ORACLE: A DVH-based inverse planning system for LDR prostate brachytherapy using MC dosimetry *(Abstract Id: 141)*

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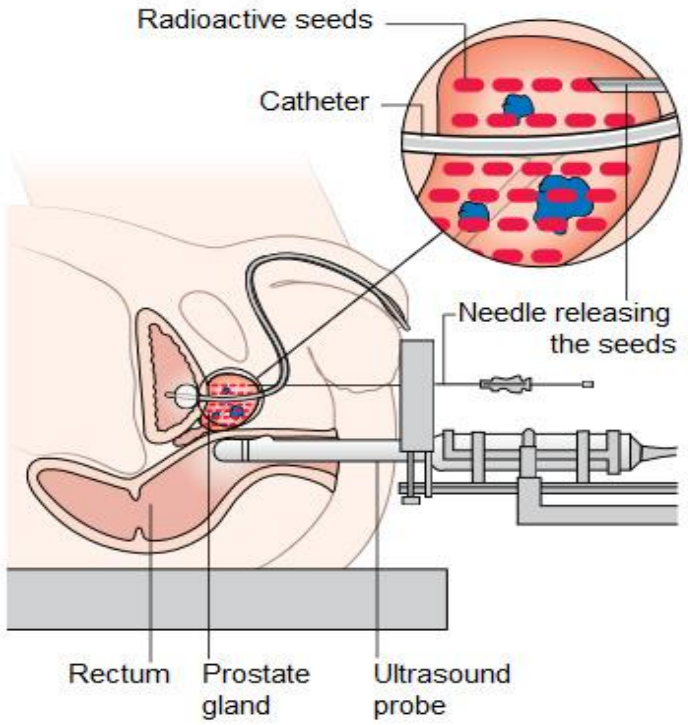
Prostate Brachytherapy[1]

- Minimally invasive
- Confined dose to the prostate
- Reduced dose at organs at risk

HDR - LDR



[1] Ragde, H., et al. 2000. *A cancer journal for clinicians*

LDR Inverse Planning State-of-the-art

Objective

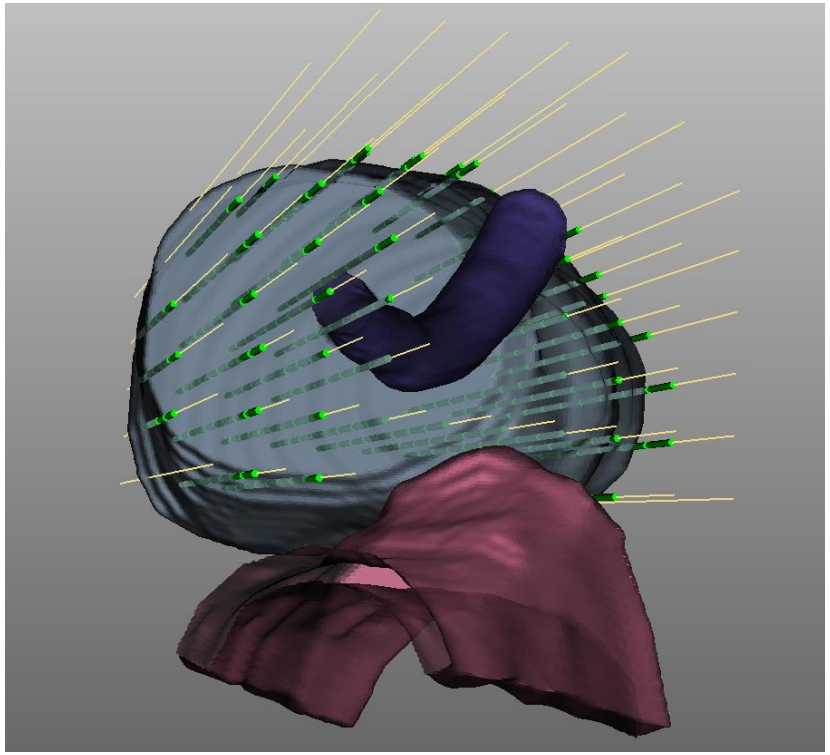
Determine the ***optimal*** seeds' locations out of a pool of possible candidates

Optimization problem

Given Cost Function (CF) f,
minimize $f(d_i)$ *over* $\{d_i \mid i$: *seeds' configuration*$\}$
i.e. find $\mathbf{d_0} \in \{d_i \mid i$:*seeds' configuration*$\}$ *s.t.* $f(d_0) \leq f(d_i), \ \forall i$

Optimization method

Fast Simulated Annealing (FSA)[2]
Dose distribution (***Di***) calculated using AAPM TG-43[3]



