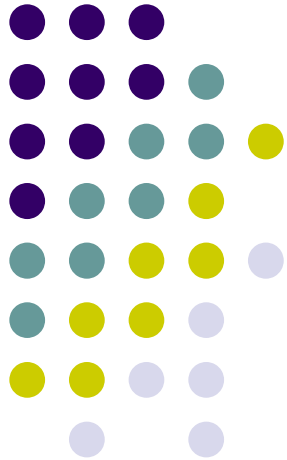
Consideraciones sobre influencia y evaluación de la incertidumbre en el posicionamiento y movimiento del paciente en Radioterapia

PhD Eduardo Francisco Larrinaga Cortina



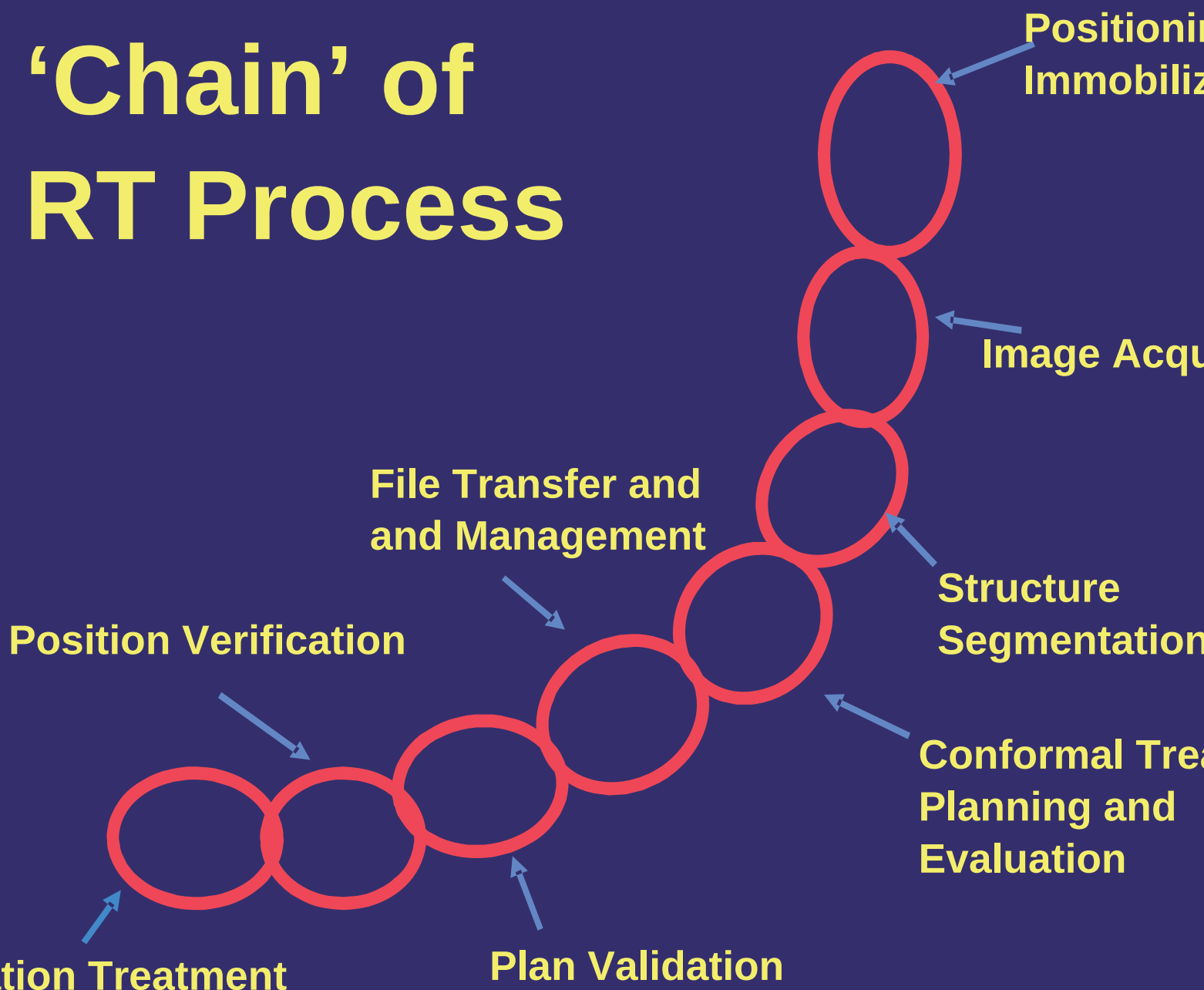
Overview of Radiation Therapy

The goal of radiation therapy is to hit something you cannot see, with something else that you cannot see, to produce a bio-chemical reaction that you do not understand and which cannot easily be measured.

Accuracy requirements and uncertainties in radiation therapy ICTP-IAEA 2013

Howard I. Amols, Ph.D.

‘Chain’ of RT Process



Requerimientos de exactitud en la administración de la dosis en Radioterapia

- **ICRU 24, 1976 : ±5% en la dosis absorbida entregada en el punto de especificación**
- **Goitein, 1983: ± 3,5%, 1 SD**
- **Brahme, 1988: ±3,3%, 1 SD**
- **Mijnheer, 1996 et al.: ±3,5%, 1 SD**
- **Van Dyk, 1999: recomendó ±5% / ±5 mm**
- **Wambersie, 2002: ±3,5%, 1 SD, en el pto de especificación; ±5% en otros puntos del PTV**

