Final volume to be treated:

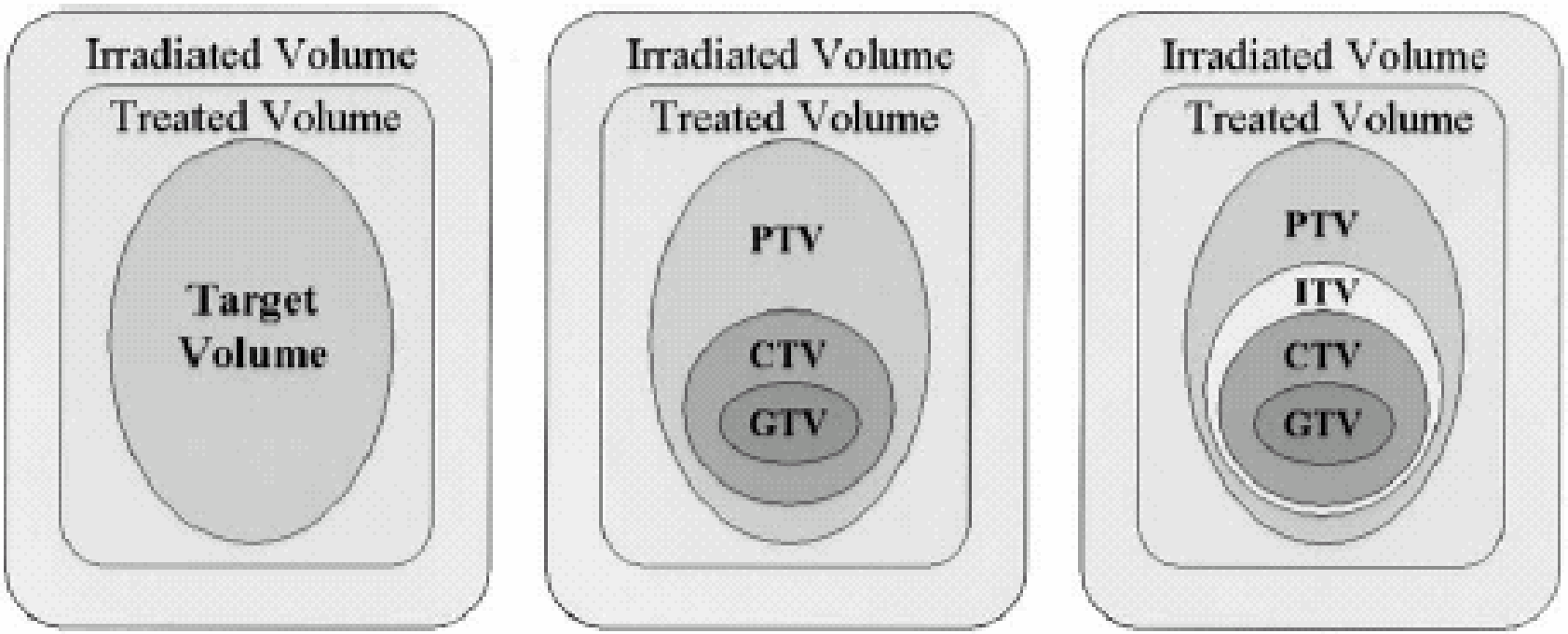
To what extent can you edit the PTV?

Shaleen Kumar
Department of Radiotherapy
SGPGIMS, Lucknow

Can you edit the PTV?

- **What is the motivation to edit a PTV**
- **What are the ‘geometric uncertainties’ that get factored into a GTV-CTV-PTV expansion**
- **What is the risk, if any, we entail in editing a PTV?**

Evolving ICRU philosophy on volumes



(A) ICRU 29
1978

(B) ICRU 50
1993

(C) ICRU 62
1999

Purdy, Seminars in Radiation Oncology, April 2004

ICRU philosophy…

Table 1. Summary of the ICRU Nomenclature for Volumes (1970s to Present)

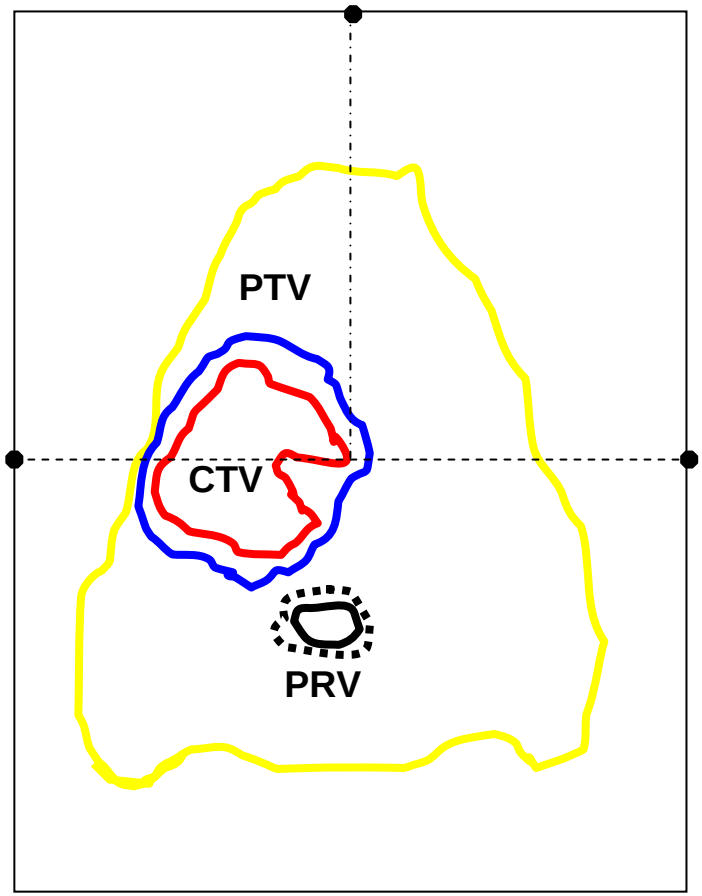
ICRU Report 29: 1970s-1993	*ICRU Report 50: 1993-1999 (Present)*	*ICRU Report 62: 1999-Present*
Target volume	GTV CTV PTV	GTV CTV Internal target volume PTV
Treatment volume	Treated volume	Treated volume
Irradiated volume	Irradiated volume	Irradiated volume
Organ at risk	Organ at risk	Organ at risk Planning risk volume
Hot spot hot spot (area outside target that receives dose larger than 100% of specified target dose) (at least 2 cm^2 in a section)	Hot spot (volume outside PTV that receives dose larger than 100% of specified PTV dose) (>15 mm diameter)	Hot spot hot spot (volume outside PTV that receives dose larger than 100% of specified PTV dose) (>15 mm diameter)
Dose heterogeneity (no value given)	Dose heterogeneity (+7 to −5% of prescribed dose)	Dose heterogeneity (+7 to −5% of prescribed dose)