Candidate seeds positions

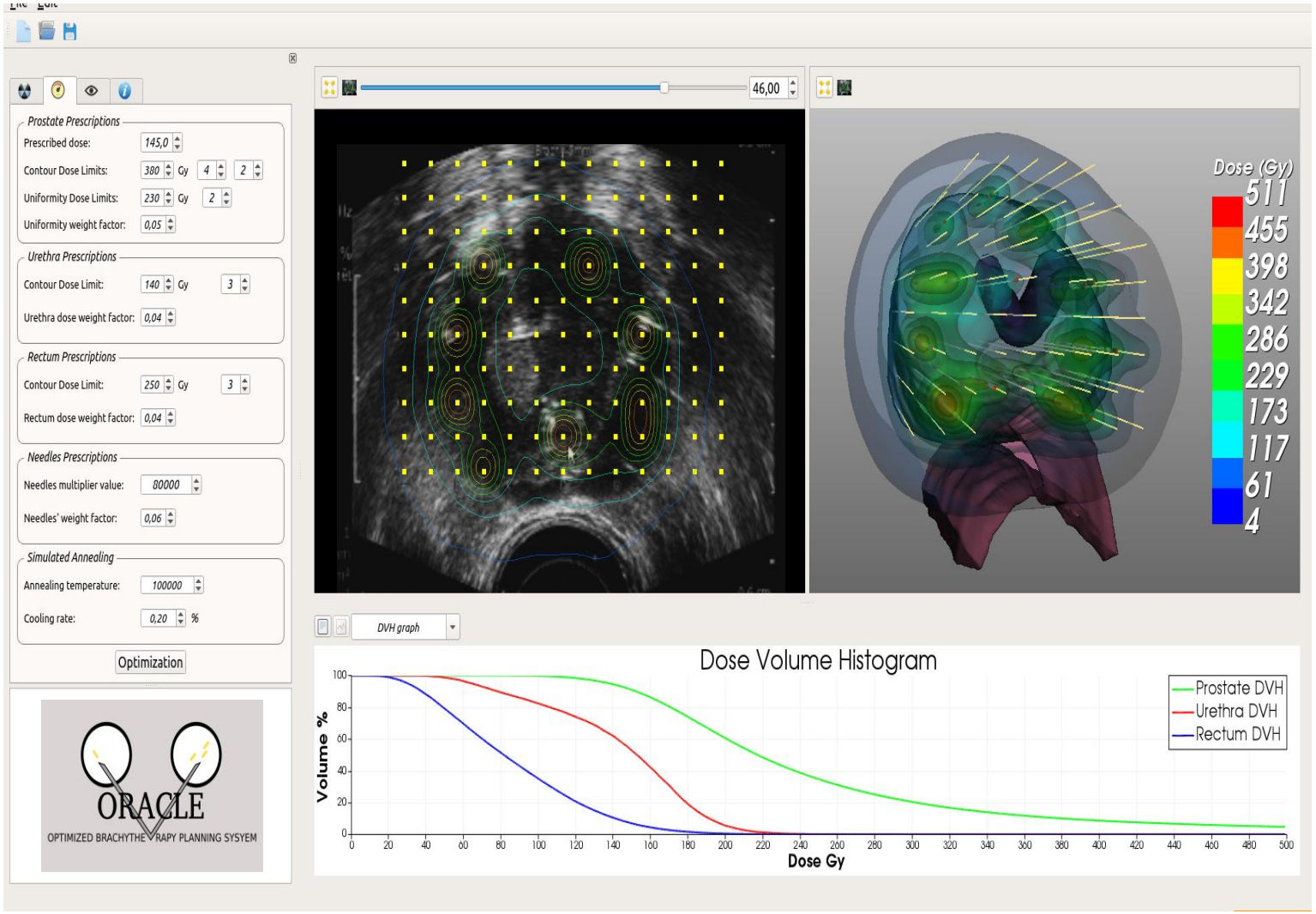
Optimality is compromised by the TG-43

[2] Pouliot, J., et al. 1996. *International Journal of Radiation Oncology * Biology * Physics*
[3] Nath, R., et al. 1995. *Medical physics*

ORACLE (Optimized brachytherapy planning system)

- Optimization using DVH-based FSA (improving state-of-the-art)

