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Using Task Group 137 to Prescribe and Report Dose

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TG137

- **AAPM Recommendations on Dose Prescription and Reporting Methods for Permanent Interstitial Brachytherapy for Prostate Cancer**

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TG 137 Charge

- **Review**
  - **Prescription**
  - **Reporting**
  - **Radiobiological models**
- **Consensus**
  - **Min requirements for prescription and reporting**
    - Pre implant
    - Post implant
- **Recommend**
  - **Optimal requirements for prescription and reporting**
    - Pre implant
    - Post implant

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Outline
Permanent Prostate Implants

- **Impact of dose reporting based upon**
  - **Imaging modalities**
  - **Timing of imaging study**
  - **Treatment planning approaches**
  - **Interoperative planning strategies**
- **Biophysical models**
  - **BED**
  - **EUD**
  - **TCP**

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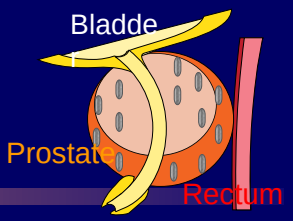
History Dose Prescription



- **Nomogram**

Table 1. Nomogram for monotherapy (125 Gy) using NASI MED3633 ^{103}Pd seed

Implant Volume (cc)	Average Dimension (cm)	Total Activity (U)	No. of Seeds (1.6 U/seed)	No. of Seeds (1.8 U/seed)	No. of Seeds (2.0 U/seed)
15	2.5	98	62	55	49
20	2.7	110	69	62	55
22	2.8	115	72	64	58
24	2.9	121	76	68	61
26	3.0	127	80	71	64
28	3.0	133	84	74	67
30	3.1	140	88	78	70
32	3.2	146	92	82	73
34	3.2	153	96	85	77
36	3.3	161	101	90	81
38	3.3	168	105	94	84
40	3.4	176	110	98	88
42	3.5	184	115	103	92
44	3.5	193	121	108	97
46	3.6	202	127	113	101
48	3.6	211	132	118	106
50	3.7	220	138	123	110
55	3.8	245	154	137	123

based on a modified peripheral loading

Zheng *et al.*, Medical Dosimetry, **28**, 185 - 188 (2003).

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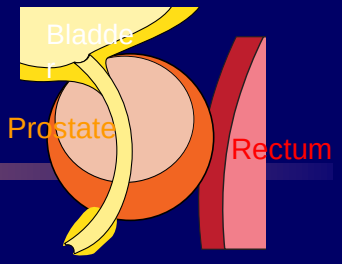
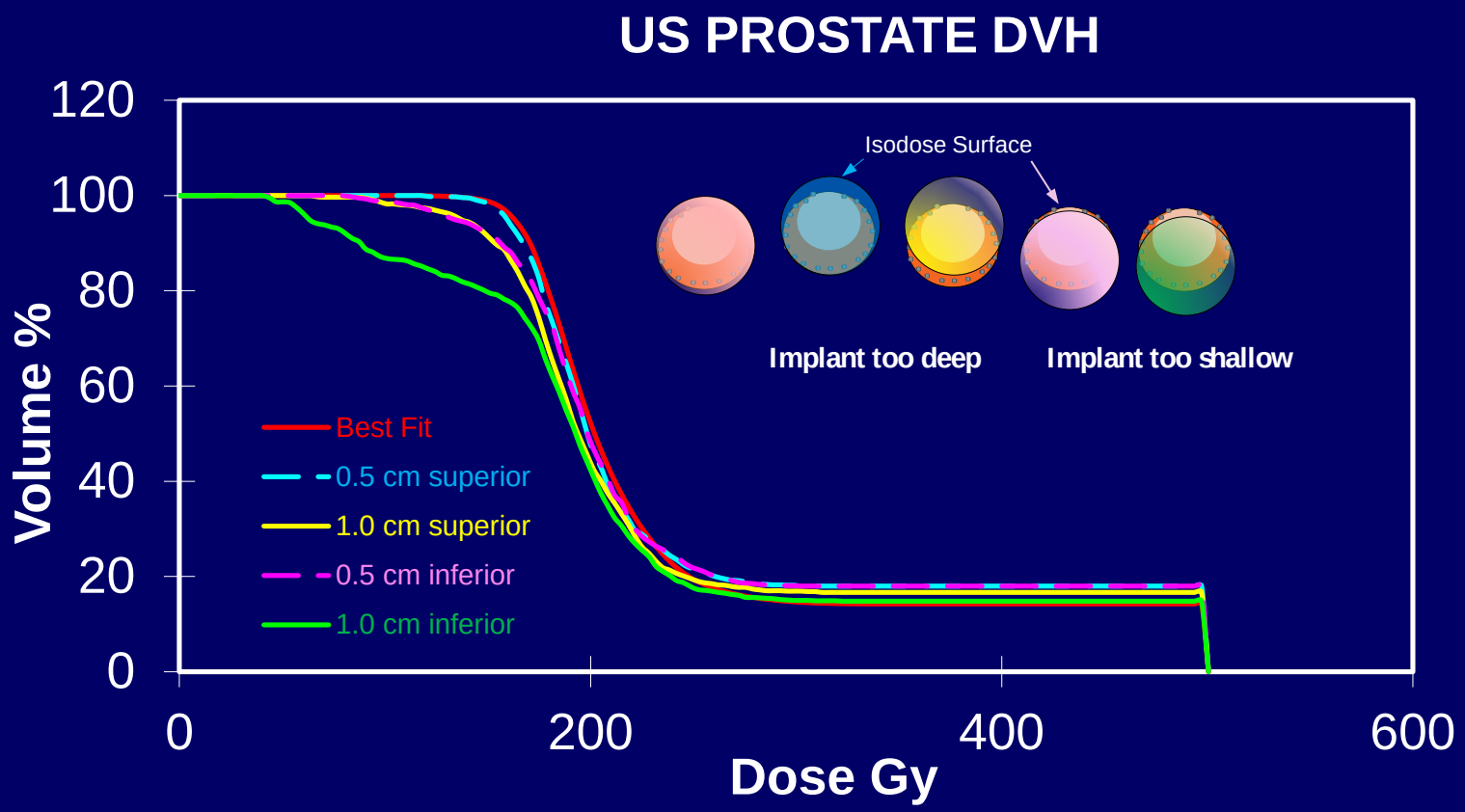
History Dose Reporting



D_{99} – Dose to 99% of target
mPD – minimum Peripheral Dose



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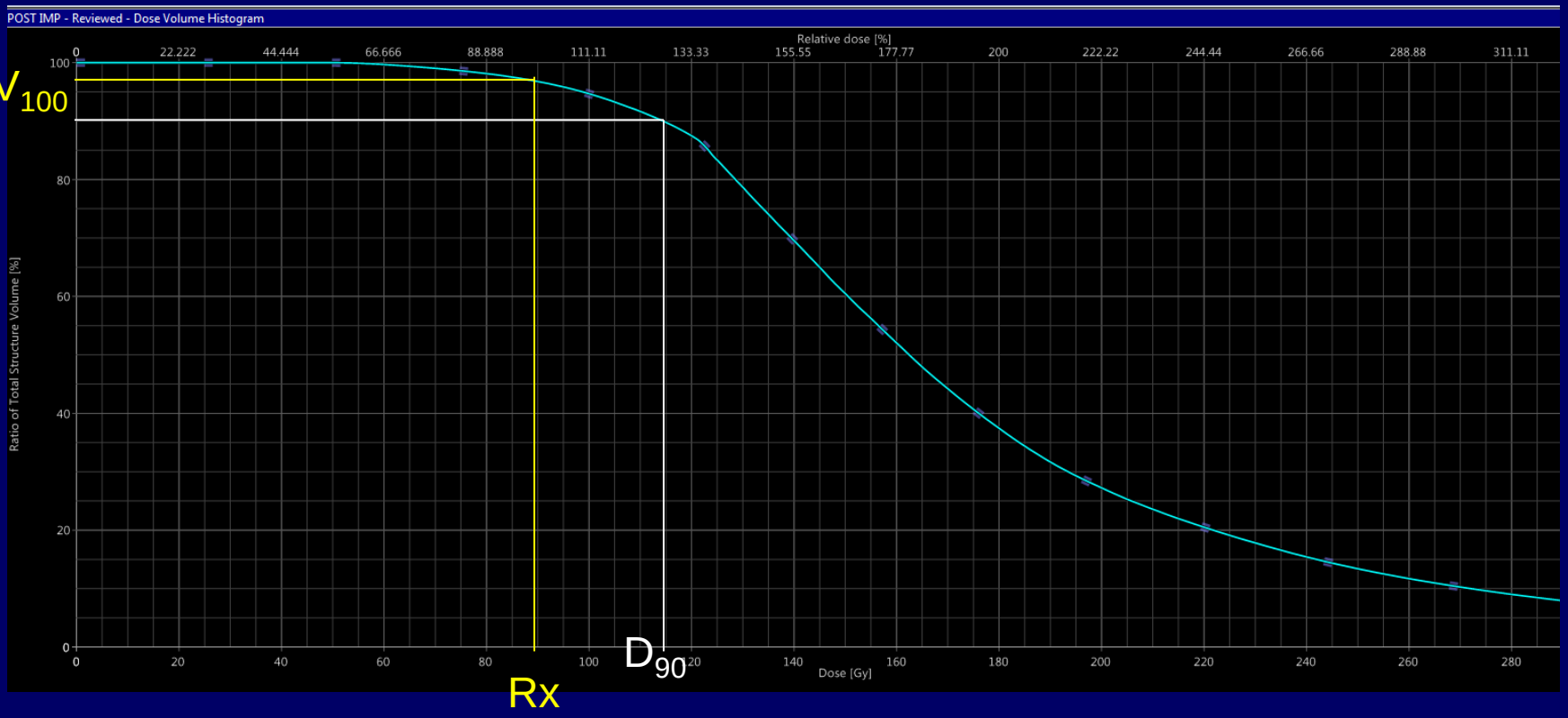
Plan evaluation today

- **V100**
  - **Vol that receives 100% of dose**
  - **90 % excellent implant**
- **D90**
  - **Dose to 90 % of the volume**
  - **Prescribed dose**

Today

- D_{90} _ Dose to 90% of target
- V_{100}- Volume that receives Rx dose



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- **Dose calculation**
- **Imaging**

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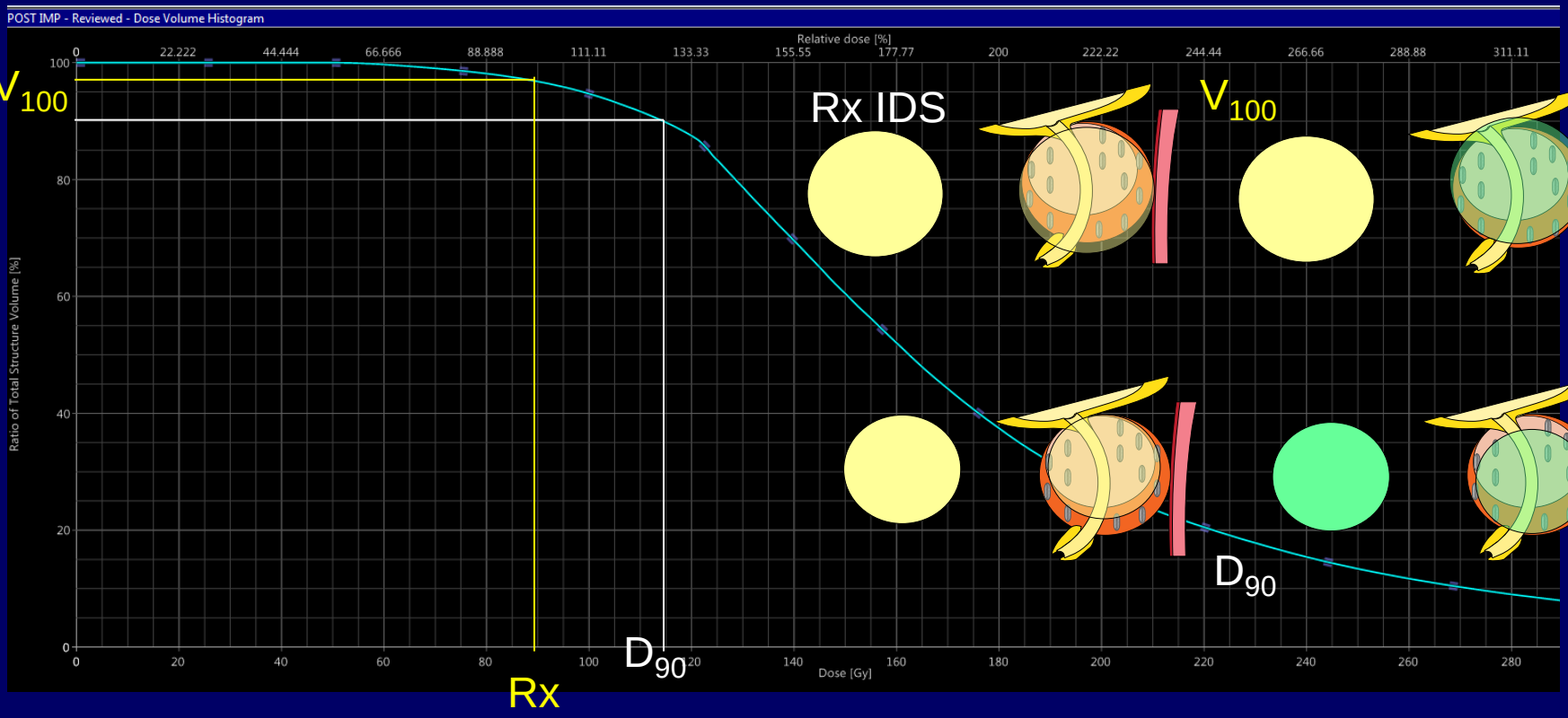
Today

- D_{90} _ Dose to 90% of target
- V_{100}- Volume that receives Rx dose



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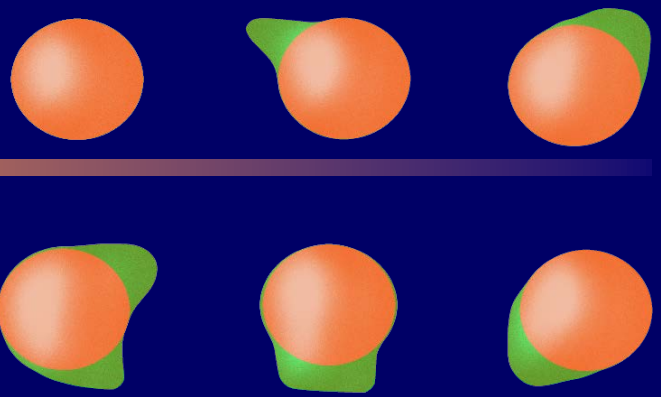
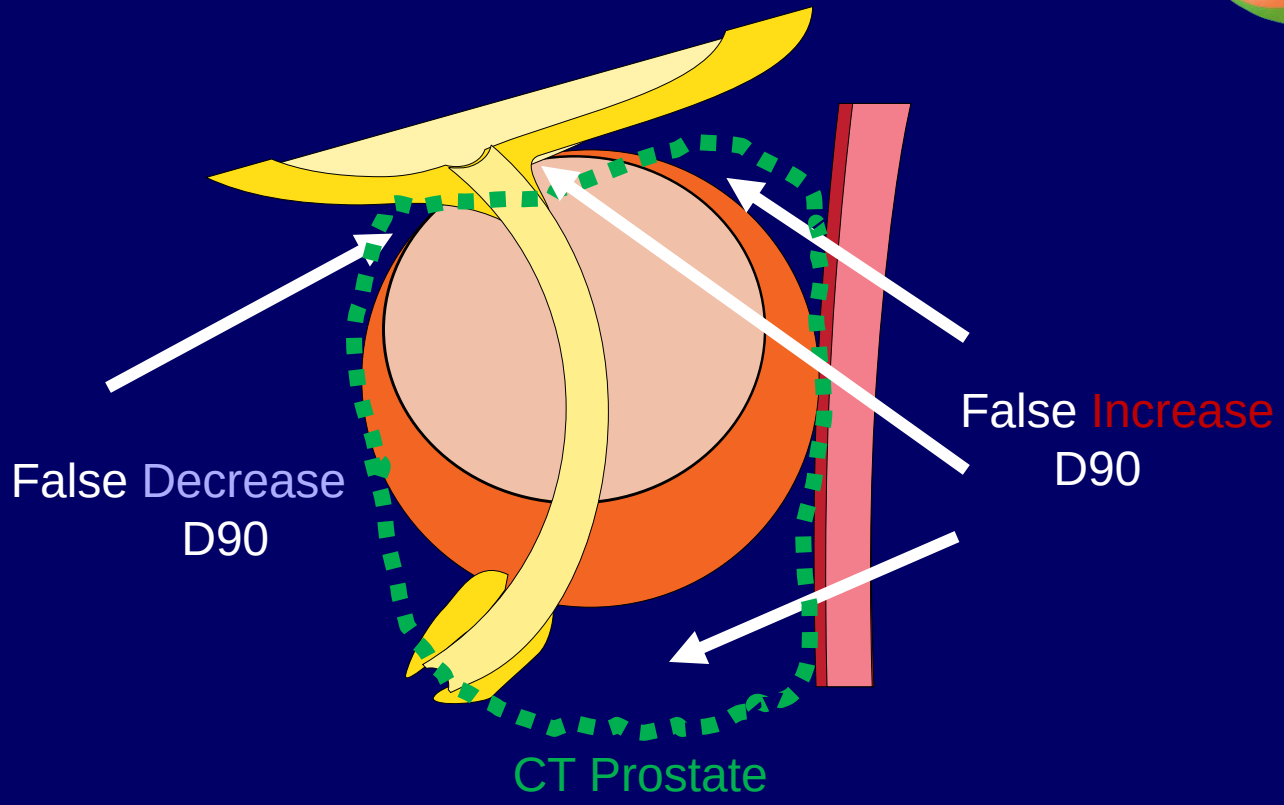
D90 issue





Impact of Imaging Modality on Dose Reporting

- **Ultrasound Imaging**
- **CT Imaging**
- **MR Imaging**
- **Recommendations on Imaging modality**

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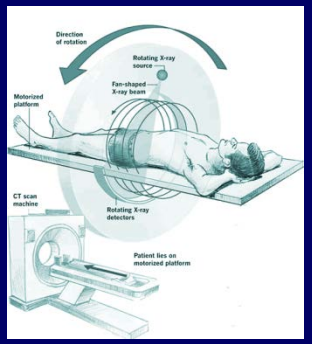
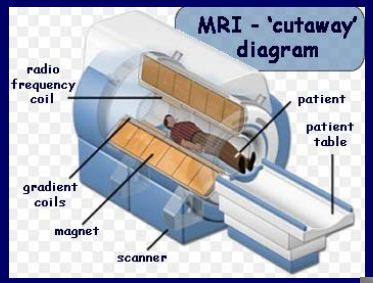
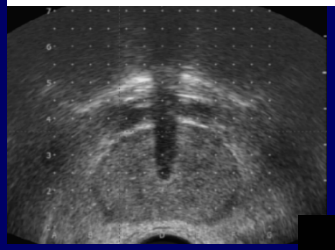
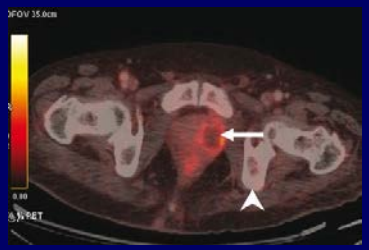
Imaging modalities