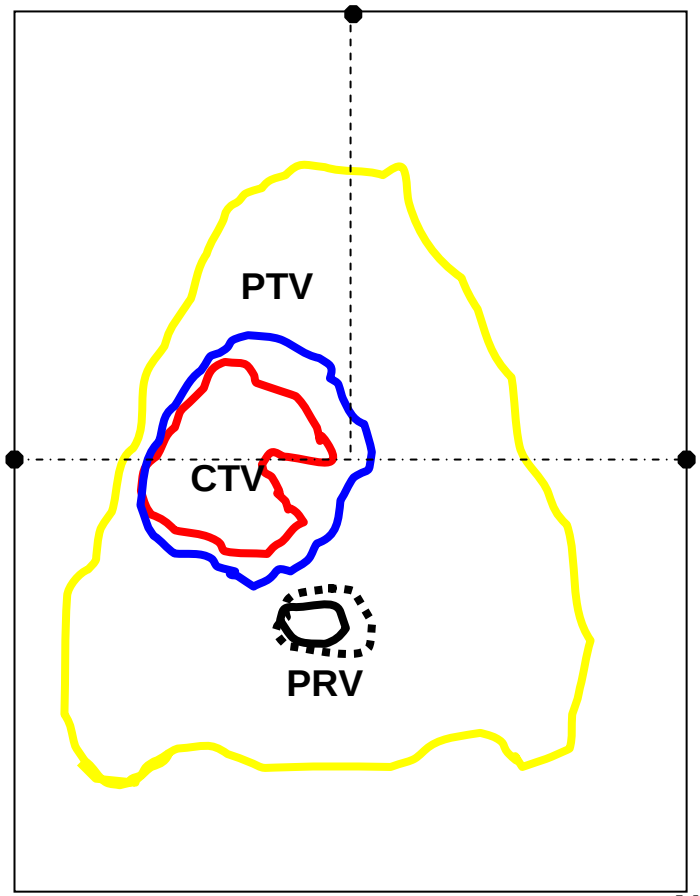
Purdy, Seminars in Radiation Oncology, April 2004

Editing PTV:
Scenario 1: To save an organ at risk

Examine the relationship between fiducials (on cast) and CTV / PRV

Patient (i.e. CTV / cord) do move within cast
PTV and PRV do not
Cord is still safe (if PTV-PRV are apart)





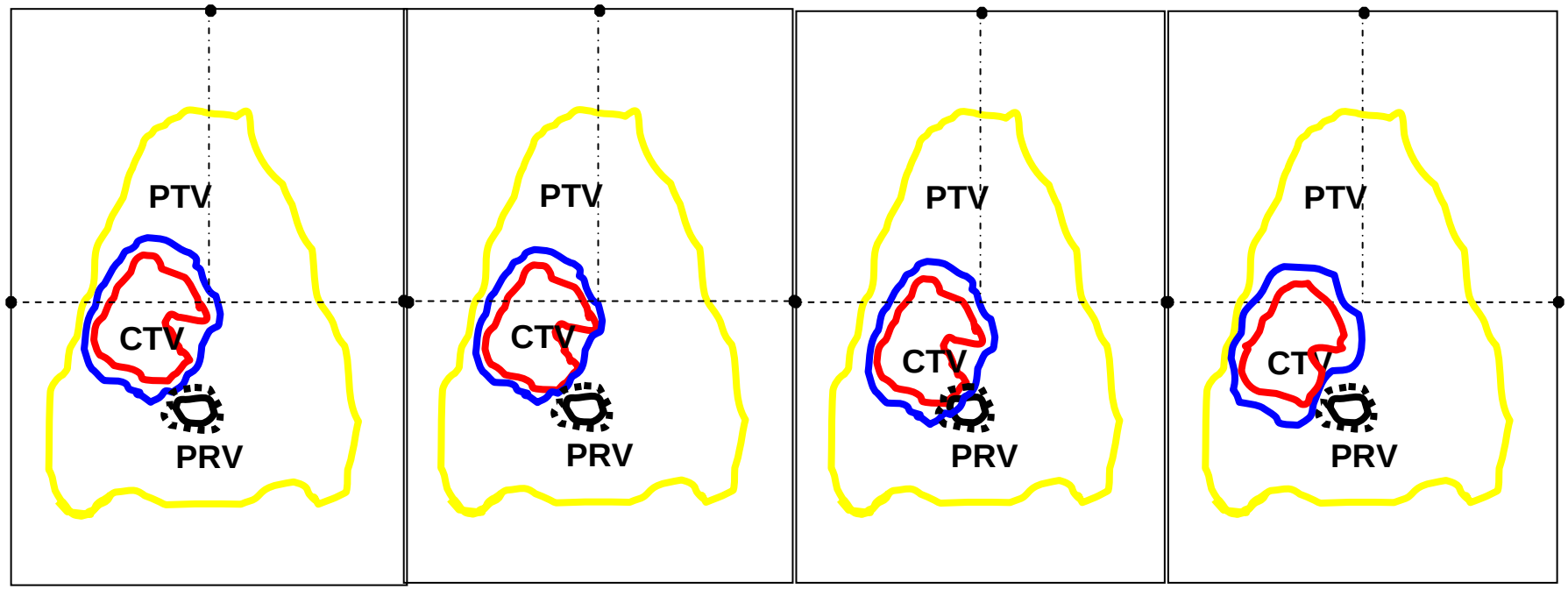
Bit if OAR is close to PTV – one edits it!

PRV shows area to avoid with high dose to save cord
Careful planning will allow cord to be safe

If CTV moves closer to cord ***PTV needs to be modified***, CTV spared

And if CTV also abuts cord ?