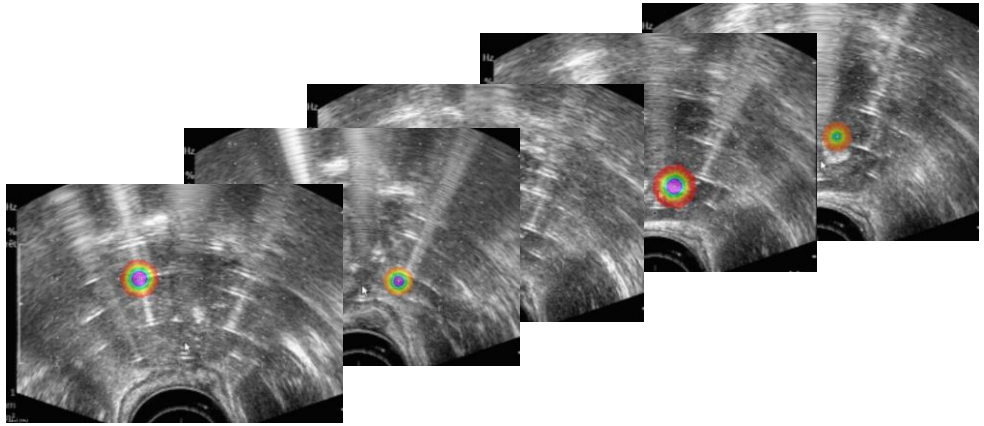
- GPU Monte Carlo dosimetry (GGEMS platform)[4-6]



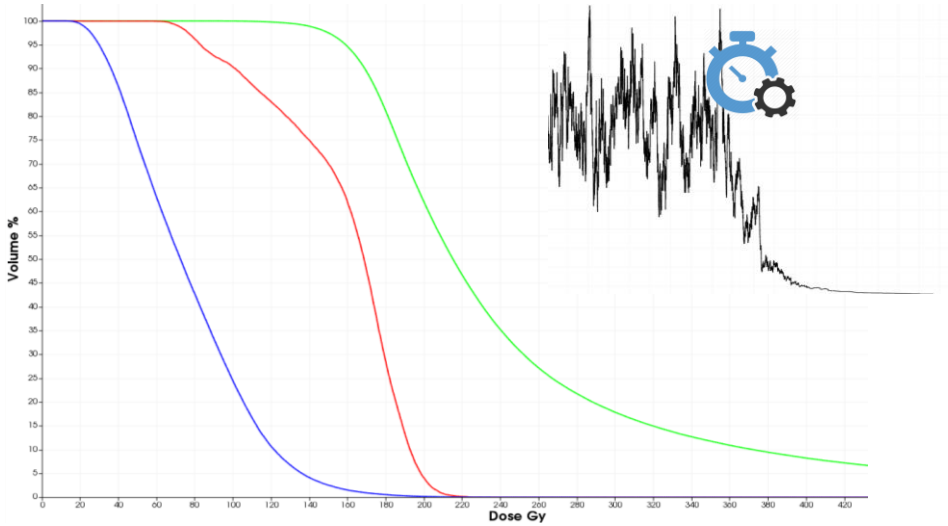
[4] Bert et al. 2016, IEEE NSS-MIC
[5] Lemaréchal et al. 2015, Phys. Med. Biol.
[6] Bert et al. 2013, Phys. Med. Biol.

ORACLE key concepts

Single-seed MC dose map pre-calculation

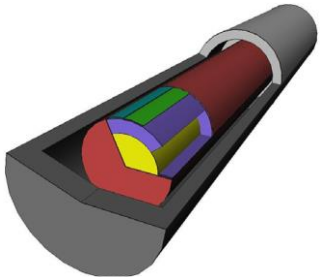


DVH-based FSA optimization

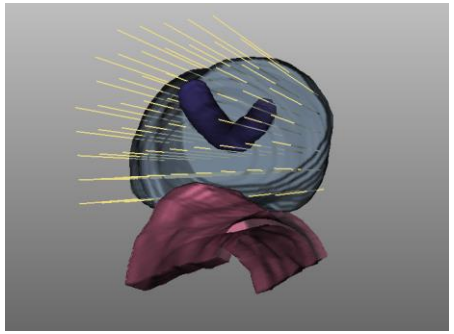


Single-seed MC dose map pre-calculation

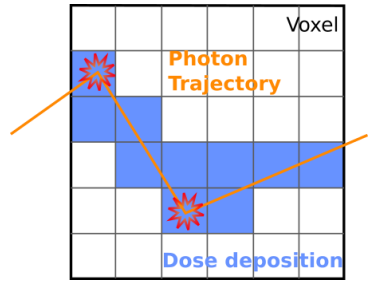
STM1251 seed phasespace



Heterogeneous computational phantom[7-9]



Track Length Estimator (TLE)



