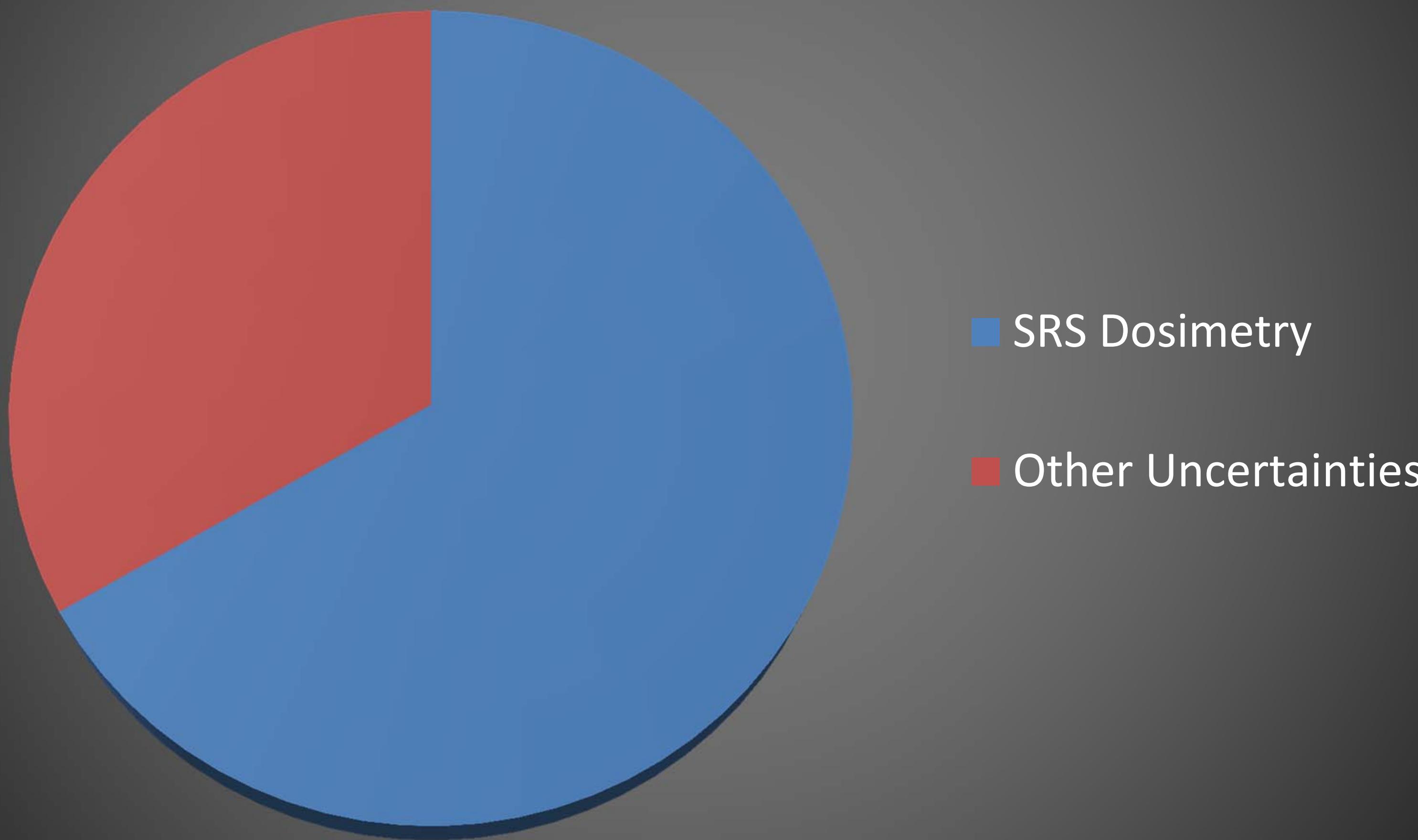
Hot Topics in SRS: Small Field Dosimetry & Other Treatment Uncertainties

Sonja Dieterich, PhD
University of California Davis

Lecture in Two Parts



SRS DOSIMETRY

Outline

1. What is a Small Field?
2. Small Field Reference Dosimetry
3. Output Factors/Total Scatter Factors
4. PDD/TPR
5. OAR and volume averaging of detectors
6. Dose rate dependence

WHAT IS A SMALL FIELD?

Small Field Targets

- SBRT (typically on linac with MLC):
  - Lung mets are smallest tumor treated
  - 2 cm x 2 cm PTV lower limit
  - Equivalent to 4 MLC leaf pairs (except HD MLCs)
- SRS (in CNS, typically cones):
  - Trigeminal neuralgia/functional Tx (∅ 4 mm)
  - Largest brain met: 40 mm in diameter
  - Human Vertebral body: 28 mm (H) x 45 mm (W)

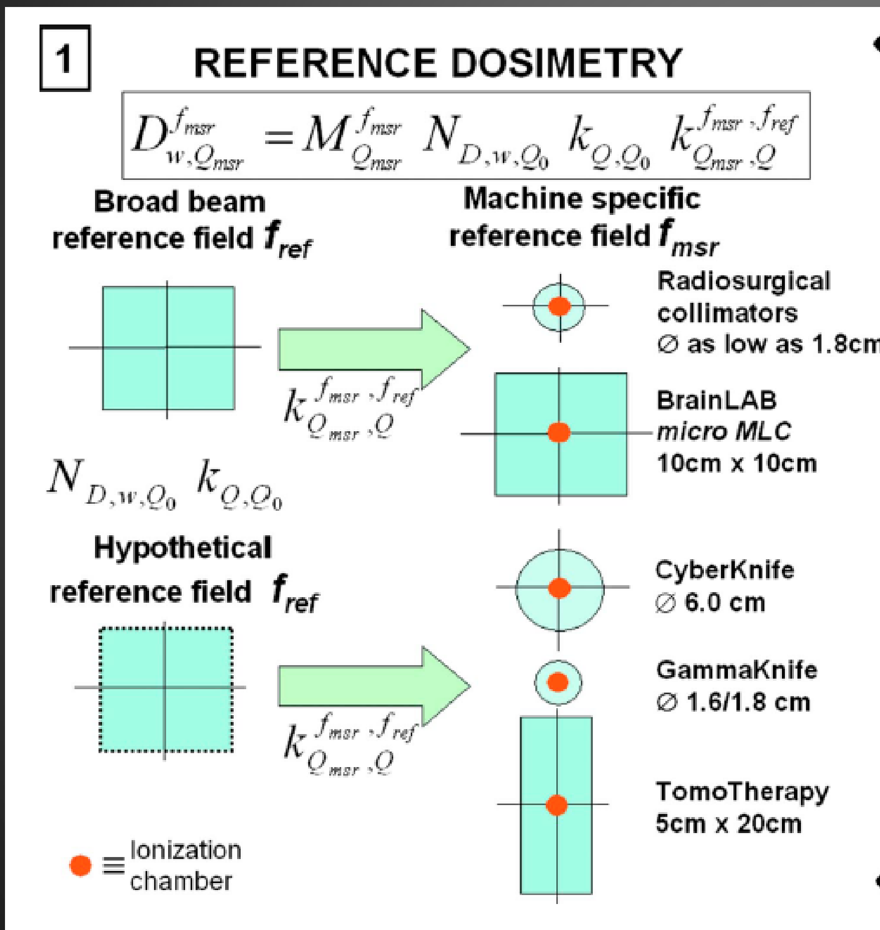
Smallest Measured Field at Commissioning

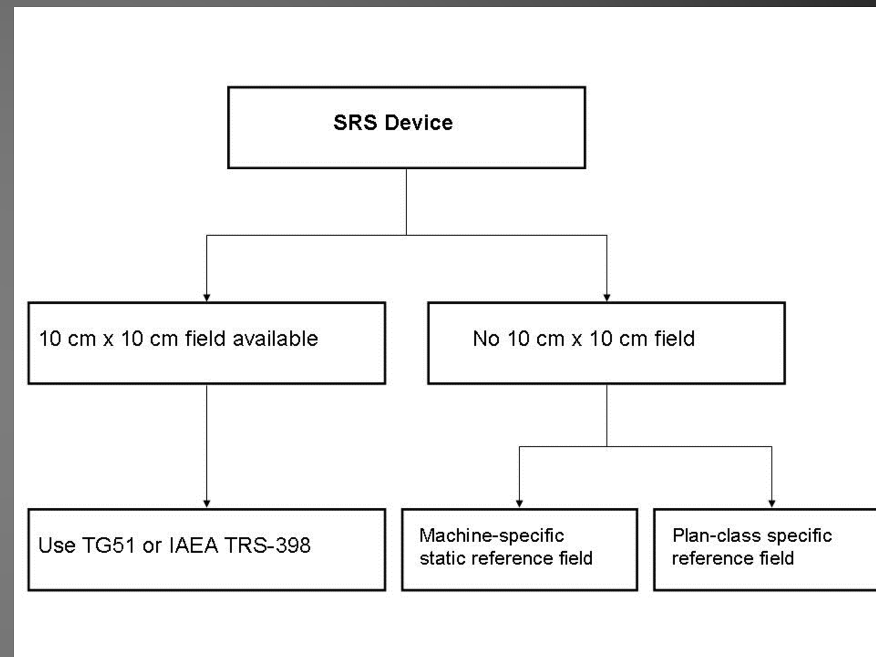
- Linac with MLC:
  - ~2000: 4 cm x 4 cm
  - ~2006: 3 cm x 3 cm
  - ~2010: 2 cm x 2 cm
  - ~2012: 0.5 cm x 0.5 cm
- Cones:
  - GK: ……………..4 mm – 16 (18) mm
  - BrainLab: …….4 mm – 50 mm
  - CK: ………………4 mm – 75 mm (across all SADs)

- AAPM TG-106: ≤ 4 cm x 4 cm
- 4 cm x 4 cm ***VERY*** different from 0.5 cm x 0.5 cm!

SMALL-FIELD REFERENCE DOSIMETRY

Reference Dosimetry: The IAEA concept

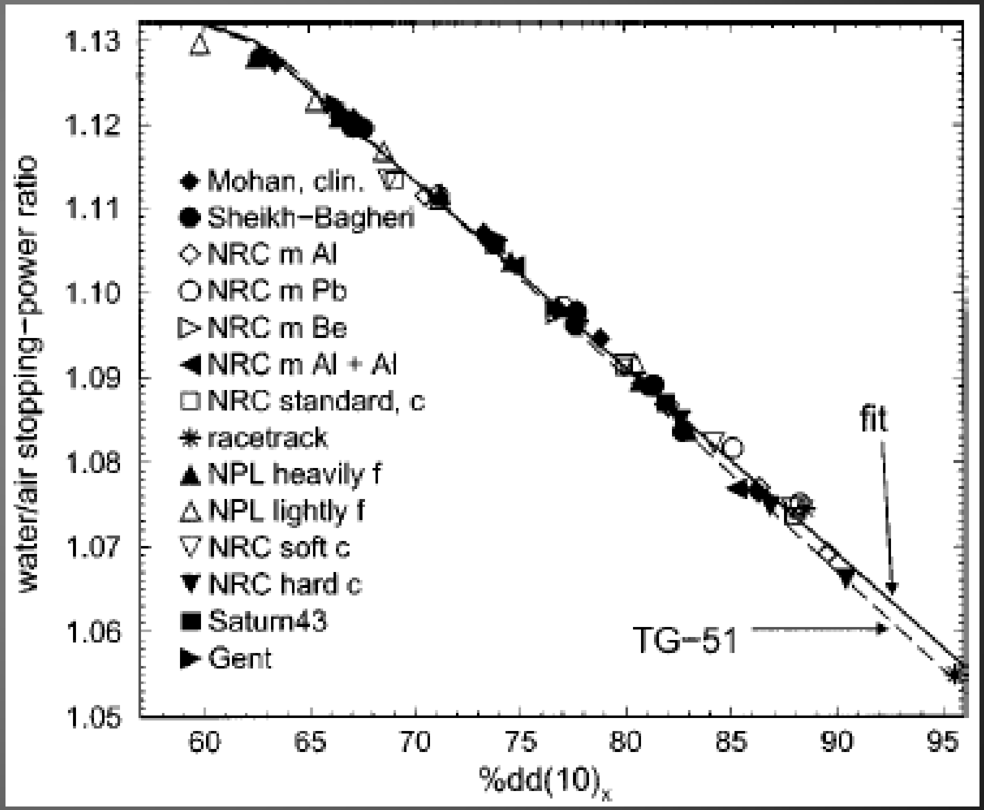




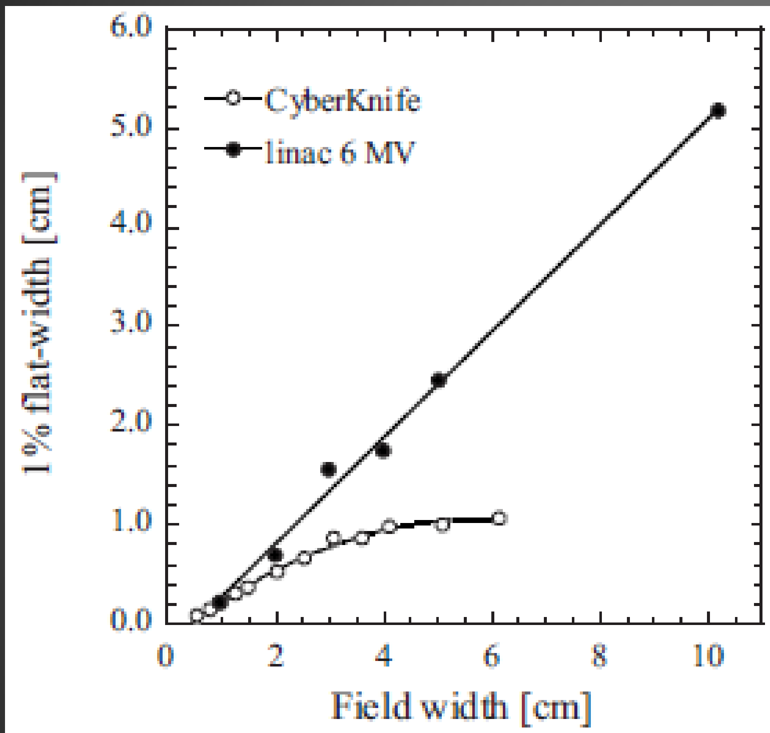
Alfonso et al, Med Phys (2008), 5179

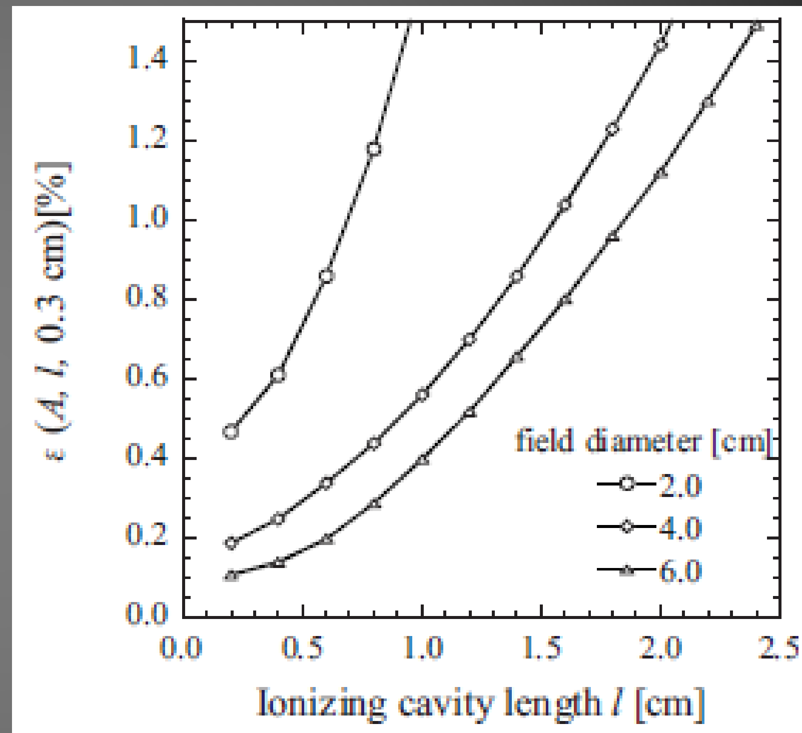
TG-51 in FFF Beams

- CyberKnife and Tomotherapy
- Linacs:
  - Siemens (Bayouth 2007)
  - Elekta (Georg 2009)
  - Varian (Vassiliev 2006)
- **Kalach & Rogers, Med Phys 30 (2003) 1546**
- TG51 is using $\%dd(10)_x$