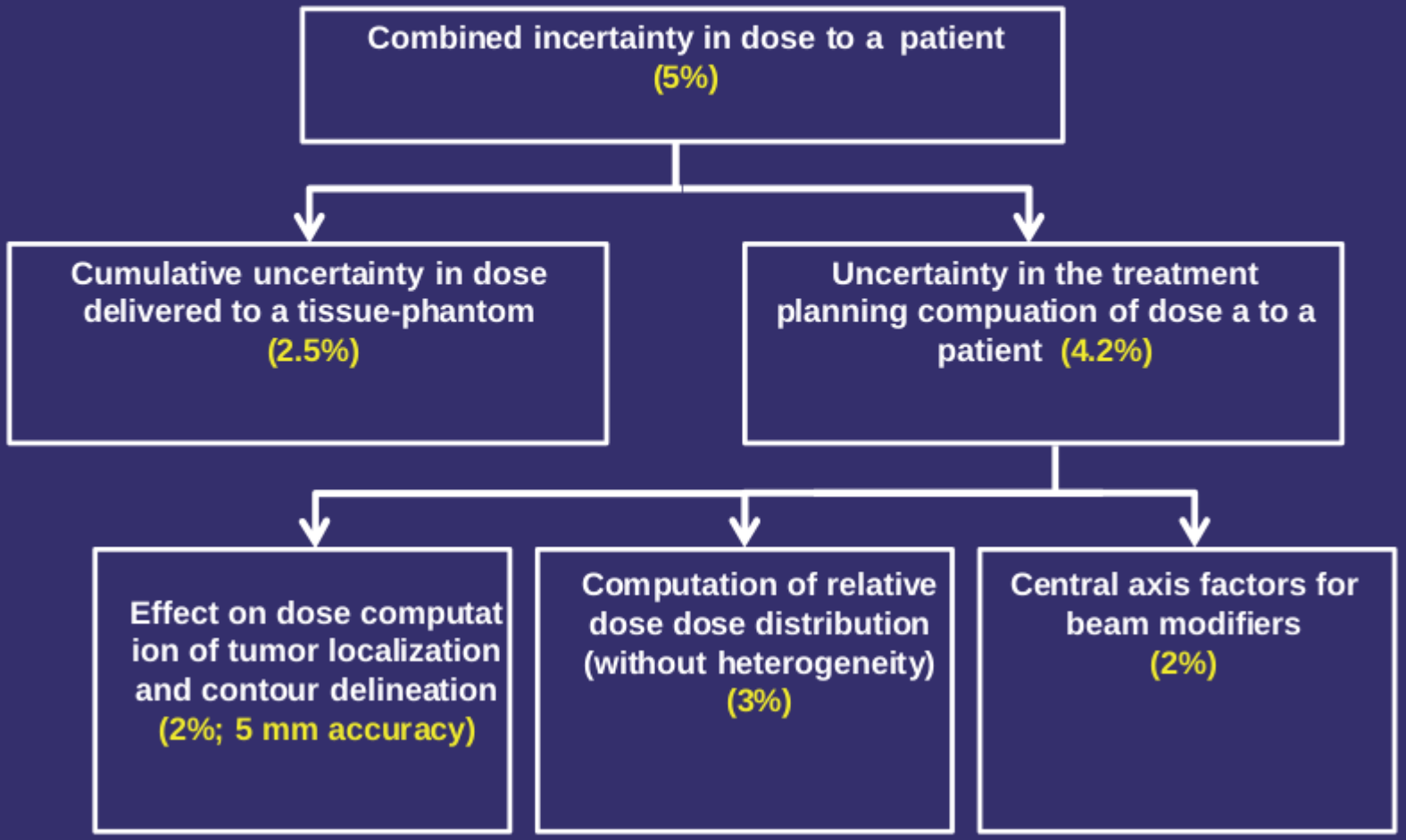
Herring DF, Compton DMJ: "The degree of precision required in the radiation dose delivered in cancer radiotherapy"

Brit J Radiol 5:1112-1118, 1970

- Recommends that the dose delivered over the course of treatment be known to within ± 5%.
- Achieving this level of accuracy and precision requires that each step of the treatment process performs at a dosimetric precision much better than 5%.
- This places stringent tolerances on both (i) the precision of the clinical dosimetry and (ii) the geometric precision in delivery and planning.
- To achieve and maintain the desired level of precision, it is recommended that a *system* of treatment delivery be constructed considering dosimetric and geometric factors.

Dosimetric Uncertainties

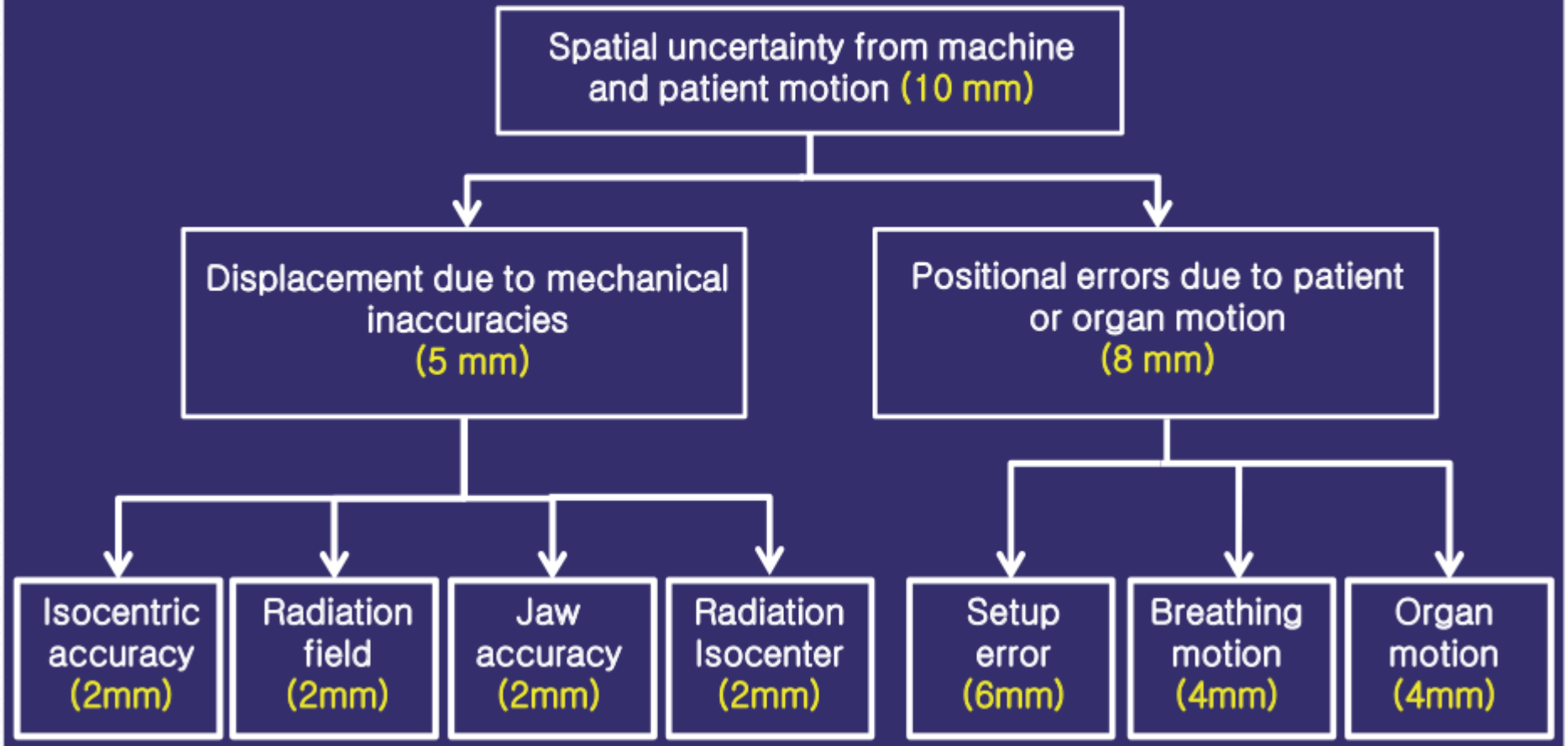
(95% confidence level)



AAPM Report #13

Spatial Uncertainties

(95% confidence level)



AAPM Report #13

What Effects Accuracy in Radiation Therapy?