Dosimetry
Precise & Intraoperative

Total dose map

5×10^6 *particles* → mean statistical uncertainty = ***2.29 ± (0.15)%***

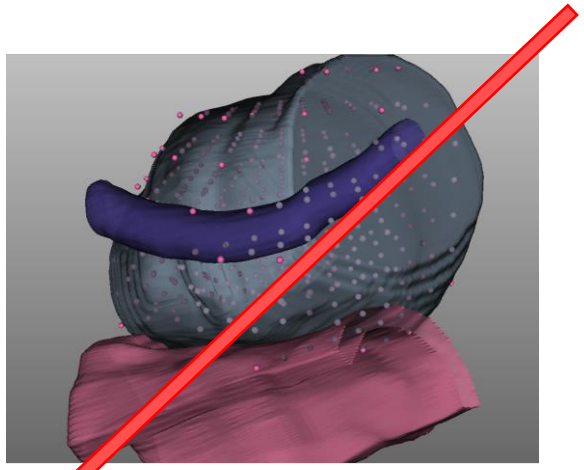
Single-seed dose map

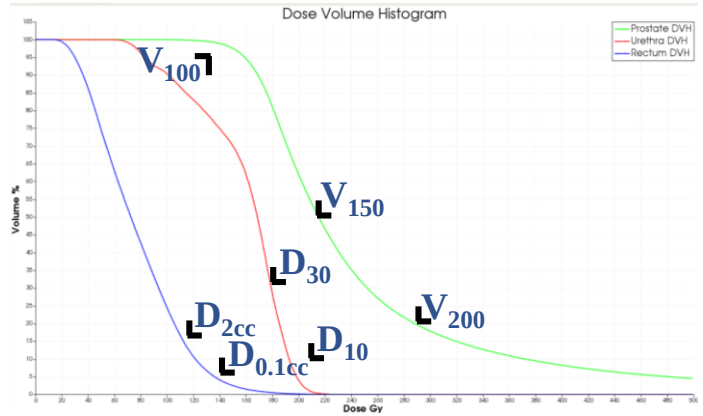
$\frac{5 \times 10^6}{N_{seeds}}$ *particles* → computational time ∝ ***100 ms***

e.g. N_{seeds}=*60*: 400-600 single-seed dose maps → **15-20 s** on NVIDIA GTX Titan X

[7] Bealieu, L., et al, 2012. *Medical Physics*
[8] Bethesda, MD., 1992. *ICRU report 46*
[9] Valentin, J., 2002. *Annals of the ICRP*

DVH-based FSA optimization





Direct optimization of $\mathbf{V_i}$, $\mathbf{D_j}$ metrics (*specified by AAPM TG-137*)

$$CF = w\Theta\left(V_{100_{LB}} - \boldsymbol{V_{100}}\right)\cdot\left(V_{100_{LB}} - \boldsymbol{V_{100}}\right) + \sum^{i} w\Theta\left(\boldsymbol{V_i} - V_{i_{HB}}\right)\cdot\left(\boldsymbol{V_i} - V_{i_{HB}}\right) + \sum^{j} w\Theta\left(\boldsymbol{D_j} - D_{j_{HB}}\right)\cdot\left(\boldsymbol{D_j} - D_{j_{HB}}\right) + w\boldsymbol{N_{needles}}$$

