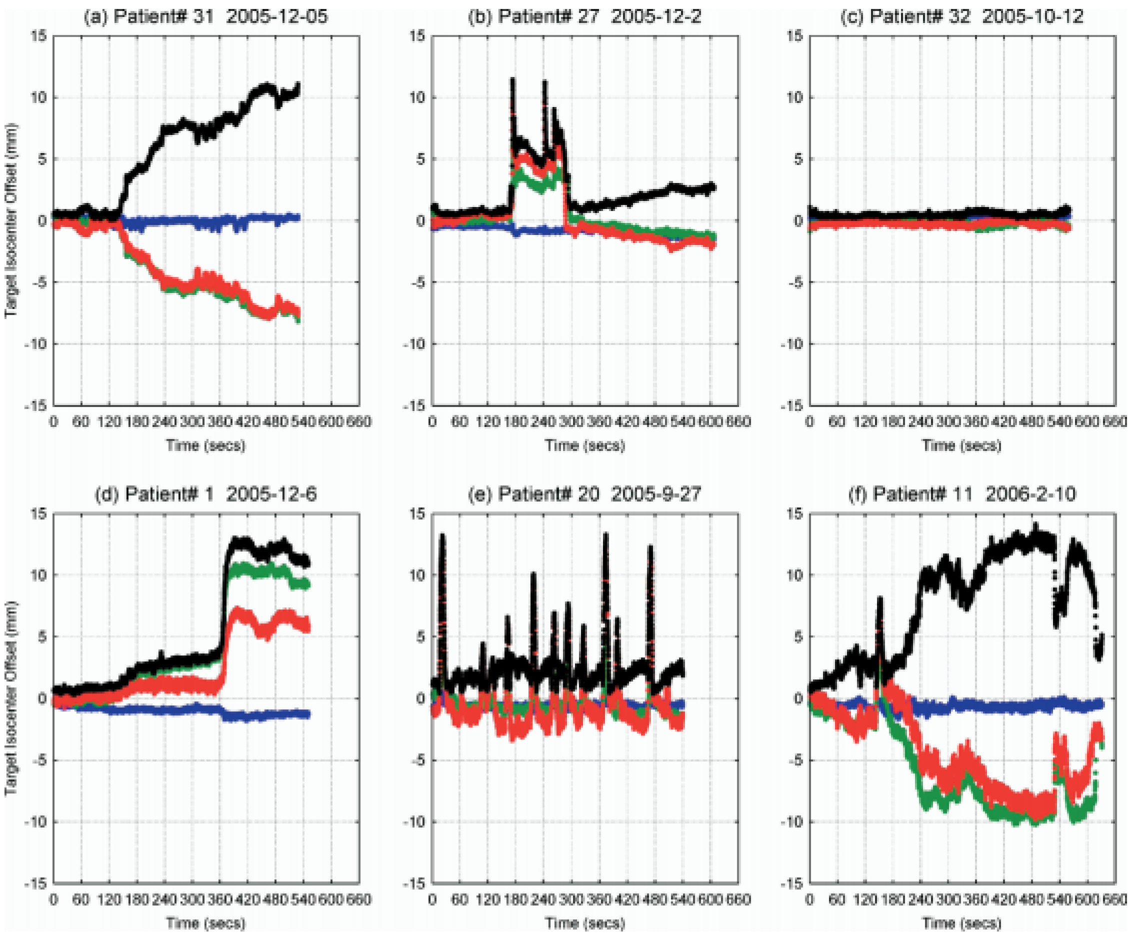
Prostate moves!