Errors, Mistakes, Uncertainties, Unknowns

Errors:

- People make mistakes
- Poor training/understanding
- Systematic mistakes in commissioning
- Random mistakes on individual patients

Uncertainties:

- Patients move
- tumors and tissues change shape
- geometry and dose of equipment not constant

Unknowns:

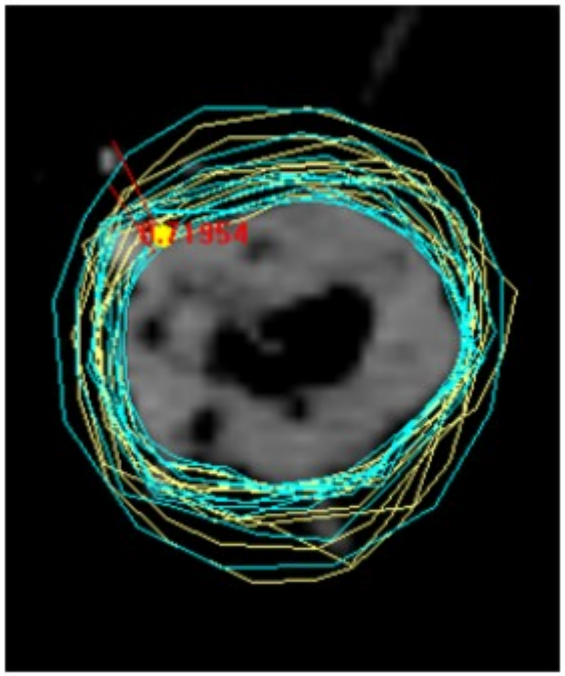
- Definition of CTV
- Tumor and normal tissue radiosensitivity

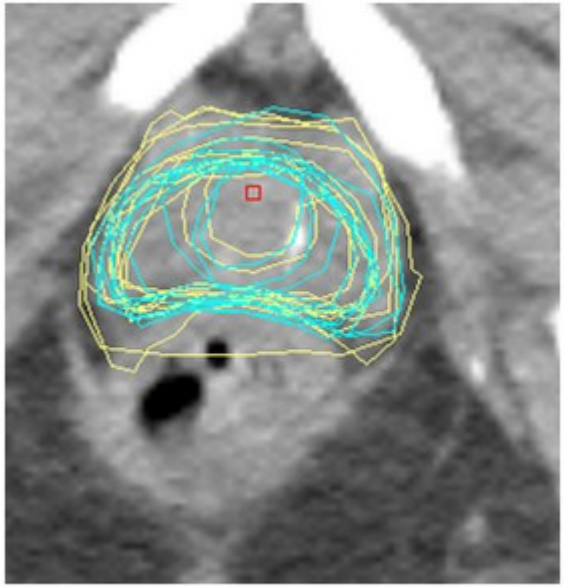
Nature of Uncertainties

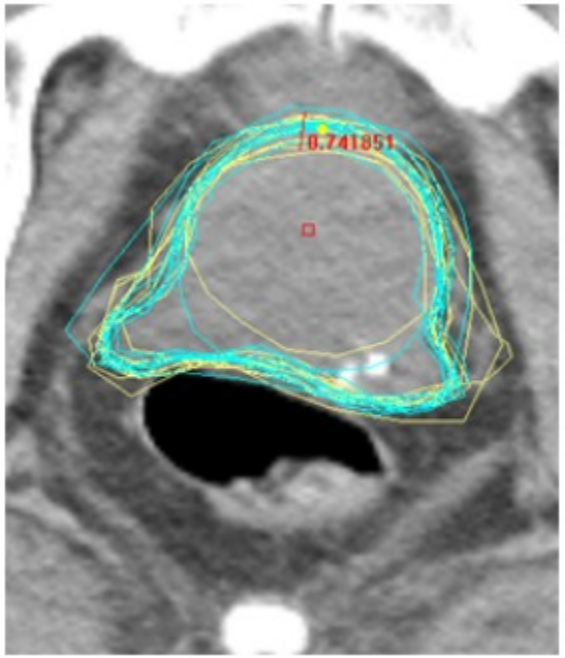
- Imaging and segmentation
  - All imaging modalities have inherent resolution
  - Inter-/Intra-observer variation in target delineation
- Setup Variation
  - Patient position/geometry differs from that in simulation and planning
  - Commonly inferred by radiography, from skeletal anatomy
  - Not necessarily indicative of target location
- Internal Organ Motion
  - Patient's tumor or normal tissues are positioned differently relative to the skeleton than they were during planning and simulation
- Volume change and deformation
  - Geometry of the target and/or normal tissues is different from simulation conditions
- Dose planning and delivery
  - All dose calculation algorithms have inherent accuracy
  - All delivery systems have inherent accuracy

Delineación de volumenes

- **Fuente fundamental de incertidumbre geométrica en la determinación del blanco**