$\boldsymbol{i}$ = {150, 200}

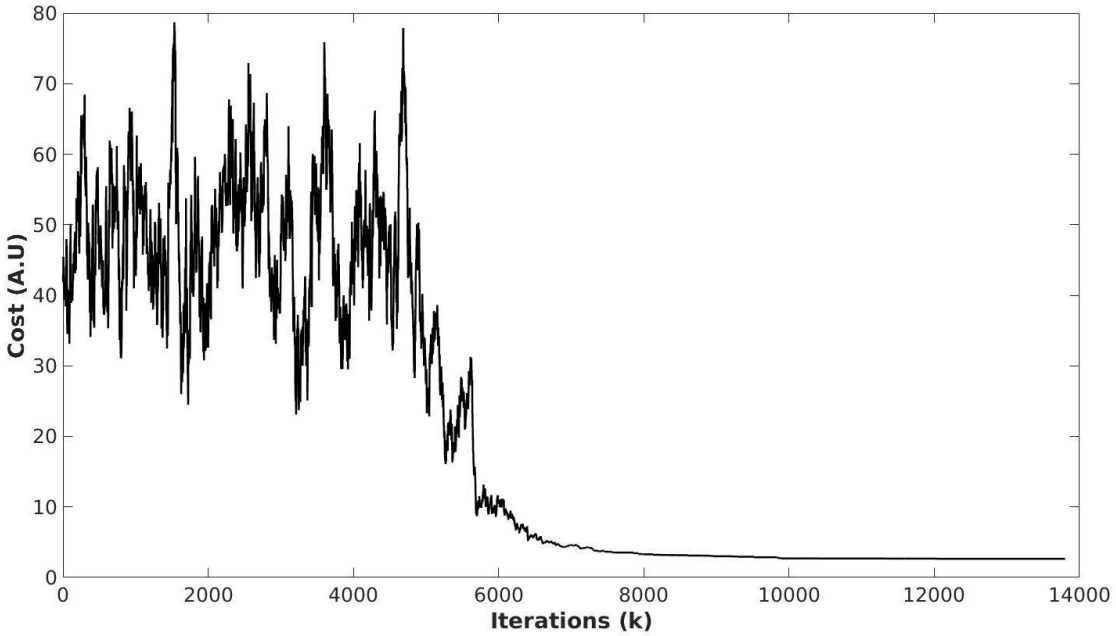
$\boldsymbol{j}$ = {10, 30, 2cc, 0.1cc}

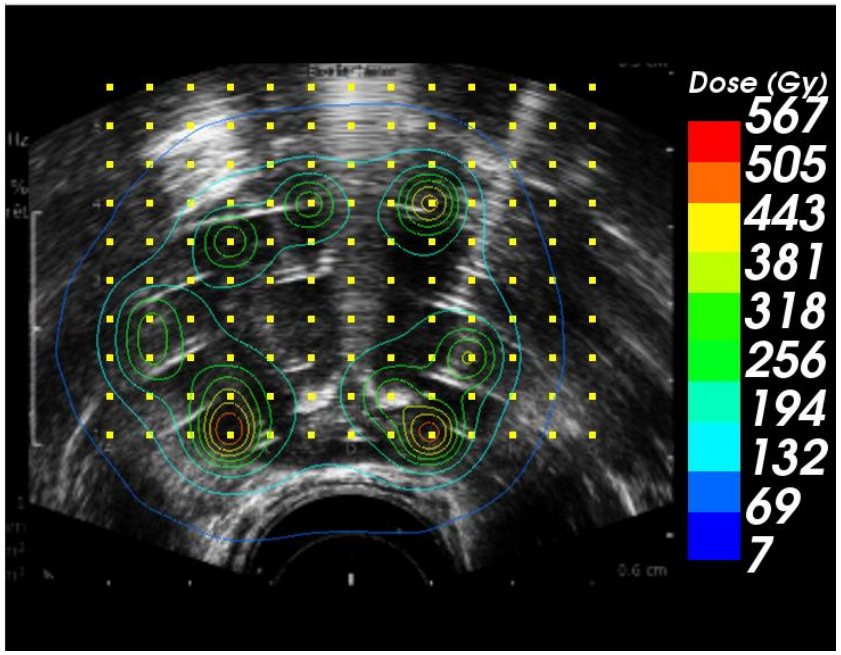
DVH-based FSA optimization

- Annealing schedule → $T(k) = T(k-1) \times (1 - CR)$

T: Annealing temperature, T(0) = 10^5 degrees
CR: Cooling Rate, CR = 0.2%

CF minimization after 13802 iterations → **15 s**





Planning quality evaluation with **AAPM TG-137** recommendations

Comparison with clinical plans (Database: **18** patients)

Organ	Metric	TG-137
Prostate	V_{100} (%)	>95
	V_{150}(%)	≤50
	V_{200}(%)	≤20
	D_{90} (Gy)	≥145.0
Urethra	D_{10} (Gy)	<217.5
	D_{30} (Gy)	<188.5
Rectum	D_{2cc} (Gy)	<145.0
	$D_{0.1cc}$ (Gy)	<217.5

Planning quality evaluation with **AAPM TG-137** recommendations

Comparison with clinical plans (Database: **18** patients)

Organ	Metric	TG-137	Clinical
Prostate	V_{100} (%)	>95	96.8 ± 1.5
	V_{150}(%)	≤50	49.0 ± 4.0
	V_{200}(%)	≤20	20.7 ± 2.2
	D_{90} (Gy)	≥145.0	161.6 ± 4.9
Urethra	D_{10} (Gy)	<217.5	184.6 ± 8.5
	D_{30} (Gy)	<188.5	171.3 ± 4.5
Rectum	D_{2cc} (Gy)	<145.0	109.4 ± 10.3
	$D_{0.1cc}$ (Gy)	<217.5	156.6 ± 14.8
Seeds			64 ± 7
Needles			18 ± 2

Planning quality evaluation with **AAPM TG-137** recommendations

Comparison with clinical plans (Database: **18** patients)