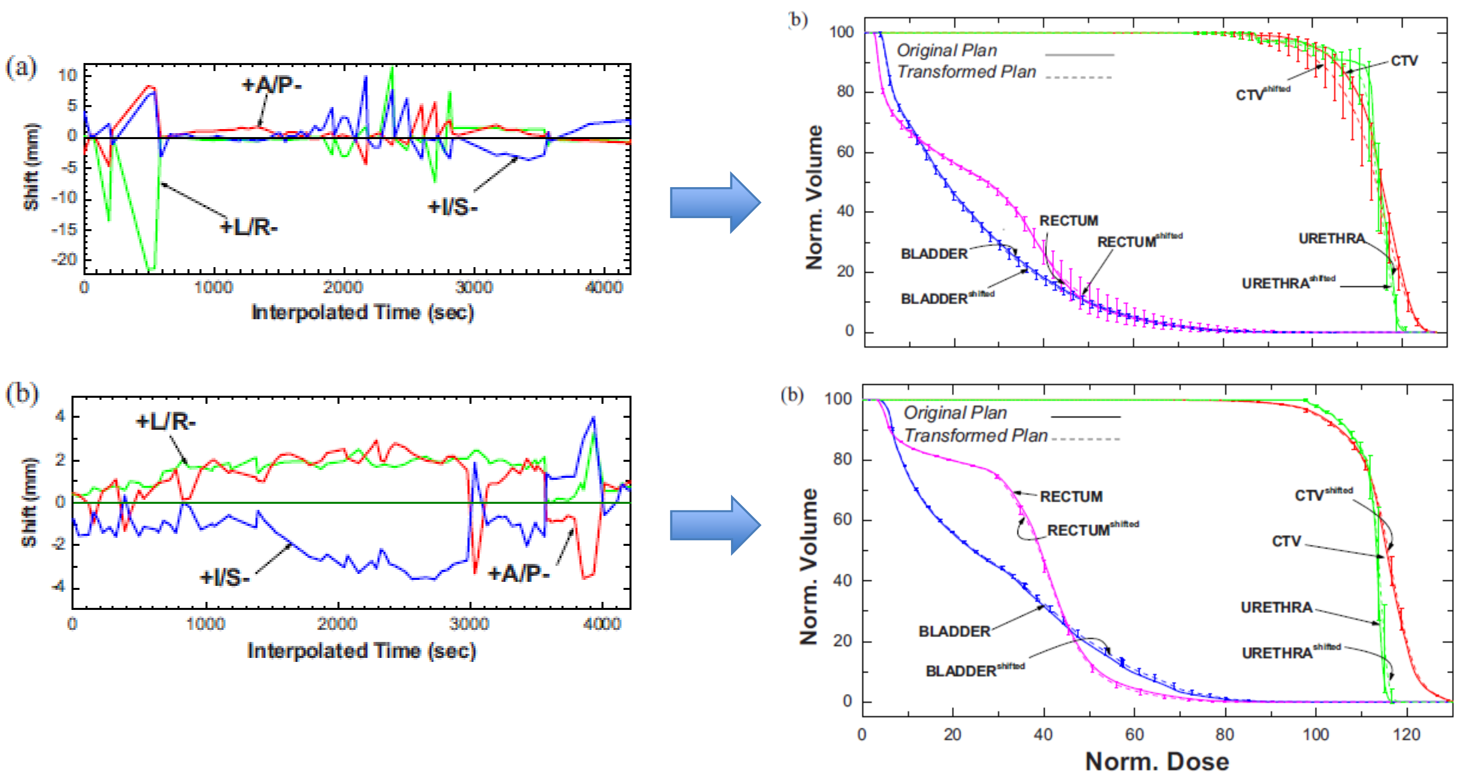


Courtesy of ViewRay®

Intra-fractional motion

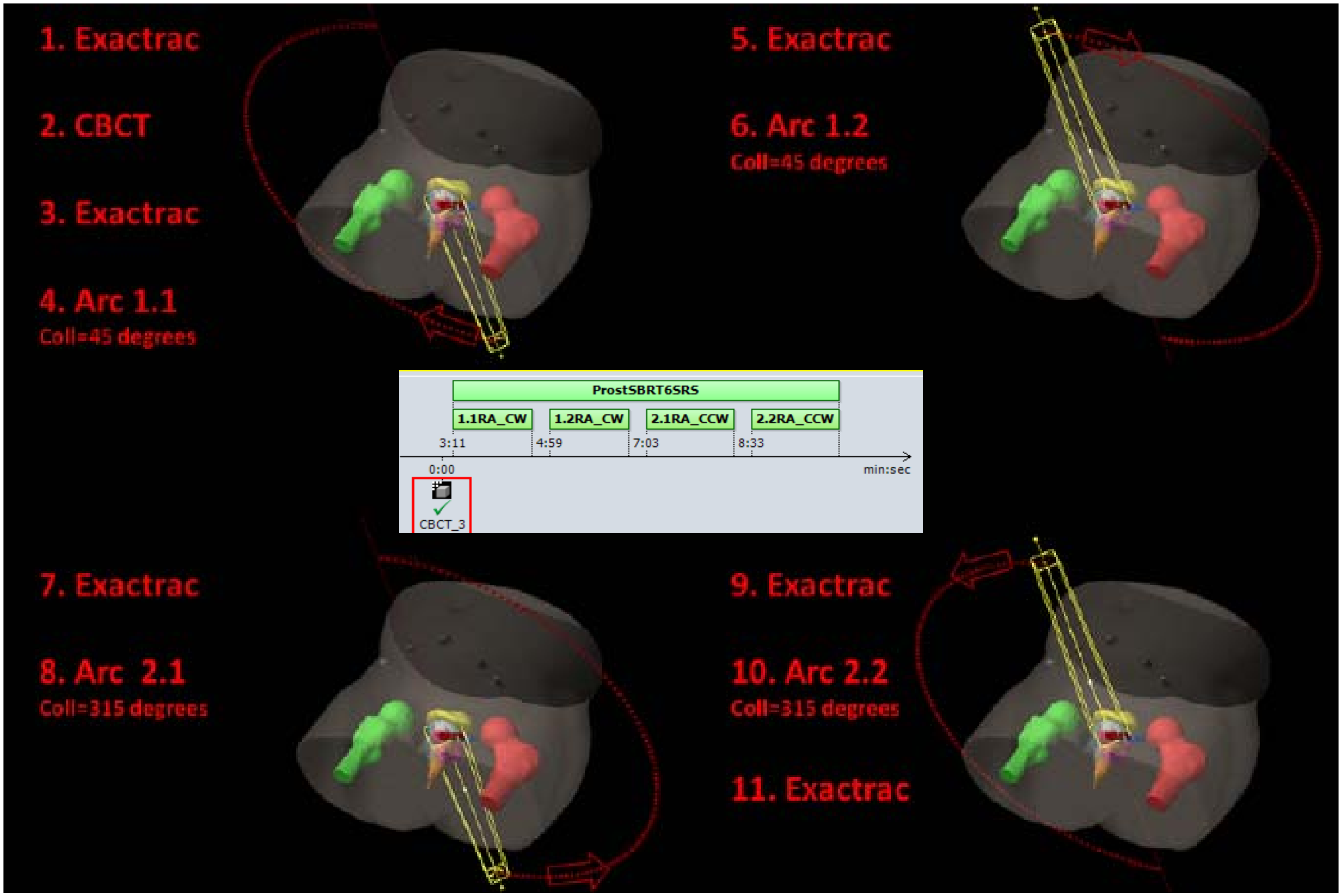


Kupelian, IJROBP, 67: 1088-1098, 2007



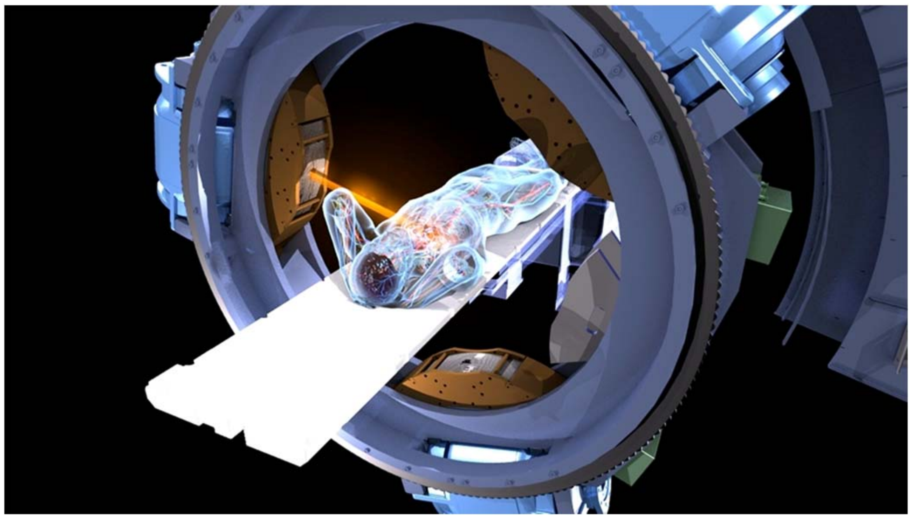
"If large movements (>5mm) could be excluded by some active correction strategies, then the average V100% for the simulated plan could be restored to within approximately 2% of the ideal treatment plans."

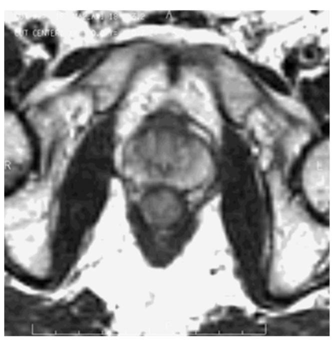
Hossain *et al.*, Med. Phys. 35 (9), 2008