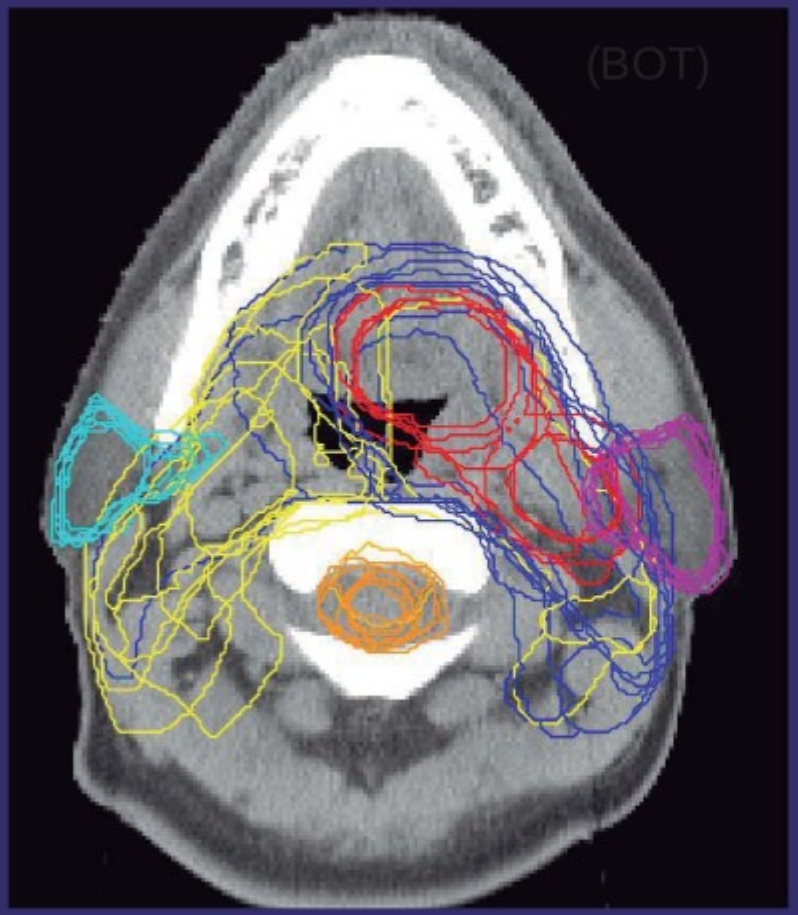


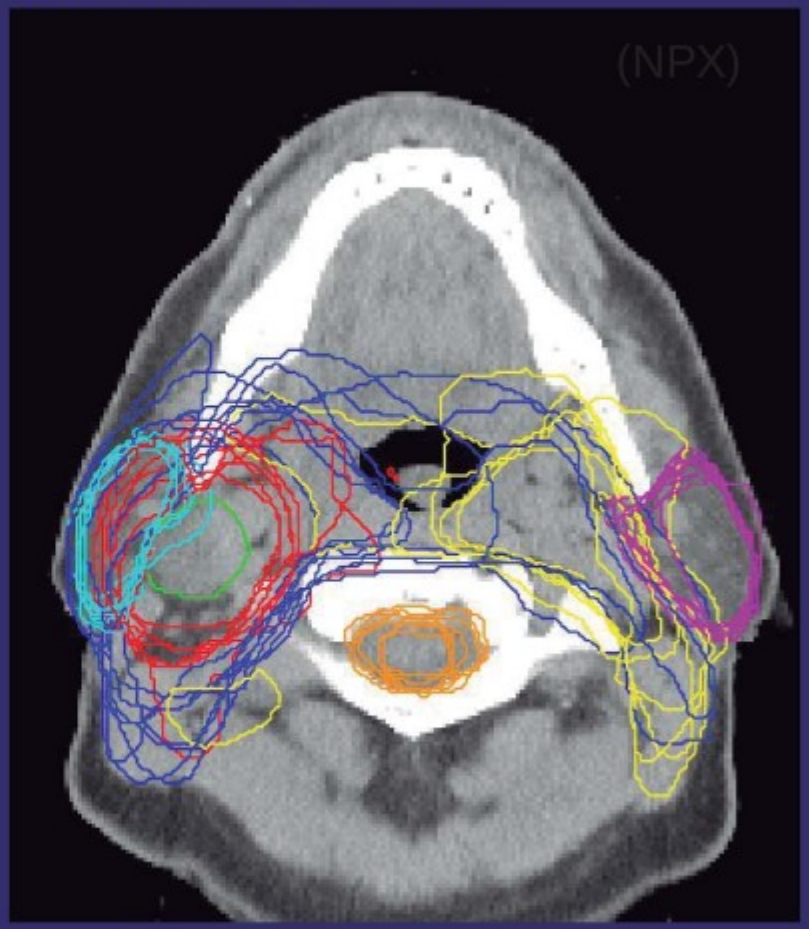


Tudor G, Bernstein D, Riley S, Rimmer Y, Thomas S, van Herk M and Webster A 2020 *Geometric Uncertainties in Daily Online IGRT: Refining the CTV–PTV Margin for Contemporary Photon Radiotherapy* British Institute of Radiology, London (https://doi.org/10.1259/geo-unc-igrt)

Target Delineation Variation

Inter-observer variations in contouring H&N patients



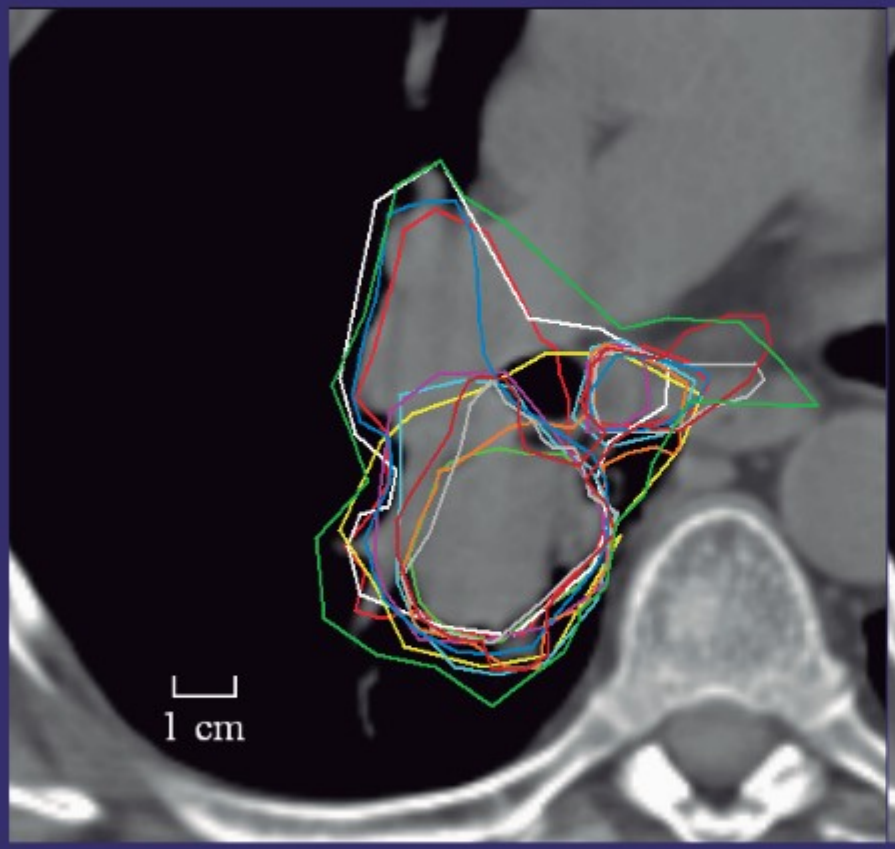


"Concordance among GTV drawn by 'experts' ranged from 82% to 0%. Average was 53%".
Cooper JS, IJROBP 67:972-5, 2007

Chao et al. IJROBP (2007)

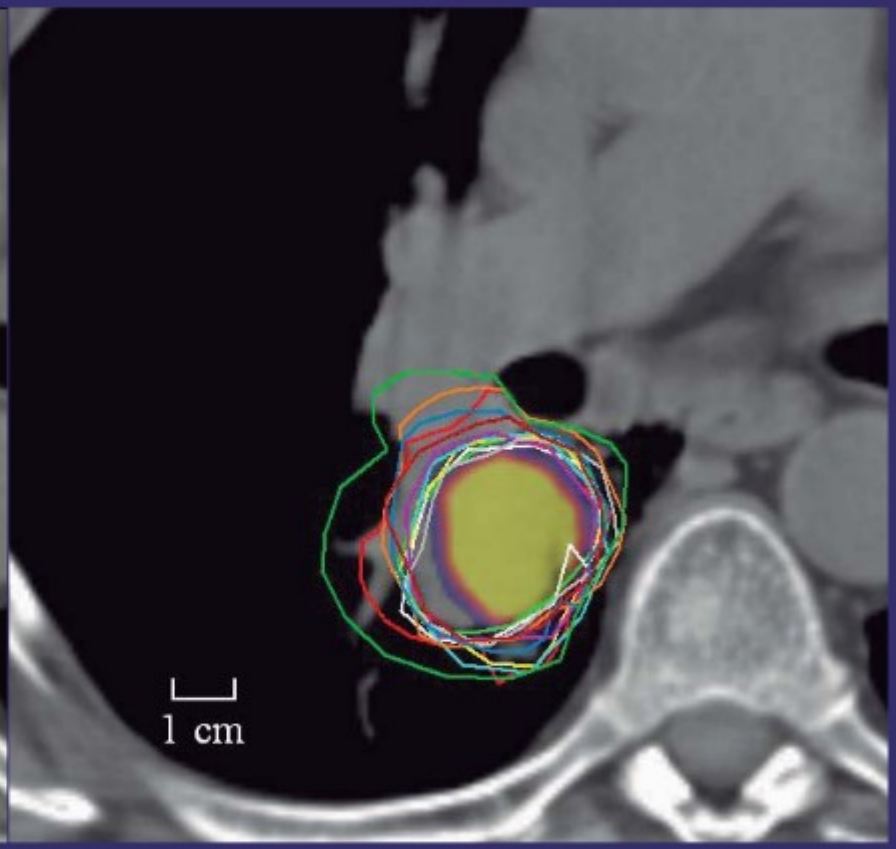
Unresolved Clinical Challenge

How to deal with residual uncertainties in target delineation?