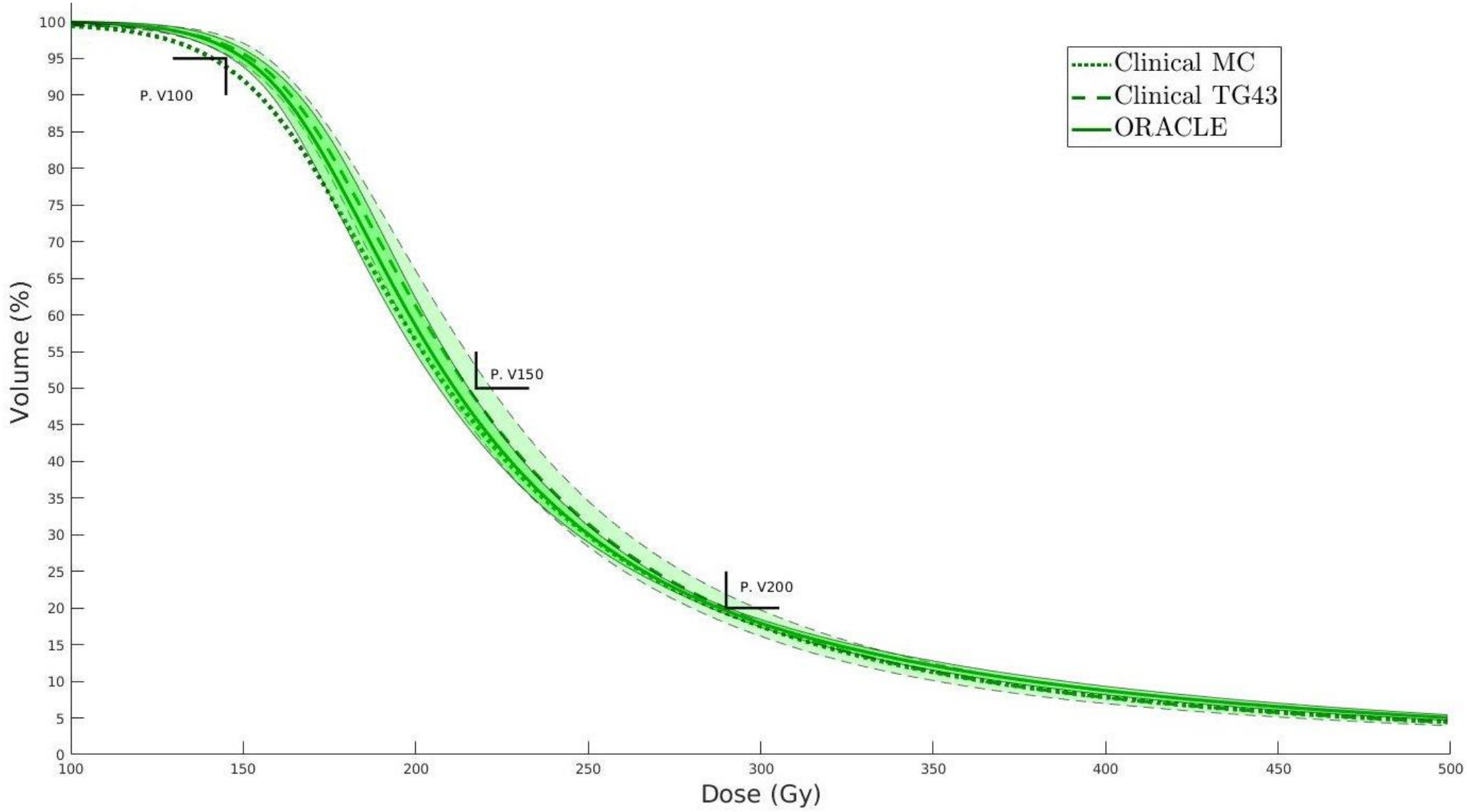
Organ	Metric	TG-137	Clinical	Clinical - MC
Prostate	V_{100} (%)	>95	96.8 ± 1.5	94.7 ± 2.3
	V_{150}(%)	≤50	49.0 ± 4.0	44.8 ± 4.8
	V_{200}(%)	≤20	20.7 ± 2.2	18.7 ± 2.5
	D_{90} (Gy)	≥145.0	161.6 ± 4.9	156.7 ± 6.4
Urethra	D_{10} (Gy)	<217.5	184.6 ± 8.5	172.7 ± 8.9
	D_{30} (Gy)	<188.5	171.3 ± 4.5	159.7 ± 5.7
Rectum	D_{2cc} (Gy)	<145.0	109.4 ± 10.3	108.1 ± 10.9
	$D_{0.1cc}$ (Gy)	<217.5	156.6 ± 14.8	153.6 ± 15.7
Seeds			64 ± 7	
Needles			18 ± 2	