Length of Reference Chamber in FFF





- Dose flatness sufficient for Farmer-type chamber?
- **Kawachi et al, Med Phys (2008) 4591**
- Option1: cross calibrate a short chamber with Farmer-type chamber
- Option 2: Use Farmer with mathematical correction

Small Reference Chamber Selection

- Irradiation conditions are different from typical reference conditions
- Small volume chambers have higher ratio of stem to irradiated volume
- Characteristics needed:
  - Stability of current as function of (continuous) irradiation time
  - Current as function of voltage
  - Current as function of polarity
- Reference:

IOP Publishing — Physics in Medicine and Biology

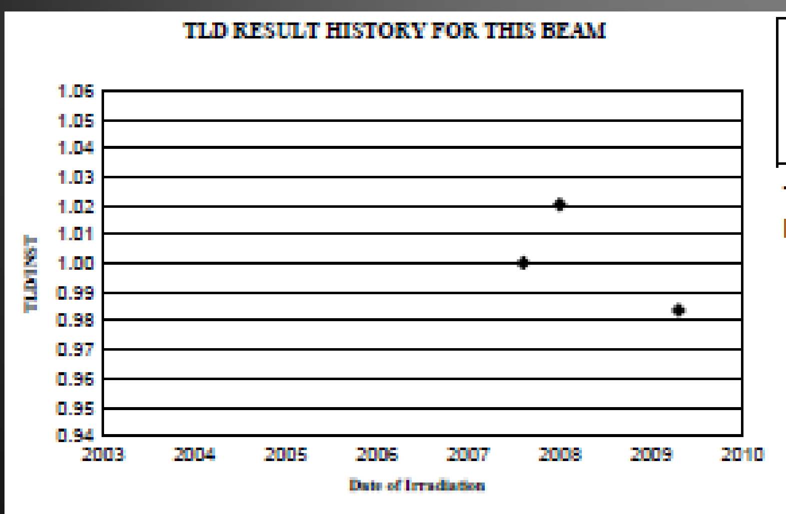
Phys. Med. Biol. **56** (2011) 5637–5650 doi:10.1088/0031-9155/56/17/011

Assessment of small volume ionization chambers as reference dosimeters in high-energy photon beams

M Le Roy, L de Carlan, F Delaunay, M Donois, P Fournier[1], A Ostrowsky, A Vouillaume[1] and J M Bordy

Independent Output Check

- **Absolutely necessary** before treating a patient!
- Too many misadministrations based on reference dosimetry gone wrong
- E.g. use TLD service
- Peer review



Person Irradiating TLD, if different from above: Name Lei Wang Phone: (650) 723 4787
For questions regarding TLD irradiation, if different from above: Name Lei Wang Phone: ( ) Same

MACHINE:	CyberKnife	IRRADIATION SET-UP FOR BLOCK:	#5942
In-House Designation:	CK 1	Date Irradiated (mm/dd/yyyy):	01/07/2009
Serial #:	22	MU (time) set at console:	300 mu (min)
Energy:	6 MV X-rays	Net Beam on:	300 mu (min)
Beam Quality: TMR $^{20}_{10}$ ______ or % dd(10)x	66.3%	Distance to top of RPC's folding plastic platform: (NOT to top of TLD)	78.5 cm

DESCRIBE YOUR CALIBRATION PROCEDURE

Distance from source to your output specification point = 80 cm (see instructions) 2610
Output at this point for a 6 cm cone at time of TLD irradiation = 1.02 cGy/mu (cGy/min.)

Output stated above is (check one):
- ☐ Nominal output
- ☐ Daily check reading (day of TLD irradiation)
- ☑ Ion chamber calibration (day of TLD irradiation)

Dose is specified to: (check one)
- ☑ Muscle (RPC standard for dose prescription is absorbed dose to muscle)
- ☐ Water

Output is specified at: (check one):
- ☑ SSD = 78.5 cm. Or
- ☐ SAD = ______ cm

At depth of (check one):
- ☑ dmax = 1.5 cm. Or
- ☐ Other depth = ______ cm

If other depth, provide TPR (or TMR) at dmax = ______
AND TPR (or TMR) at other depth = ______

Calibration Protocol (check one) ☑ TG-51 ☐ TG-21 ☐ Other ______

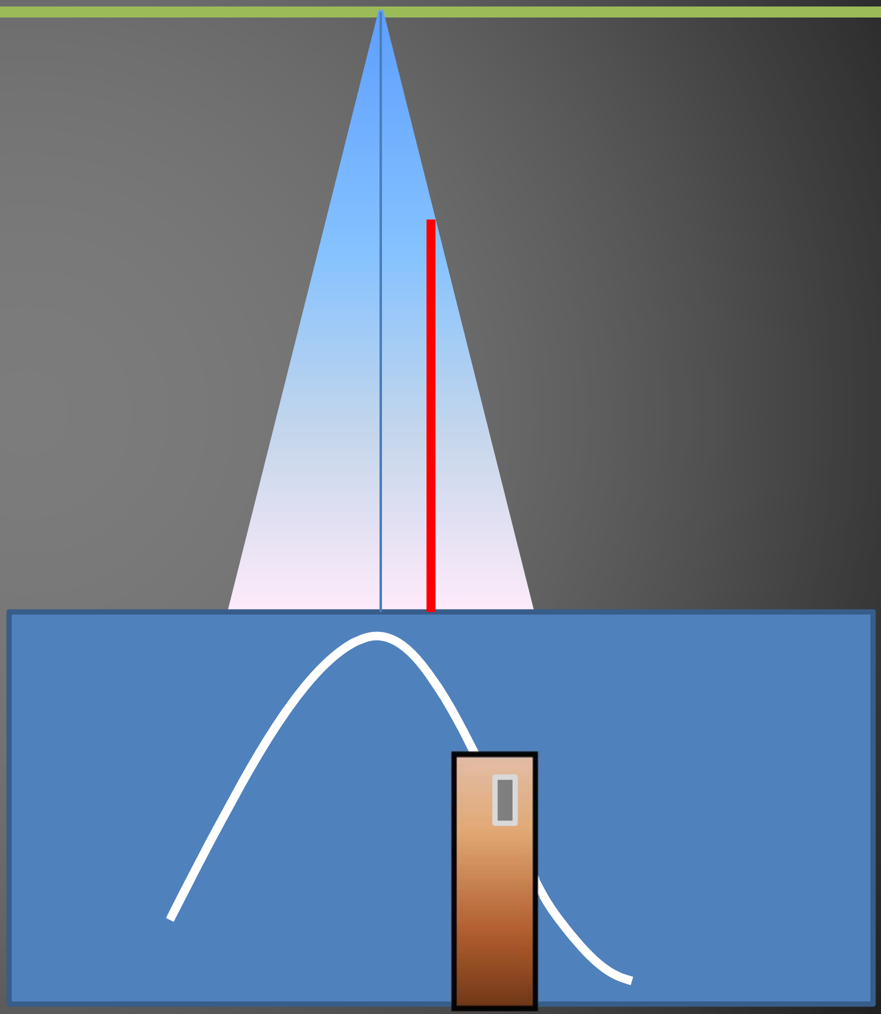
DOSE DELIVERED

Dose to output specification point for MU (time) setting given above = 309 cGy
For Co-60 only, date dose is exact (mm/dd/yyyy): ___/___/______

OUTPUT (TOTAL SCATTER) FACTORS

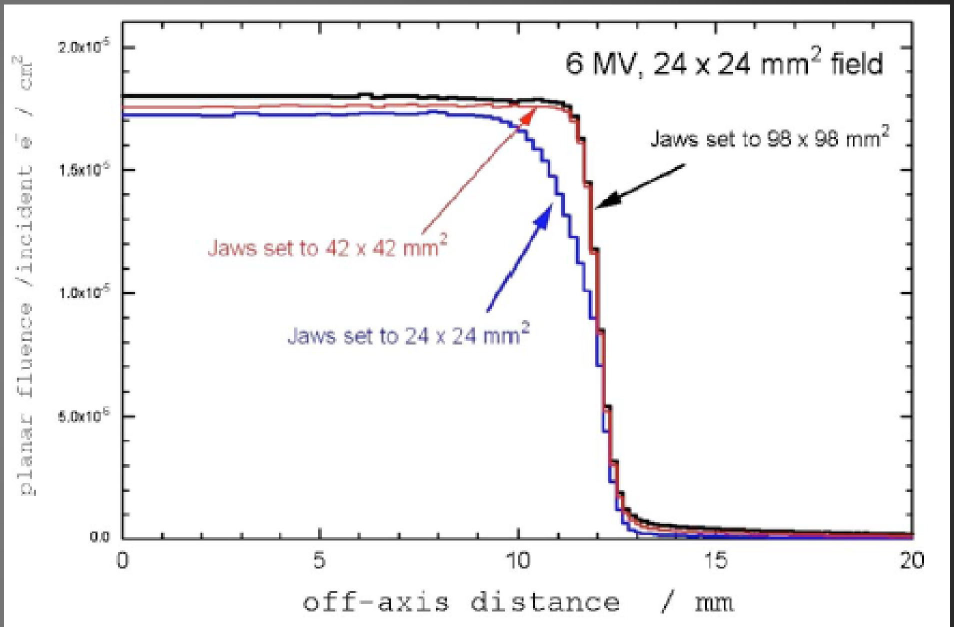
Experimental Setup Consistency I

- Beam lasers are not *exactly* on central axis
- Detector manufacturing uncertainties
- Method:
  - Do cross-profile scan
  - Set detector to maximum profile in either direction
  - Repeat cross profile scan



Experimental Setup Consistency II

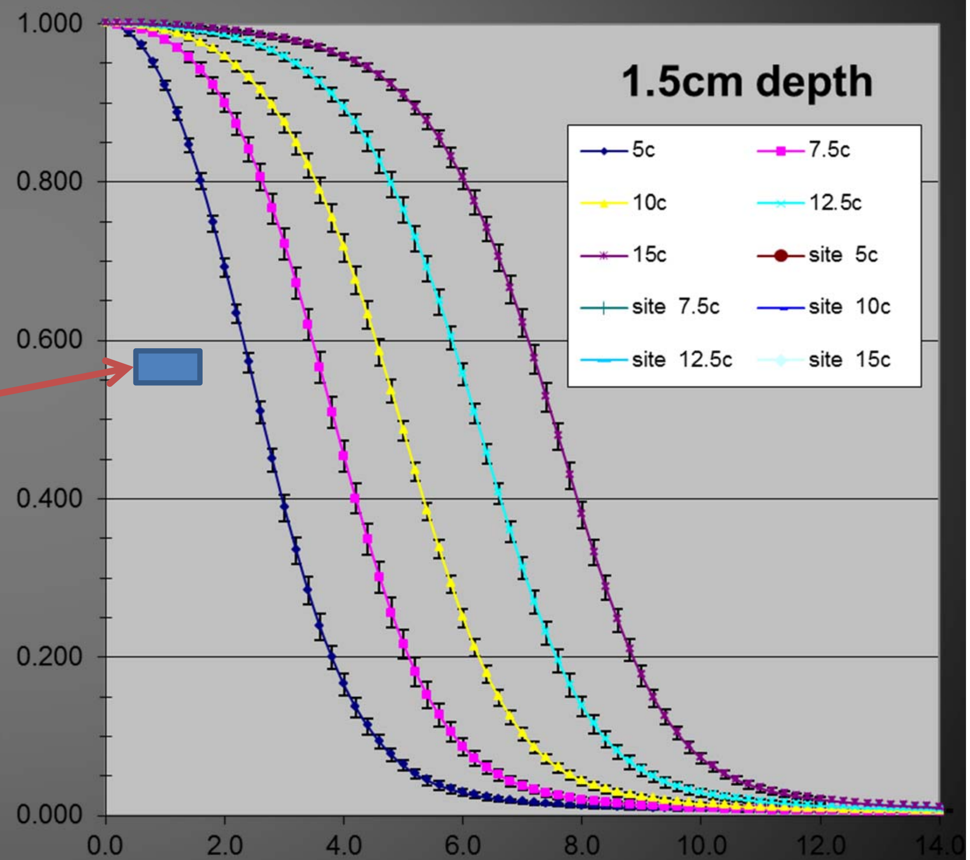
- 3rd party device
- mMLC with backup jaws
- Jaw settings change field geometry
- Set jaws to reflect clinical plans