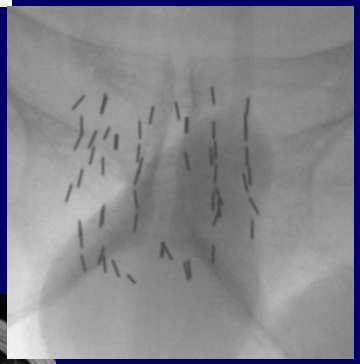
- **Target delineation**

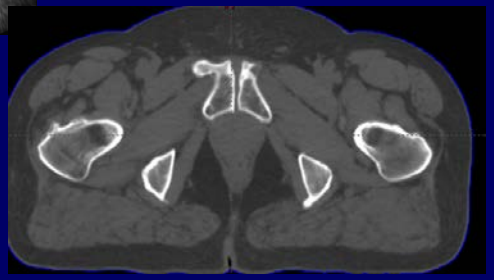


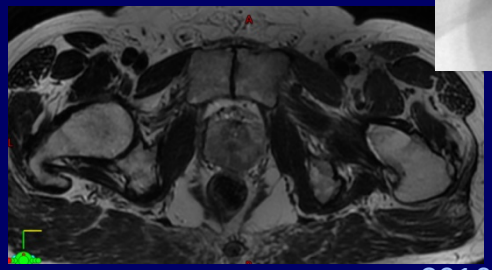












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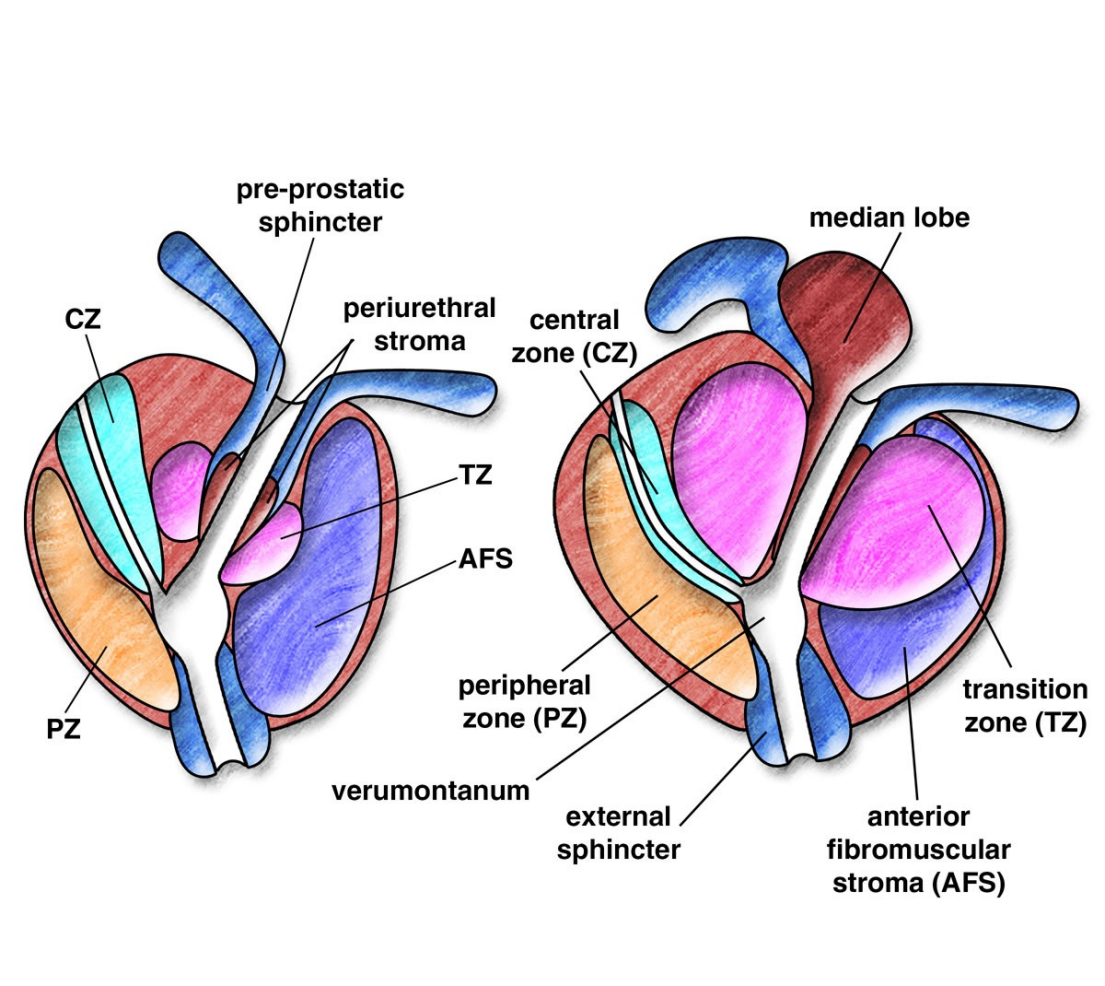
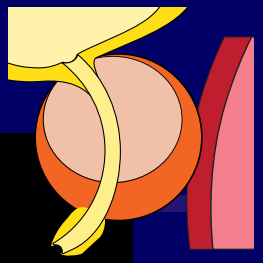
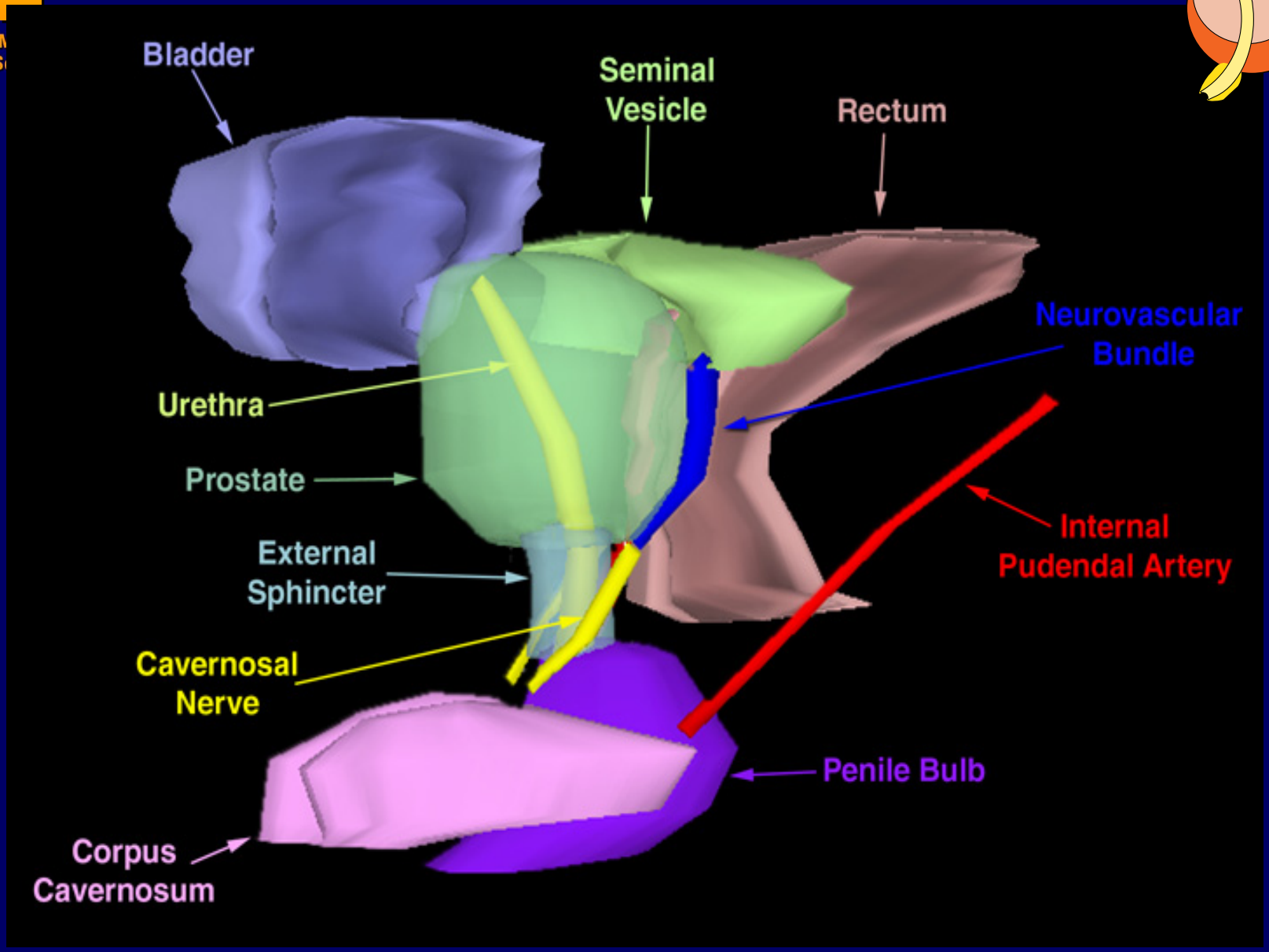
Prostate Anatomy






Bladder
Seminal Vesicle
Rectum
Neurovascular Bundle
Urethra
Prostate
External Sphincter
Internal Pudendal Artery
Cavernosal Nerve
Penile Bulb
Corpus Cavernosum

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Imaging Modalities

	Plane films	CT	MRI	TRUS
* Identification	++	+	-	--
* Localization	+	++	0	--
Prostate Delineation	--	+	++	+
Critical St Delineation	--	+	++	0
Comfort	+	+	-	--
Cost & Convenience	++	-	--	+

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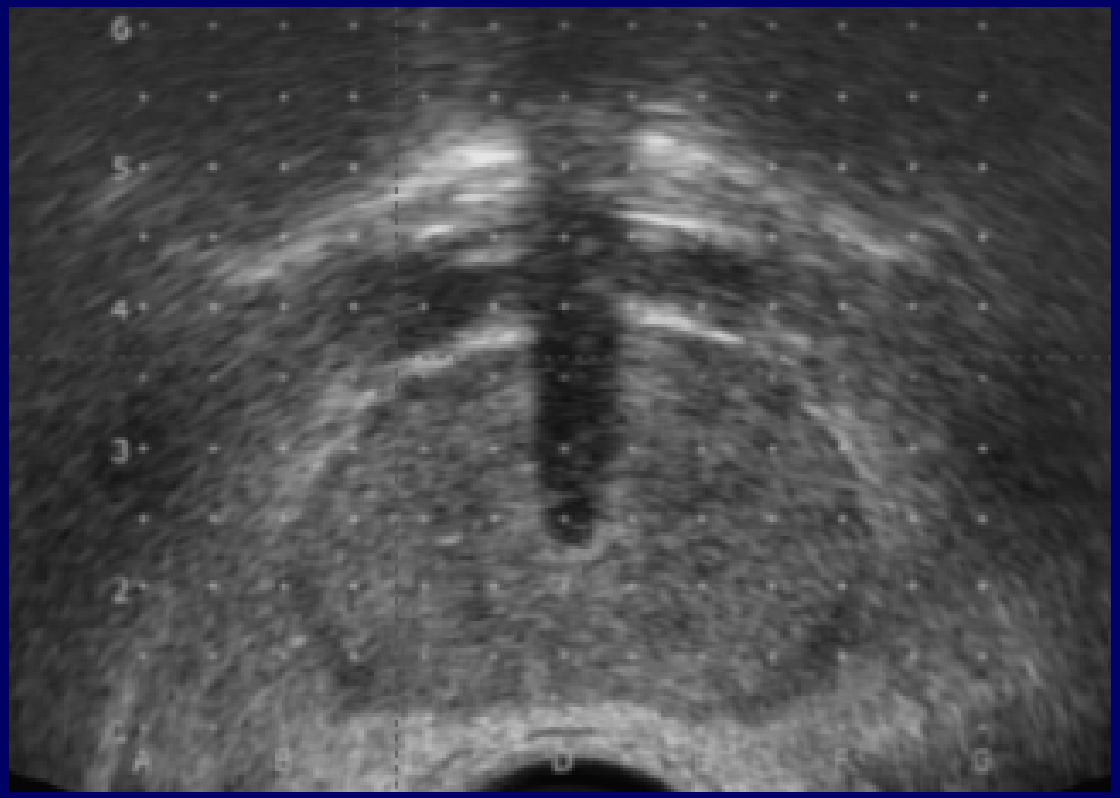
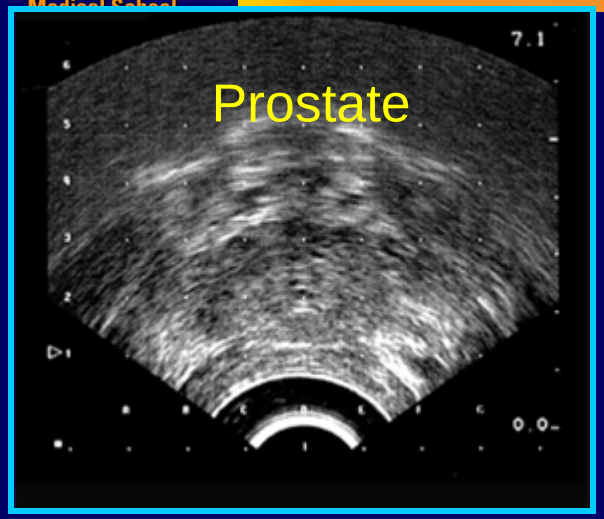
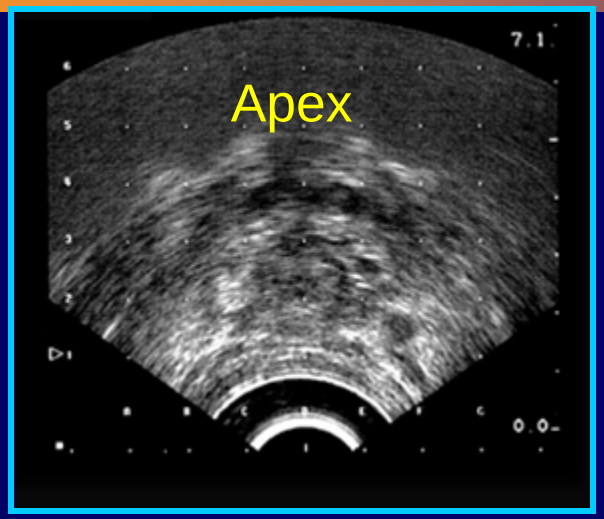
Ultrasound

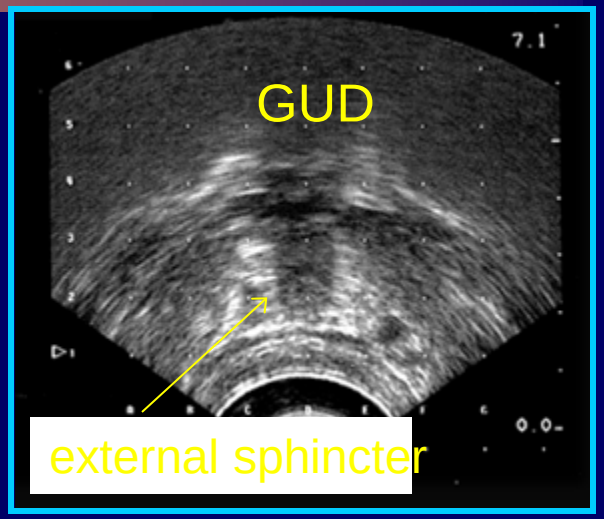
- **Prostate**
- **Urethra**
- **Rectal wall**

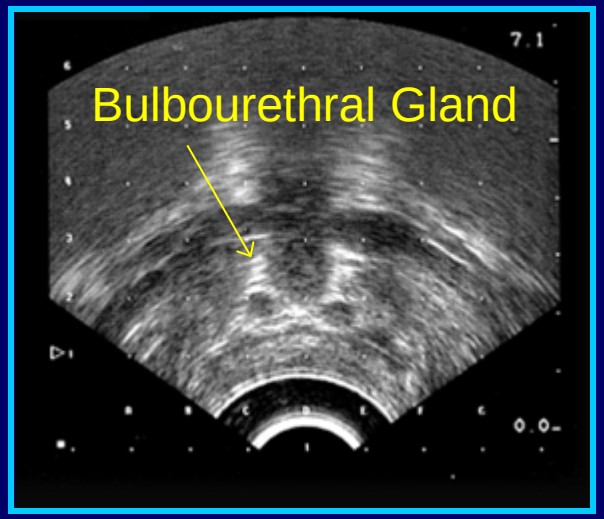


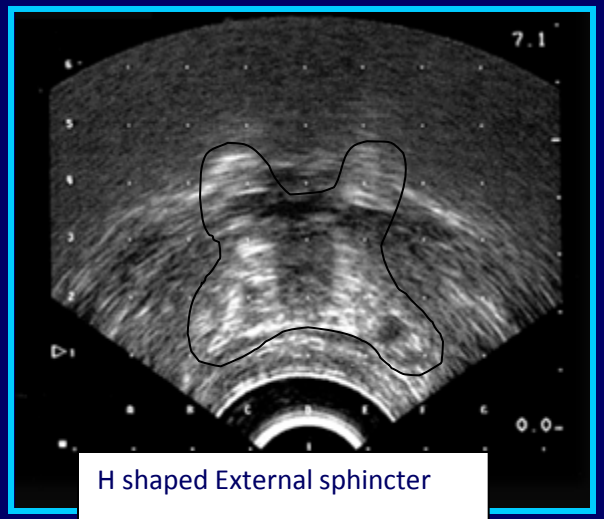
Ultrasound Apex / GUD Transition











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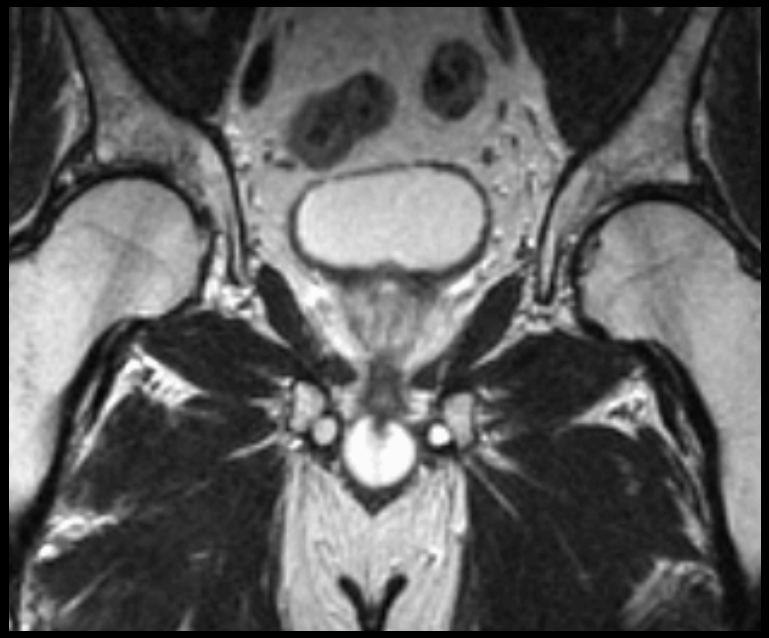
MRI Coronal vs. CT Coronal



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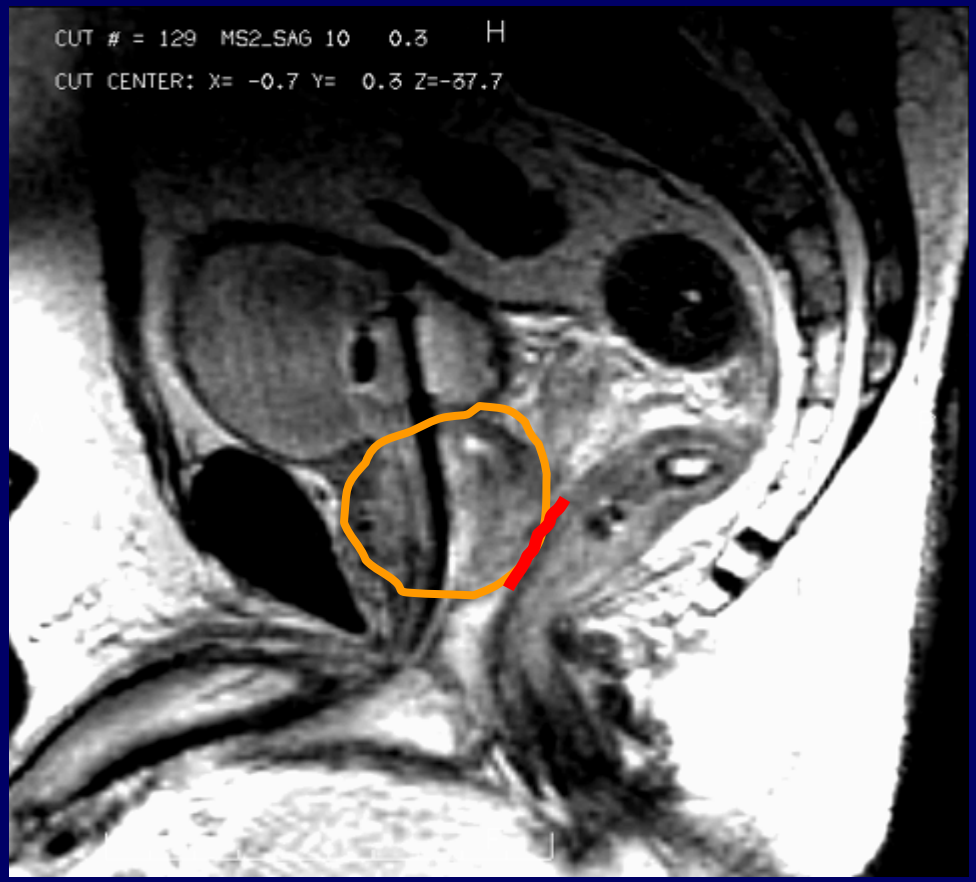
MR Anatomy