CT (T_2N_2)

SD 7.5 mm



CT + PET (T_2N_1)

SD 3.5 mm

Steenbakkers et.al., IJROBP, 2006

Nature of Uncertainties

- Imaging and segmentation
  - All imaging modalities have inherent resolution
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- Setup Variation
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  - All dose calculation algorithms have inherent accuracy
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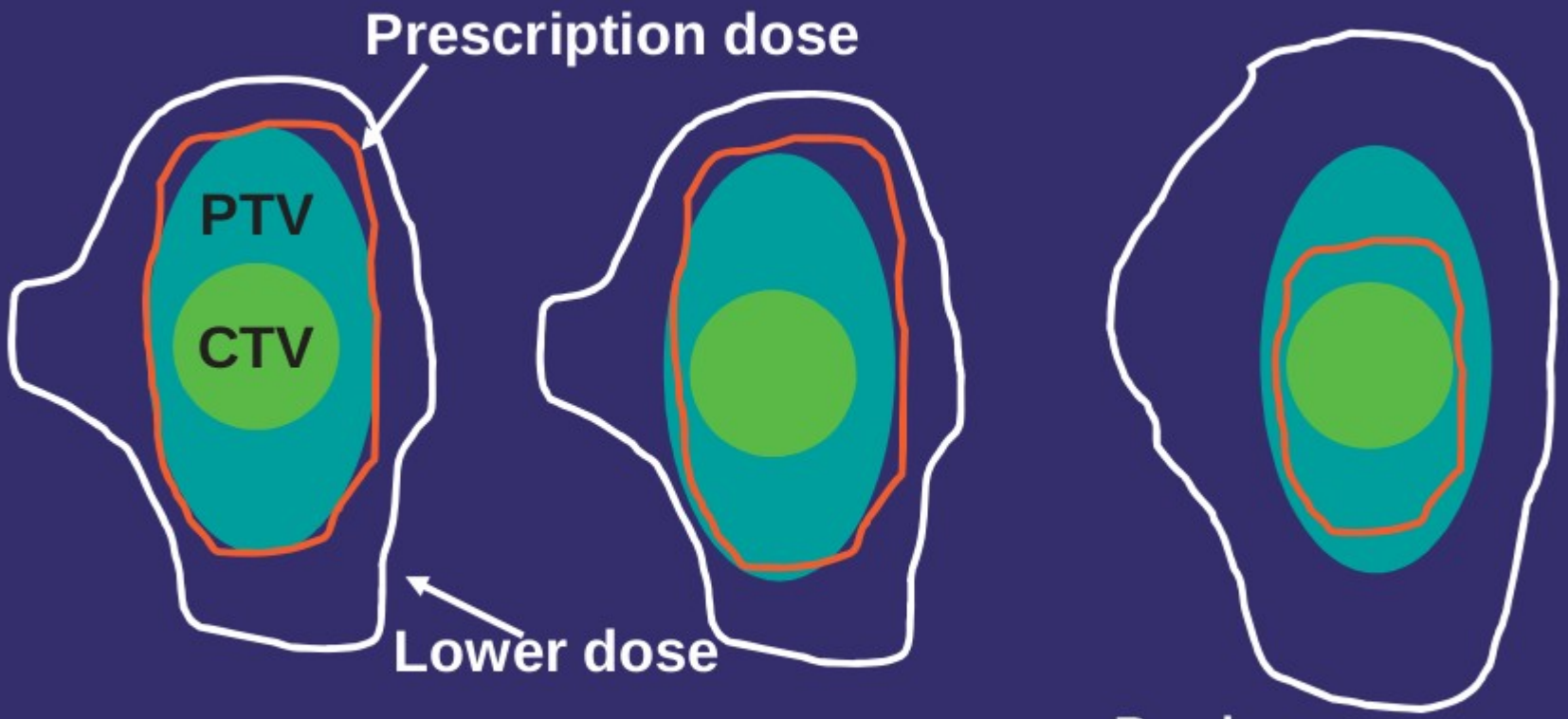
Systematic and Random Uncertainty in EBRT

- Targeting uncertainty (TU) of i^{th} fraction of j^{th} patient = x_{ij} = planned isocenter (CT_0) – treated isocenter (CT_i)
- Systematic uncertainty (SU), μ_j for j^{th} patient, = average of x_{ij} over fractions i=1,…,N
  - standard deviation $\Sigma(\mu_j)$ of μ_j over the patient population is common SU measure

- Random uncertainty (RU): Standard deviation, σ_j, of x_{ij} about μ_j
  - RMS mean, σ_{RMS}, over patient population is common RU measure