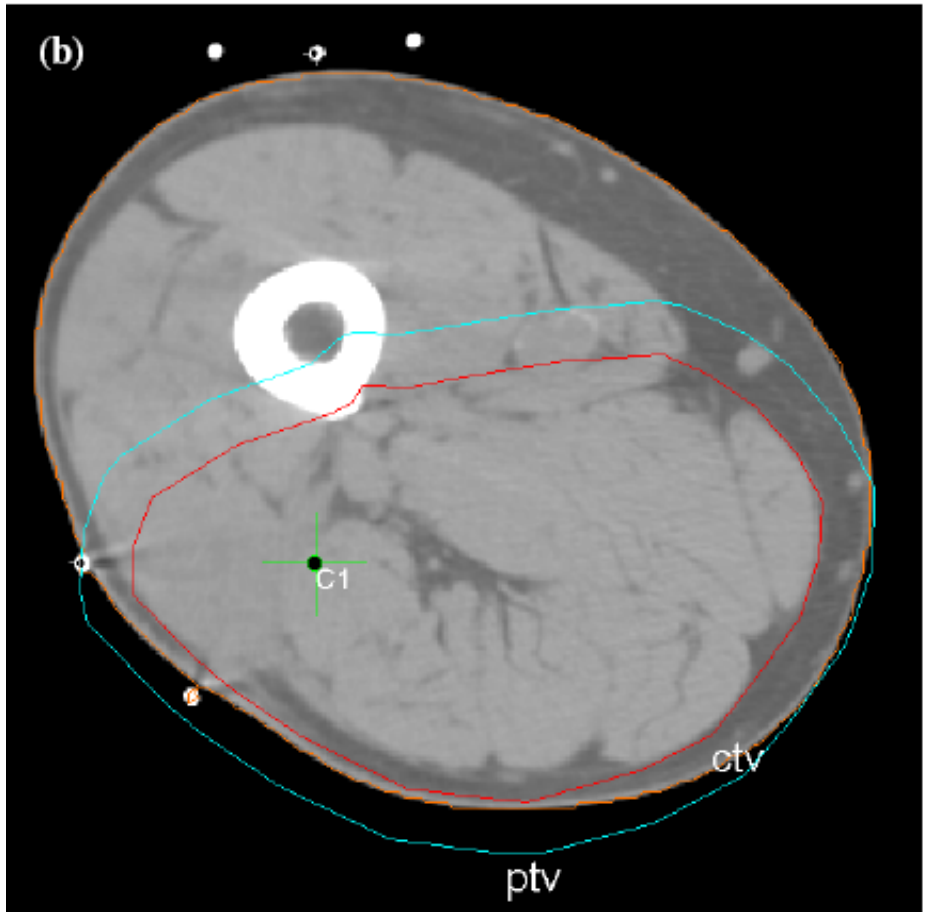
CTV & PTV both need to be modified



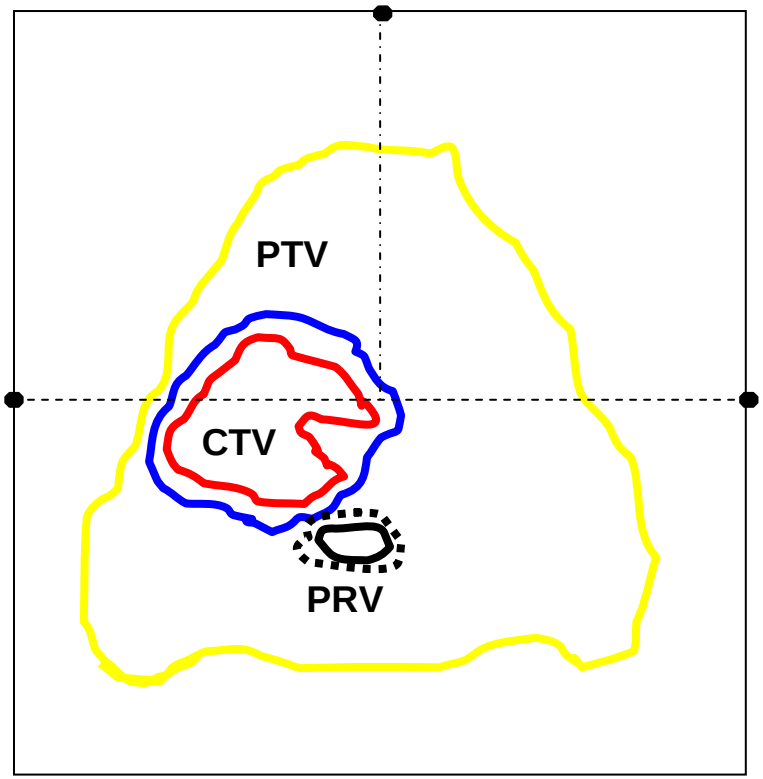
Neil Burnet

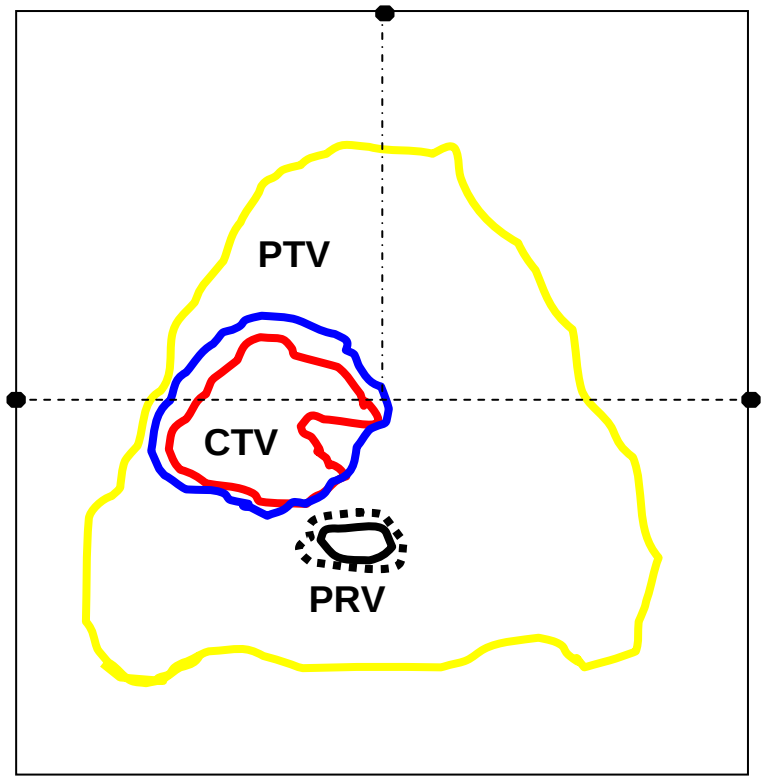
Editing PTV:
Scenario 2: To allow the TPS to calculate!!