- Prostate
- Urethra
- Rectal wall
- Corpus Cavernosum
- Pudendal Arteries
- Sphincter
- Neurovascular bundle



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CT Prostate

- **Apex – when do you stop**
- **Base – bladder neck oblitaration**

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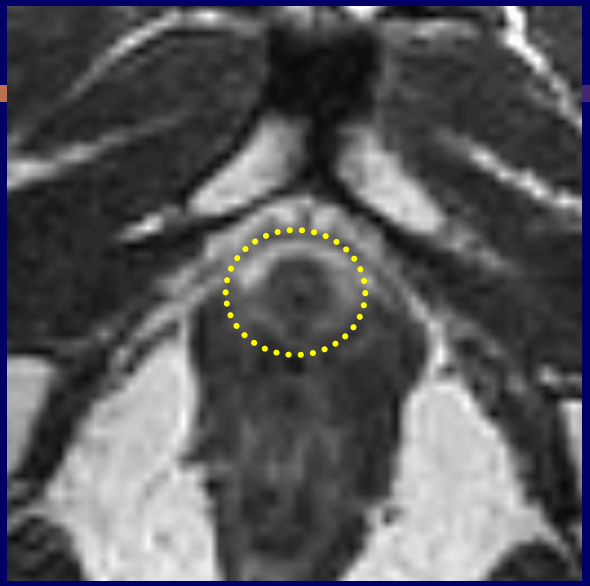
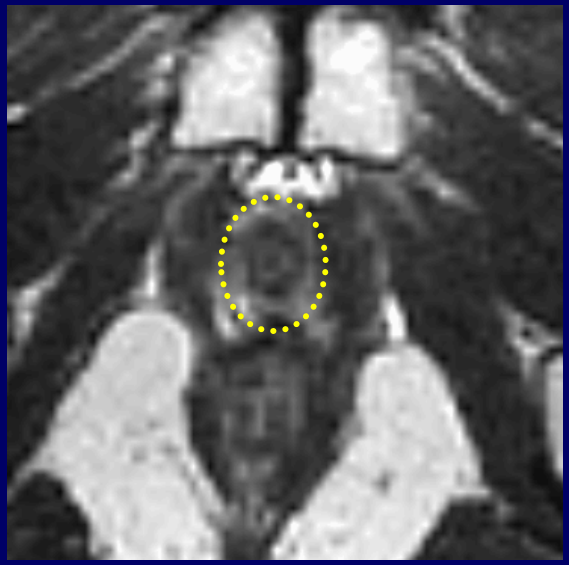
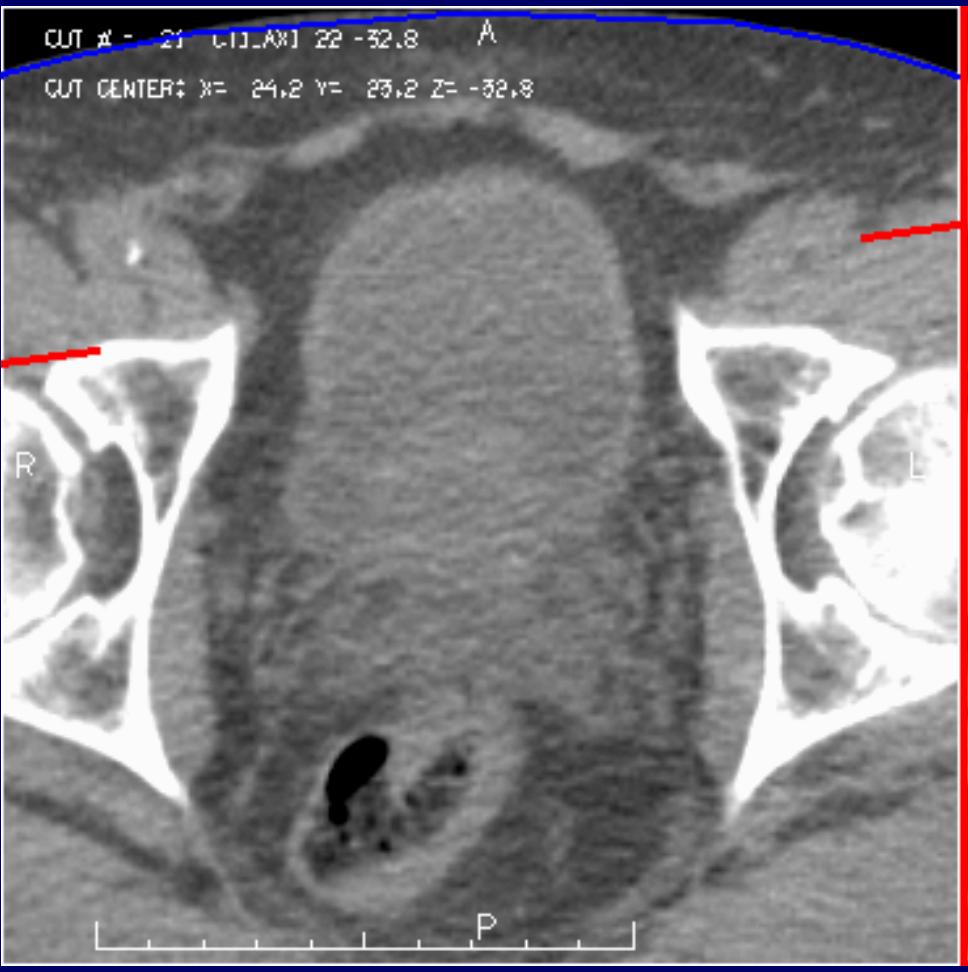




Intra - lumen bladder density-small gland



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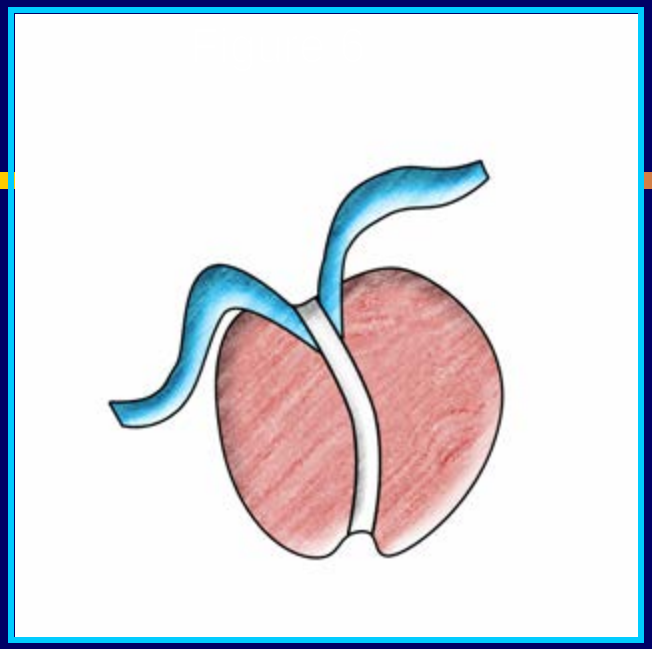

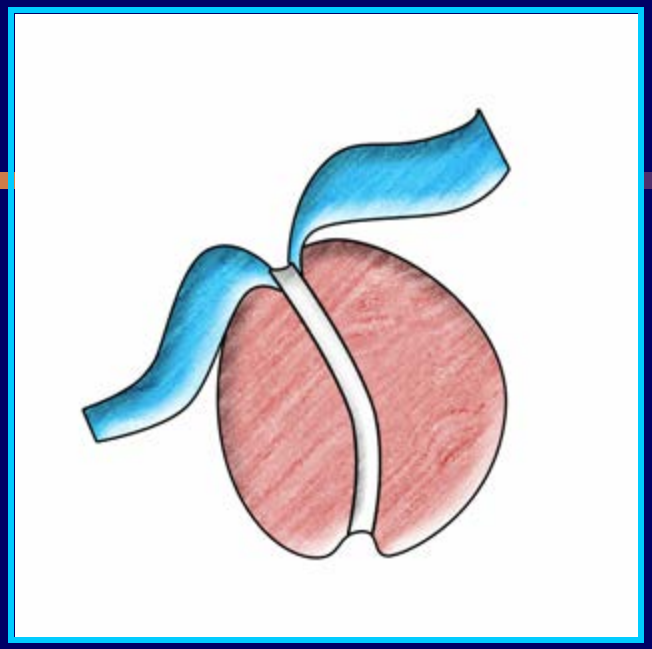

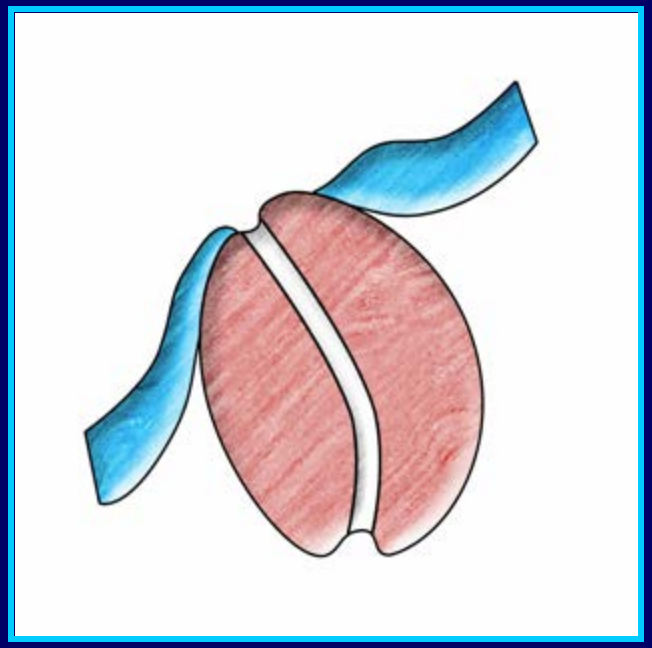

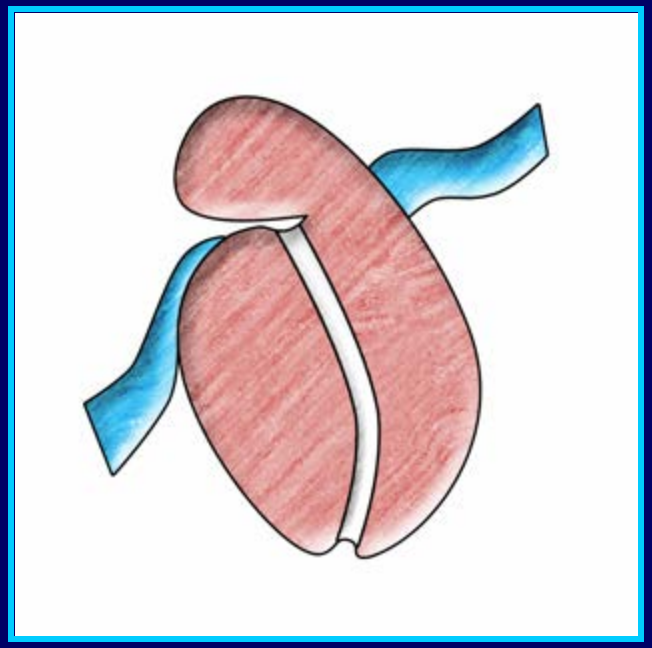

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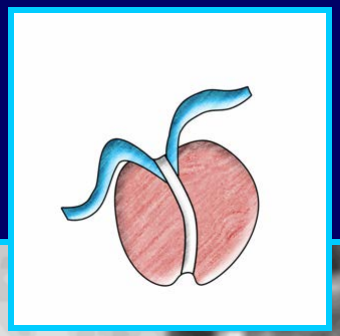
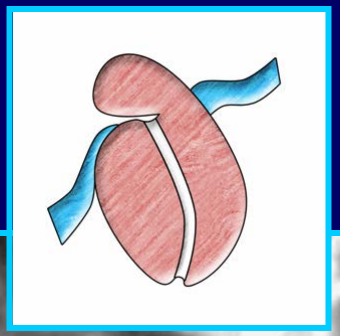
Bladder Neck Obliteration





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MRI Coronal vs. CT Coronal

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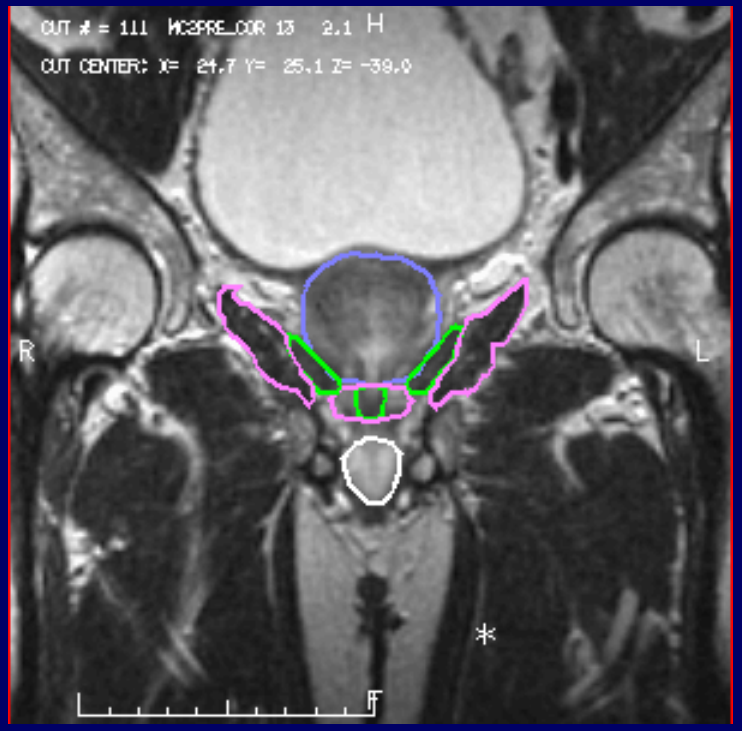
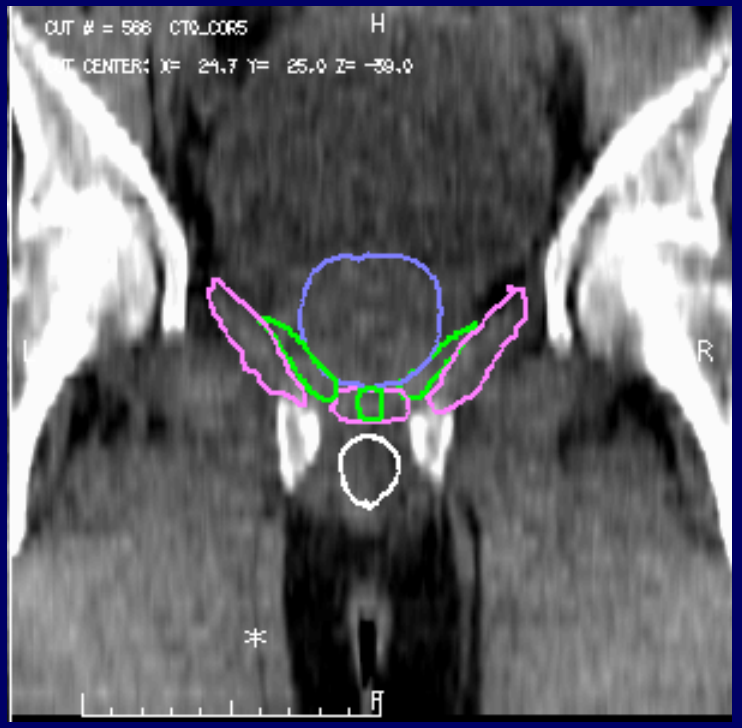
MRI Coronal vs. CT Coronal





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CT Prostate – post implant

- **Apex – when do you stop**
- **Base – bladder neck obliteration**
- **Seminal vesicles**
- **Rectal surface**

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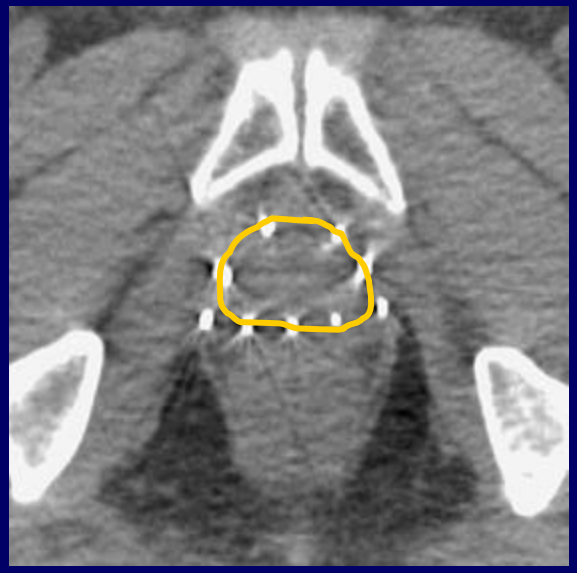
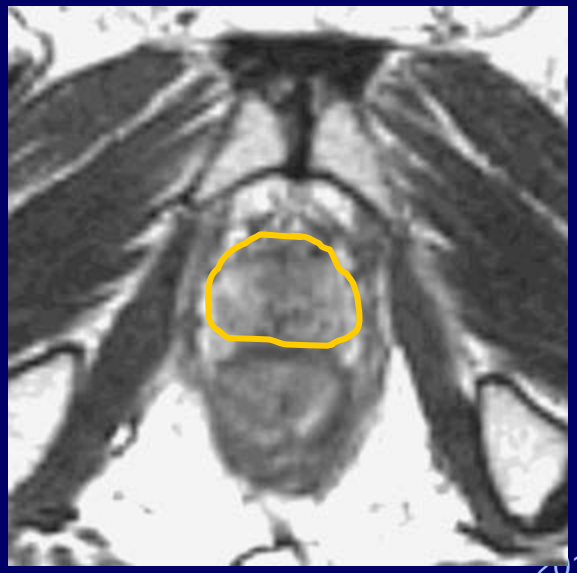
Axial CT
without Contour