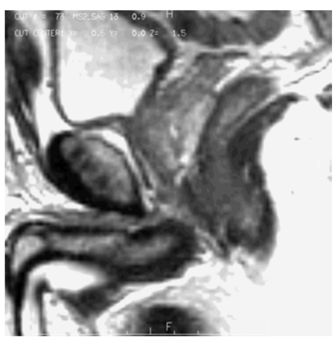


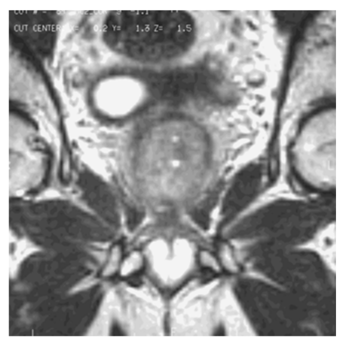
Agazaryan N. et. al. ASTRO 2010

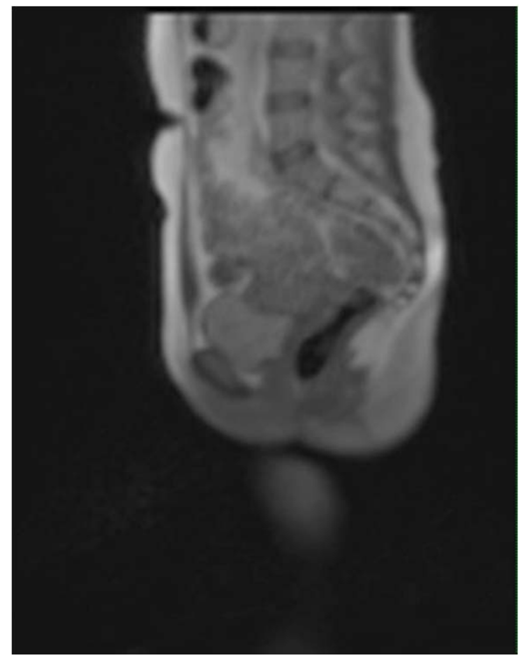
MRI guided radiotherapy











Courtesy of ViewRay®

References

1. Alongi, F., et al., Linac based SBRT for prostate cancer in 5 fractions with VMAT and flattening filter free beams: preliminary report of a phase II study. Radiat Oncol, 2013. 8(1): p. 171.
2. Benedict, S.H., et al., Stereotactic body radiation therapy: the report of AAPM Task Group 101. Med Phys, 2010. 37(8): p. 4078-101.
3. Buyyounouski, M.K., et al., Stereotactic body radiotherapy for primary management of early-stage, low- to intermediate-risk prostate cancer: report of the American Society for Therapeutic Radiology and Oncology Emerging Technology Committee. Int J Radiat Oncol Biol Phys, 2010. 76(5): p. 1297-304.
4. Chen, L.N., et al., Stereotactic body radiation therapy (SBRT) for clinically localized prostate cancer: the Georgetown University experience. Radiat Oncol, 2013. 8: p. 58.
5. Descovich, M., et al., Improving plan quality and consistency by standardization of dose constraints in prostate cancer patients treated with CyberKnife. J Appl Clin Med Phys, 2013. 14(5): p. 162-72.
6. Fuller, D.B., et al., Virtual HDR CyberKnife treatment for localized prostatic carcinoma: dosimetry comparison with HDR brachytherapy and preliminary clinical observations. Int J Radiat Oncol Biol Phys, 2008. 70(5): p. 1588-97.
7. Hossain, S., et al., Simulated real time image guided intrafraction tracking-delivery for hypofractionated prostate IMRT. Med Phys, 2008. 35(9): p. 4041-8.
8. Hossain, S., et al., Dose gradient near target-normal structure interface for nonisocentric CyberKnife and isocentric intensity-modulated body radiotherapy for prostate cancer. Int J Radiat Oncol Biol Phys, 2010. 78(1): p. 58-63.

References

9. Jones, B.L., et al., Effect of endorectal balloon positioning errors on target deformation and dosimetric quality during prostate SBRT. Phys Med Biol, 2013. 58(22): p. 7995-8006.
10. King, C., Stereotactic body radiotherapy for prostate cancer: current results of a phase II trial. Front Radiat Ther Oncol, 2011. 43: p. 428-37.
11. King, C.R., et al., Long-term outcomes from a prospective trial of stereotactic body radiotherapy for low-risk prostate cancer. Int J Radiat Oncol Biol Phys, 2012. 82(2): p. 877-82.
12. King, C.R., et al., Stereotactic body radiotherapy for localized prostate cancer: pooled analysis from a multi-institutional consortium of prospective phase II trials. Radiother Oncol, 2013. 109(2): p. 217-21.
13. Kupelian, P., et al., Multi-institutional clinical experience with the Calypso System in localization and continuous, real-time monitoring of the prostate gland during external radiotherapy. Int J Radiat Oncol Biol Phys, 2007. 67(4): p. 1088-98.
14. Pawlicki, T., et al., Investigation of linac-based image-guided hypofractionated prostate radiotherapy. Med Dosim, 2007. 32(2): p. 71-9.
15. Ruan, D., et al., Evolving treatment plan quality criteria from institution-specific experience. Med Phys, 2012. 39(5): p. 2708-12.
16. Udrescu, C., et al., Potential interest of developing an integrated boost dose escalation for stereotactic irradiation of primary prostate cancer. Phys Med, 2014. 30(3): p. 320-5.

Summary | Conclusion

- Hypofractionation has the potential to biologically dose-escalate radiotherapy for prostate cancer.
- Establishing SBRT procedures and guidelines from CT simulation to treatment planning, verification, delivery, and reporting methodology is essential to the success of the implementation of prostate SBRT treatment
- Personal training is another important aspect of implementation of a SBRT prostate program

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