Planning quality evaluation with **AAPM TG-137** recommendations

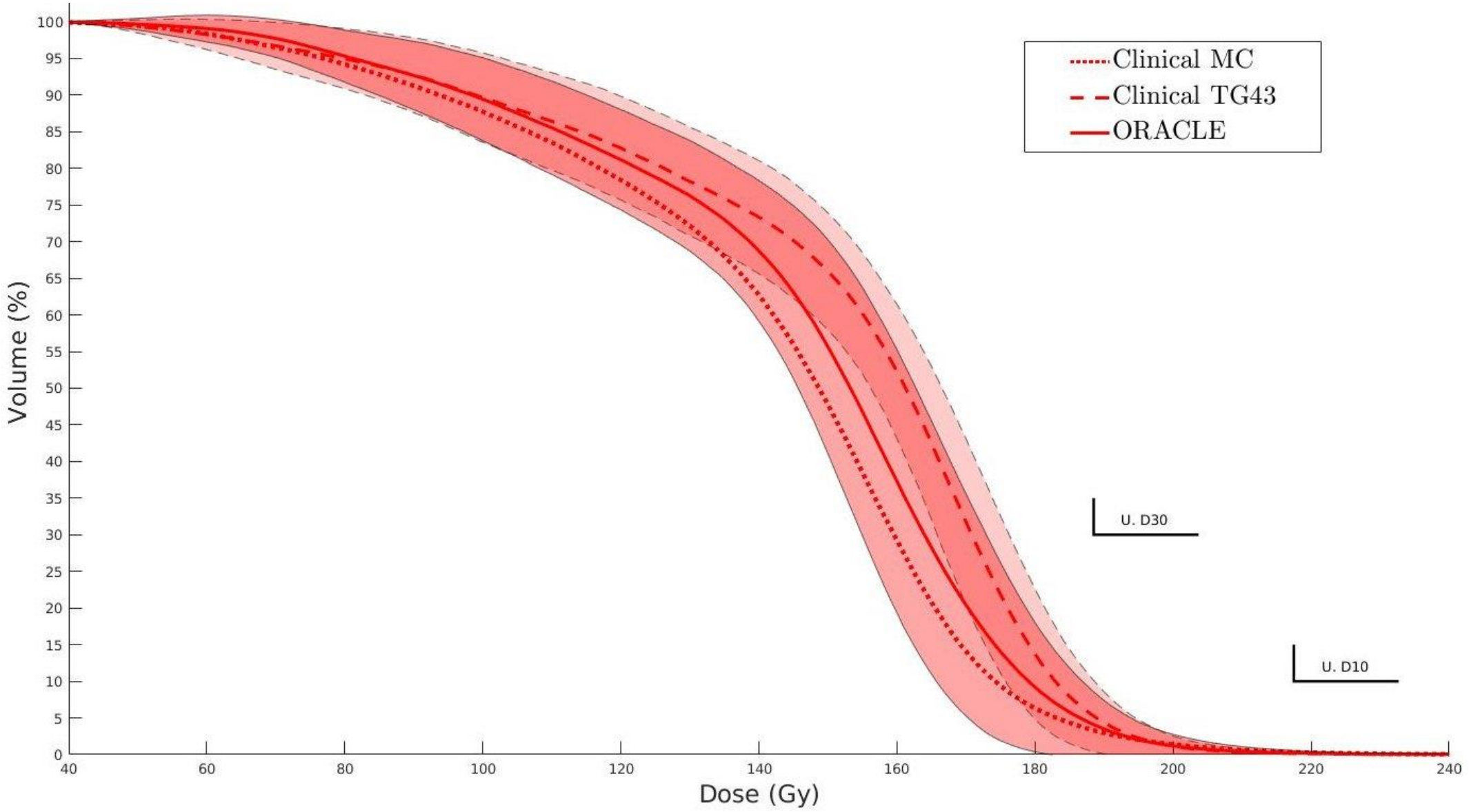
Comparison with clinical plans (Database: **18** patients)

Organ	Metric	TG-137	Clinical	Clinical - MC	ORACLE
Prostate	V_{100} (%)	>95	96.8 ± 1.5	94.7 ± 2.3	96.6 ± 1.0
	V_{150}(%)	≤50	49.0 ± 4.0	44.8 ± 4.8	46.0 ± 2.7
	V_{200}(%)	≤20	20.7 ± 2.2	18.7 ± 2.5	19.6 ± 0.5
	D_{90} (Gy)	≥145.0	161.6 ± 4.9	156.7 ± 6.4	162.4 ± 3.8
Urethra	D_{10} (Gy)	<217.5	184.6 ± 8.5	172.7 ± 8.9	177.3 ± 11.8
	D_{30} (Gy)	<188.5	171.3 ± 4.5	159.7 ± 5.7	165.0 ± 9.2
Rectum	D_{2cc} (Gy)	<145.0	109.4 ± 10.3	108.1 ± 10.9	108.7 ± 7.8
	$D_{0.1cc}$ (Gy)	<217.5	156.6 ± 14.8	153.6 ± 15.7	166.7 ± 21.2
Seeds			64 ± 7		64 ± 5
Needles			18 ± 2		17 ± 2