Axial MRI
without
Contour

Axial CT
with Contour





Axial MRI
with Contour

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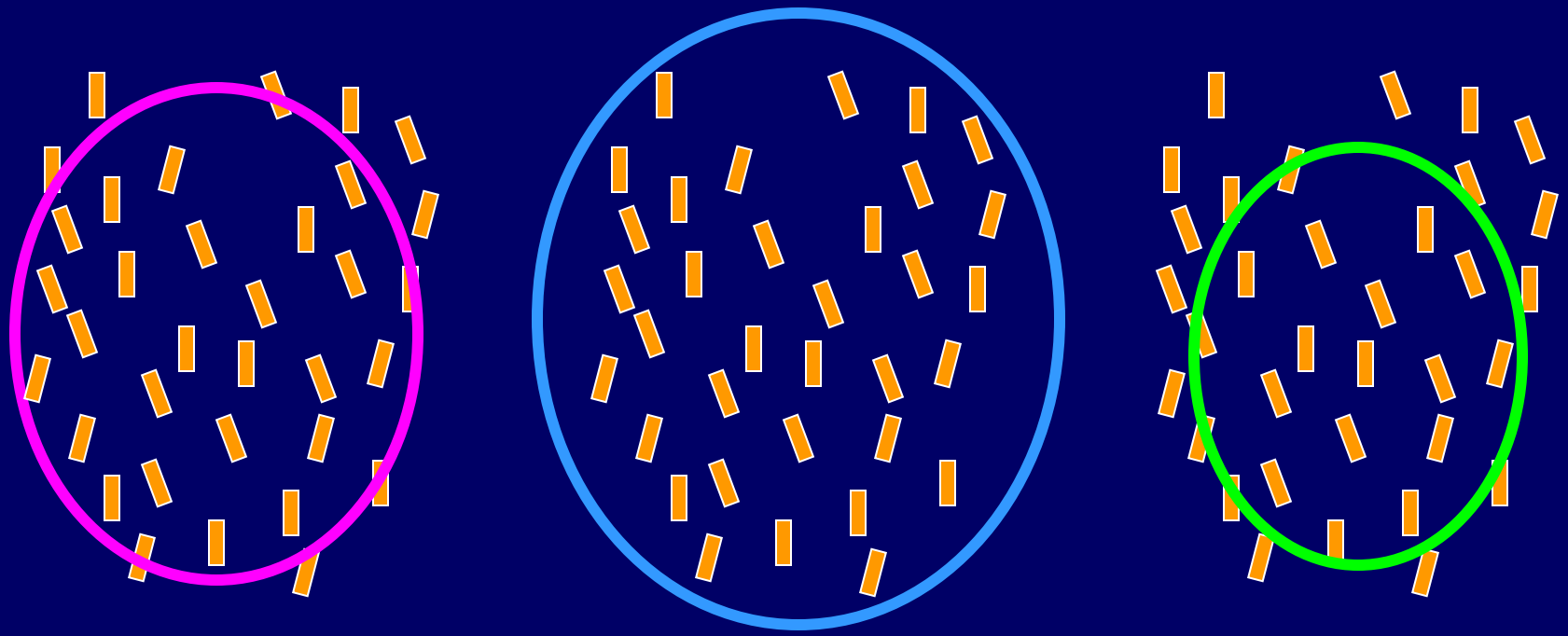
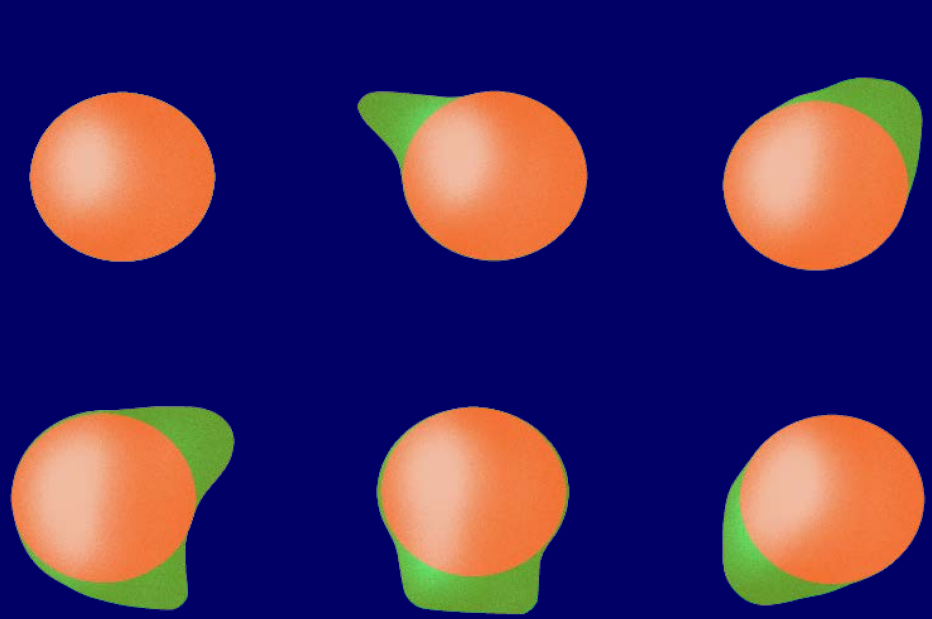
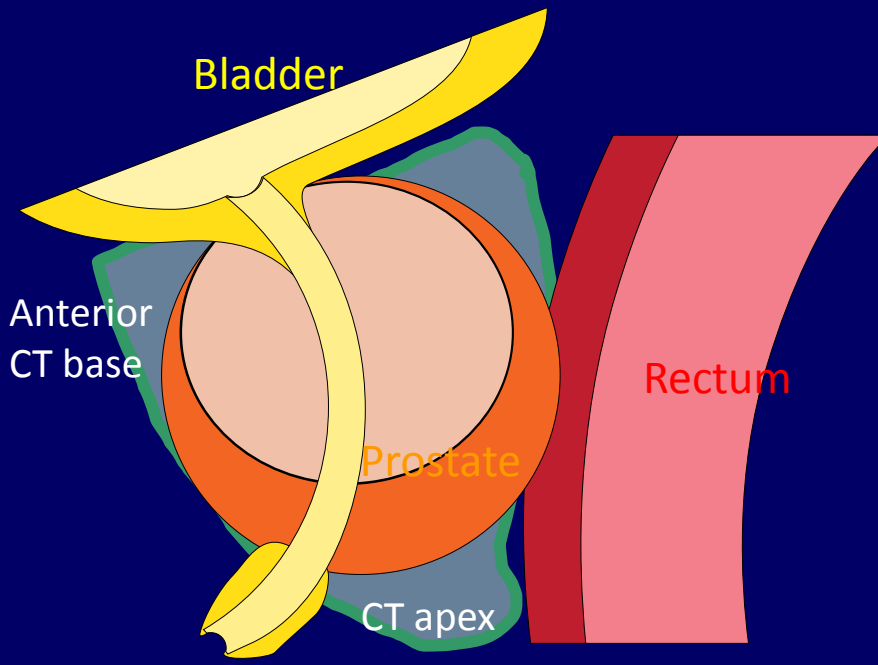
Variations without a Standard (Lee)



	Observer 1	Observer 2	Observer 3
Vol	39 cc	48 cc	32 cc
D90	142 Gy	123 Gy	155 Gy
V100	93%	86%	99%

Perils of CT contouring





Saggital

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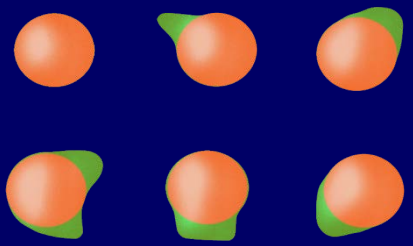
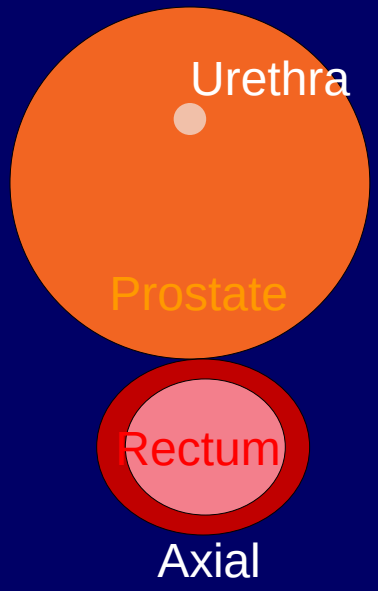
CT

- **Prostate**
- **Outer Rectum**
- **Inner Rectum – de-expansion 5 mm**
- **Urethra – Foley**
- **Penile Bulb**





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Why MR? EXPECT VARIATION

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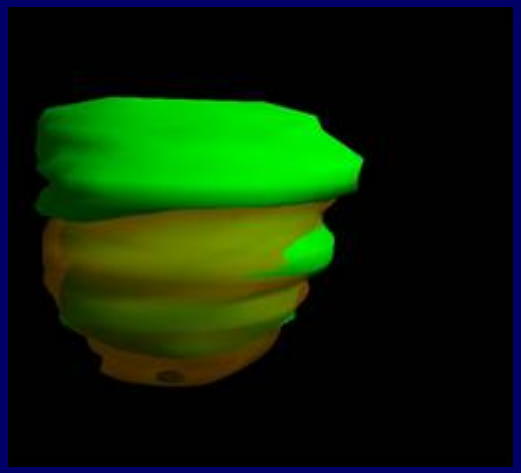
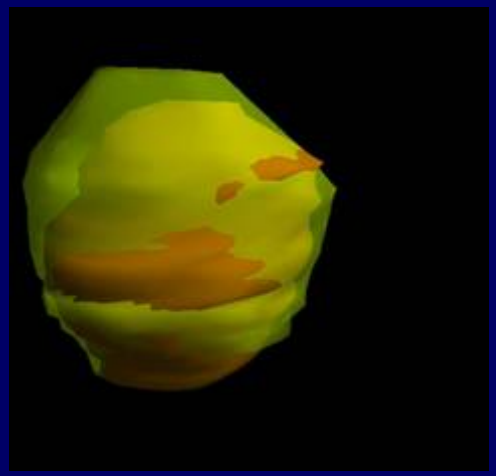
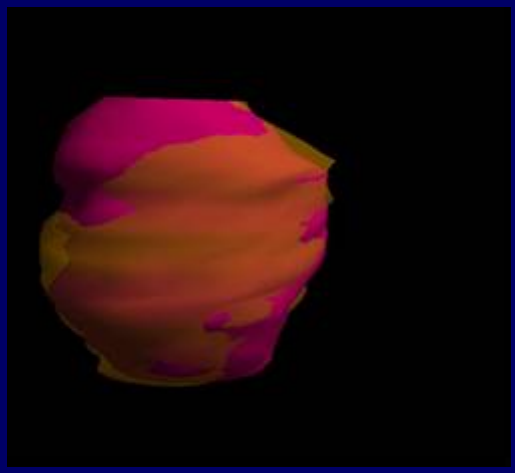
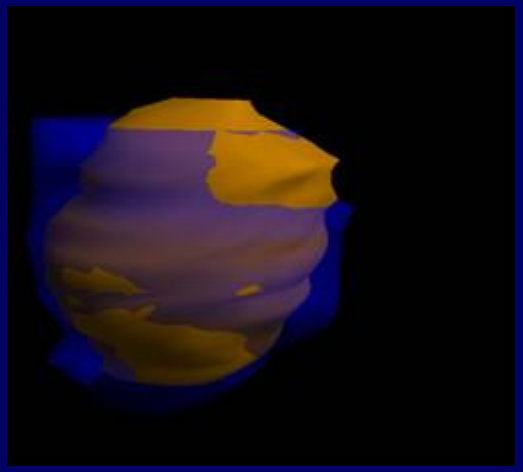
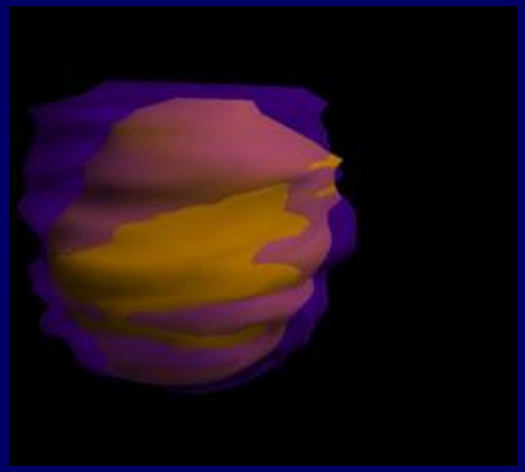
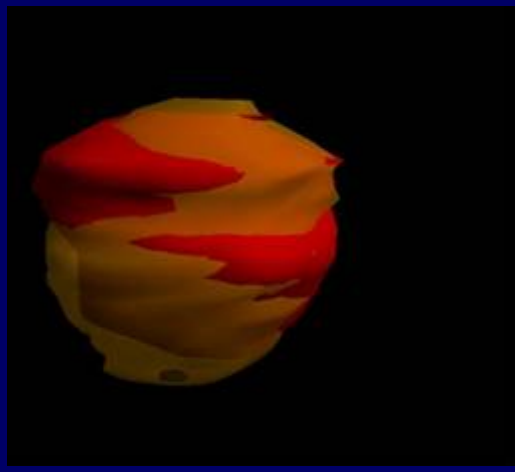
CT contouring / 6 national experts

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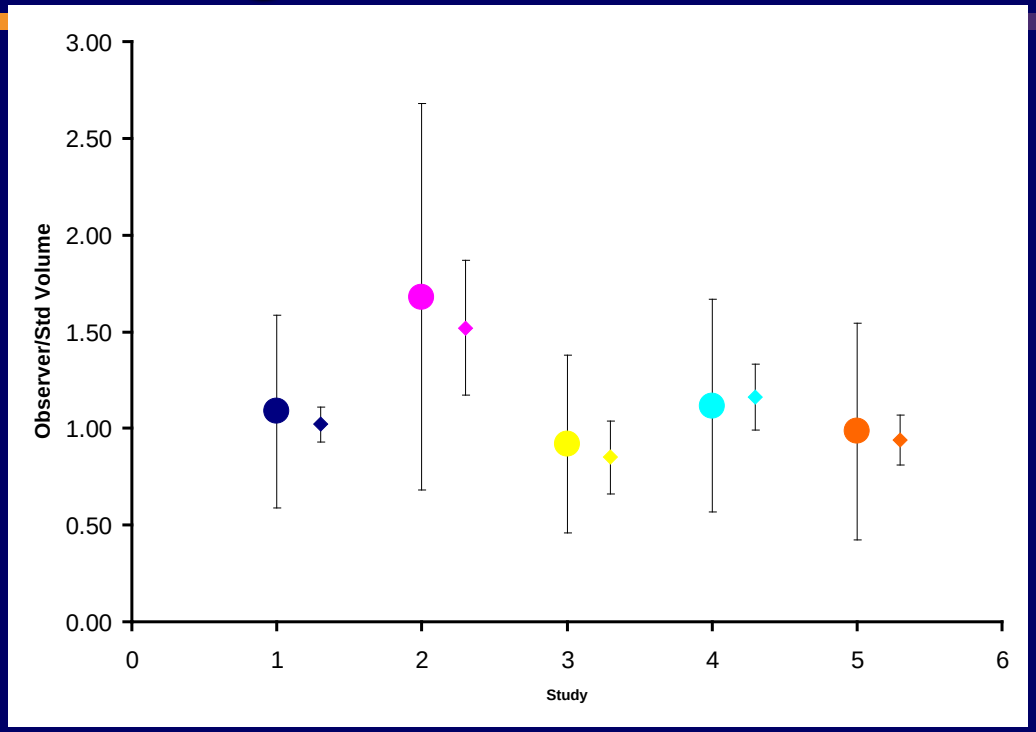
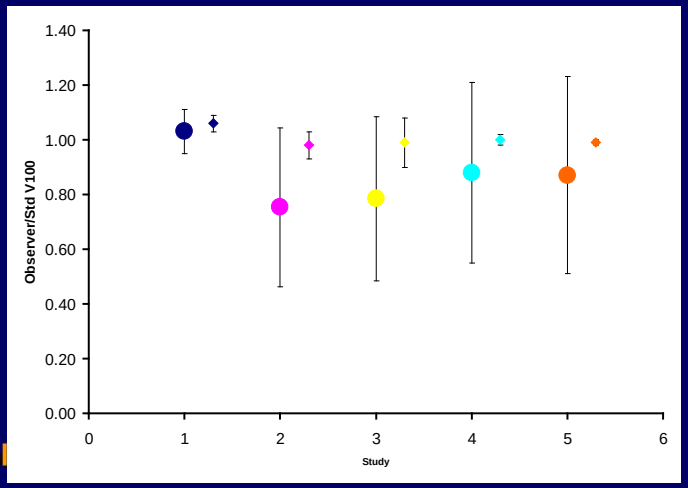
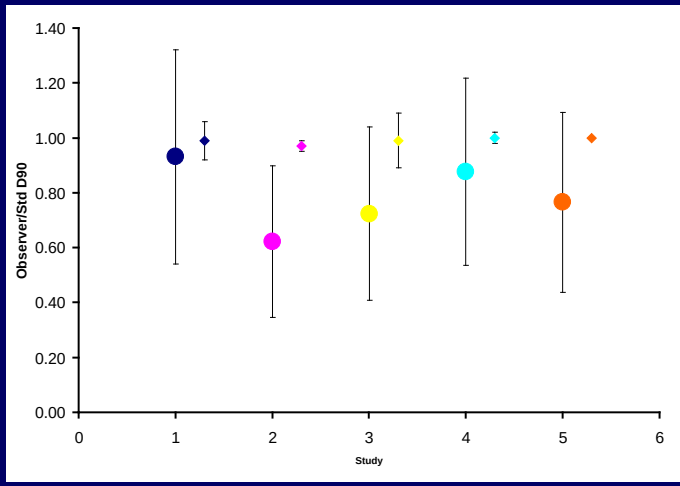
CT contouring

Wide margin implants







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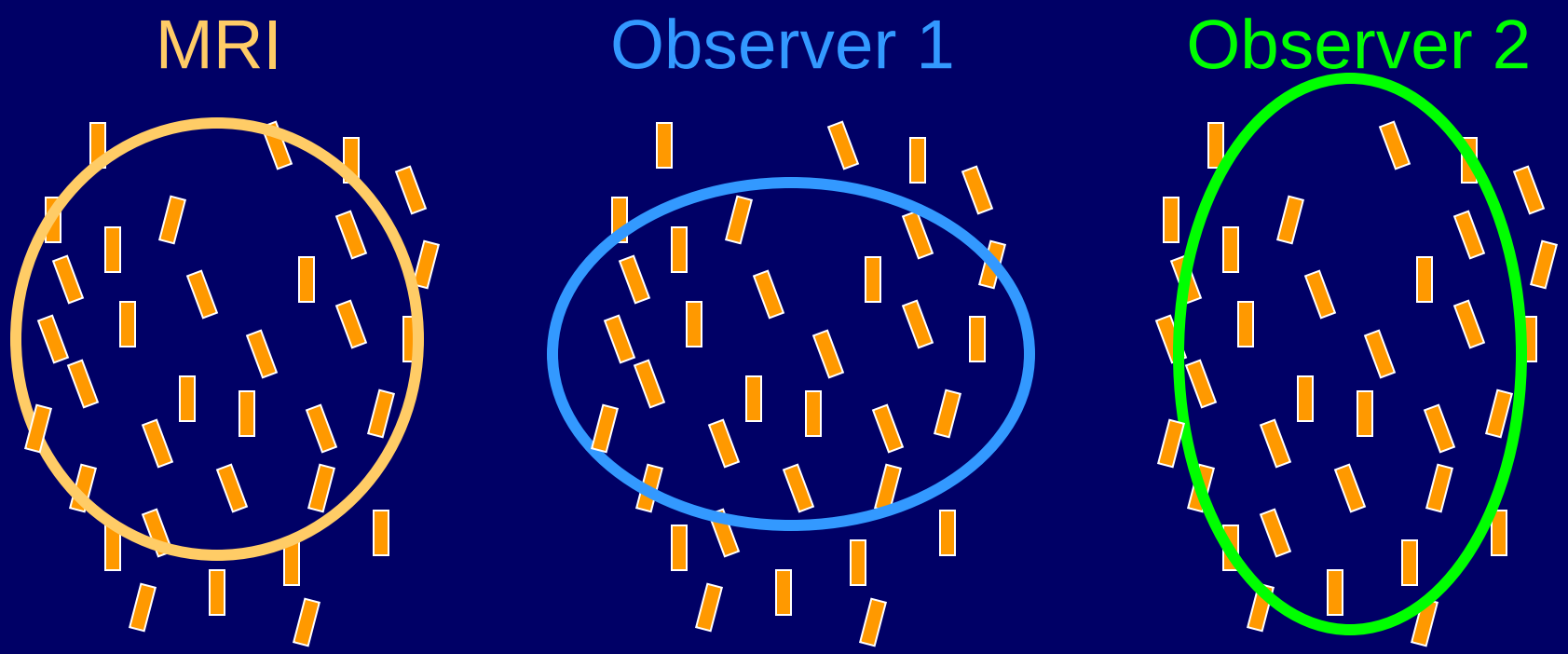
Deviation from a Standard (6 experts)



36cc

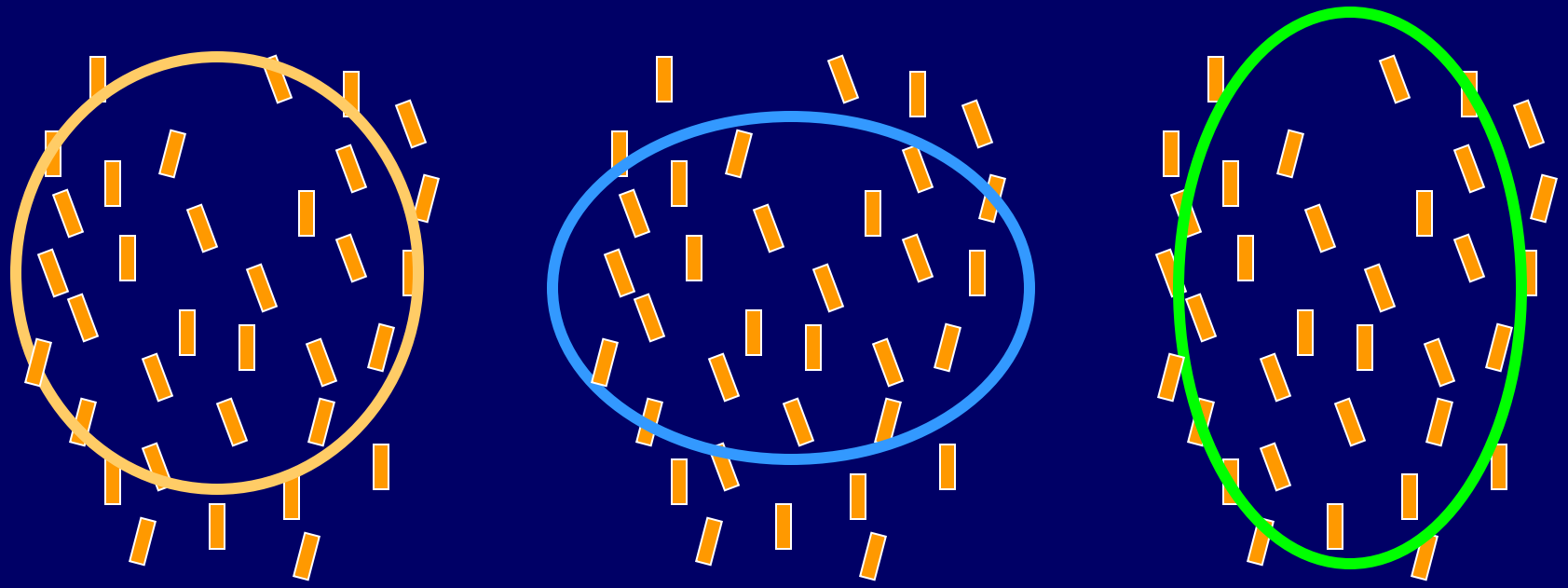
34cc

38cc

Prostate Volume Agreement

Deviation from a Standard (6 experts)