- PTV may extend beyond contours of the patient
- The TPS can not give you a meaningful dose distribution in PTV!!
- So you edit the PTV
- PTV is also edited by say 3-5 mm inside the skin to take into account buildup and give a meanful DVH (which you sometimes use for defining objectives)



Editing PTV:
Scenario 3: To allow the TPS to optimise





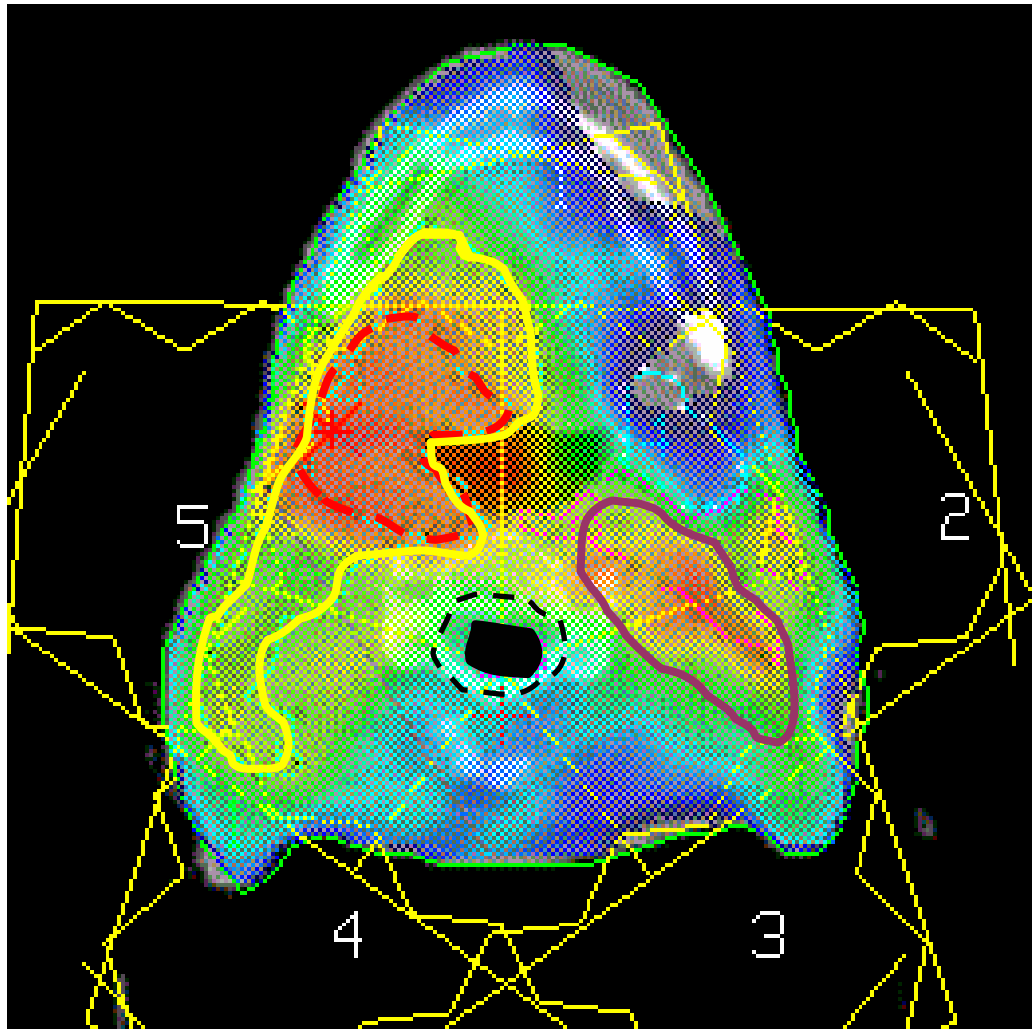
Objective PTV: 70Gy/35Fx
Upper: 100% PTV receives at-least 70Gy
Lower: 0% PTV receives no more than 73.5Gy
Objective PRV:
Lower:0% PRV receives no more than 45Gy

PTV is edited away from PRV to allow the TPS to put a gradient (model a fluence) between two widely differing objectives (as far as photons are concerned!)

What are the Geometric Uncertainties in GTV-CTV-PTV?

Why do we use the word ‘geometric’?

- Geometry: the area of mathematics relating to the study of space and the relationships between points, lines, curves and spaces
- Geometric: describes a pattern or arrangement that is made of shapes such as points, lines, curves and spaces