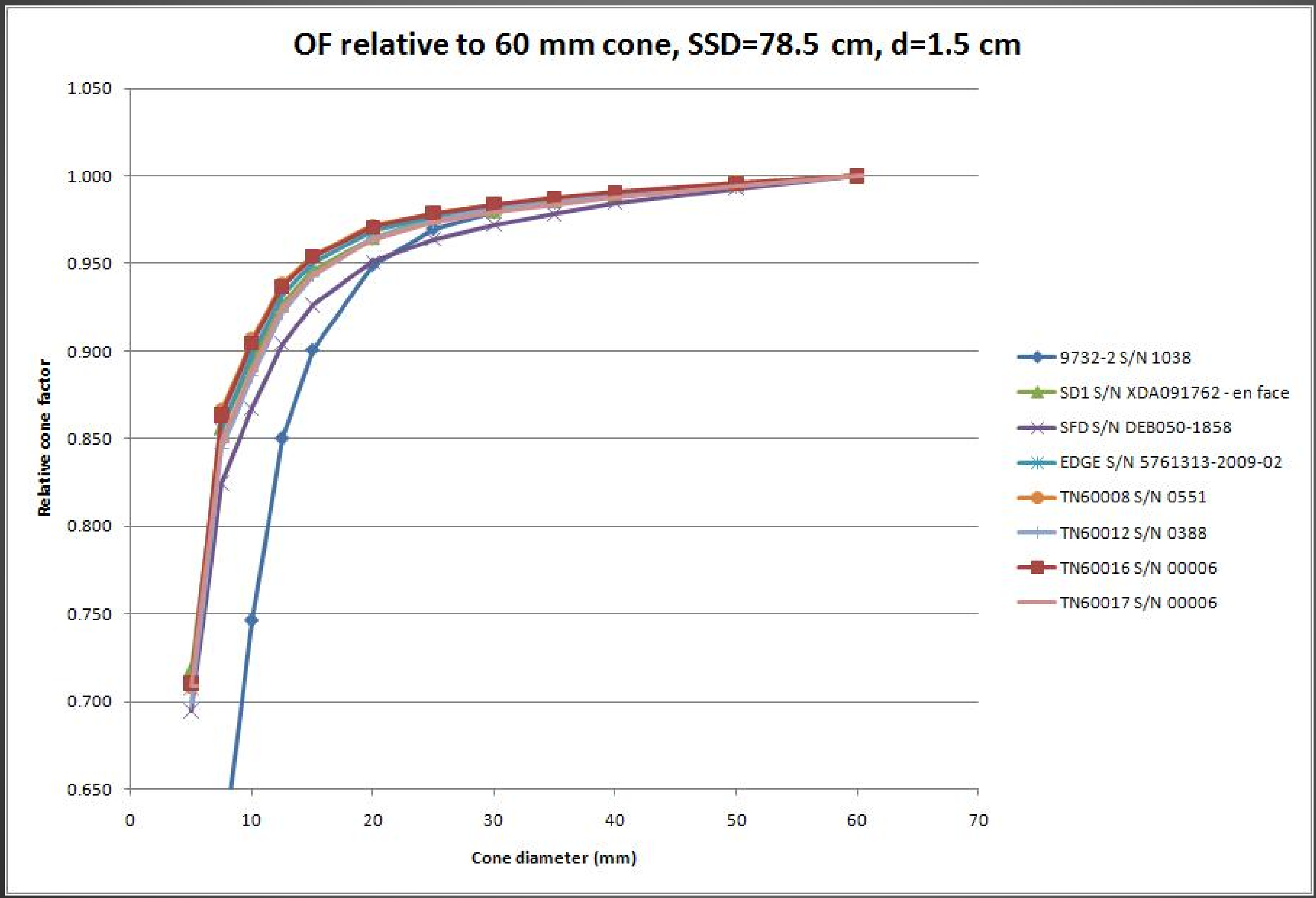
Das et al, MedPhys 35 (1)

Detector Selection for Output Factor

- In water
- Measure at depth (5 cm or 10 cm) because d_{max} =f(field size)
- Personal experience: diodes
  + ~1 mm diameter
  + Good size down to 5 mm beam
  – Some diode models degrade with dose
  – Energy-dependence
  ! Daisy-chain at 4 cm x 4 cm for 10 cm x 10 cm reference field



OF: Which Diode is “Best”?



Dieterich & Sherouse, MedPhys 38 (7)

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Is the OF Measurement Correct?

- RPC published data sets **JACMP Vol 13 (5) 2012**
- CyberKnife MP has reference data set available in commissioning tool
- "Golden" beam data sets
- Literature

TABLE 2. The RPC-measured and institution treatment planning system-calculated small field size dependence output factor values for Elekta machines. The values in square brackets and parentheses beneath each energy for each field size value are the average absolute percent differences and standard deviations of the values, respectively. For each energy and field size, the number of measurements (accelerators) is also shown.

Field Size (cm × cm)	*Elekta 6 MV* RPC	*Elekta 6 MV* Institution	*Elekta 10 MV* RPC	*Elekta 10 MV* Institution	*Elekta 18 MV* RPC	*Elekta 18 MV* Institution
10 × 10	1.000	1.000	1.000	1.000	1.000	1.000
6 × 6	**0.930**	0.934	**0.937**	0.940	**0.945**	0.947
	(0.010)	(0.009)	(0.004)	(0.005)	(0.002)	(0.003)
	[0.5%] (n=18)		[0.7%] (n=6)		[0.3%] (n=5)	
4 × 4	**0.878**	0.888	**0.890**	0.891	**0.901**	0.918
	(0.015)	(0.027)	(0.009)	(0.010)	(0.002)	(0.039)
	[1.3%] (n=22)		[0.6%] (n=8)		[0.4%] (n=6)	
3 × 3	**0.842**	0.848	**0.857**	0.862	**0.861**	0.863
	(0.012)	(0.009)	(0.003)	(0.005)	(0.003)	(0.004)
	[0.9%] (n=17)		[0.6%] (n=6)		[0.6%] (n=4)	
2 × 2	**0.790**	0.796	**0.796**	0.802	**0.786**	0.798
	(0.007)	(0.010)	(0.009)	(0.008)	(0.006)	(0.019)
	[1.6%] (n=17)		[1.3%] (n=6)		[2.4%] (n=4)	

Journal of Applied Clinical Medical Physics, Vol. 13, No. 5, 2012

Typical OF Values for 6MV

		10 x 10	6 x 6	4 x 4	3 x 3	2 x 2	1 x 1	.5 x .5
Elekta *	MLC	1	0.930	0.878	0.842	0.790	N/A	N/A
Varian *	MLC	1	0.921	0.865	0.828	0.786	N/A	N/A
BrainLab	mMLC	See Next Slide						
BrainLab	Cone	1	N/A	N/A	0.969	0.926	0.85	0.711
CK	Cone	N/A	1	0.997	0.993	0.974	0.911	0.709

- ***JACMP Vol 13 (5) 2012:**
- Elekta field size defined by secondary jaw that included an MLC
- Varian defined by tertiary MLC with jaws set to 10 x 10
- **Wilcox and Daskalov, MedPhys 34 (6) 2007** for CyberKnife data

➢ Values depend on *field shape*

➢ Values depend on *normalization field*

OF of mMLC is function of linac!

Variation of output factors of mMLC (m3) with the make and model of the medical linear accelerator

Square field size (mm²)	**Output factor of mMLC (m3) installed at**			
	Siemens primus (H1)	*Siemens primus (H2)*	*Varian clinac 2100 CD*	*Varian clinac 2300 CD*
6 × 6	0.612	0.621	0.661	0.650
12 × 12	0.800	0.808	0.786	0.810
18 × 18	0.859	0.869	0.847	0.865
24 × 24	0.881	0.889	0.874	0.889
30 × 30	0.895	0.904	0.884	0.906
36 × 36	0.904	0.916	0.906	0.913
42 × 42	0.913	0.925	0.917	0.925

J Med Phys 2007 32(1)

Up to **8%** difference for smallest field across accelerators!

Other Suitable Detectors

- Micro-chambers
- Diamond Detectors
- Film
- TLD
- Gel
- …

Do all of these give the same OF values?

Detector Response

- **Francescon, Cora, Cavedon, Med Phys (2008) 504**
- OF (= $s_{c,p}$) for 3 smallest CK cones:
  - 2 micro-chambers, **PTW60012 diode**, diamond detector
  - Measurements
  - Monte Carlo simulation
- MC:
  - Dependency of OF on FWHM of electron beam
  - Correction factors for detector response

MC-OF as Function of Electron-Beam FWHM

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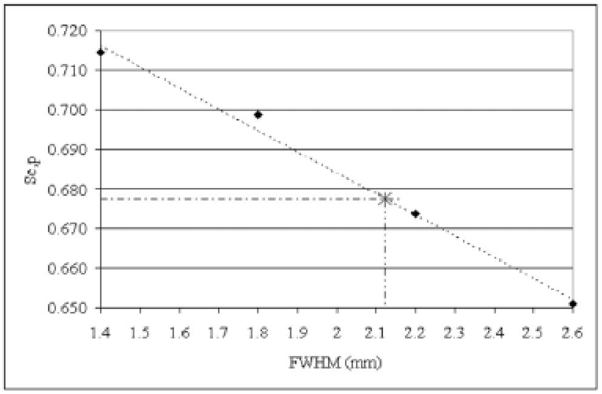

FIG. 5. True Monte Carlo $s_{c,p}$ as a function of the FWHM: the estimated $s^*_{c,p}$ allows the FWHM of the electron beam to be estimated for the Cyberknife system under investigation.

Point source assumption starts breaking down for 5 mm collimator!

TABLE IV. Measured and MC-simulated $s_{c,p}$, for the four detectors and for the 5, 7.5, and 10 mm collimators, for the various FWHM of the Gaussian spatial distribution of the electron source.

		FWHM 1.4 mm	FWHM 1.8 mm	FWHM 2.2 mm	FWHM 2.6 mm
Coll 5 mm	Measured $s_{c,p}$	Simulated $s_{c,p}$	Simulated $s_{c,p}$	Simulated $s_{c,p}$	Simulated $s_{c,p}$
A16	0.614	0.669	0.643	0.611	0.585
PinPoint	0.613	0.661	0.636	0.607	0.582
Diode	0.710	0.757	0.732	0.704	0.679
Diamond	0.613	0.677	0.639	0.609	0.580
Coll 7.5 mm					
A16	0.801	0.809	0.808	0.799	0.792
PinPoint	0.798	0.805	0.802	0.795	0.789
Diode	0.852	0.757	0.850	0.843	0.842
Diamond	0.815	0.833	0.818	0.813	0.803
Coll 10 mm					
A16	0.859	0.874	0.870	0.860	0.857
PinPoint	0.858	0.867	0.865	0.860	0.857
Diode	0.895	0.909	0.896	0.890	0.886
Diamond	0.871	0.889	0.876	0.872	0.866

OF Correction Factor F_{corr}

- Detector response : F_{corr} = OF (MC) / OF (measured)
- Combine detector response with (small) FWHM correction to get $s^*_{c,p}$

TABLE III. Estimated values of F^*_{corr} and $s^*_{c,p}$ for the 5, 7.5,, and 10 mm collimators, for the four detectors.

	5 mm		7.5 mm		10 mm	
	F^*_{corr}	$s^*_{c,p}$	F^*_{corr}	$s^*_{c,p}$	F^*_{corr}	$s^*_{c,p}$
A16	1.098	0.675	1.021	0.818	1.010	0.867
PinPoint	1.107	0.679	1.027	0.819	1.014	0.870
Diode	0.957	0.679	0.966	0.823	0.978	0.875
Diamond	1.104	0.677	1.006	0.820	1.000	0.871
Mean $s_{c,p}$		0.677		0.820		0.871
$\pm 2\sigma$		±0.004		±0.008		±0.008

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Dosimetry: Variation in $S_{c,p}$

- Vicenza study for several detectors results in low uncertainty of OFs (if all corrections apply)

  (Francescon et al, Med Phys (2008) 504)

- BANG gel measurement <u>strong indication</u> for OF correction factor

  Pantelis Med Phys (2008) 2312

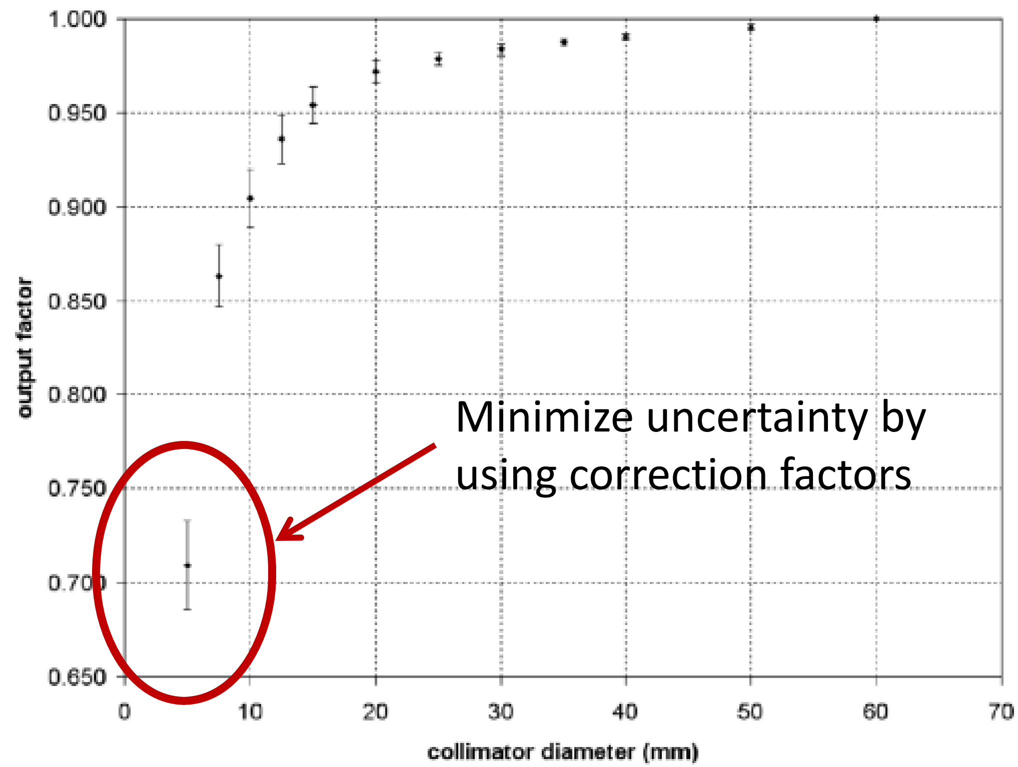

Figure 20-2. Example of rapidly decreasing output factor with decreasing field size from CyberKnife® data. Composite data from several centers, measured by means of diode detectors and normalized to the 60 mm collimator output factor.