MRI | Observer 1 | Observer 2



148 Gy | 153 Gy | 143 Gy

D90 Agreement

Deviation from a Standard (6 experts)

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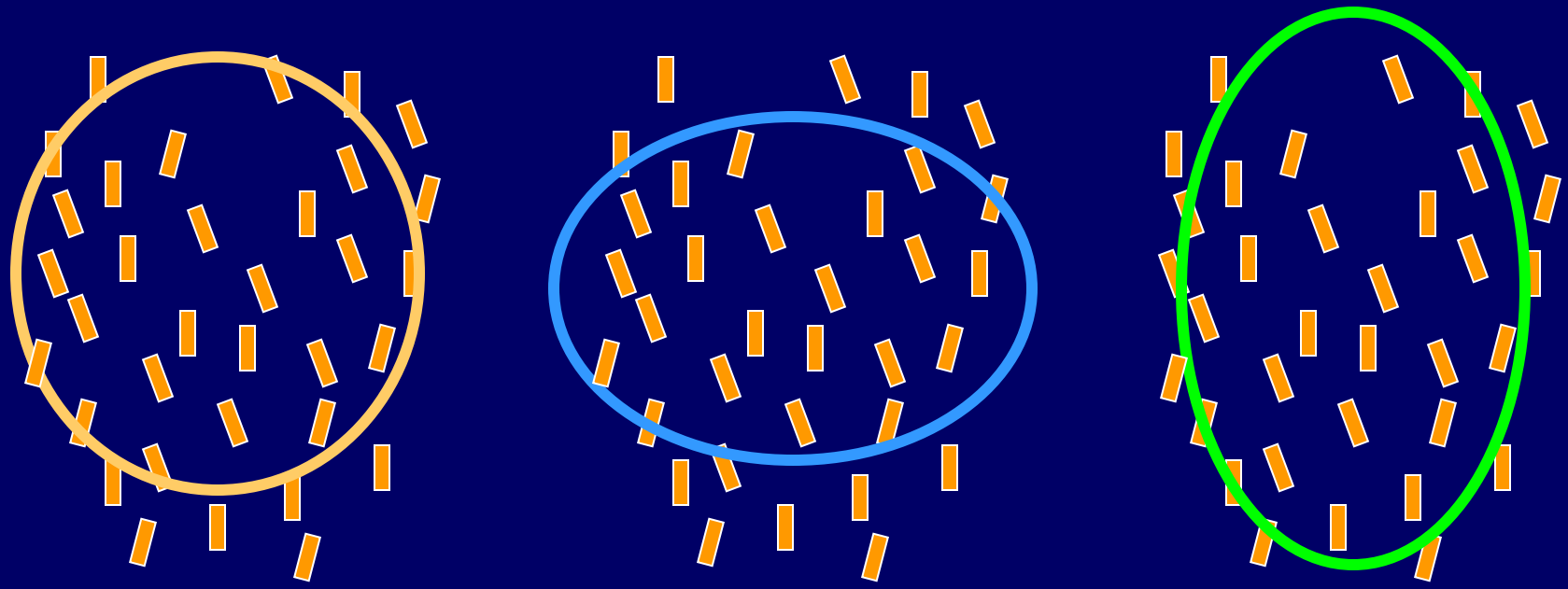
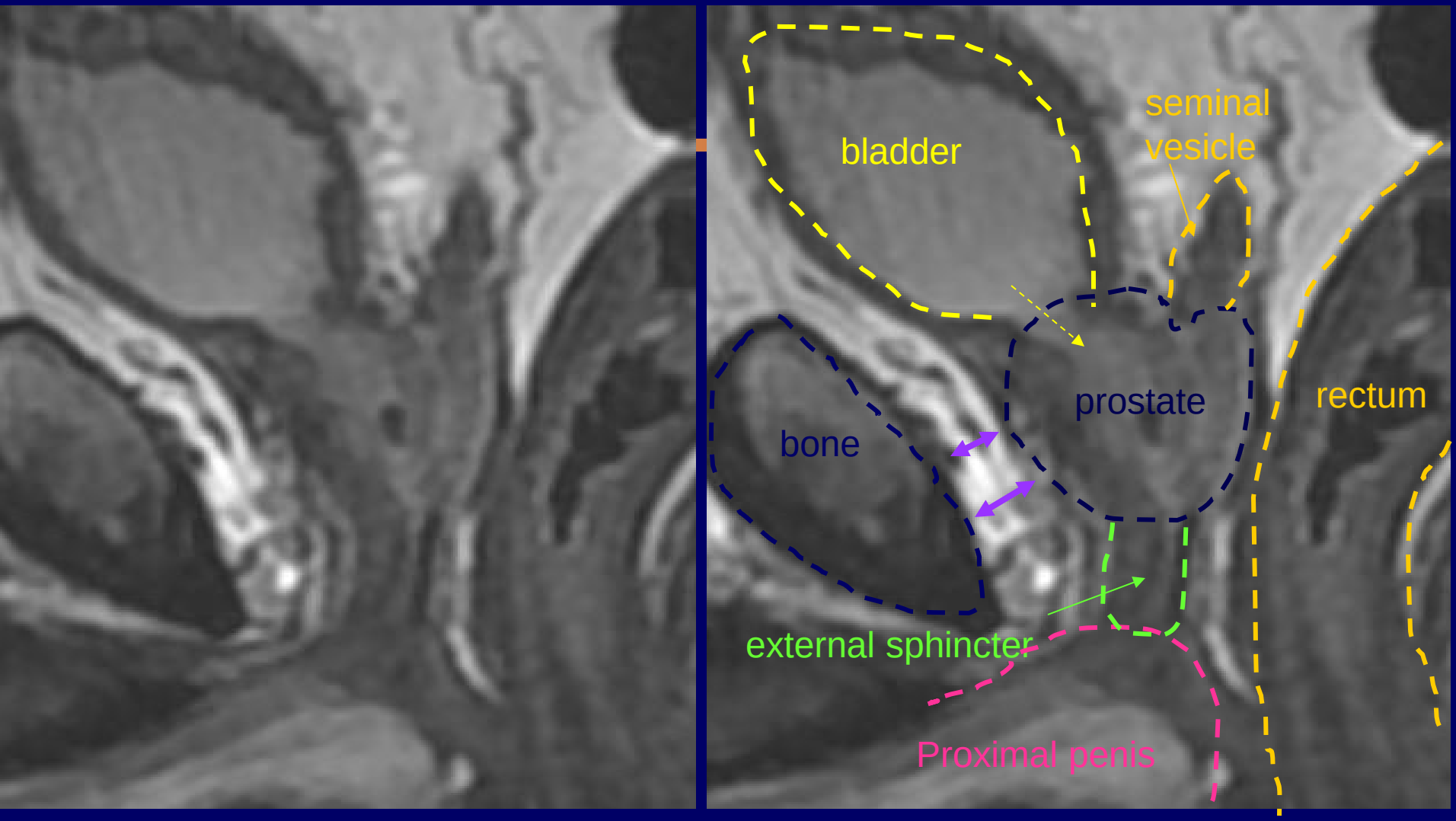
MRI | Observer 1 | Observer 2

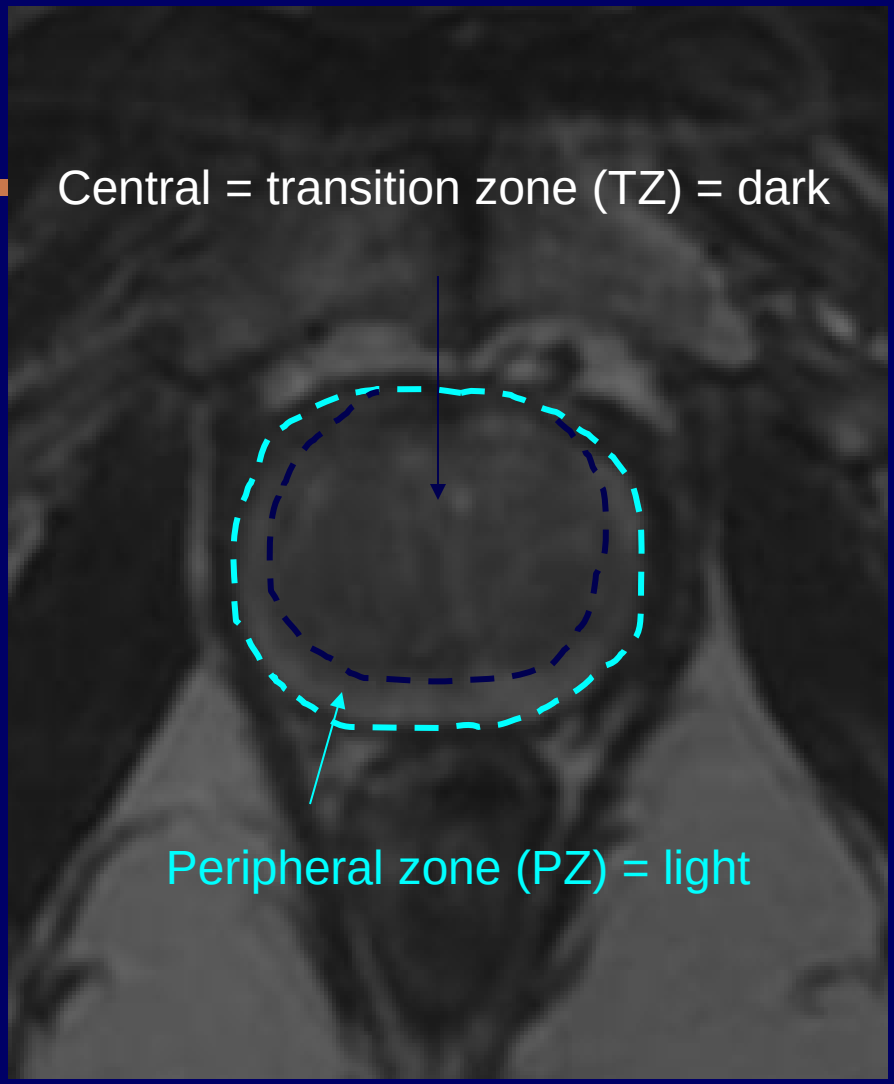


95% | 98% | 92%

V100 Agreement ✔



Prostate side view: Note labels on right. Prostate is not enlarged and does not extend into the bladder. Urethra opening from the bladder is open (yellow arrow). Sphincter is normal length and there is no bony restriction – note space between the bone and prostate (purple arrows)



normal prostate - normal appearance with light peripheral zone where tumors form and the dark central area called the transition zone – this enlarges with age

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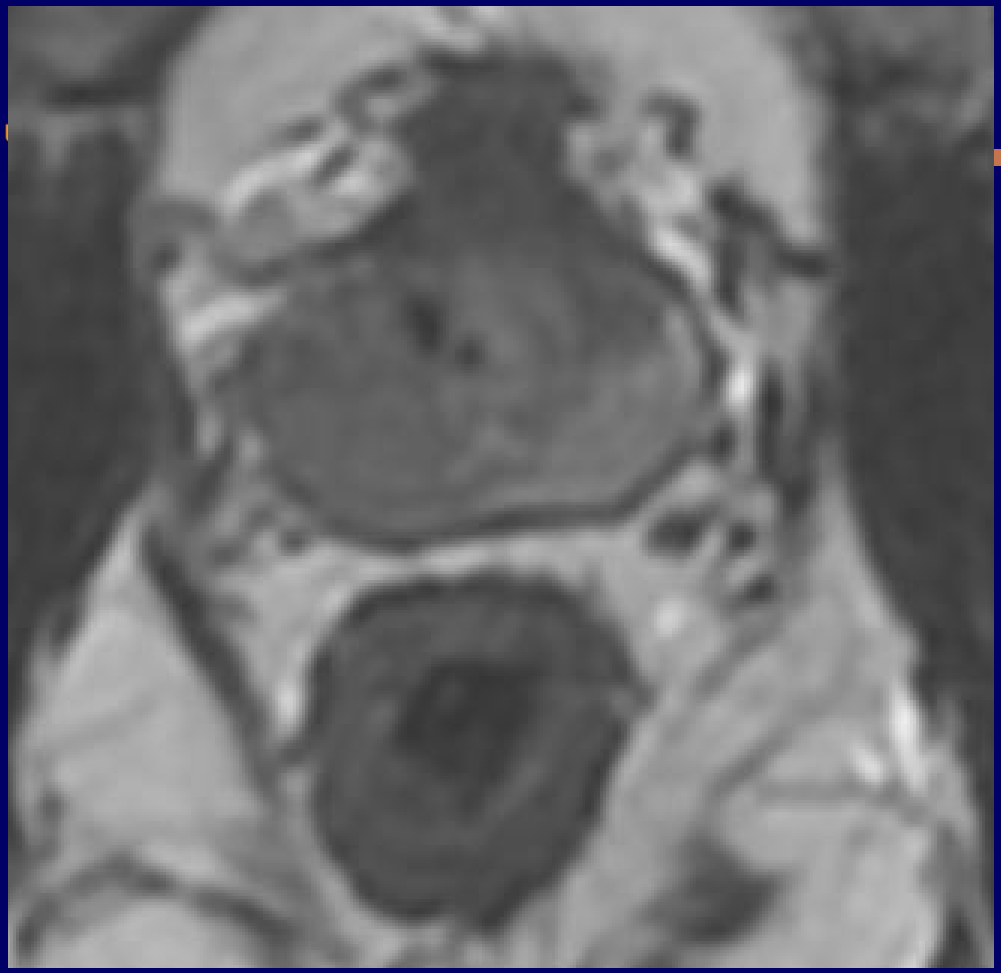
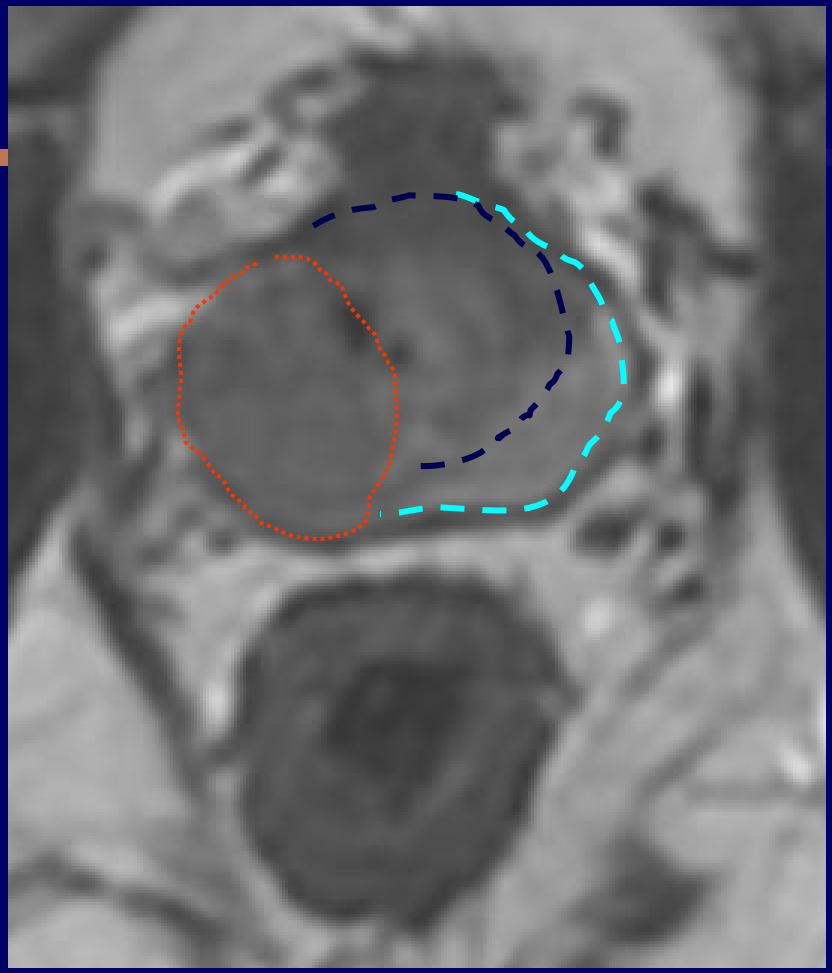
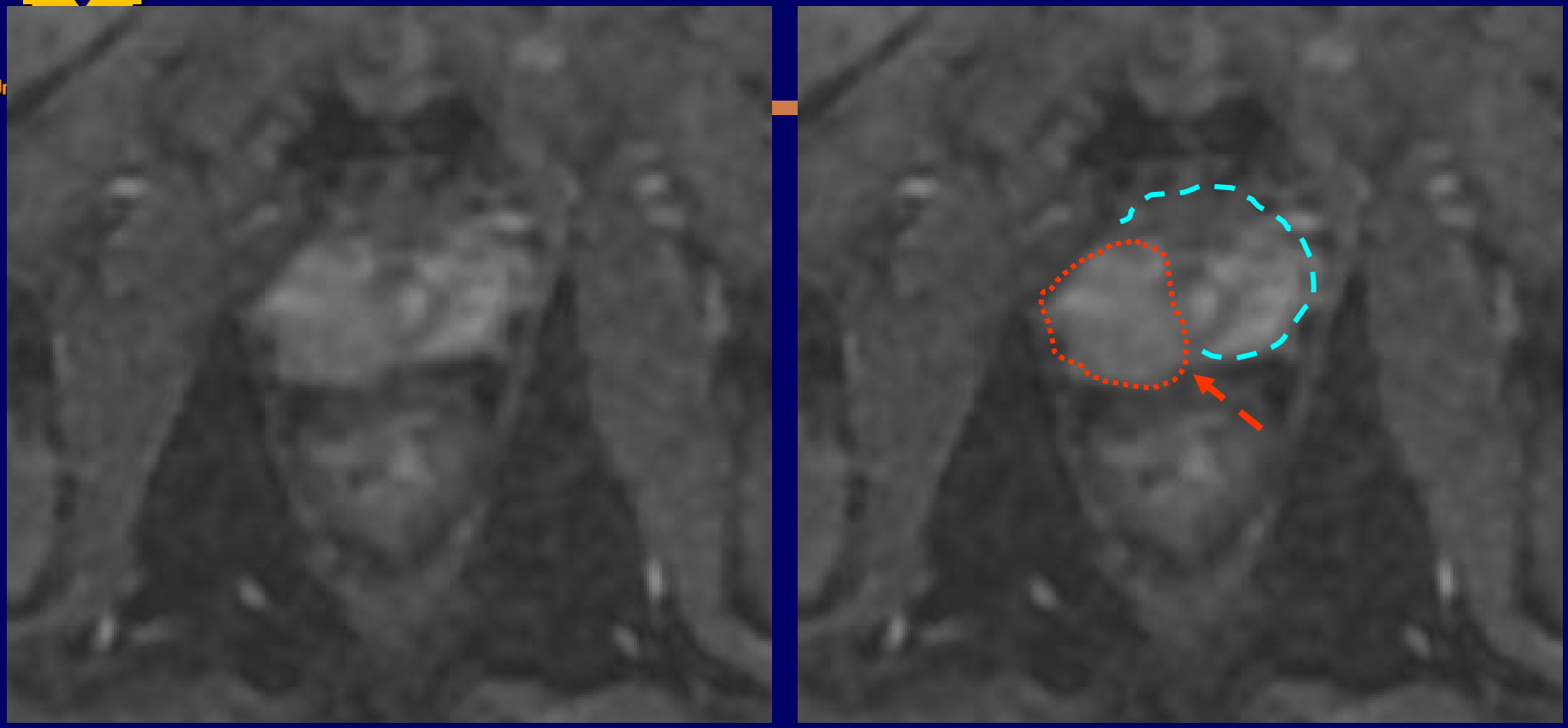
Multiparameter Imaging