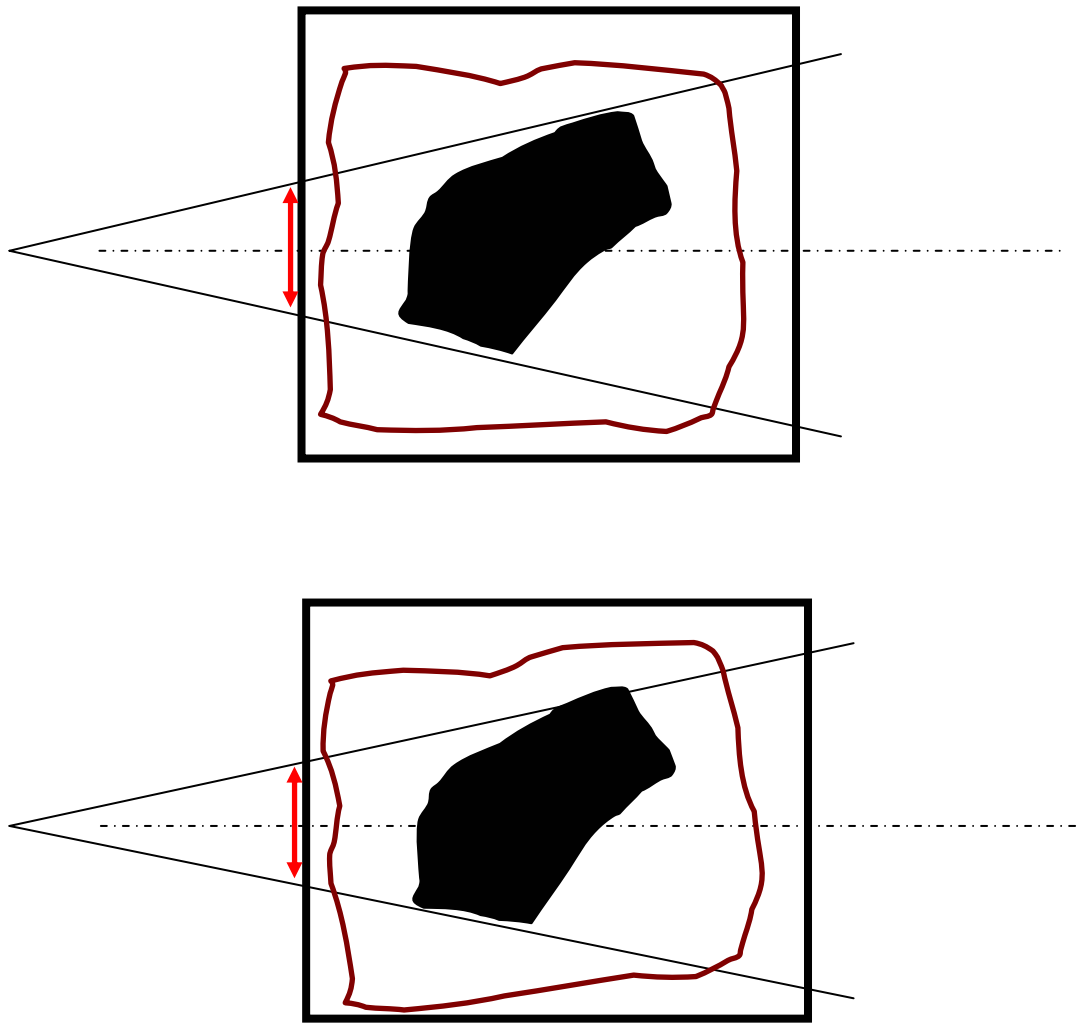


Geometric uncertainty #1: GTV & CTV

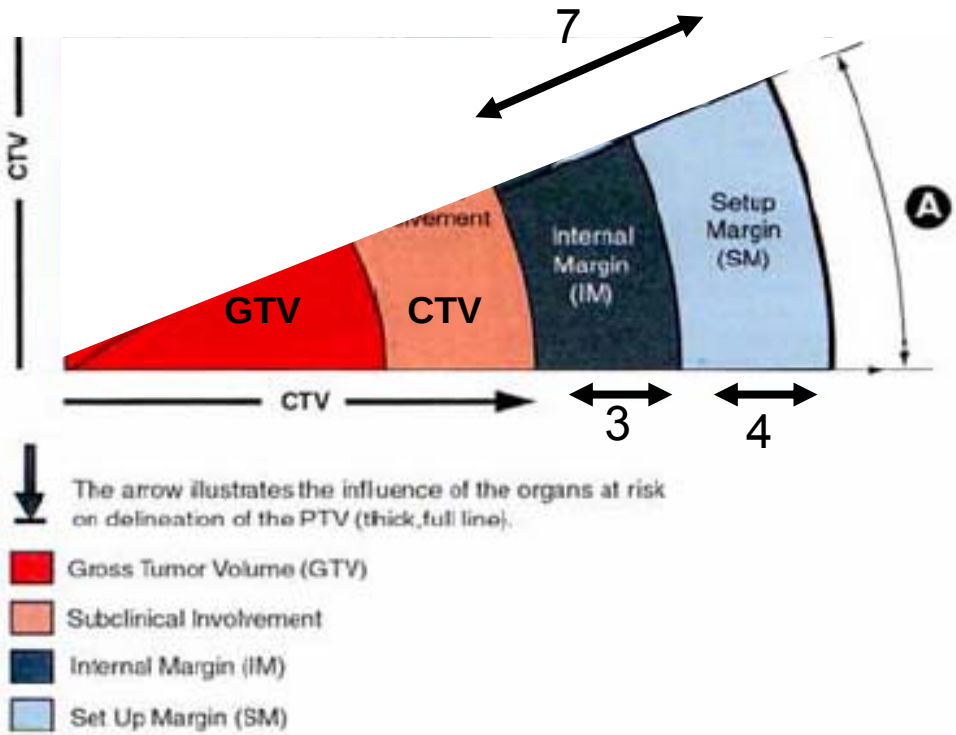
- Determining the size, shape and location of GTV &
- Choosing margins to expand into CTV will remain clinical responsibilities
- Method of evaluation of GTV is of critical importance
  - Rely on imaging
  - Inter-operator variations inevitible
  - Solution is –good and detailed training
- Expanding GTV to CTV is the biggest source of geometric uncertainty

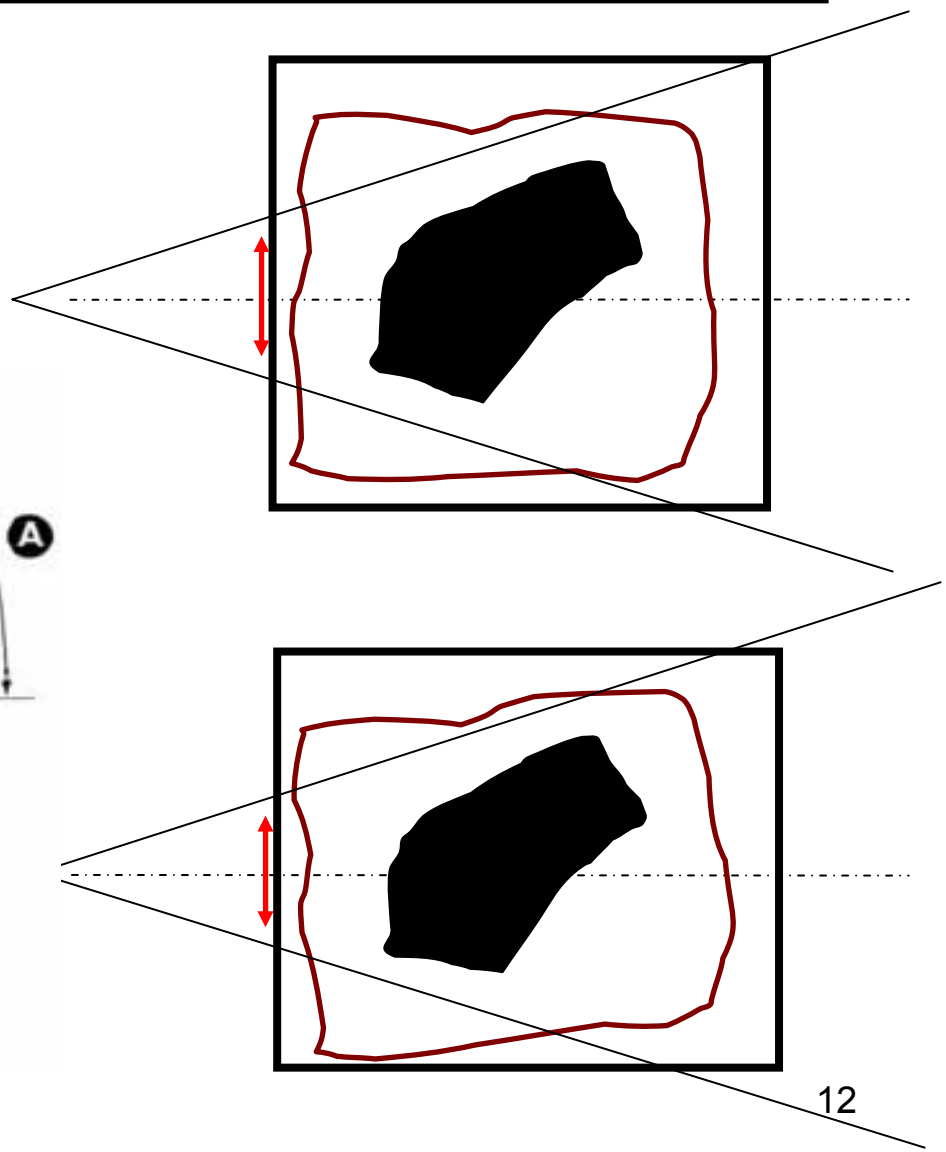
Geometric uncertainty #2 : Expanding CTV to PTV