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2012 Update with 9 Detectors

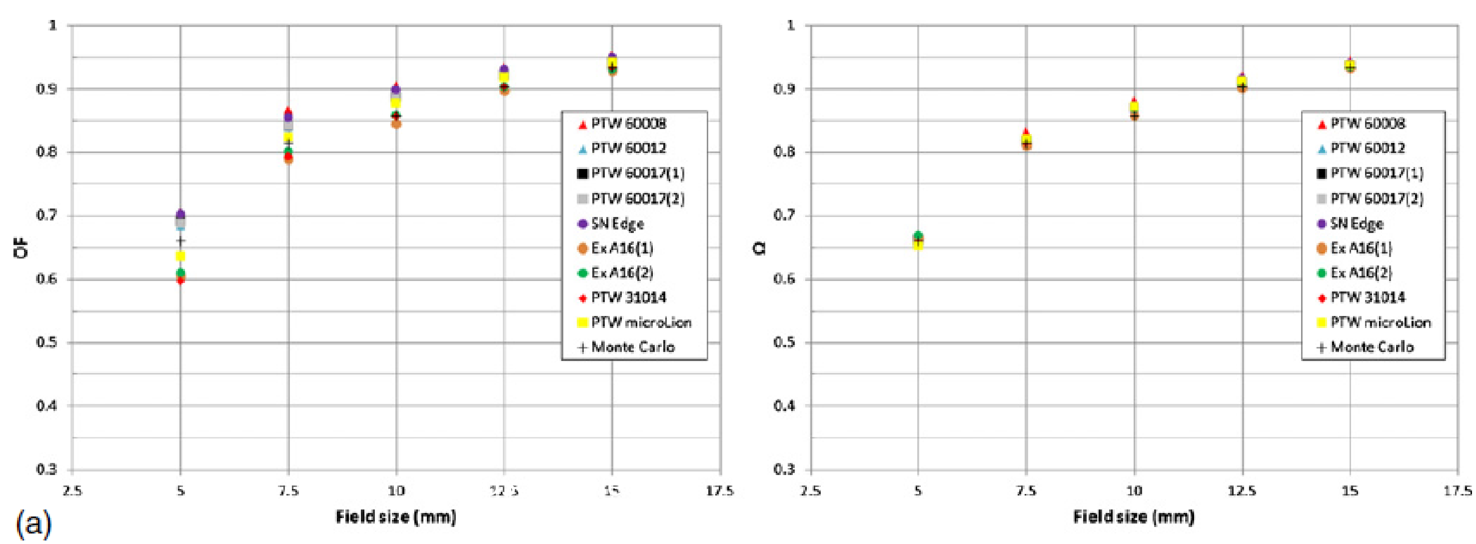
- **Includes 9 detectors**
- **MC differs from TRS-398**
- **Effects of correction for several collimator systems**

(Francescon et al, PMB 57 (2012) 3741)

Table 1. Values of k_{Q_{msr},Q_0} calculated by Monte Carlo simulation of the CyberKnife system and a reference Co-60 beam. For comparison, $k_{Q,Q0}$ extracted from TRS-398 using a hypothetical 100×100 mm^2 TPR20/10 converted using the method of Sauer (2009) from the measured TPR20/10 at 60 mm circular field size is shown, together with the difference between these two calculations.

Chamber	k_{Q_{msr},Q_0}	$k_{Q,Q0}$ (TRS-398)	Difference (%)
PTW 30006 Farmer	1.000	0.993	+0.7%
PTW 31014 PinPoint	0.990	0.995	−0.5%
Exradin A12 Farmer	1.006	0.997	+0.9%
NE 2571 Farmer	1.003	0.995	+0.8%
PTW 31010 Semiflex	0.990	–	–

Correction factors for CyberKnife dosimetry 3753



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Visualizing the Difference

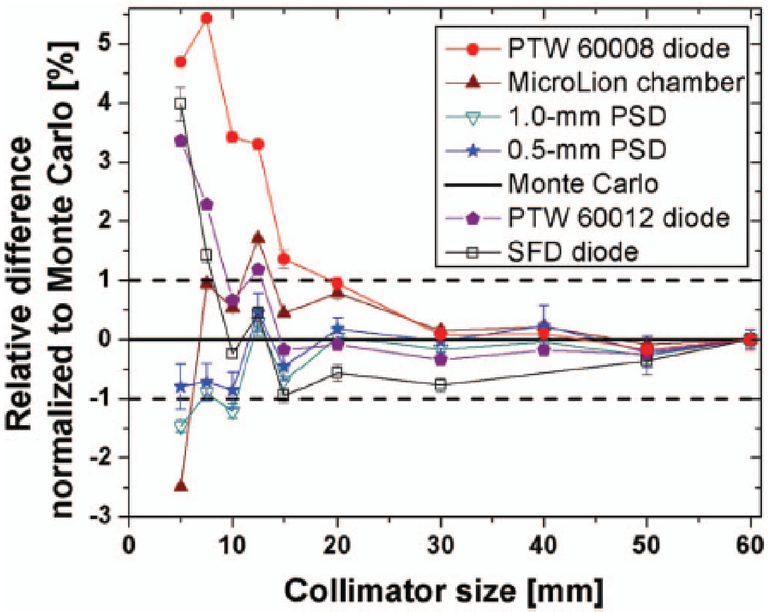
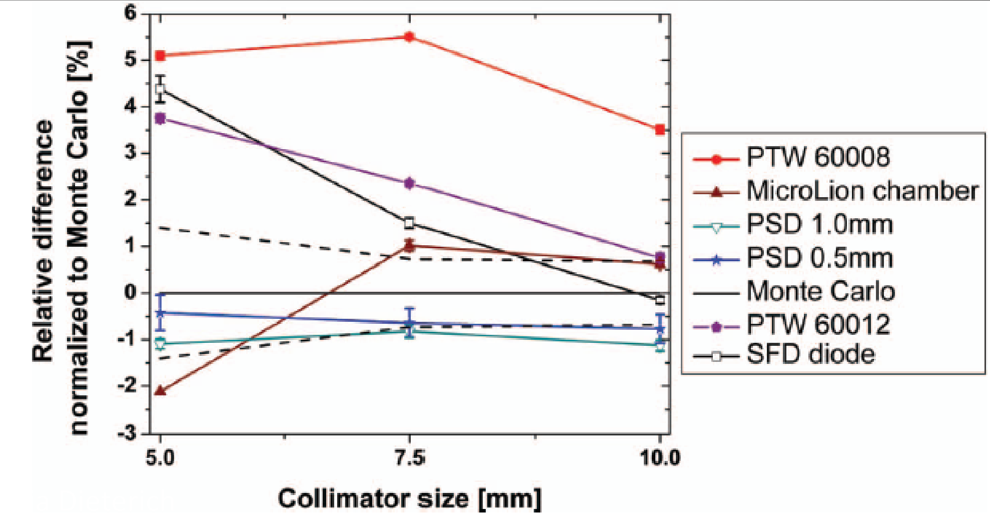


FIG. 3. Relative total scatter factors difference normalized to Monte Carlo [Araki (Ref. 8)]. The y-axis represents the relative total scatter factor differ-

Morin, MedPhys 40 (1), 2013



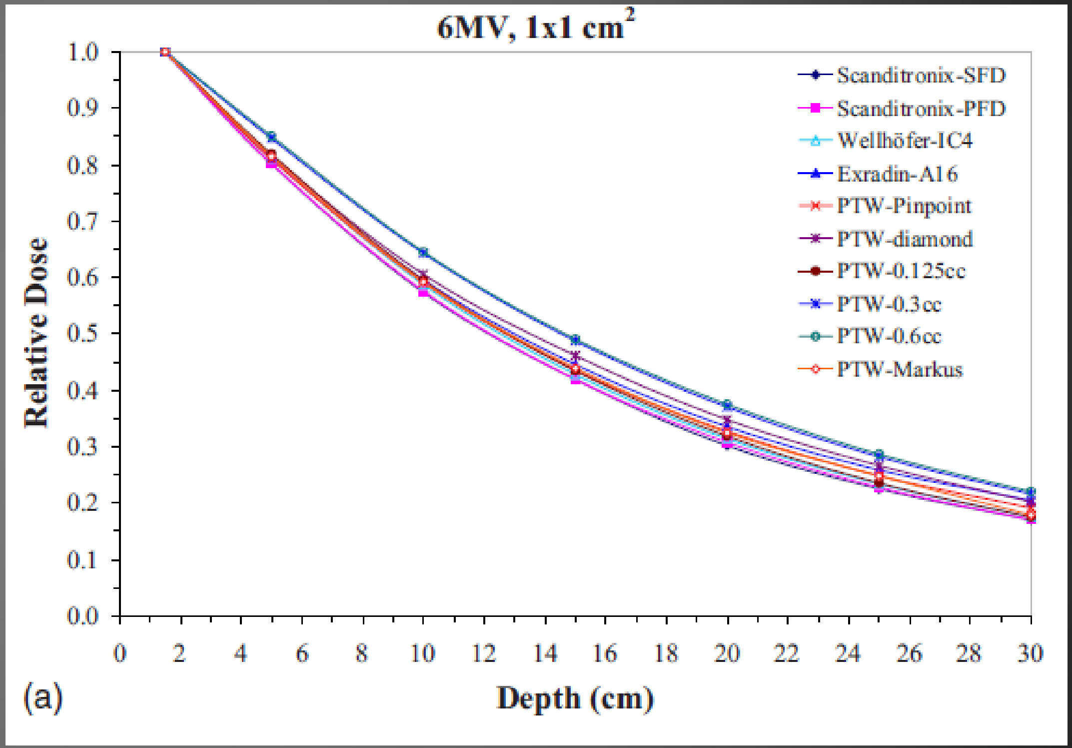
atter factors difference normalized to Monte Carlo [Francescon *et al.* (Ref. 5)]. The y-axis represents the

Heads-Up: Upcoming IAEA report

- **IAEA Small Field Dosimetry Working Group**
- **Establishing correction factors for a range of detectors**
- **Not published yet**

PDD/TPR in Small Fields

- Some detector dependence
  - Energy dependence?
  - Cax alignment?
- PDD *very* sensitive to water tank/CAX alignment!
- PDD/TPR conversion does not work well for small fields
- Measure TPRs directly if planning system requires
- Special small-field water tanks for TPR measurements



AAPM TG-106 Accelerator Beam Data Commissioning

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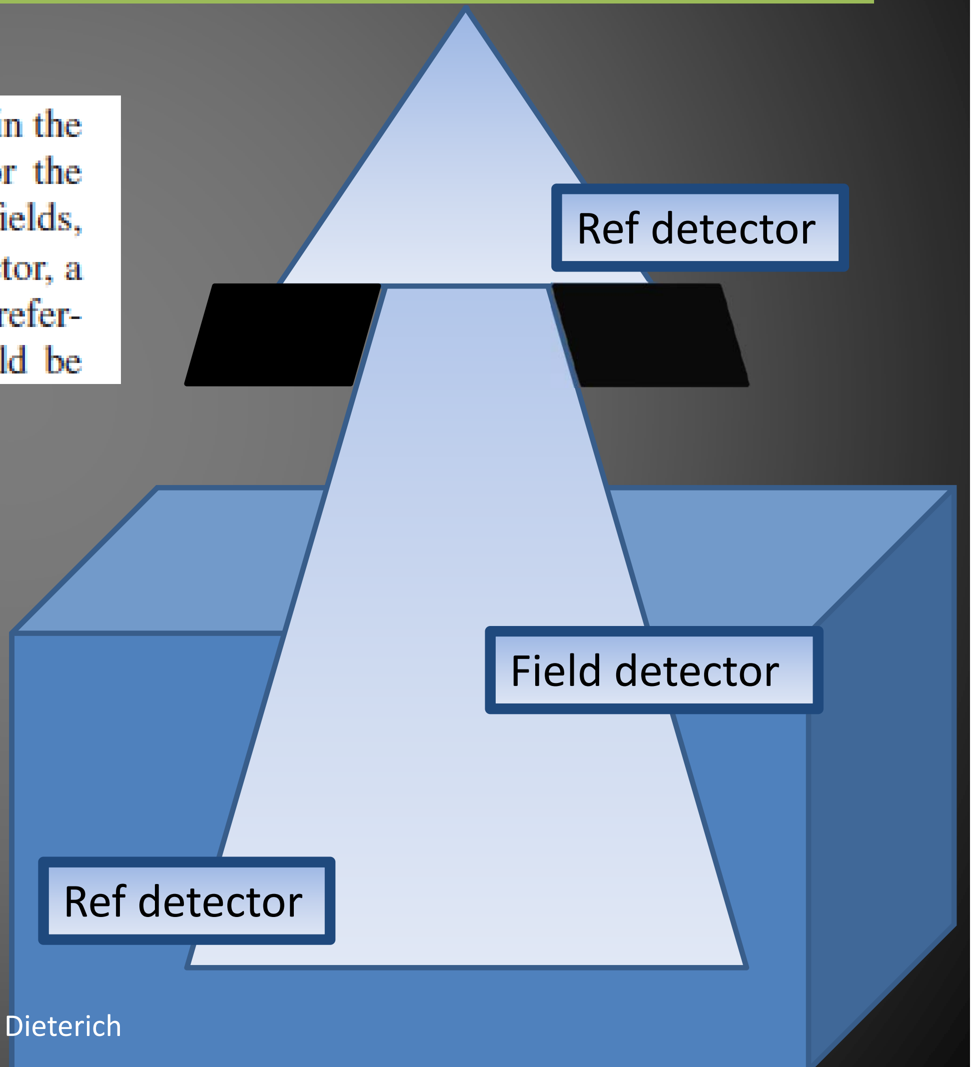
OAR AND VOLUME AVERAGING

Placement of Reference Detector

- AAPM TG 106:

The reference detector may be positioned anywhere in the beam where it does not shadow the field detector for the entire area of programmed positions. For very small fields, where the reference detector may shadow the field detector, a time integration method could be used instead of the reference chamber. The field and reference detectors should be

- Ref detector above field
- Works well if above secondary collimation
- Alternate option: place below field detector
- Out of field: too much noise!