- T2
- DCE
- DWI

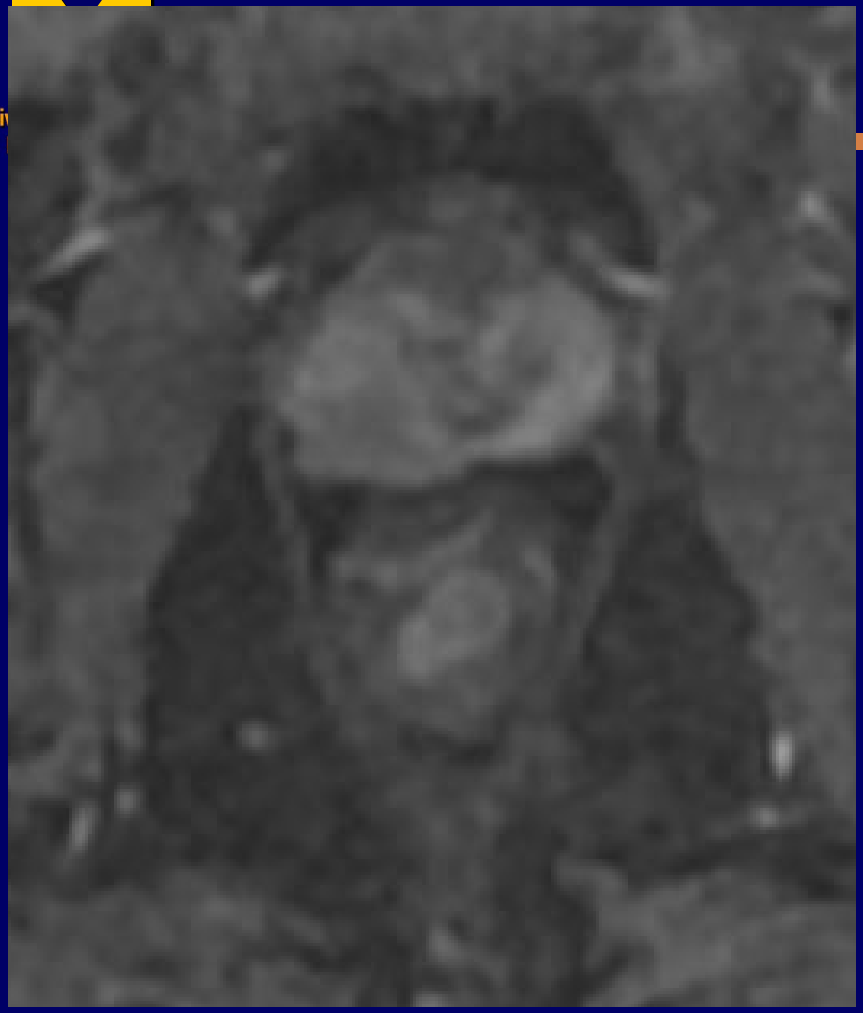


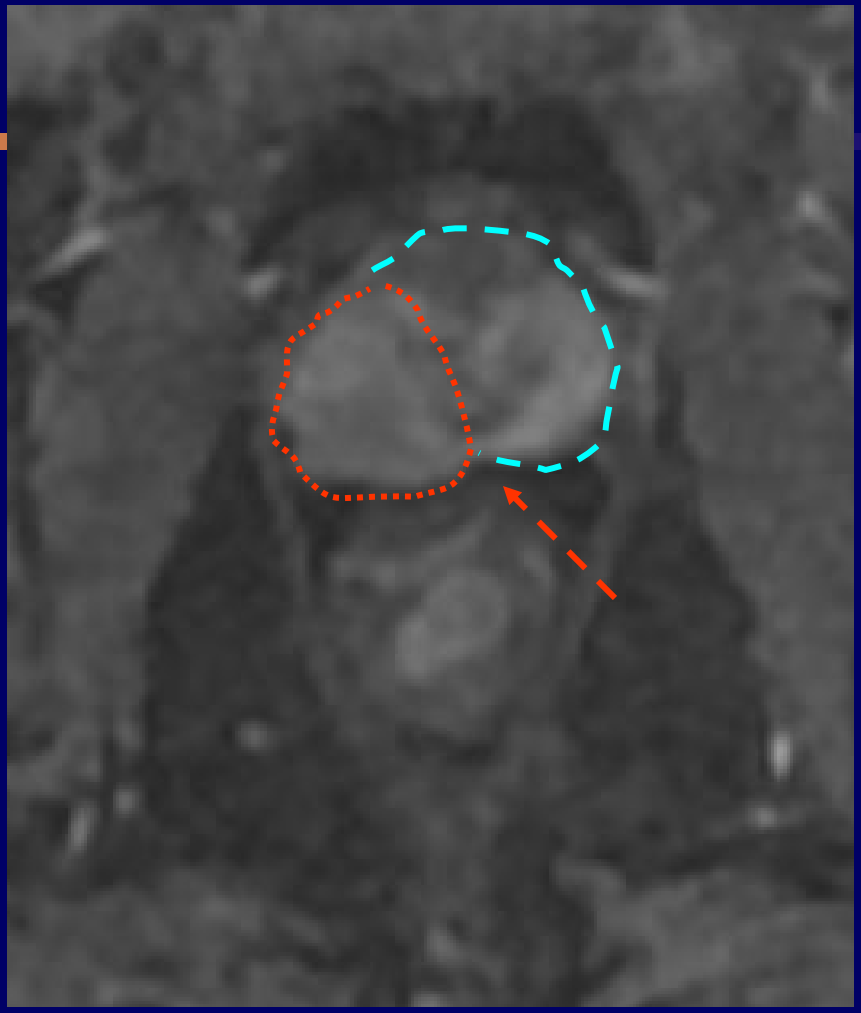


Right side of the gland panel is normal prostate with clear PZ and TZ. On the left side (red) note the dark area that extends into the TZ and from front to back. This is tumor



with contrast the area of concern on the left side of the panel is clearly seen, with a suggestion of extension beyond the gland (arrow).





Note the tumor on the left side of the panel (red) and possible extension beyond the capsule

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Imaging Recommendations

- CT – 2/3 mm cuts
- Prostate – mindful of pitfalls
- Rectum outer – 1 cm sup and inf
- Rectal wall - 0.5 cm contraction
- Urethra
  - Foley Day 0
  - Foley Optional later scans
- Penial Bulb

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Imaging Guidelines MR

- **T2 3 mm cuts (no rectal coil)**
  - **immediately before or after CT**
  - **Axial, coronal, sagittal**
- **Rectum – 1 cm above & below**
- **Bladder – axial MR**
- **Urethra – axial and Sag MR**
- **Register CT-MR around prostate only**
- **CT – seed positions**

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Impact of timing of imaging on dose reporting

- **Prostate edema**
- **Source displacement with time**
- **Optimal timing for post implant dosimetry**
- **Recommendations on timing of imaging**

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Edema

? **Needle insertion**

? **Bleeding – needle pentration**

? **General inflamation**

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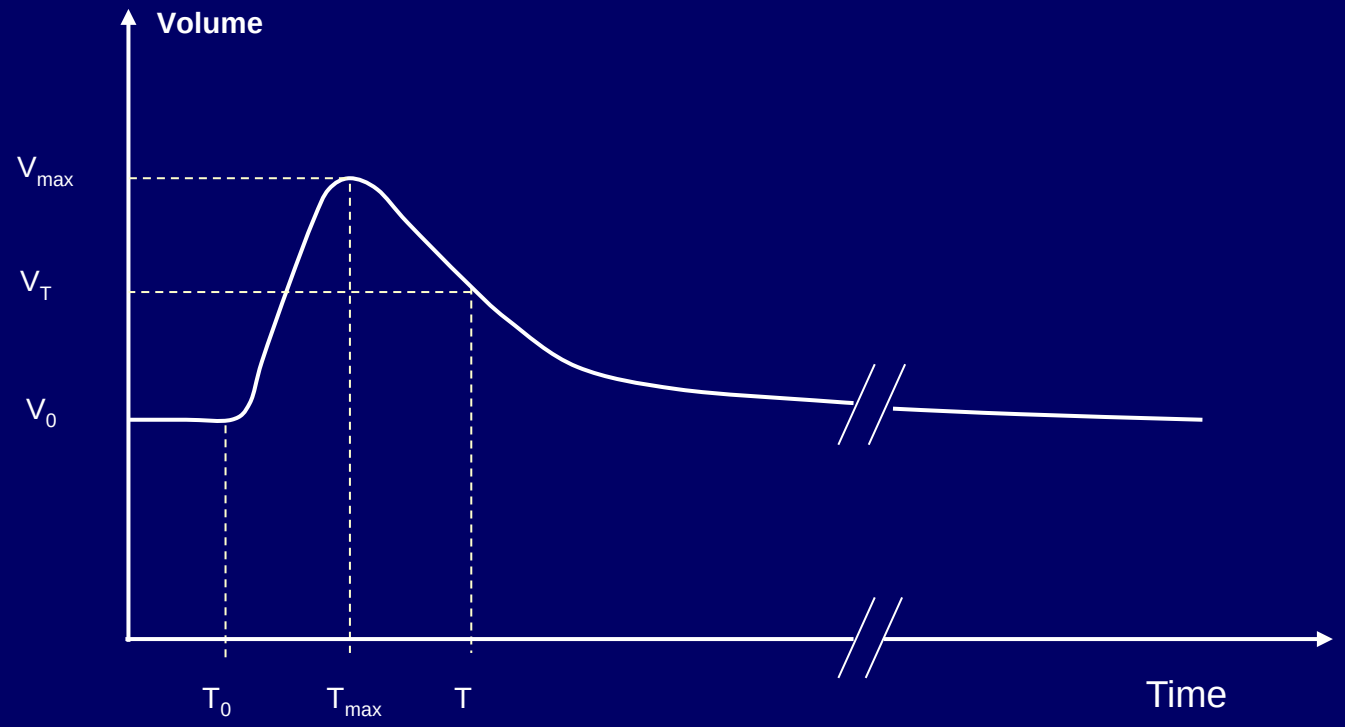
Edema Model



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Edema Model

- ? **T max**
- ? **Different imaging modalities**
- ? **Prostate Volumes**

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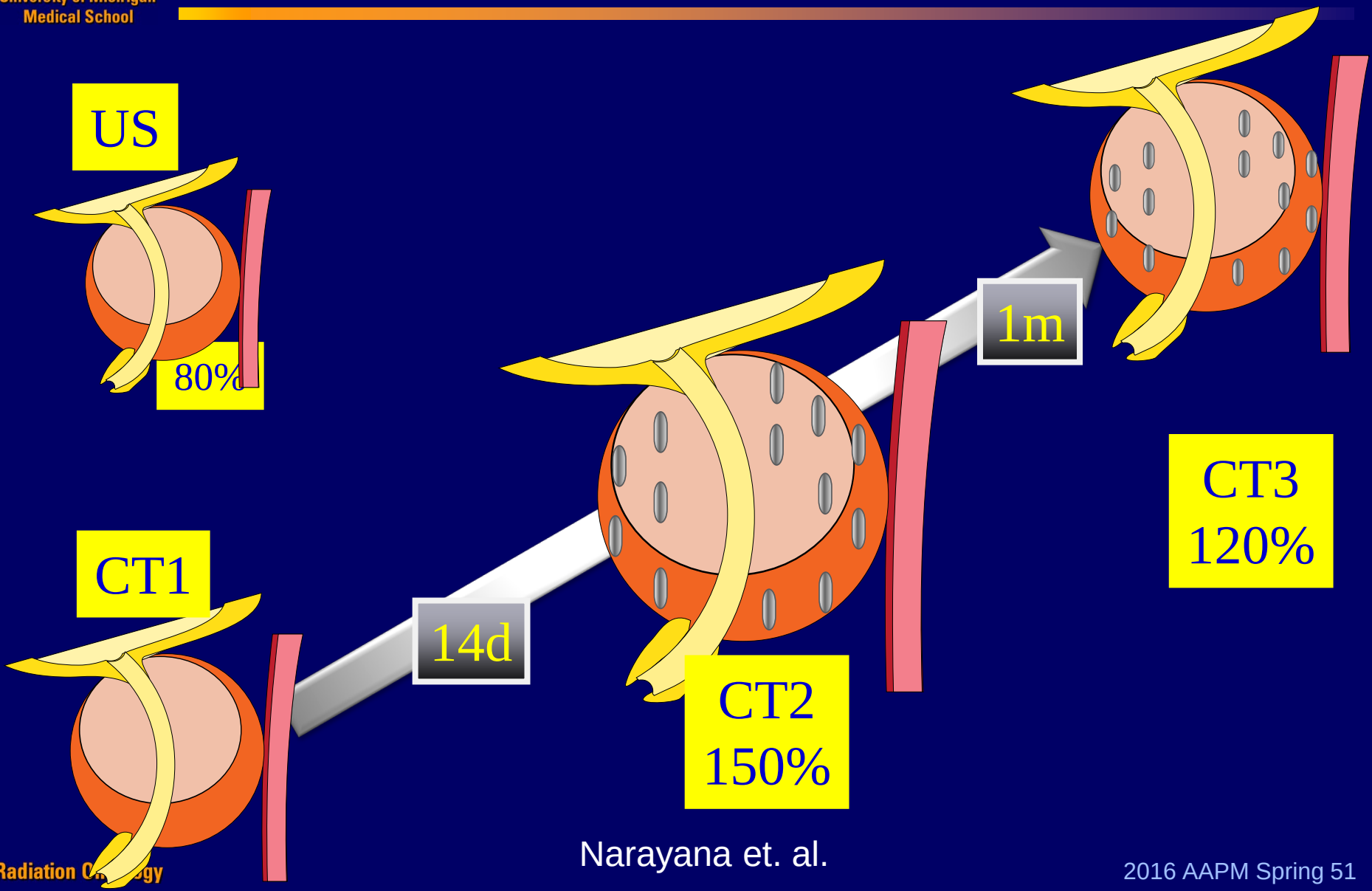
Edema



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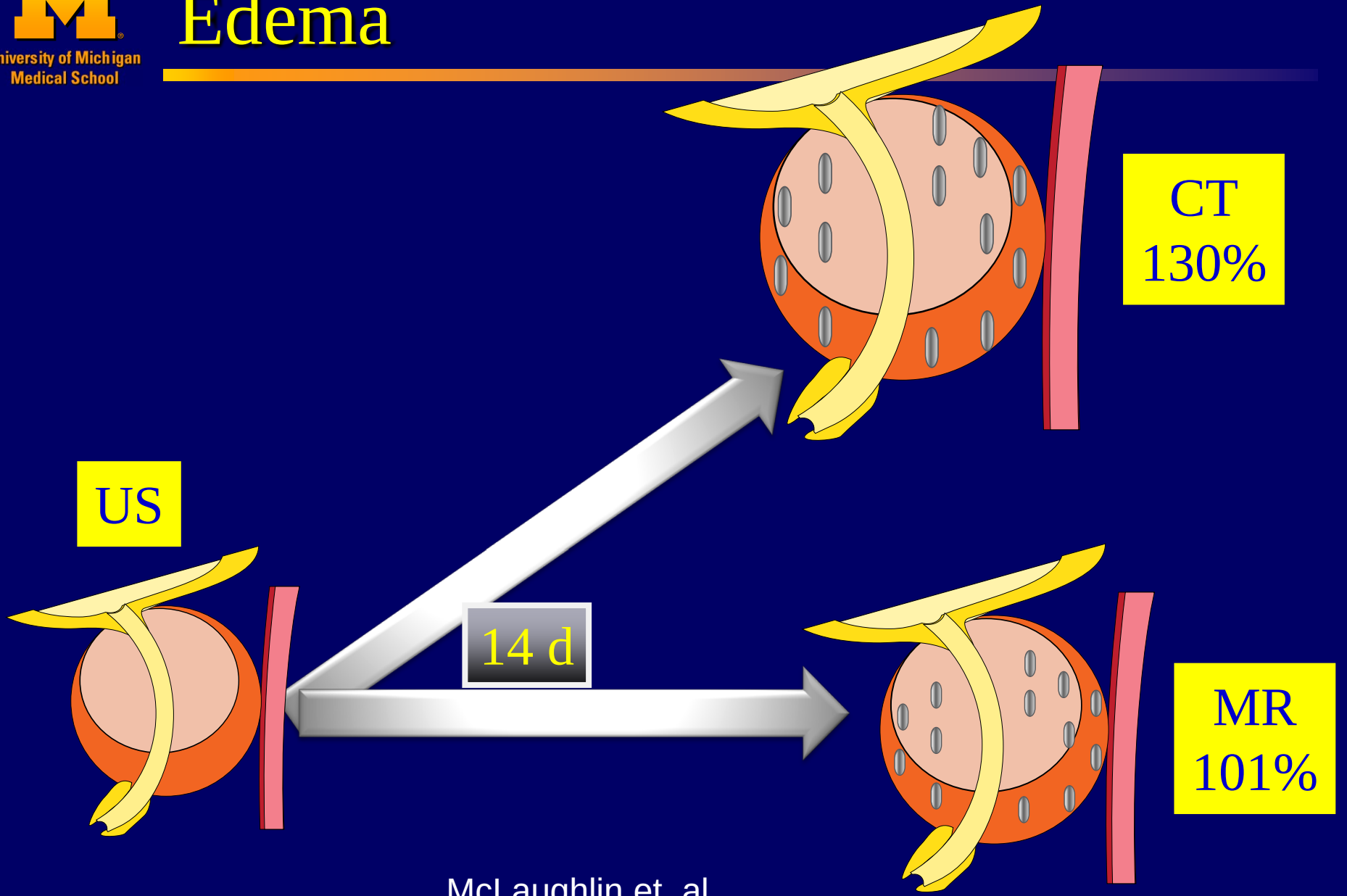
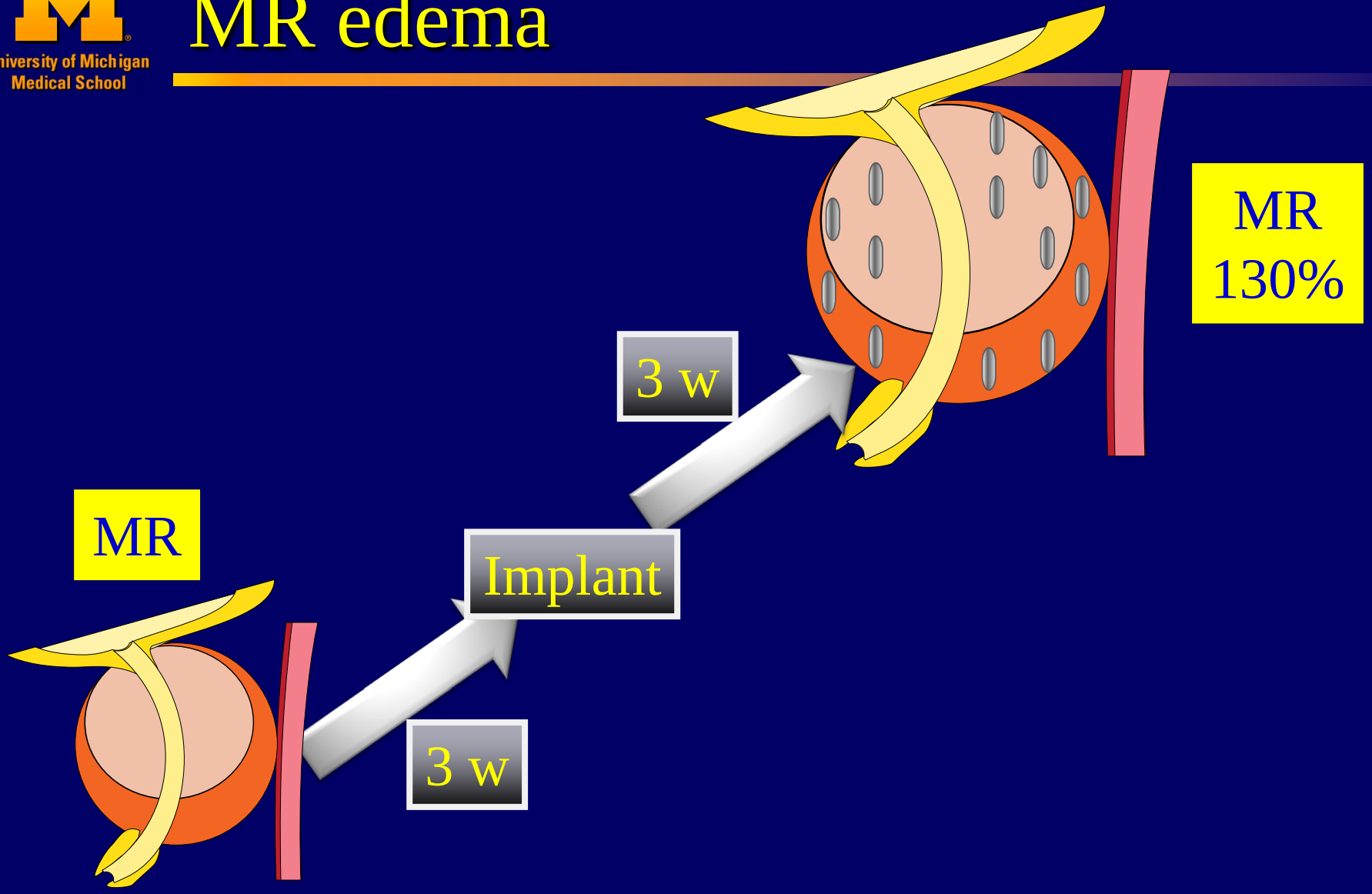
Edema