- It's a technical issue BUT
- Clinician must remain closely involved
- Movement problems are patient related
  - Expected movements (breathing)
  - Expected changes in shape (bladder filling, tumor regression / growth, weight changes)
  - Inaccuracies or variations in treatment setup



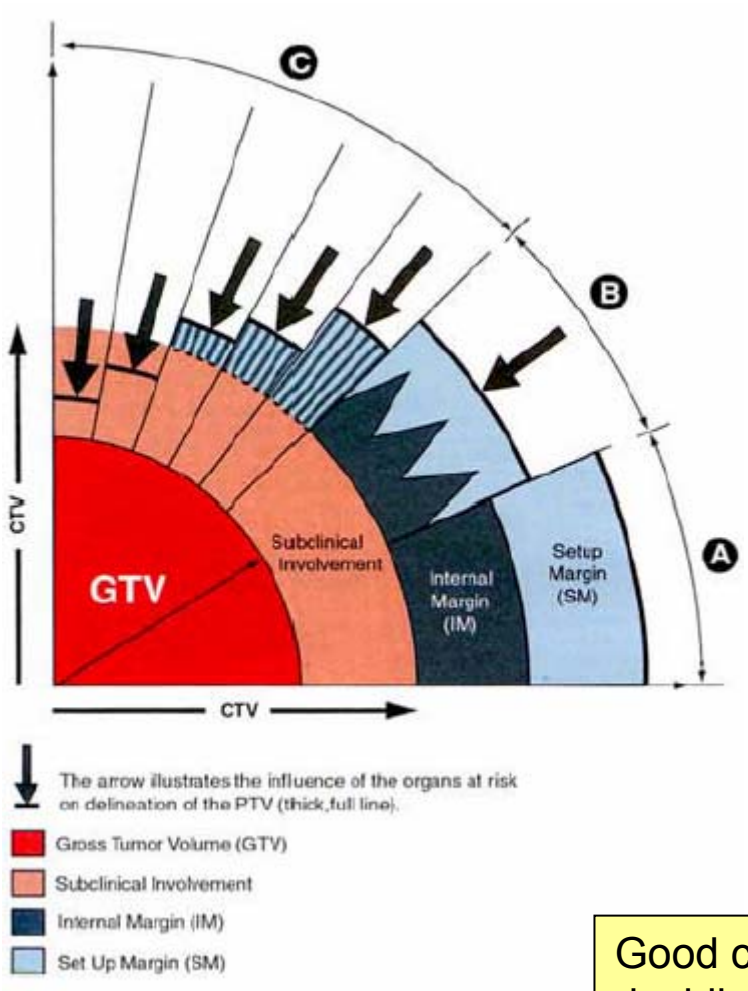
Successively adding margins means PTV too large!





So, generating a PTV…

ranges from a mathematical construct to a risk philosophy



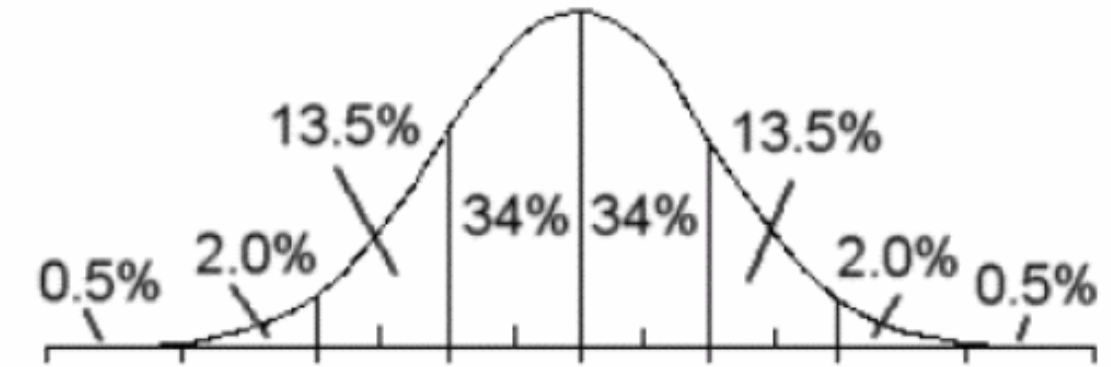
ICRU 62

- Scenario C: Presence of OARs dramatically reduces the width of acceptable safety margins. Reduced margin for **CTV** may be compatible with cure, albeit at a lower probability!
- Scenario B: Quadrature sum the squares of the SDs of uncertainties (IM, SM)
- Scenario A: CTV + IM + SM =PTV

Good clinical judgment will always be required in deciding whether or not to compromise

So how are they combined?