OAR Width vs. Detector Size

- Fields predominantly penumbra
- Penumbra = f(detector size)

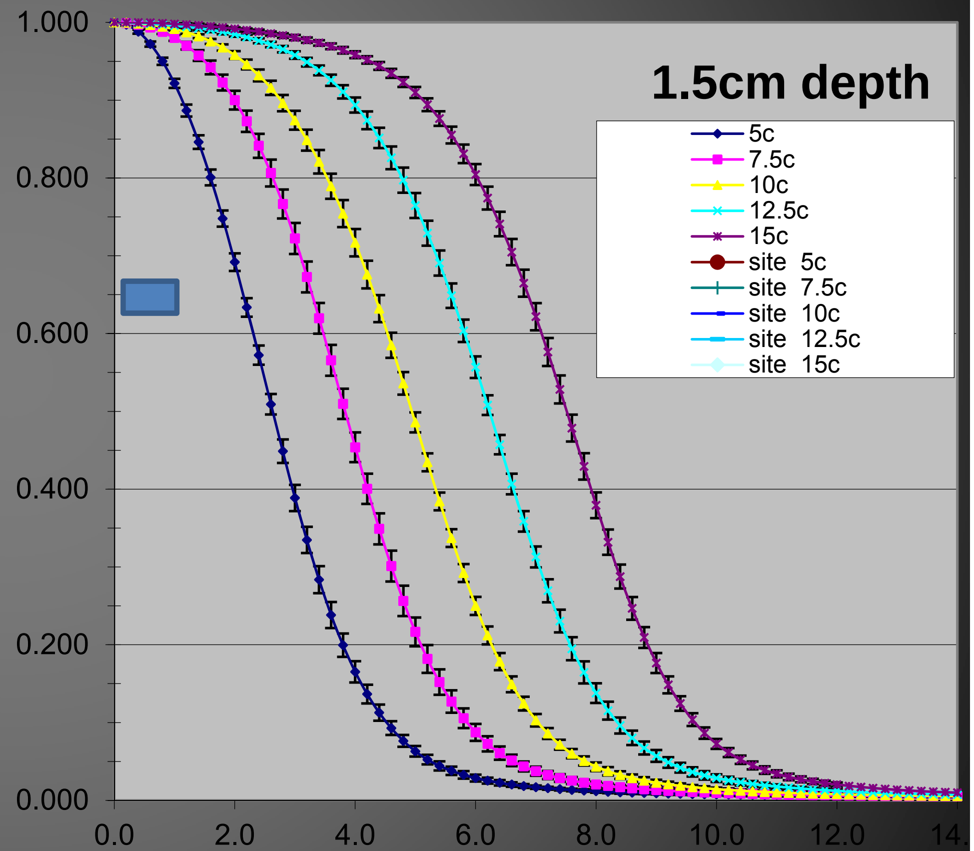


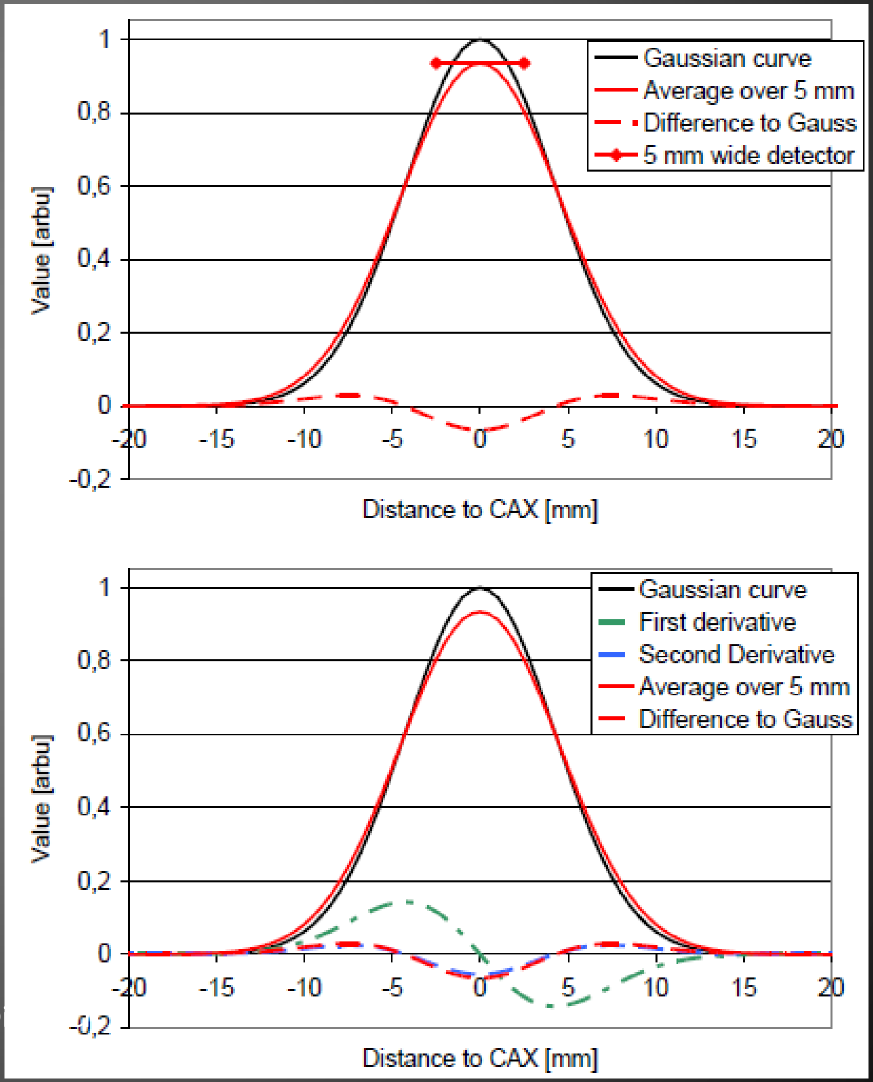
TABLE IV. Comparison of the 80%–20% penumbra measured with EBT film, diode, and ion chamber. The standard deviation for all detectors is within ±0.1 mm.

Collimator diameter (mm)	80%–20% penumbra (mm)		
	EBT film	Diode	Ion chamber
5	2.09	2.05	2.4
7.5	2.21	2.25	2.7
10	2.55	2.55	2.85
20	2.66	2.85	3.1
30	2.74	3	3.2
60	3.47	3.85	4.4

Medical Physics, Vol. 34, No. 6, June 2007

OAR Volume Averaging

- **Wuerfel, MIP 1,1 (2013)**
- Volume averaging for finite detector
- FWHM will stay constant
- Choose smallest detector available!
- Detector : FWHM = 1:3
- Slow scan speed to increase signal-to-noise ratio



OAR: Energy Change Across Field

- **Energy spectrum change across fields affects diodes**
- **Effect most pronounced for LARGE SRS fields**

Morin, MedPhys 40 (1), 2013

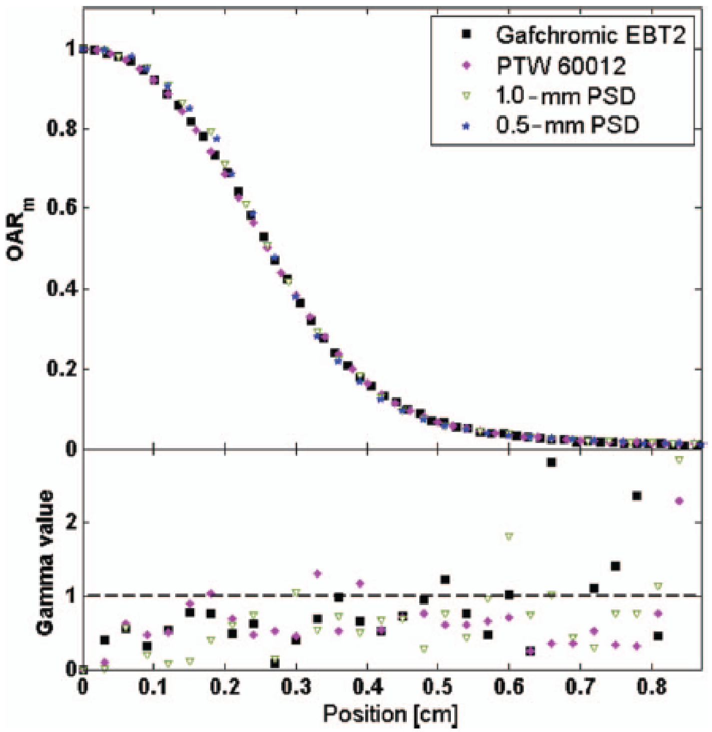


FIG. 6. Dose profile measured at 1.5 cm depth and 80 cm SAD with the 5-mm cone normalized to the dose measured at the center of the field. Error bars are not shown to simplify the visualization. The gamma evaluation used acceptance criteria of 2% and 0.2 mm.

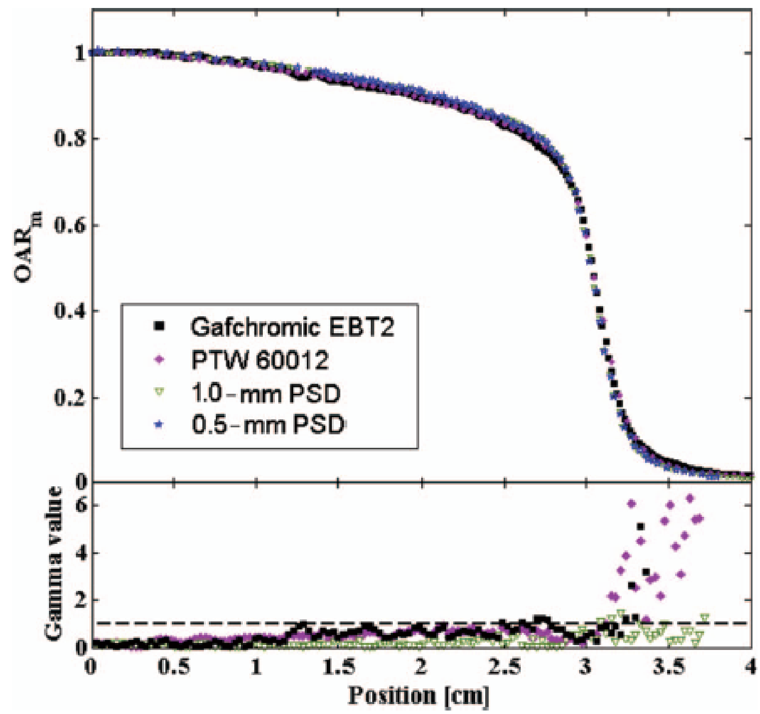
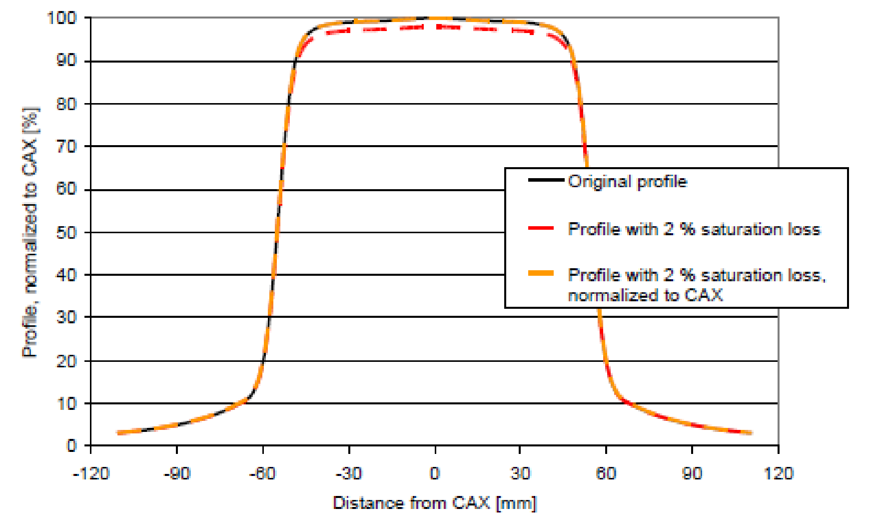
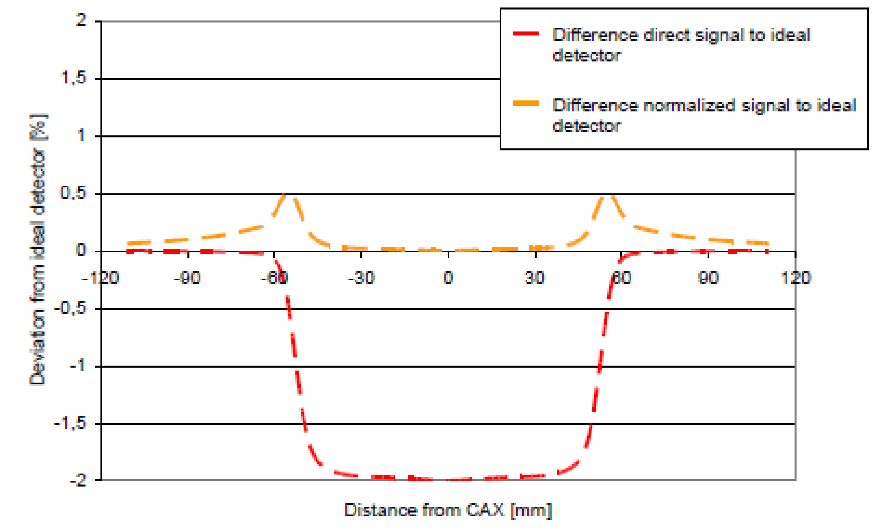


FIG. 7. Dose profile measured at 1.5 cm depth and 80 cm SAD with the 60-mm cone normalized to the dose measured at the center of the field. Error bars are not shown to simplify the visualization. The gamma evaluation used acceptance criteria of 2% and 0.2 mm.