Impact of Targeting Errors

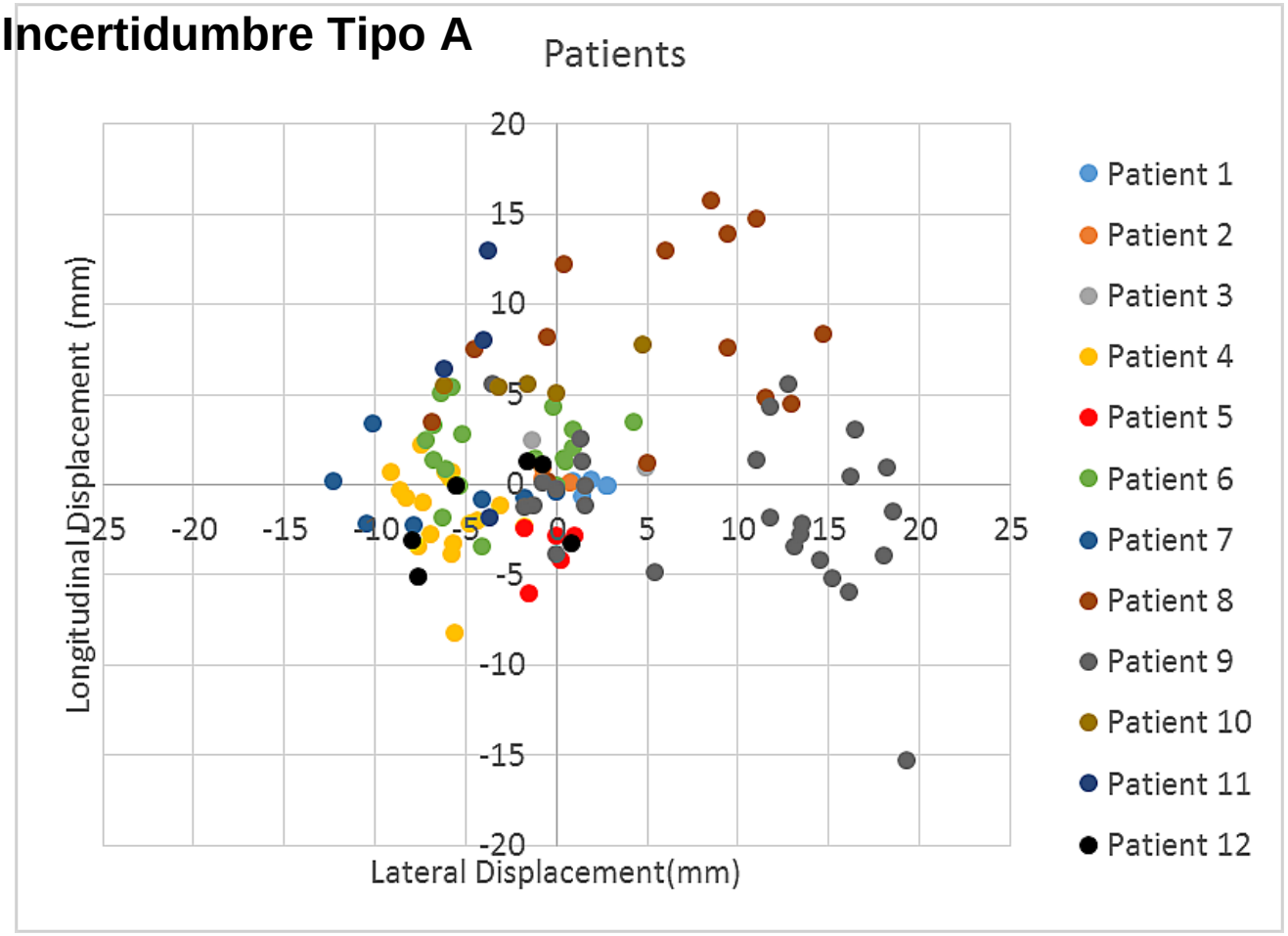


"Static" plan:
Prescription dose
Covers PTV

Systematic error:
Shifts dose distribution
(CTV still covered)

Random error:
Blurs doses (high dose volumes reduce, lower dose volumes increase)

Incertidumbre Tipo A

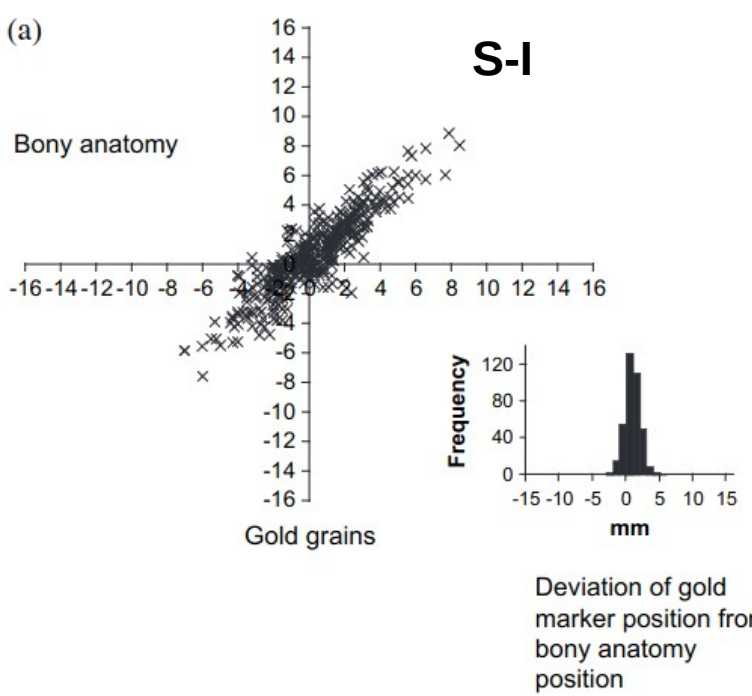


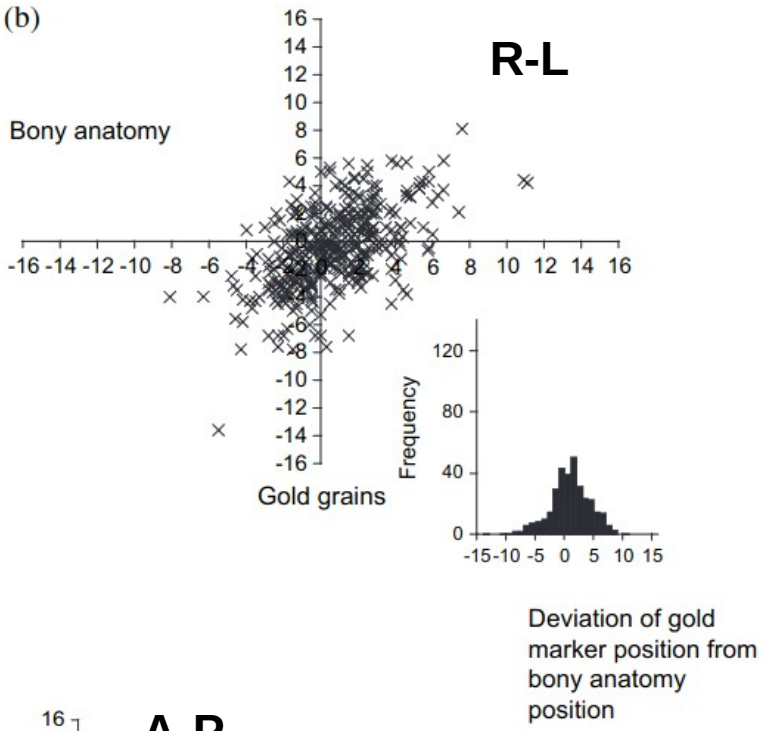
$$M_{AP} = a\Sigma_{AP} + 0.7\sigma_{AP} \qquad M_{AP} = \sqrt{(\Sigma_{AP})^2 + (\sigma_{AP})^2}$$

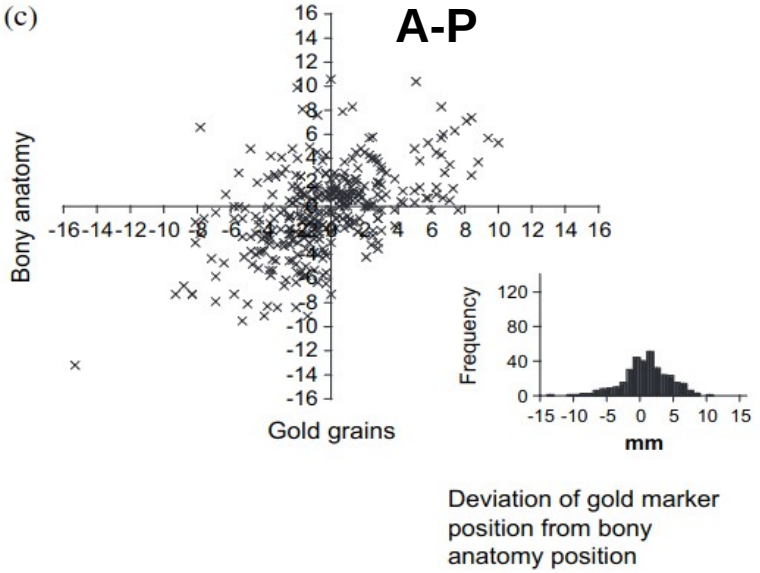
Estimating setup margins using IGRT techniques. Preliminary results R. Argota, et al. WC 2015

van Herk M, Remeijer P, et al (2000) The probability of correct target dosage: Dose-Population histograms for deriving treatment margins in radiotherapy. Int. J. Radiat. Oncol. Biol. Phys. 1121-1135, 2000.