- Must distinguish between systematic errors: which at some point in time during the preparation of treatment become fixed and then remain fixed AND
- Treatment execution errors, specially those due to daily set up errors and random inter-fractional anatomical movement, which will vary
- Breathing is NOT random; so breathing positional errors are treated separately, more like systematic errors
- Must distinguish between Gaussian and Non gaussian errors
  - Movement is Gaussian; breathing is non-Gaussian
  - Gaussian errors are best described by SDs



BIR 2003 (Describes source of uncertainty & how to combine margins)

Systematic errors (contributing to CTV to STV margin)	SD
Gaussian	
Doctors delineation error	Σ_{doctor}
Organ position and shape (except breathing) at time of localisation	Σ_{motion}
Phantom transfer error (geometric imaging error [TPS and linac])	$\Sigma_{transfer}$
Systematic set up error	$\Sigma_{set\ up}$
Combined systematic Gaussian errors	Σ
Linear	
Breathing positional error	$\boldsymbol{b}$
TPS beam algorithm error	a
Treatment execution errors (Contributing to STV to PTV margin)	
Gaussian	
Daily set up error	$\sigma_{set\text{-}up}$
Organ position and shape (except breathing)	σ_{motion}
Unblurred beam penumbra width	σ_{p}
Combined treatment execution errors	σ

McKenzie et al. Geometric Uncertainties in RT, BIR 2003

Doctors delineation error: Σ_{doctor}

- This can be the single greatest source of geometric uncertainty in the treatment process
- Once a CTV has been drawn by the doctor, this error will be promulgated throughout the treatment, hence a systematic error
- Attempts to quantify errors are actually measurements of variations in the CTVs rather than indications of absolute errors
- This error may be greatest in the sup-inf direction because of spacing of CT slices (add 30% of slice width to the SD)

Organ position and shape at the time of localisation: Σ_{motion}

- Includes translational motion of CTV and changes in CTV shape
- Examples include rectal filling and bladder distension but not effects of breathing on CTV
- Organ motion error used to calculate CTV- STV is also used to calculate STV – PTV margin

Phantom transfer error: $\Sigma_{transfer}$

- So called because of the error accumulated in the transfer of image data from the CT scanner through TPS to linear accelerator can be measured by imaging a phantom containing structures on a CT scanner
- Measured by comparing the DRR and the portal image of the treated phantom
- This measures most of the uncertainties in the transfer process, though not errors in say volume growing facility or preparation of shielding blocks
- Does not include differences between couches of CT scanner and LA as a rigid phantom is unaffected by couch sag

Components of the phantom transfer error

A. Geometric imaging error:

- CT alignment laser errors and error in the indication of the couch position (tolerances ± 2mm, SDs 1mm)
- SDs of errors in placing skin marks will be of same order
- Open C type MR scanners are prone to image distortion

B. Treatment planning system error

- Potential errors are in localisation of skin markers (≈0.5mm), errors in volume growing facility, templates to produce/position shielding blocks (SD 1mm)

C. LA geometry error

- Field-edge position, FSD indicator, isocentre location, patient positioning lasers, MLC leaf position, lead shielding position (combined SDs 2mm)

Combination of A+B+C = SDs 3mm (use only when data from portal imaging is unavailable)

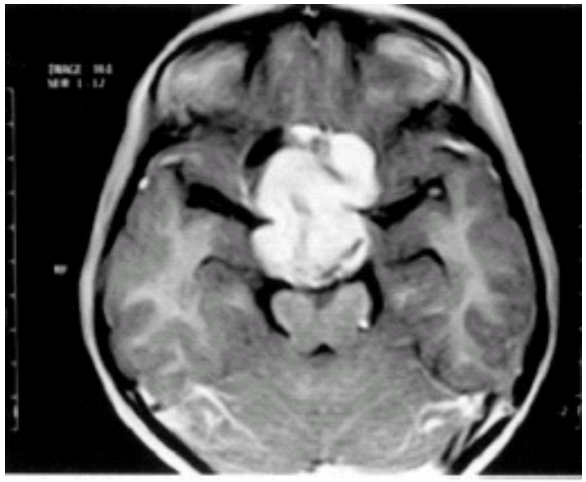
Breathing positional error

- This is defined as the amplitude of motion of the CTV caused by breathing.

- The positional probability of a target moving under the influence of breathing is very different from a Gaussian distribution – as the target spends time either at end of inhalation or exhalation

- The breathing amplitude **‘b’** should be added linearly to both the positive and negative direction of the axis, especially if the phase of breathing at the time of image capture is unknown

CTV to PTV expansion using relatively well demarcated brain tumors as a model using high precision techniques



- GTV = tumor / presumed tumor
- **CTV: add 5 mm in 3D**
- PTV: add 5 mm for mask system and **2mm for SCRT**

- Dose 54Gy/30#
- Follow-up median:25mo (12-47)
- 3 yr DFS 96%

Systematic errors	SD	SD (mm)
Gaussian		
Doctors delineation error	Σ_{doctor}	1
Organ position and shape	Σ_{motion}	0
Phantom transfer error	$\Sigma_{transfer}$	1.2
Systematic set up error	$\Sigma_{set\ up}$	
Combined systematic Gaussian errors	Σ	**1.6**
Linear		
Breathing positional error	***b***	0
TPS beam algorithm error	*a*	0.2
Treatment execution errors		
Gaussian		
Daily set up error	$\sigma_{set\text{-}up}$	**1.3**
Organ position and shape	σ_{motion}	0
Van Herk: **2.5** Σ **+ 0.7** σ (2.5x1.6 + 0.7x1.3)		**4 + 0.9**
		≈5mm

Jalali et al. R&O 2005

Brada & Bidmead, BIR 2003

Brain tumors - LGG

- LGG (EORTC 22844; 45 Gy vs. 59.4Gy, trial initiated 1985, reported 1996)
  - 'Target Volume': Up to 45 Gy = contrast enhancing (pre-op CT scan) + 2 cm; 45 Gy – 54Gy = + 1cm; >54Gy = 'minimal margin'
  - If non-enhancing (pre-op CT scan) add 1 cm
  - Extent of resection: Biopsy / <50% resection : 45%; 50-89% : 30%; 90-100% : 25%
- LGG (NCCTG/RTOG/EORTC; 50.4 vs. 64.8 Gy, trial initiated 1986, reported 2002)
  - 'RT fields' = Pre-op tumor volume (CT or MR) + 2cm margin (to 50.4Gy) and +1 cm margin to 64.8Gy
  - Failure patterns known for 65/114 patients who progressed; 92% within field, 3% outside field but within 2 cm, 5% outside field but beyond 2 cm
- LGG (RTOG 98-02) (54Gy/30fx)
  - T2w post op MRI (pre-op MRI acceptable if biopsy) + 2cm margin to block edge