A Word on Dose Rate Dependence

- **Wuerfel, MIP 1,1 (2013)**
- Hypothetical detector:
  - Assume dose rate dependence linear with dose/pulse
  - Max saturation loss at highest dose/pulse
- Assume 2 % saturation loss
- Effect is smaller than volume-averaging effect





Summary

Attribute	Ionization chamber	Micro Chambers	Stereotactic Diodes	Diamond detector	Plastic Scintillator	Gels
Field size	≥ 2 cm x 2 cm	≥ 3 mm x 3 mm	≥ 3 mm x 3 mm	≥ 3 mm x 3 mm	≥ 3 mm x 3 mm	≥ 3 mm x 3 mm
Energy dependence	Use k_Q to correct energy dependence	Use k_Q to correct energy dependence	Normalize at 4 cm^2 for energy dependence	Almost none	Almost none	Depends on gel material
Drawbacks	Volume effect	Stem and cable effect, S/N ratio	Some models: Aging, dose rate	Weak dose rate dependence; availability	S/N ratio; temperature dependence; cable irradiation	Availability
Advantage	Familiarity/ Availability	Spatial resolution	Small size, availability	Near ideal	Small size	Spatial resolution

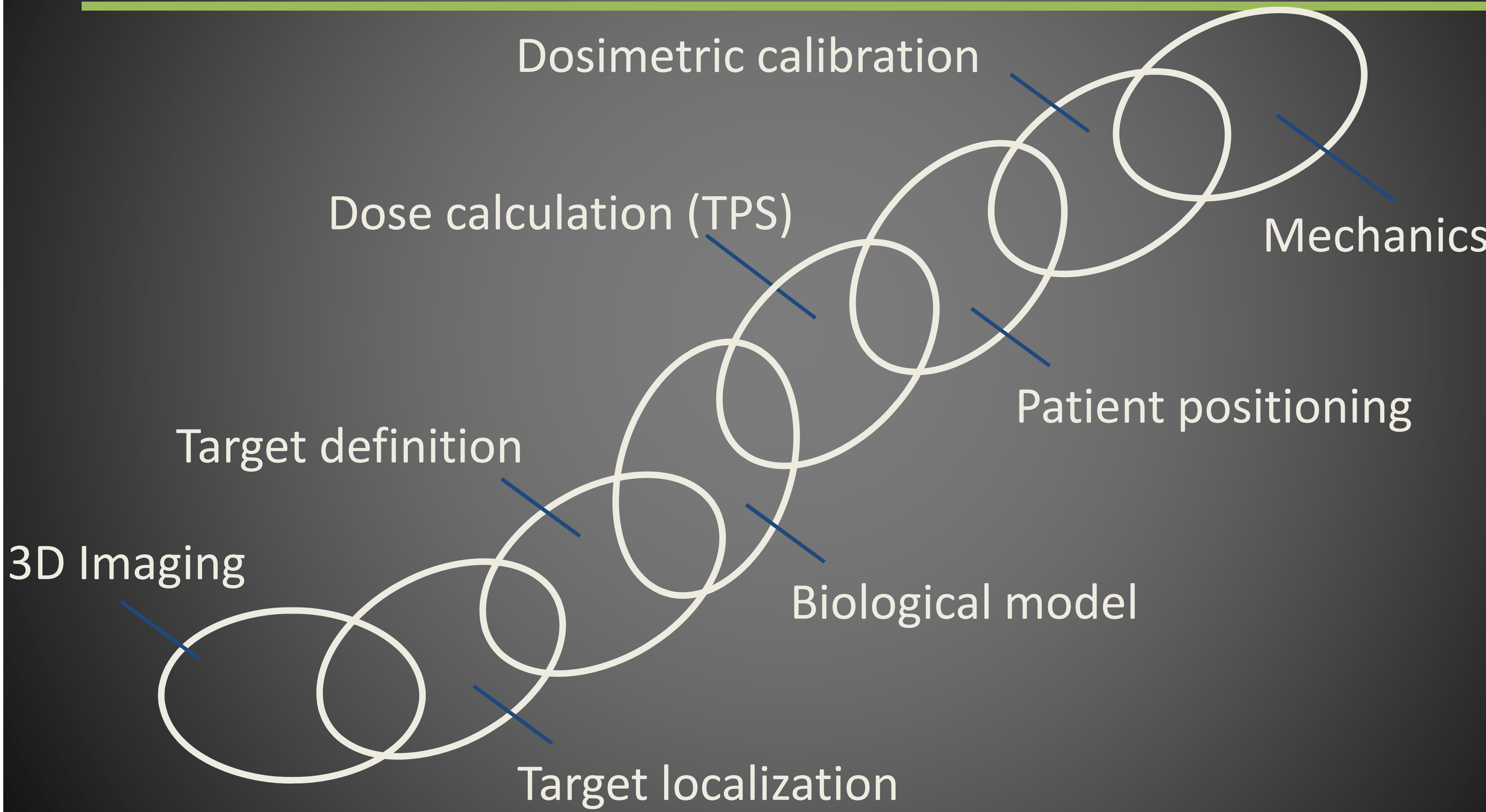
Conclusion

- Small fields require special techniques
- Guidance documents are becoming available
- Detector selection becoming larger (and coming down in price)
- Match detector/equipment to need
- Research detector performance
- Compare measurements to published data

THE OTHER UNCERTAINTIES

Disclaimer: This section is about the big picture, ongoing research, and ideas.

Radiosurgery Chain of Uncertainty

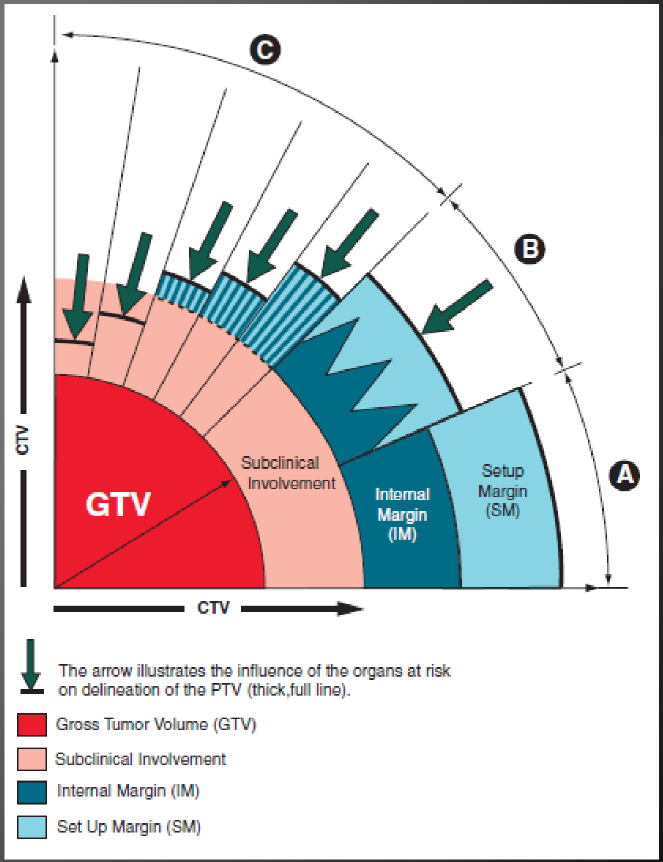


(Selected) SBRT margins from Literature

Paper	Target	Type	Motion compensation	Margin
2009 Rusthoven	Liver	Phase 1 &2	ABC	5 mm radial 10 mm cranio-caudal
			Compression	7 mm radial 15 mm cranio-caudal
2006 Dawson	Liver	Phase 1 & 2	Free, breath-hold, compression	> 5 mm
2010 Timmermann	Lung	Phase 2	Free, breath-hold, compression, gating	≤ 5 mm radial ≤ 10 mm cranio-caudal
RTOG-0813	Lung		Free, breath-hold, compression, gating, tracking	Helical scan: • 5 mm radial • 10 mm cranio-caudal 4DCT: • 5 mm ITV Other methods per approval

What is an appropriate margin?

- Internal margin (IM or ITV):
  - Residual motion, deformation
- Setup margin (SM):
  - Ensures adequate clinical coverage
  - Includes all uncertainties
- Appropriate for hypofractionation



Type A and B

- Replaces "random" and "systematic"
- **Type A evaluation**
  method of evaluation of uncertainty by the **statistical analysis** of series of observations,
- **Type B evaluation**
  method of evaluation of uncertainty by means **other than the statistical analysis** of series of observations.

Margins – not your simple PTV anymore

- Margin recipes based on many fractions:

Van Herk et al, 2000[43]	Target	$2.5\,\Sigma + 0.7\,\sigma$ or (more correct): $2.5\,\Sigma + 1.64\,(\sigma - \sigma_p)$	Minimum dose to CTV is 95% for 90% of patients. Analytical solution for perfect conformation

- Small fraction number in SBRT requires adaptation
- Heijmen et al. adapted v Herk recipe for SBRT:
  - mean random error added to systematic error
- Gordon and Siebers (2007), proposes **A**lternative **M**ethod:
  - systematic << random error (AM1)
  - weighted sum of AM1 when Systematic << random does not hold (AM1)
- Herschtal, A., et al. "Calculating geometrical margins for hypofractionated radiotherapy." *PMB* 58.2 (2013): 319.

Herschtal Margin for SBRT

- Adjusted van Herk formula as lower limit
- Develops method for estimating upper limit
- Derives a model to interpolate between limits
- Verification using MC simulation

- Data generation:
  - MC to generate displacement data for 10,000 patients (max 0.5% standard error)
  - Generate Dose Population Histograms
  - Generate data for varying random & systematic errors, number of fractions

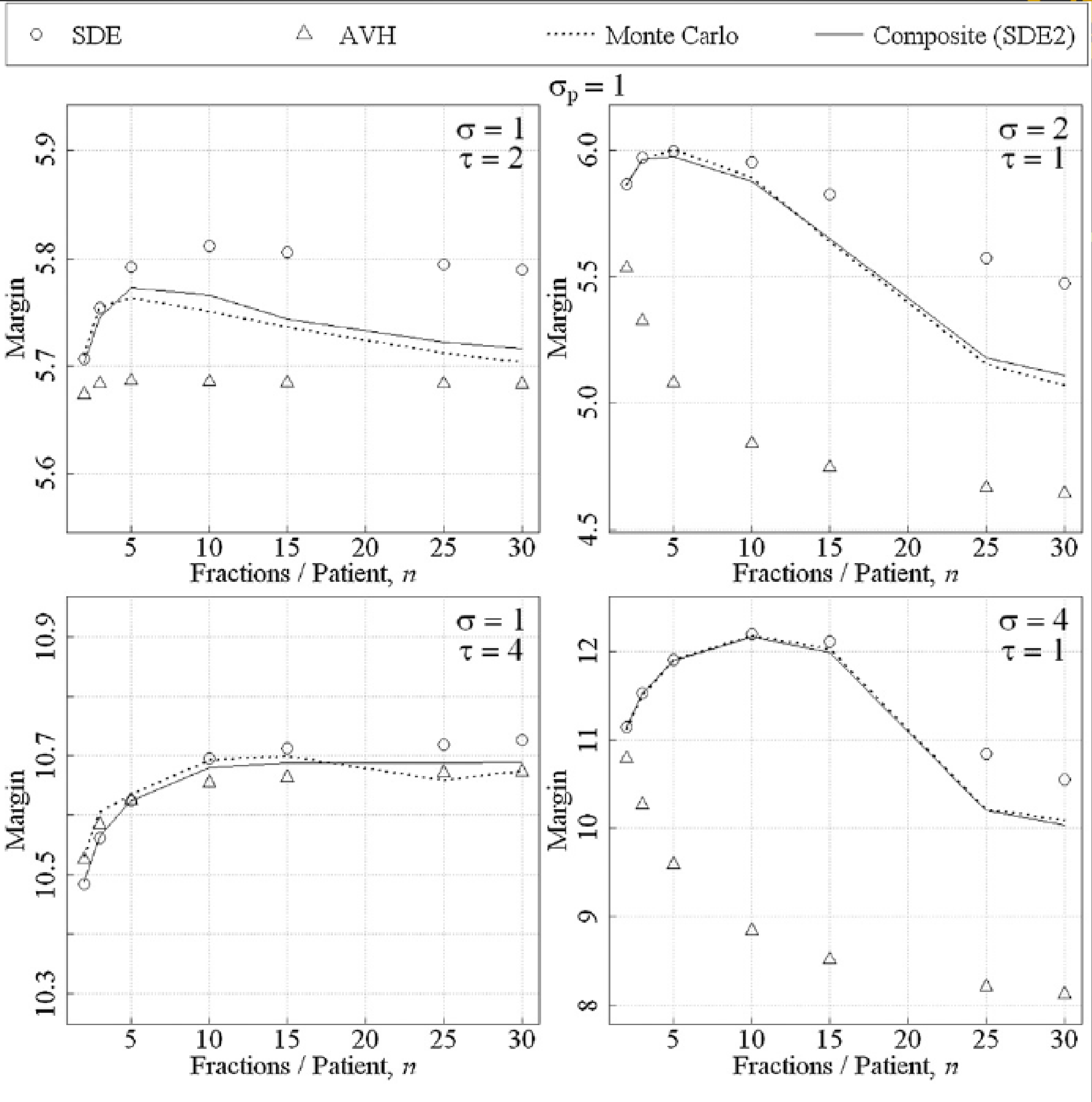
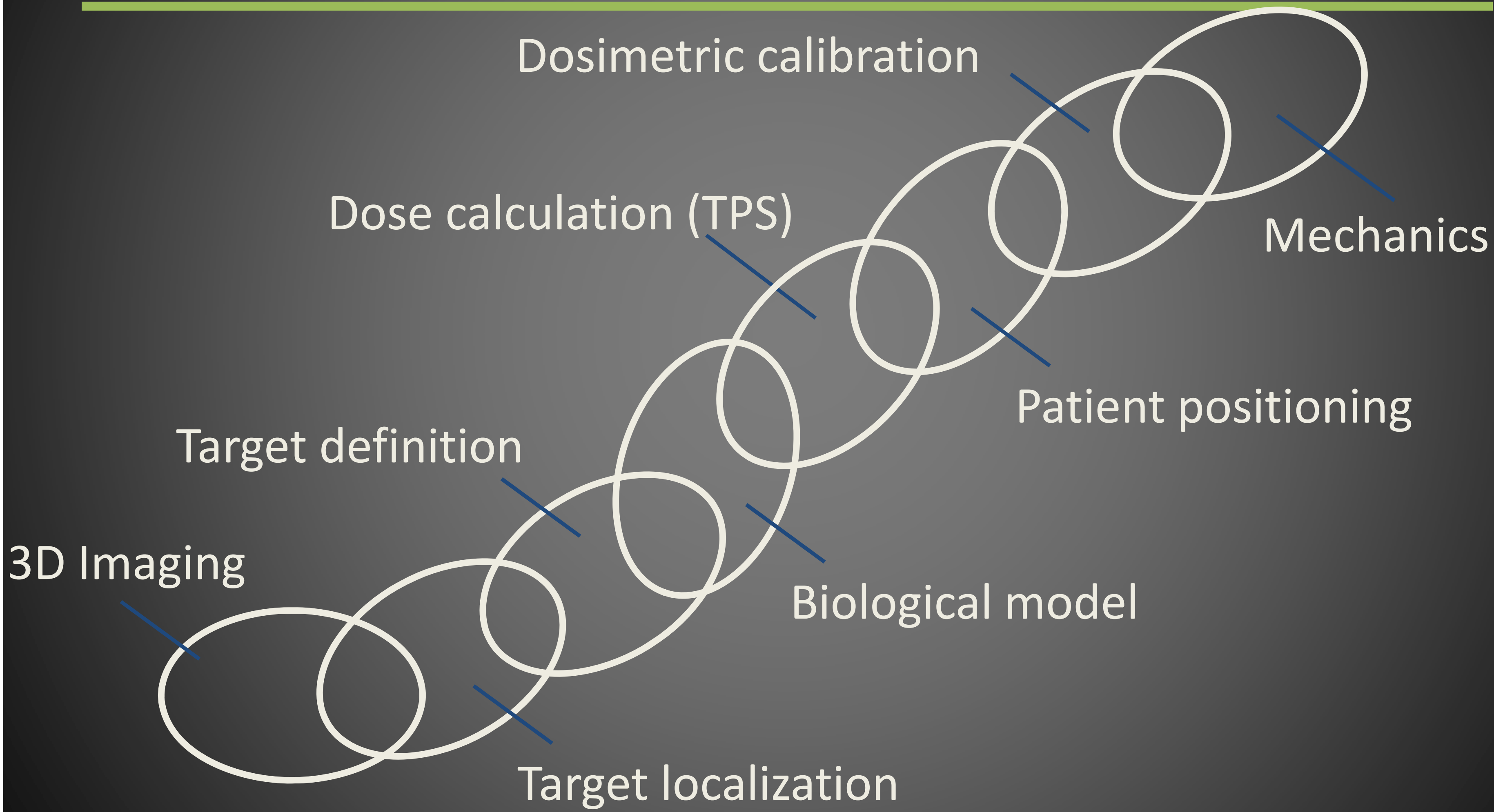
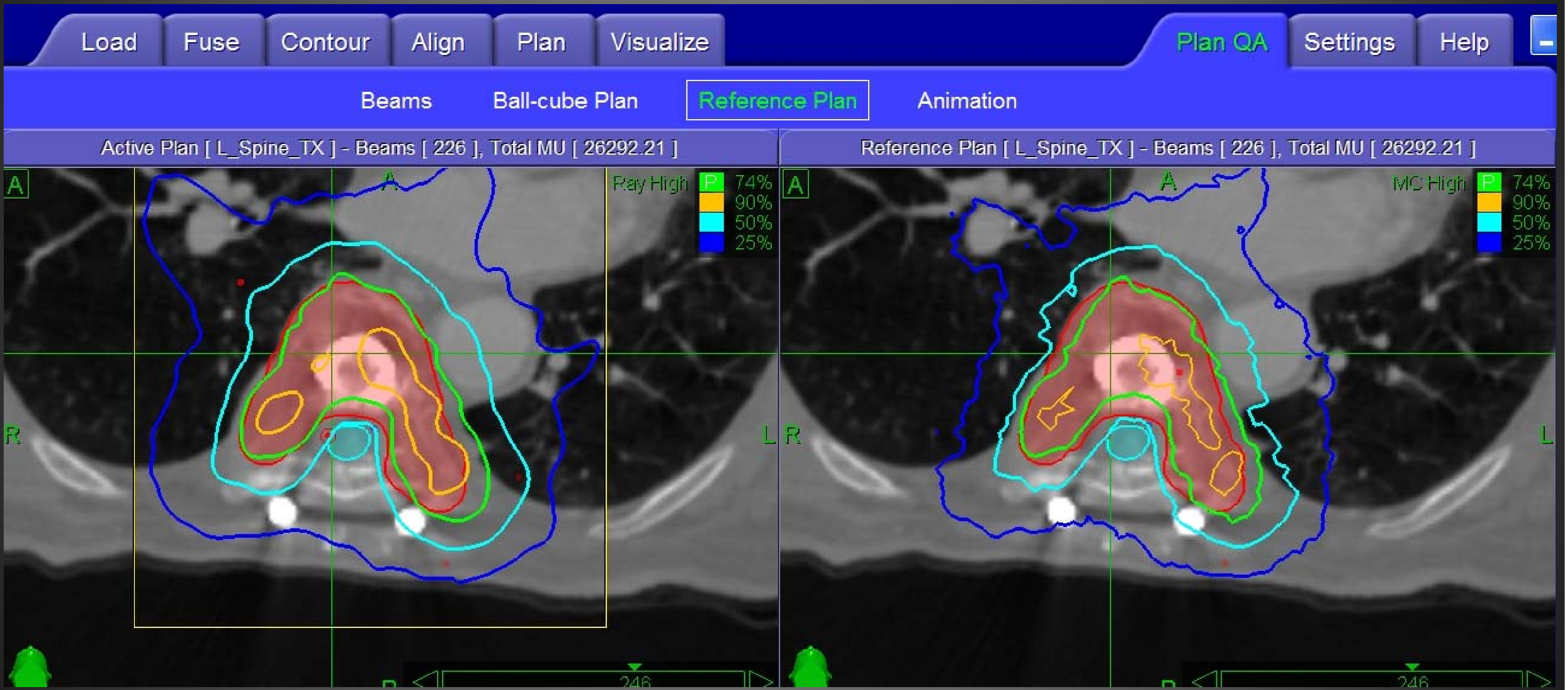