McLaughlin et. al

MR edema



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Edema Model

- **Max – 1 day**
- **Longer to resolve than initial swelling**
- **Quick resolution - 2 weeks**
- **Slow resolution – 2 to 4 weeks**
- **T1/2 ~ 10 d (4 to 25 days)**

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Effect on post implant dosimetry

- **Day 1 – edema large**
  - **underestimate dose**
- **Day 100 – edema resolved**
  - **overestimate dose**

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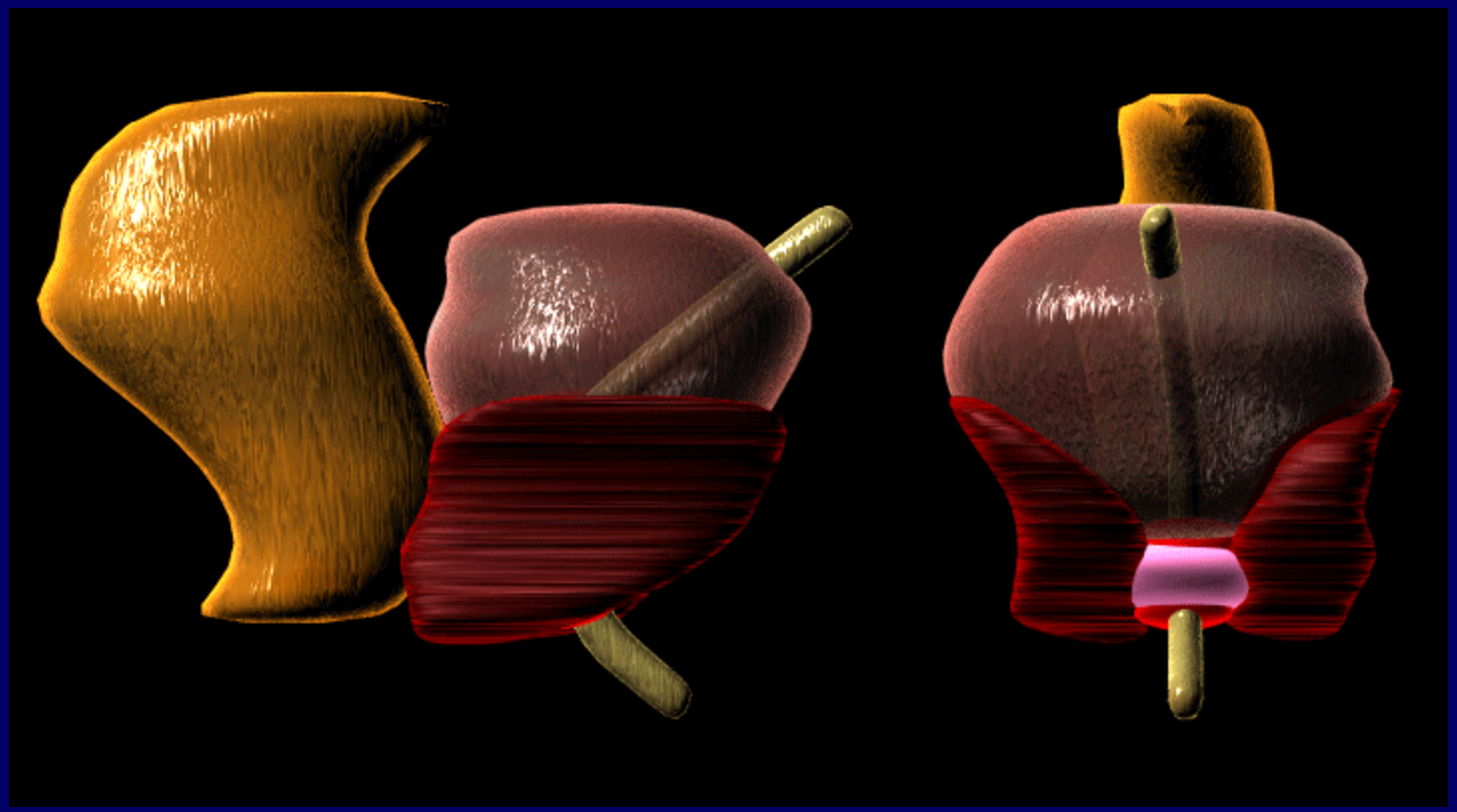
Edema Model

- **Assumes seeds move with the prostate**
  - **Seeds inside the prostate**
- ? **Stranded seeds**



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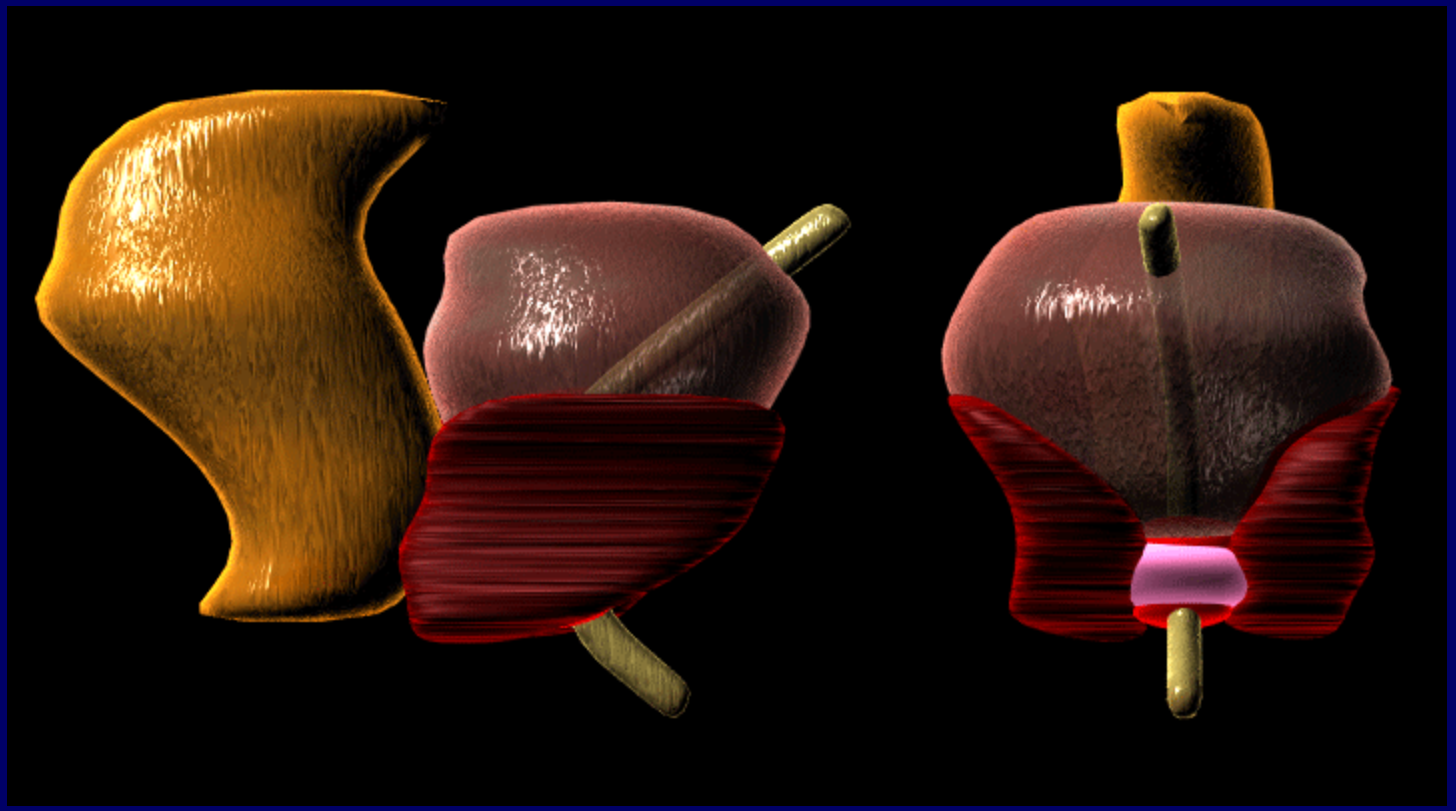

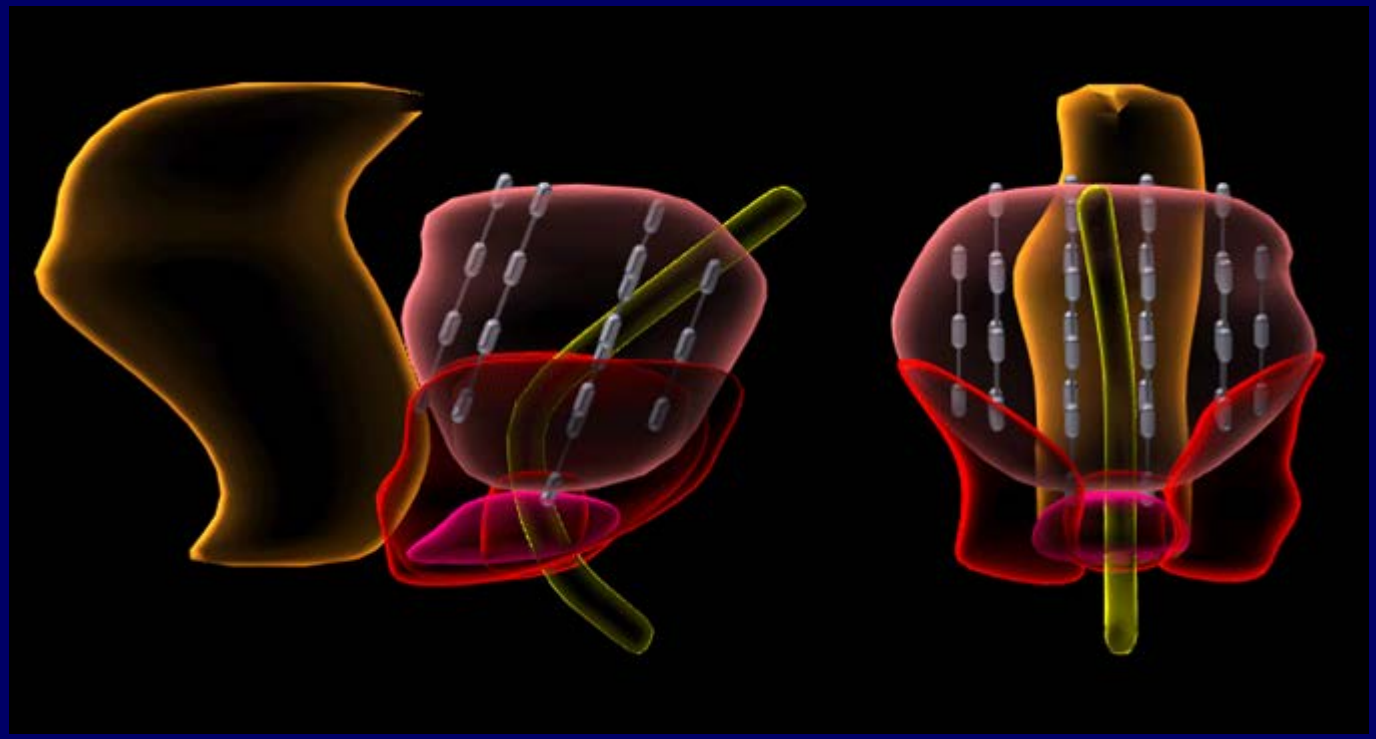

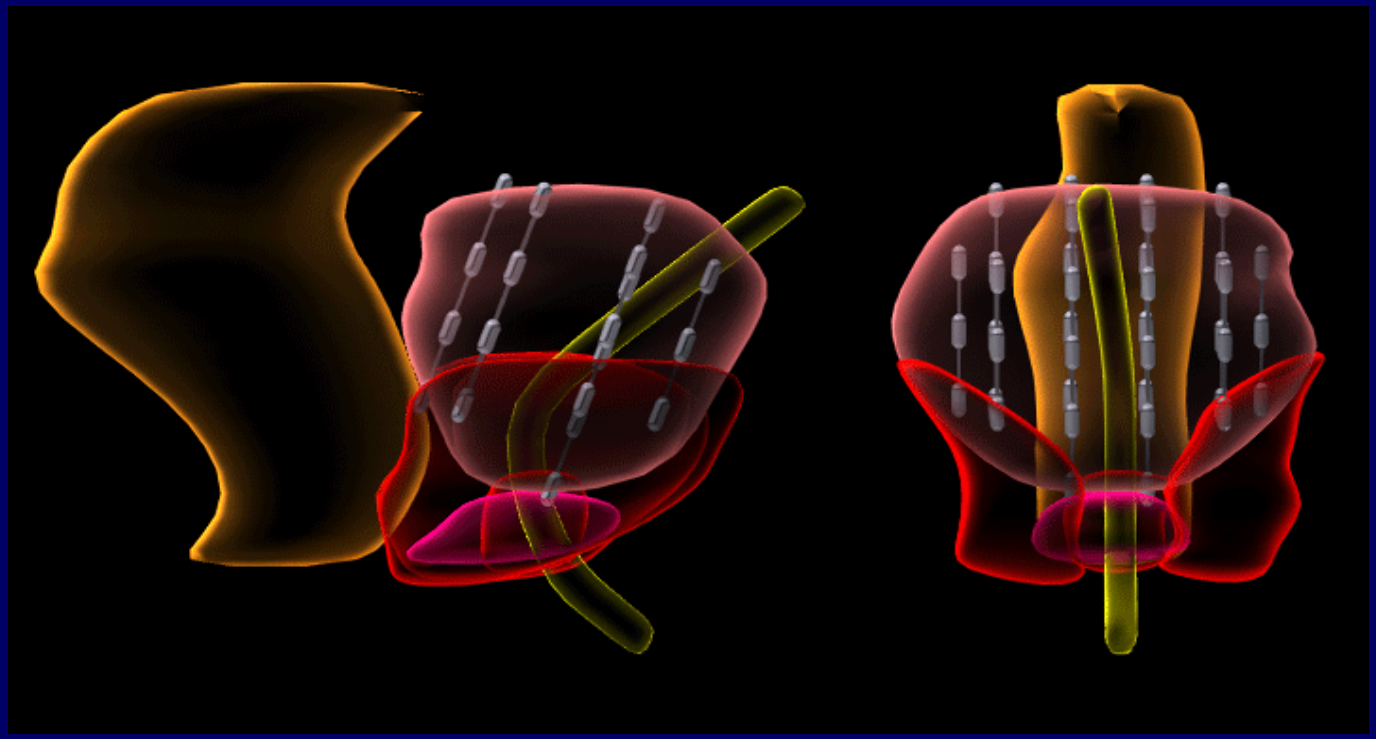

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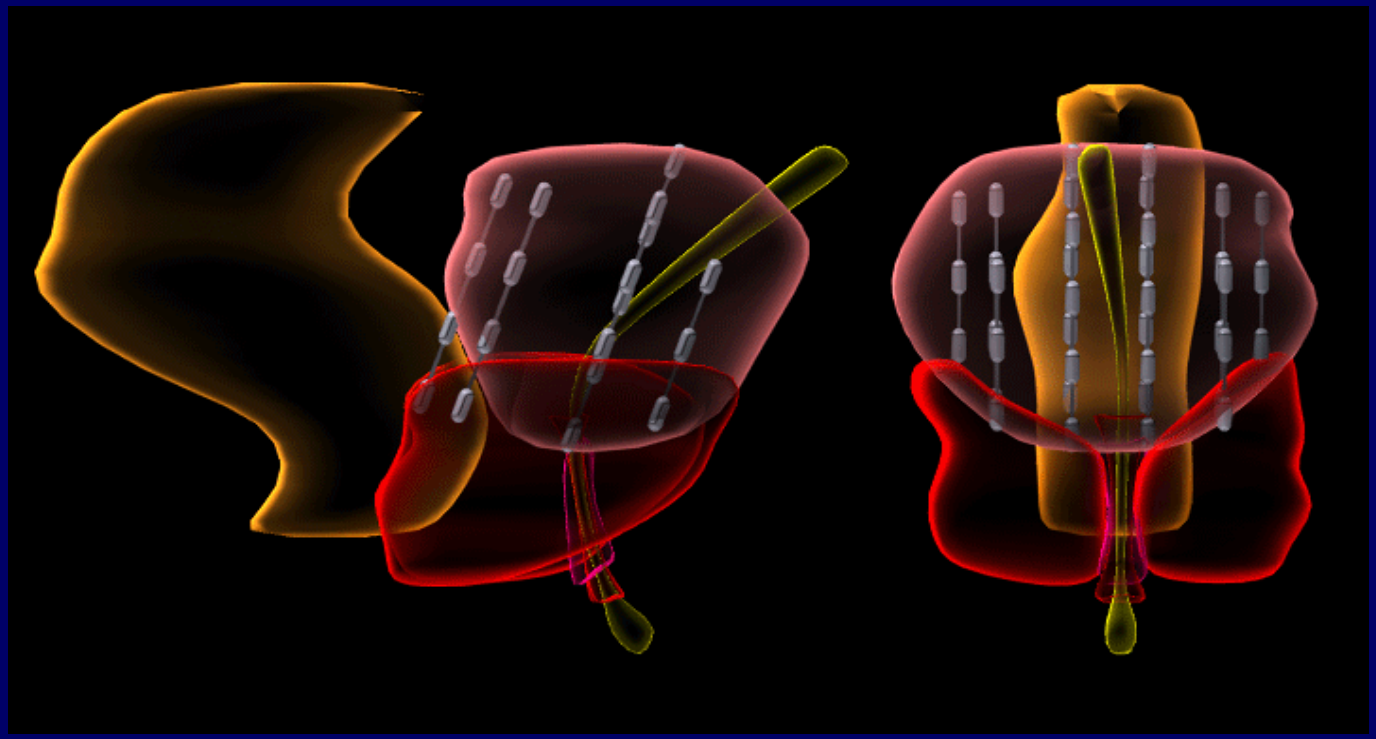

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By how much?