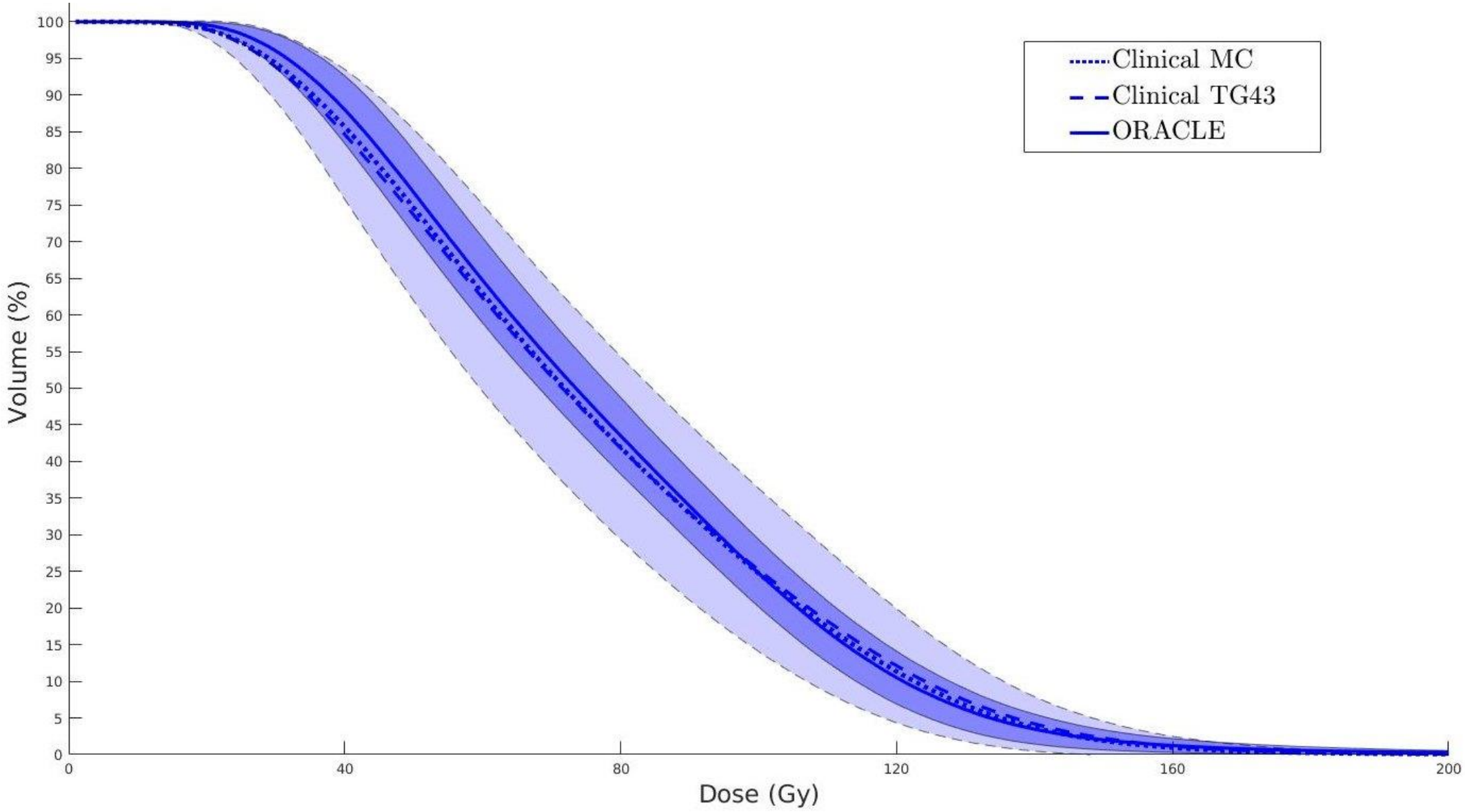
Prostate DVH comparison



Urethra DVH comparison



Rectum DVH comparison



Contributions

- Intra-operative MC dosimetry in LDR brachytherapy inverse planning (≈15-20 s)
- Fast & Robust inverse planning based on DVH optimization (15 s)
- No learning curve in inverse planning

Perspectives

- Consideration of edema – Biomechanics in treatment planning[10]
- Adaptation in HDR brachytherapy

[10] Mountris et al. 2017, Phys. Med. Biol.

Acknowledgements

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Your plan

Thank you for your attention!

Questions?

Reality

Directions determine destinations…