Figure 5. Graphs of margin against n for varying values of σ and τ, for $\sigma_p = 1$.

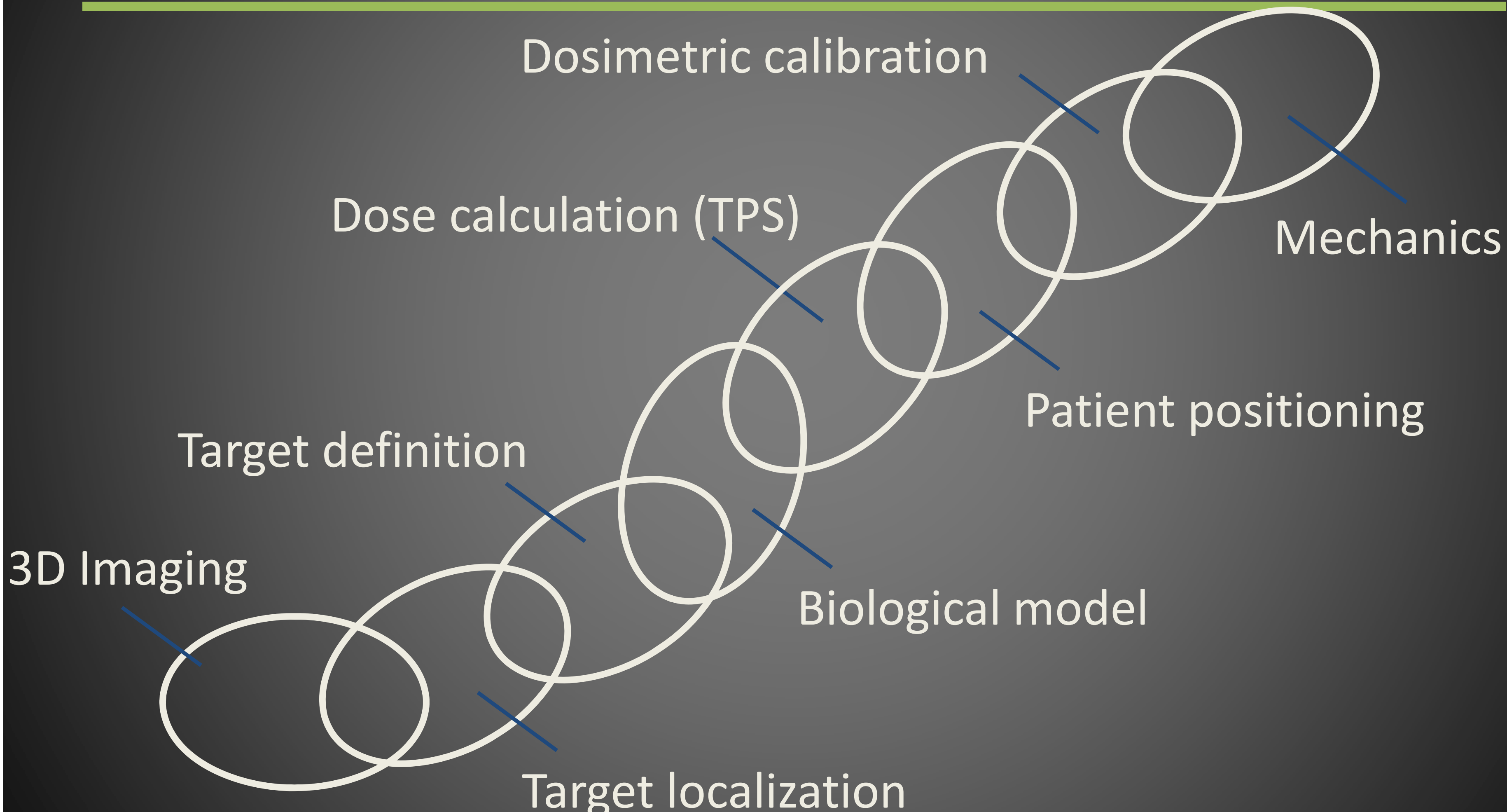
Radiosurgery Chain of Uncertainty



TPS Dose Calculation = Spatial Shift!



Radiosurgery Chain of Uncertainty



The Famous “Expert Users” Papers

- X expert users are given the same patient to contour
- Example of AVM (similar numbers in many papers)
- Agreement ratio < 60%
- 50% time absolute positional shift > 2mm

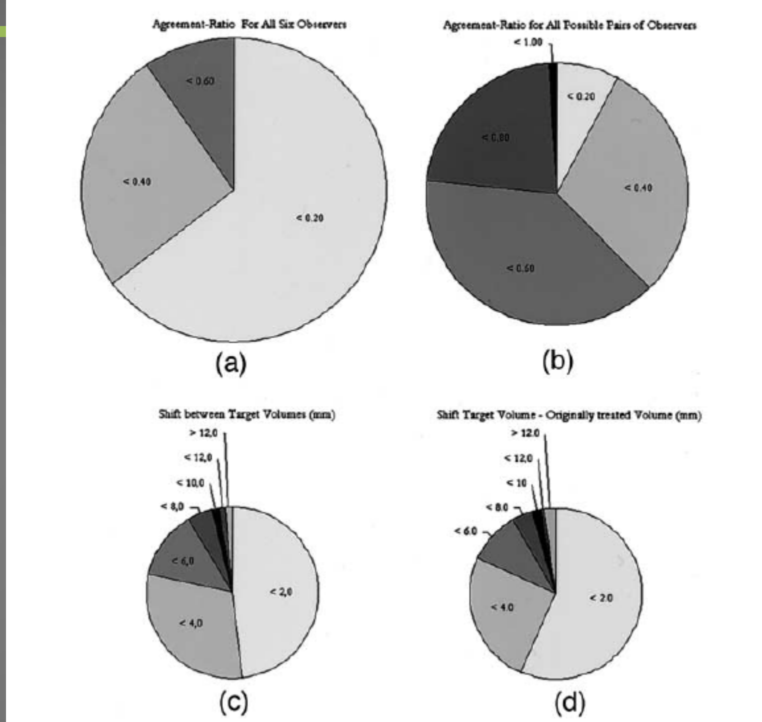


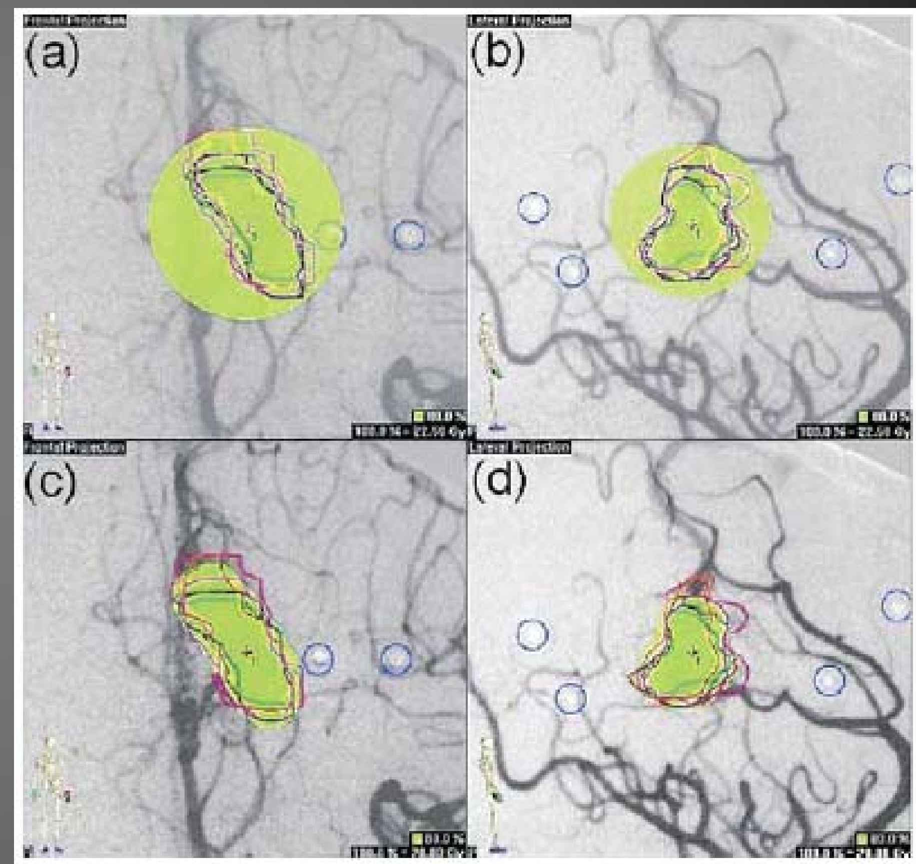
Fig. 3. (a) Agreement ratio, defined as VOA/ECV for all six observers (AR_6) was <60% in all cases. (b) Ratio improved when all possible pairs of observers were compared; however, 76% remained at <60% of agreement. (c) In about 50%, absolute positional shift was <2 mm between mutual individually contoured target volumes (TV) and between target volumes and center of mass of originally treated volume (OTV). (d) However, this shift may increase up to 12 mm.