ICRU Report 62. Prescribing, Reporting and Reporting Photon Beam Therapy (Supplement to ICRU Report 50). International Commission on Radiation Units and Measurements, 1999







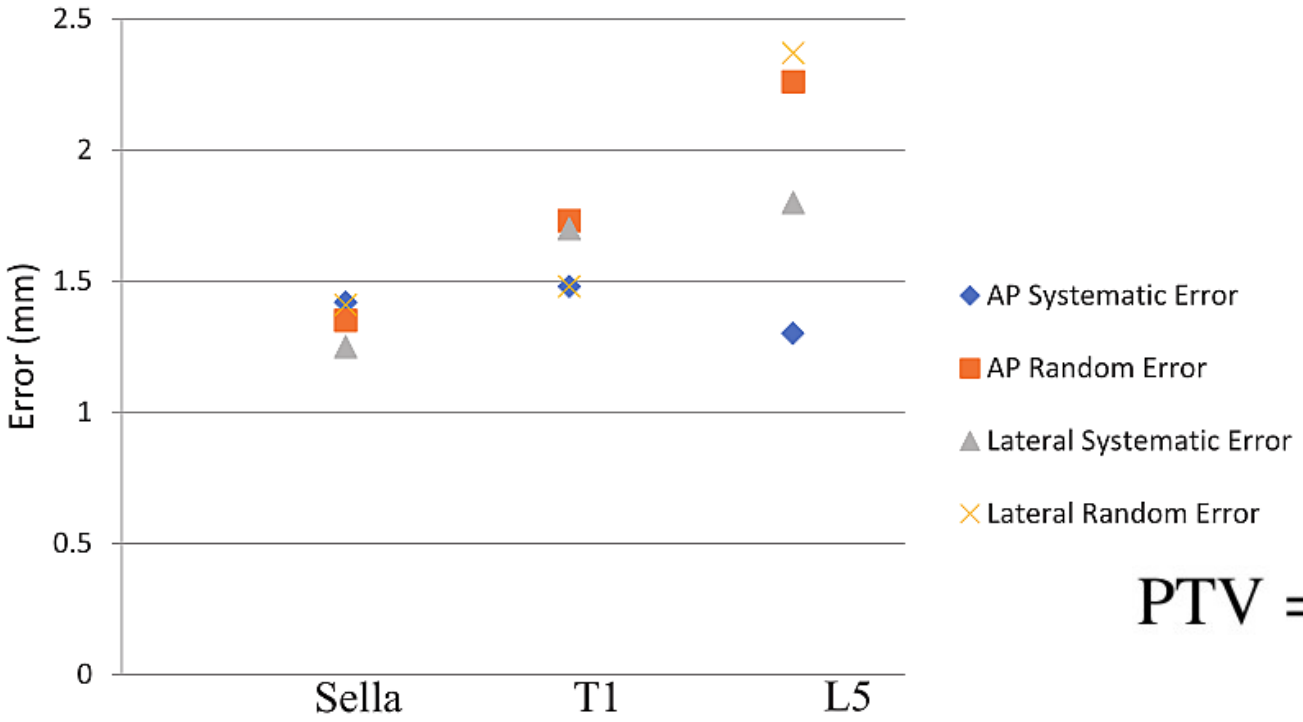
A COMPARISON OF THE USE OF BONY ANATOMY AND INTERNAL MARKERS FOR OFFLINE VERIFICATION AND AN EVALUATION OF THE POTENTIAL BENEFIT OF ONLINE AND OFFLINE VERIFICATION PROTOCOLS FOR PROSTATE RADIOTHERAPY H. McNair et al. 2007

Table 2. The effect of no correction protocol, an offline correction protocol using bony anatomy, and an offline protocol using gold markers

Correction protocol	Reference used	Error/margin	RL (mm)	SI (mm)	AP (mm)
None	Skin marks	Σ_{sm}	1.8	2.4	3.6
None	Skin marks	σ_{sm}	2.1	2.2	2.8
None	Skin marks	Margin*	6	7.5	11.0
Offline	Bony anatomy	Σ_{ba}	1.3	1.9	2.5
Offline	Bony anatomy	σ_{ba}	2.2	2.2	3.1
Offline	Bony anatomy	Margin*	4.7	6.3	8.4
Offline	Gold markers	Σ_{gm}	1.1	1.1	1.5
Offline	Gold markers	Σ_{gm}	2.2	2.1	3.2
Offline	Gold markers	Margin*	4.3	4.2	6.0

Abbreviations: Σ = systematic error; σ = random error; RL = right-left direction; SI = superoinferior direction; AP = anteroposterior direction.
* Margin required for set-up error calculated using Van Herk formula $2.5\ \Sigma + 0.7\ \sigma$.

A COMPARISON OF THE USE OF BONY ANATOMY AND INTERNAL MARKERS FOR OFFLINE VERIFICATION AND AN EVALUATION OF THE POTENTIAL BENEFIT OF ONLINE AND OFFLINE VERIFICATION PROTOCOLS FOR PROSTATE RADIOTHERAPY H. McNair et al. 2007



$$PTV = 2.5(\Sigma) + 0.7(\sigma)$$

Fig. 2 Total random and systematic errors in the anteroposterior and lateral planes by anatomic level.

Table 2 Mean value, standard deviation, and random error by anatomic level

	AP plane			Lateral plane		
	M (mm)	Σ (mm)	σ (mm)	M (mm)	Σ (mm)	σ (mm)
Sella	2.49	1.01	1.35	2.85	0.75	1.41
T1	3.40	1.09	1.73	4.00	1.37	1.48
L5	3.82	1.30	2.26	5.43	1.50	2.37

Abbreviation: AP = anteroposterior.

Setup Accuracy in Craniospinal Irradiation: Implications for Planning Treatment Volume Margins. J, Novak et al. 2021