Brain tumors - LGG

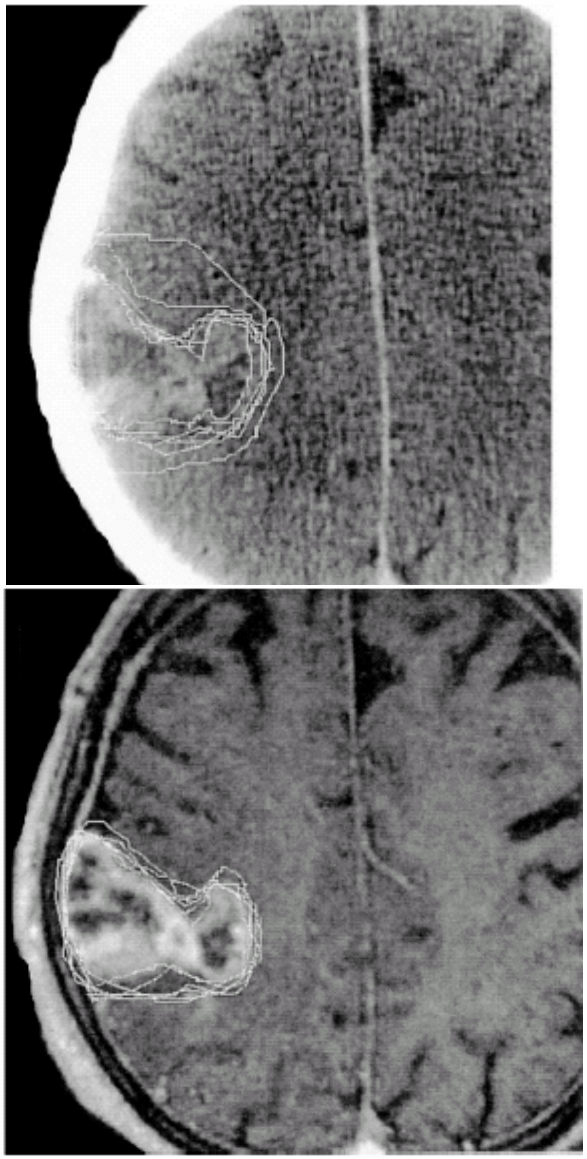
- Failure patterns with 3D planning
  - Grade 1, 2 - AA, OAS, ODG, n=46, Jan 85 - Dec 92
  - 5 mm CT slices; IV contrast; aquaplast immobilization (Σ=1.7mm, σ = 1.4mm; 5.3 mm)
  - Post op CT scan: enhancing area on CECT

    If non-enhancing – entire low attenuation area; T2-w signal abnormality
  - Target volume: Microscopic spread + set-up errors + 1-3 cm in 3D to give 45 - 50.4Gy

    Boost volumes: + 0 – 2 cm in 3D for doses up to 54 - 59.4Gy
  - Treatment portals cover target volume in 3D
  - 11 recurrences / 46, at a median of 32.7 months, all within the 'boost' volumes
- **Conclusion: No relationship between tumor volumes expanded and ultimate outcome**
- Until control of disease in radiographically abnormal volume is achieved, need for large fields to treat prophylactically microscopic disease is questionable.

Pu et al, IJROBP, 31;461-466, 1995

Inter-observer variability in volume definition



V in cm^3	CT	Patient
Radiation Oncol.	Observer 1	57.6
	Observer 2	20.8
	Observer 3	25.1
Radiologist	Observer 4	30.8
	Observer 5	34.7
	Observer 6	39.1
Neuro-surgeon	Observer 7	33.4
	Observer 8	24.0
	Observer 9	32.0
	Mean V	33.0
	S	10.8
	Range	36.8
	V intersection	12.6
	V encompass	67.2

Weltens et al. R&O 60:49-59, 2001

PTV is often edited without apparent compromise

- For brain tumors, different volumes with CECT, T1w with gadolinium, T2-w or FLAIR images
- Probability of tumor infiltration along white matter tracts is uncertain
- LGG do not have a dose response relationship between 45-64.8Gy
- So, does irradiating these volumes influence patterns of failure?
- Physician delineation systematic errors are probably large. Over delineate??
- So, volume of expansion of CTV to PTV in the range of (5-10mm) or editing it to small amounts does not seem to influence clinical outcome

Other sites

Table 2 Overview of the Geometric Errors in External-Beam Radiation of Prostate and Head and Neck (CT and MRI)

	Treatment Execution (Random) Errors (mm)			Treatment Preparation (Systematic) Errors (mm)		
	LR	SI	AP	LR	SI	AP
Prostate						
Target volume delineation[64]	—	—	—	1.7	2.3.5	2
Organ motion[40]	0.9	1.7	2.7	0.9	1.7	2.7
Setup error	2.5	1.6	1.9	0.9	0.9	1.3
Total error (quadrature sum)	2.7	2.3	3.3	2.1	2.8-3.9	3.6
Margin from CTV to PTV[106]	6.1	7.2-9.4	9.5			
Head and neck						
Target volume delineation[65]	—	—	—	3.2	3.3	2.7
Setup error	1.7	1.6	1.9	1.2	1.1	1.3
Total error (quadrature sum)	1.7	1.6	1.9	3.4	3.5	2.9
Margin from CTV to PTV[106]	7.9	8.1	9.7			

NOTE. The margin from CTV to PTV is calculated for coverage of the CTV in 95% of the treatment sessions according to Stroom et al[106] (ie, the summation of 2 times the systemic variation and 0.7 times the random variation. The indicated set up variation includes correction of setup errors with an EPID and an offline correction protocol.[26]

C. Rasch, R. Steenbakkers, and M. van Herk Semin Radiat Oncol 15:136-145 © 2005

Conclusions
(theory & practice of editing PTV expansion)

- Target (GTV / CTV) delineation is a major source of variability (It is very much a large geometric uncertainty)
- Given the good local control with smaller margins for PTV expansion than calculated, it is likely that delineated GTV-CTV overestimates actual volume
- However, recurrences in H&N sites as a consequence of parotid sparing IMRT in regions adjacent to parotids warn us that information on sub-clinical disease spread is uncertain
- PTV expansion is necessary and edit PTVs with caution