Interobserver variation of brain AVMs on DSA ● D. R. Buis *et al.*

Higher Accuracy Means Less Room for Uncertainty

a) Isocentric, 1 cone
b) Isocentric, 1 cone
coverage 96.8%±4%

c) Dynamic Conf. Arc
d) Dynamic Conf. Arc
coverage 78%±4.4%



Interobserver variation of brain AVMs on DSA ● D. R. Buis *et al.*

More References on the Topic

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DOI: 10.1259/bjr/68080920

Delineation of brain metastases on CT images for planning radiosurgery: concerns regarding accuracy

[1]K SIDHU, MD, FRCPC, [2]P COOPER, MD, FRCPC, [1]R RAMANI, PhD, [3]M SCHWARTZ, MD, FRCPC, [1]E FRANSSEN, BSc, MSc and [1]P DAVEY, MD, FRCPC

Interobserver variations in gross tumor volume delineation of brain tumors on computed tomography and impact of magnetic resonance imaging

Caroline Weltens[a,*], Johan Menten[a], Michel Feron[b], Erwin Bellon[b], Philippe Demaerel[c], Frederik Maes[b], Walter Van den Bogaert[a], Emmanuel van der Schueren[a]

Target delineation in post-operative radiotherapy of brain gliomas: Interobserver variability and impact of image registration of MR(pre-operative) images on treatment planning CT scans

Giovanni Mauro Cattaneo[a,*], Michele Reni[b], Giovanna Rizzo[c], Pietro Castellone[d], Giovanni Luca Ceresoli[b], Cesare Cozzarini[b], Andrés José Maria Ferreri[b], Paolo Passoni[b], Riccardo Calandrino[a]

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Autosegmentation Can Help

Phys. Med. Biol. 58 (2013) 4071–4097 doi:10.1088/0031-9155/58/12/4071

Segmentation editing improves efficiency while reducing inter-expert variation and maintaining accuracy for normal brain tissues in the presence of space-occupying lesions

M A Deeley[1], A Chen[2], R D Datteri[3], J Noble[3], A Cmelak[2], E Donnelly[4], A Malcolm[2], L Moretti[5], J Jaboin[2,6], K Niermann[2], Eddy S Yang[2,7], David S Yu[2,8] and B M Dawant[3]

- De novo, segmented edit, peer and self-edit
- Segmented edits remained closest to ground truth

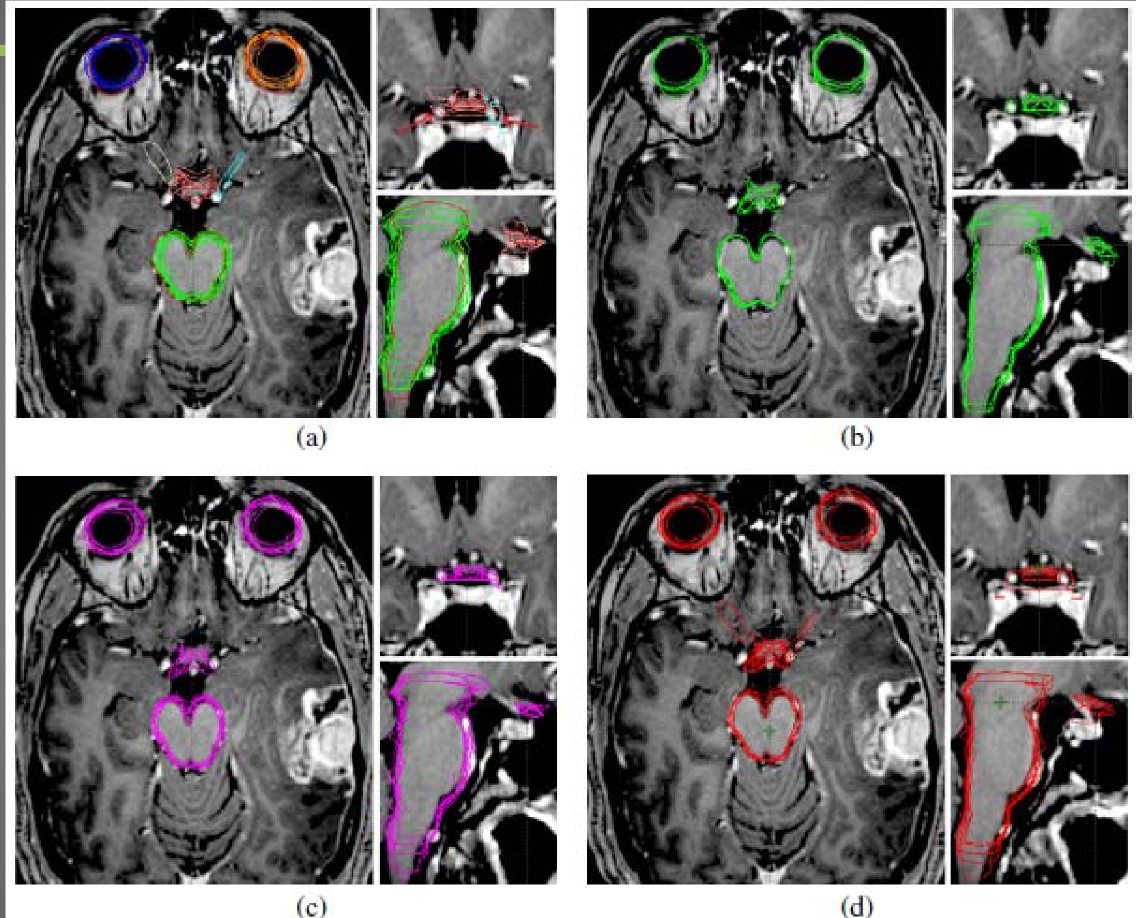
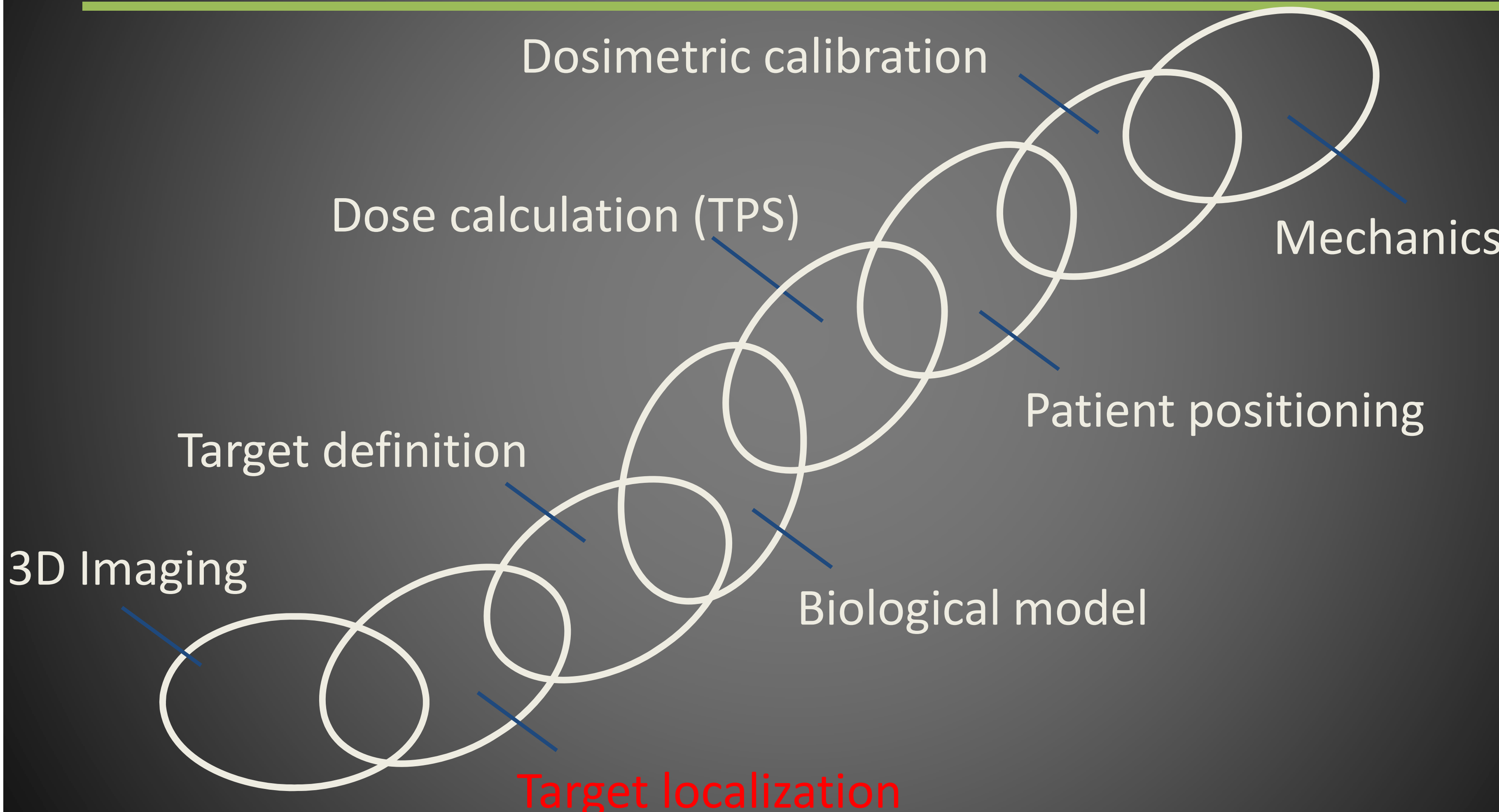


Figure 4. Orthogonal views comparing group results from (a) *de novo*, (b) A_1-edited, (c) self-edited, (d) peer-edited. The red arrows in the upper right (coronal section) of panel (a) point to the internal carotid arteries, which were often erroneously included as part of the optic chiasm in the *de novo* study as well as self- and peer-edited groups. In panel (a) the red contours are those of the A_1 while the other colors represent manual expert segmentations.

…could continue for hours. Dinner?



Accurate, but not precise

Precise, but not accurate

Accuracy and precision are NOT interchangeable!

Images: http://en.wikipedia.org/wiki/Accuracy_and_precision

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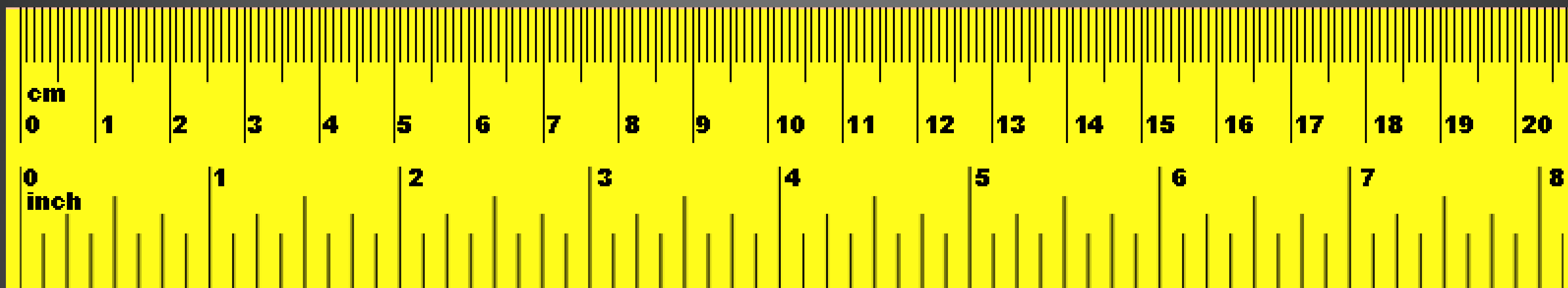

Precision ≠ Resolution

http://www.istl.nist.gov

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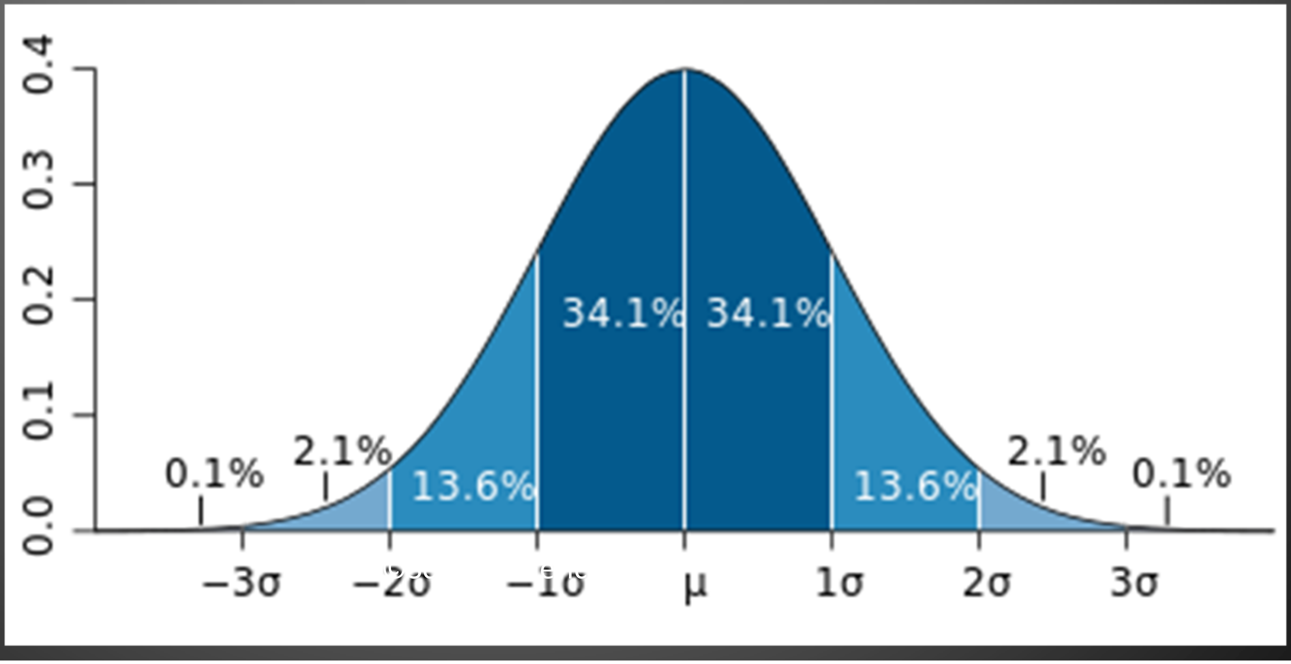
Repeatability: The closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement

Reproducibility: The closeness of the agreement between the results of successive measurements of the same measurand carried out under changing conditions of measurement

Both are part of the concept of precision.

http://physics.nist.gov

Uncertainty: Parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.



http://physics.nist.gov

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- Dave Schlesinger (UVa) for slides on uncertainty