- **Timing of imaging**
- **Magnitude of prostate swelling**
- **Rate of resolution**
- **Radioactive $T_{1/2}$**
  - **↑ Short T1/2 & low energy**

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Optimal time

- ^{131}Cs 10±2 days
- ^{103}Pd 16±2 days
- ^{125}I 42±2 days

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Recommendation Timing of imaging

- **Pre-Implant prostate volume**
- **Implant day dosimetry**
  - **US immediate**
  - **CT/MR 2 to 4 h**
- **Post-Implant dosimetry**
  - **^{131}Cs 10±2 days**
  - **^{103}Pd 16±2 days**
  - **^{125}I 1month±1week**

The optimal timing for post implant dosimetry is

20% 1. Immediately following the implant

20% 2. 2 weeks after the implant

20% 3. 1 month after the implant

20% 4. 10, 16 and 42 days for ^{131}Cs, ^{103}Pd, ^{125}I respectively

20% 5. No post implant dosimetry is required

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Answer: 4

Reference: AAPM TG137, Nath et. al. 2009

Post implant prostate volume under- or overestimation is a result of

20%	1. The timing of dosimetry
20%	2. Magnitude of preimplant prostate swelling
20%	3. The rate of edema resolution
20%	4. The radioactive decay half-life
20%	5. All of the above

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20%	1. The timing of dosimetry
20%	2. Magnitude of preimplant prostate swelling
20%	3. The rate of edema resolution
20%	4. The radioactive decay half-life
20%	5. All of the above

Answer: 5
Reference: AAPM TG137, Nath et. al. 2009

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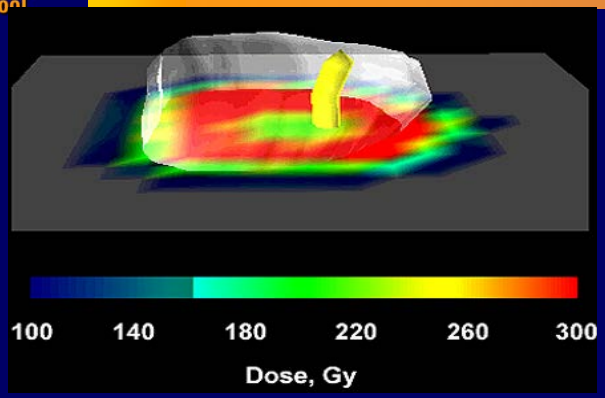
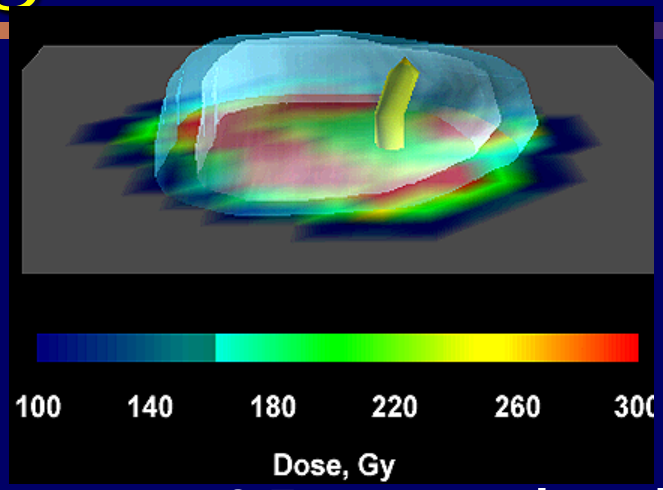
Impact of treatment planning approaches on dose reporting

- **Planning techniques**
- **Choice of isotope**
- **Choice of source strength**
- **Calculation Algorithm**
- **Dose indices for target and normal tissue**
- **Recommendations for planning and dose reporting**

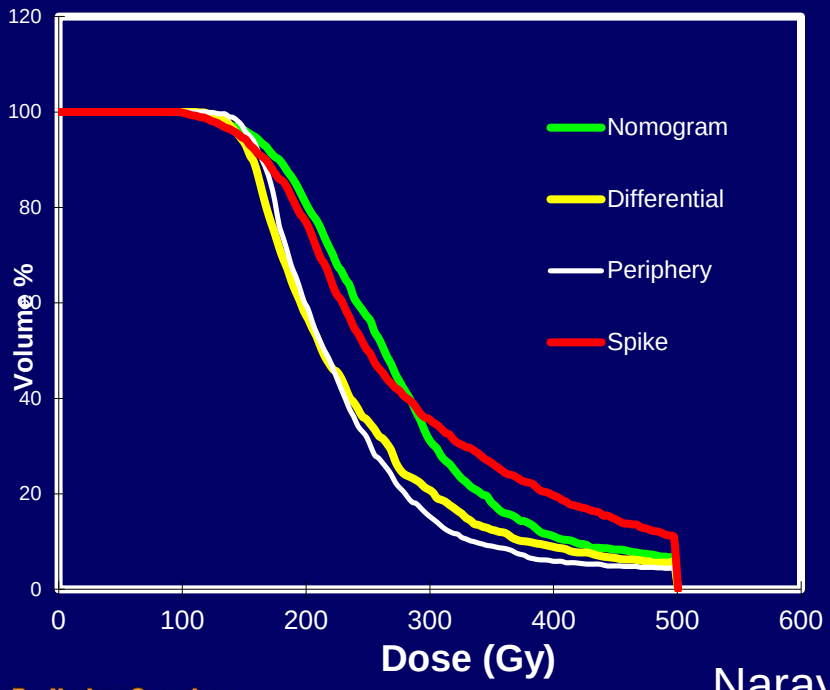
Peripheral loading?

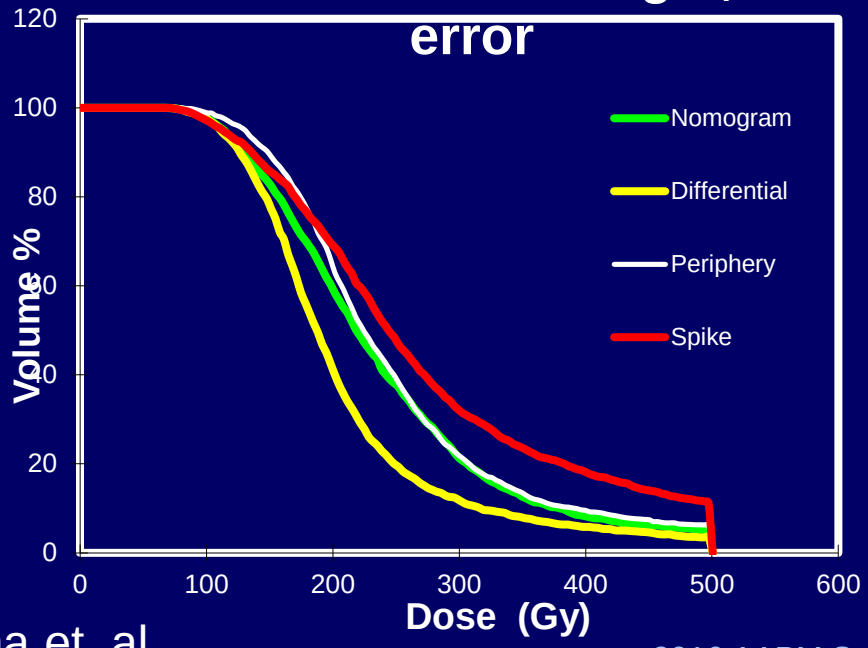


Prostate, with error



Prostate + 0.5 cm margin, with error





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Loose seeds vs strands

- **Loose Seeds**
  -  **Expand with the prostate**
  -  **Migrate to the lung**
- **Strands**
  -  **No migration**
  -  **May not track with the prostate**

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Seed Drop off

- **Stranded preloaded**
- **Mick applicator**
- **Thin stranded seeds**
- **Preloaded cartridge**

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Seed Drop off

	Rapid Strand	Mick applicator	Thin strand	Preloaded cartridge
Prostate V100 %	96.5±2	93.2±5	93.4±4	94.1±3
Prostate D90 Gy	109±7	102±19	106±17	101±8
Rec wall D1cc Gy	95±18	70.4±8	70±23	73±11
Rec wall D2cc Gy	59±17	53±18	52±18	54±10
Urethra D10 Gy	156±25	163±36	164±21	158±31

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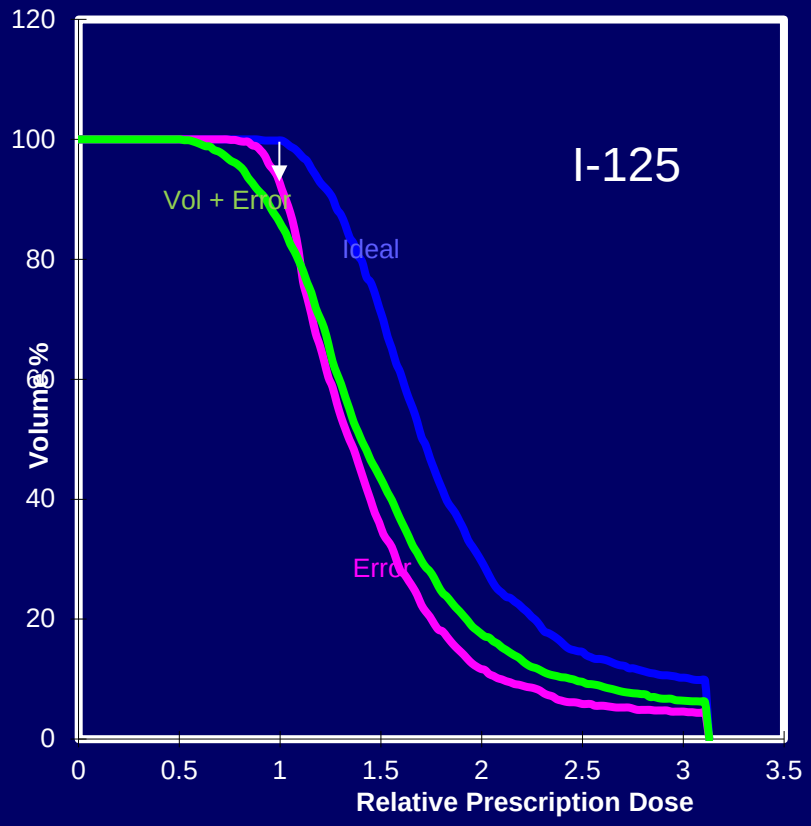
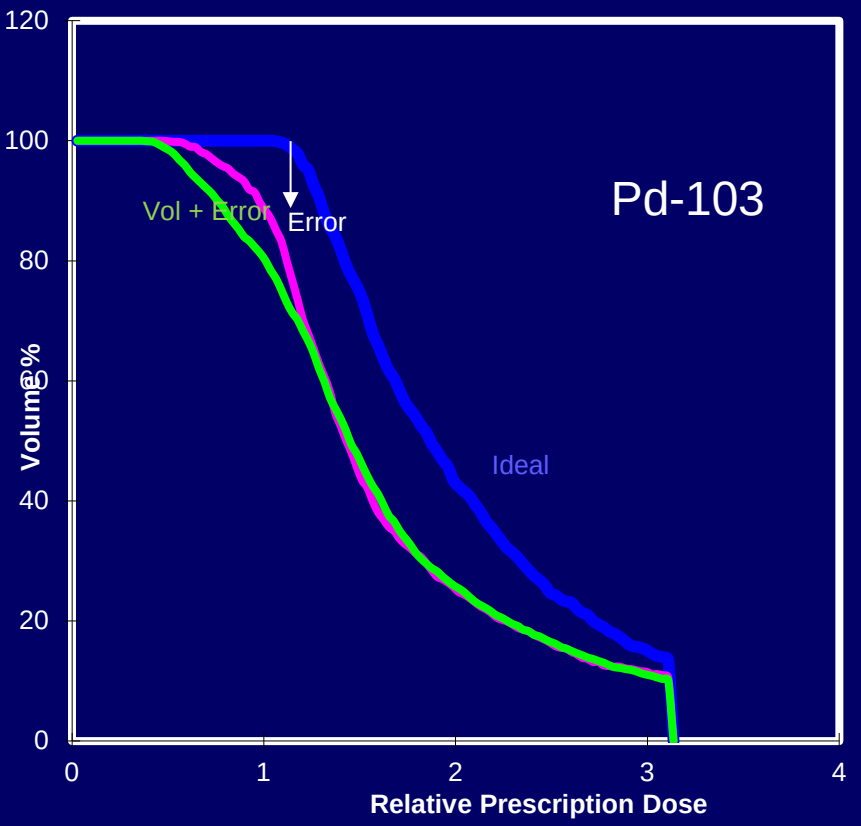
Choice of Isotope

- ^{131}Cs
- ^{103}Pd
- ^{125}I

I125

- **I-125 vs. Pd-103**





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Seed Drop off

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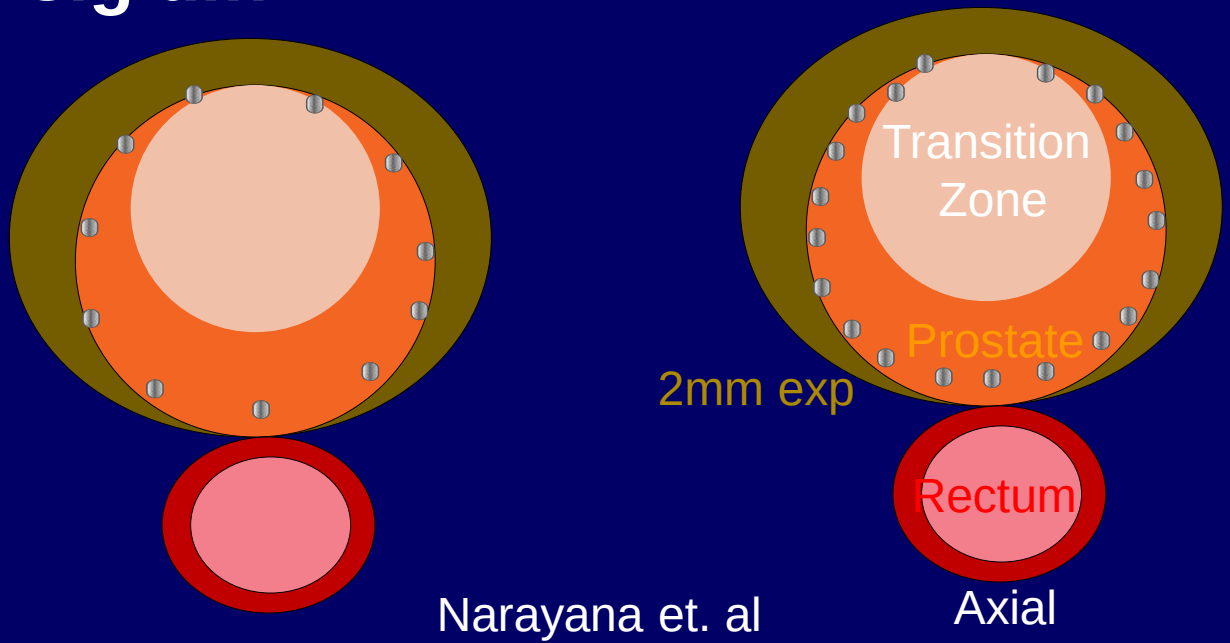
Rec wall D2cc Gy	59±17	53±18	52±18	54±10
Urethra D10 Gy	156±25	163±36	164±21	158±31

Source strength?

- **Prospective Randomized Trial**
  - **high vs. low mCi**
  - **No sig diff**



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Calculation Algorithm

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Recommendations

- GTV
- CTV – no posterior expansion
- PTV=CTV
- OAR
  - Urethra
  - Rectum
  - Penile bulb

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Recommendations

- **Dose clinical decision**
  - **^{131}Cs 115 Gy ? (100-125 Gy)**
  - **^{103}Pd 125 Gy**
  - **^{125}I 145 Gy**

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Recommendations Planning criteria

- **CTV**
  - **V100> 95% of CTV**
  - **D90 > 100 % of Rx**
  - **V150 < 50% of CTV**
- **Rectum D2cc < Rx dose**
- **Urethra**
  - **D10 < 150% Rx dose**
  - **D30< 130% of Rx dose**
- **Penile bulb - investigational**

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Recommendations Dose Reporting

- **DVH for target**
  - **Primary, D90,V100, V150**
  - **Secondary V200, V90,D100**
- **Urethra – D10**
  - **Secondary: D0.4cc, D30, D5**
- **Rectum – D2cc,**
  - **Secondary: D0.1 cc, V100**

Primary dose parameters for prostate implant that should always be reported are

20%	1. D_{90}
20%	2. V_{100}
20%	3. D_{90} & V_{150}
20%	4. D_{90} V_{100} & V_{150}
20%	5. D_{90} D_{100} V_{90} V_{100} & V_{150}

Primary dose parameters for prostate implant that should always be reported are

20%	1. D_{90}
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20%	5. D_{90} D_{100} V_{90} V_{100} & V_{150}

Answer: 4

Reference: AAPM TG137, Nath et. al. 2009

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Intraoperative treatment planning strategies

- **Intraoperative preplanning**
- **Interactive planning**
- **Dynamic dose calculations**
- **Recommendations on Intraoperative planning and evaluation**

Pre vs. OR planning

Pre

- 2 procedures
- Reproducible setup
- Time pressure
- # of seeds ordered

OR

- Target Volume
- Stress

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Techniques

- **Intraoperative**
  - **Creation of plan in OR just before the implant**
  - **Immediate execution**
- **Interactive**
  - **Stepwise refinement**
  - **Computerized dose calculations based on image feedback**
- **Dynamic**
  - **Calculations constantly updated using continuous deposited-seed-position feed back**

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Recommendations

- **Enhanced implant quality**
- **Post implant dosimetry**
  - **Edema**
  - **Seed migration**

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Sector anaylsis

- **Research setting**

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Biophysical Models

- **BED for prostate implants**
- **EUD calculations**
- **TCP**
- **Recommendations for reporting radiobiological response**

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BED

$$BED = D[1 + D/(\alpha/\beta)]$$

$$BED = D(T_{eff})RE(T_{eff}) - \ln 2 \frac{T_{eff}}{\alpha T_p}$$

$$RE(T) = 1 + (\frac{\beta}{\alpha}) \frac{\dot{D}_0}{(\mu - \lambda)} \times \frac{1}{1 - e^{-\lambda T_{eff}}} \{1 - e^{-2\lambda T_{eff}} - \frac{2\lambda}{\mu + \lambda}(1 - e^{-(\mu+\lambda)T_{eff}})\}$$

$$T_{eff} = T_{avg} \ln[\alpha \cdot D \cdot \frac{T_p}{T_{1/2}}]$$

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BED for inhomogeneous dose

$$BED = -\frac{1}{\alpha}\ln\left(\sum_i v_i e^{-\alpha \cdot BED_i}\right)$$

$$D(T_{eff})RE(T_{eff}) - \ln 2\frac{T_{eff}}{\alpha T_p} = -\frac{1}{\alpha}\ln\left(\sum_i v_i e^{-\alpha \cdot BED_i}\right)$$

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Equivalent uniform EBRT dose

$$EUD_d = \frac{-\ln\left(\sum_i v_i e^{-\alpha \cdot BED_i}\right)}{\alpha + \beta d - \gamma \ln 2/(d \cdot T_p)}$$

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TCP

$$TCP(D) = \frac{1}{1 + \left(TCD_{50} / D\right)^{k}}$$

$$TCP = \exp[-N_0 \exp(-\alpha \cdot BED)]$$

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Example

Indices	Radionuclide		
	^{125}I	^{103}Pd	^{131}Cs
Dose (Gy)	145.0	125.0	120.0
BED (Gy)	110.9	115.4	117.3
EUD (Gy)	69.7	72.6	73.8
TCP (%)	74.1	85.9	89.2
T_{eff} (day)	235.3	93.9	60.8

Calculated with: α = 0.15 Gy^{-1}, β = 0.05 Gy^{-2}, α/β = 3.0 Gy, T_p = 42 days, repair half-life of 0.27 hour, and $N_0 = 5x10^6$

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Linear Quadratic Model

$$ERD = Nd\left[1 + \frac{d}{\alpha/\beta}\right]$$

- **N= # fx**
- **D = dose/fx**
- **α/β = 3Gy**

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Linear Quadratic Model

$$ERD = NRt\left[1 + G\frac{Rt}{\alpha/\beta}\right]$$

- **R = dose rate**
- **t = time**

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Linear Quadratic Model

$$G_{LDR} = \frac{2}{\mu t}\left[1 - \frac{\left(1 - e^{-\mu t}\right)}{\mu t}\right]$$

- μ = repair rate const

$$ERD = NRt\left[1 + G\frac{Rt}{\alpha/\beta}\right]$$

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Linear Quadratic Model

$$ERD_{IMP} = R/\lambda\left[1+\frac{R}{(\mu+\lambda)\alpha/\beta}\right]$$

- **R = dose rate**
- **λ = decay constant**
- **μ = repair rate constant**
- **α/β = tissue specific parameter**

Linear Quadratic Model

- **Beam ?**
  - **d = 2 Gy/fx**
  - **α/β = 3Gy**
- **Brachy**
  - **R = 4.4 cGy/h**
  - **λ = 0.693/59.4 d^{-1}**
  - **α/β = 3Gy**
  - **μ = .4 h^{-1}**

$$ERD = D_{eq}\left[1+\frac{d}{\alpha/\beta}\right]$$

$$ERD = R/\lambda\left[1+\frac{R}{(\mu+\lambda)\alpha/\beta}\right]$$

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Recommendations

- **Adequate information**
  - **BED**
  - **EUD**
  - **TCP**
  - **Other**

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Recommendation

- **Model parameters should be specified**
- **All parameters required to calculate the biodose should be specified**
- **Encourage vendors to provide models**

What is the cause of most inconsistencies in dose reporting?

20%	1. Identification of source positions
20%	2. Dose calculations
20%	3. Target delineation
20%	4. Timing of the imaging study
20%	5. Type of isotope used

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20%	5. Type of isotope used

Answer: 3
Reference: AAPM TG137, Nath et. al. 2009