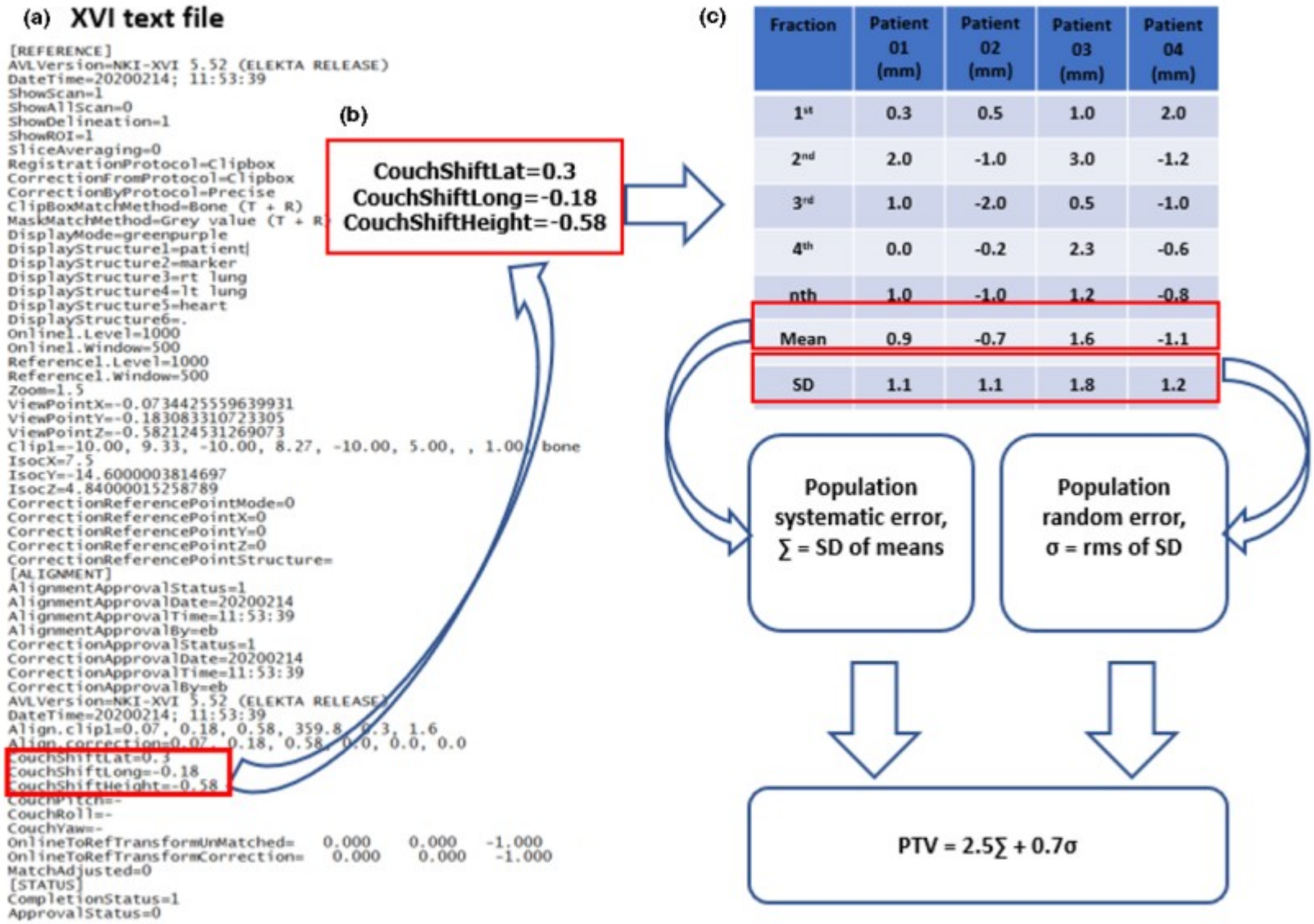
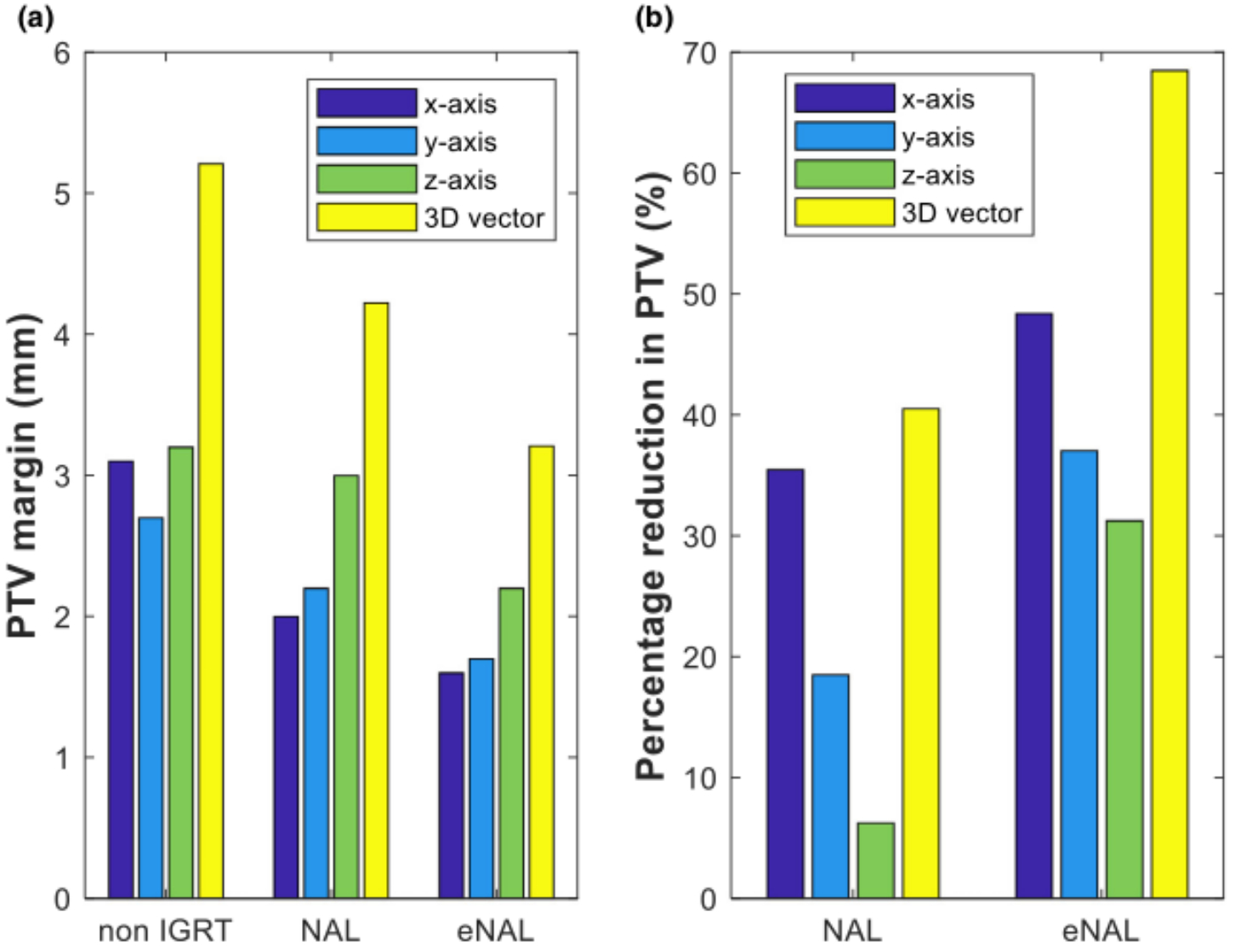
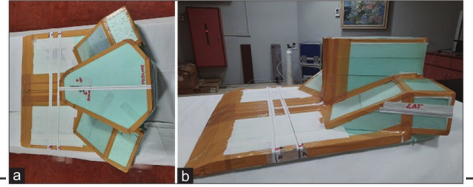


FIG. 2. Illustration of planning target volume (PTV) calculation using the automated algorithm.

Automated algorithm for calculation of setup corrections and planning target volume margins for offline image-guided radiotherapy protocols. A. Abubakar et al, 2021



Automated algorithm for calculation of setup corrections and planning target volume margins for offline image-guided radiotherapy protocols. A. Abubakar et al, 2021



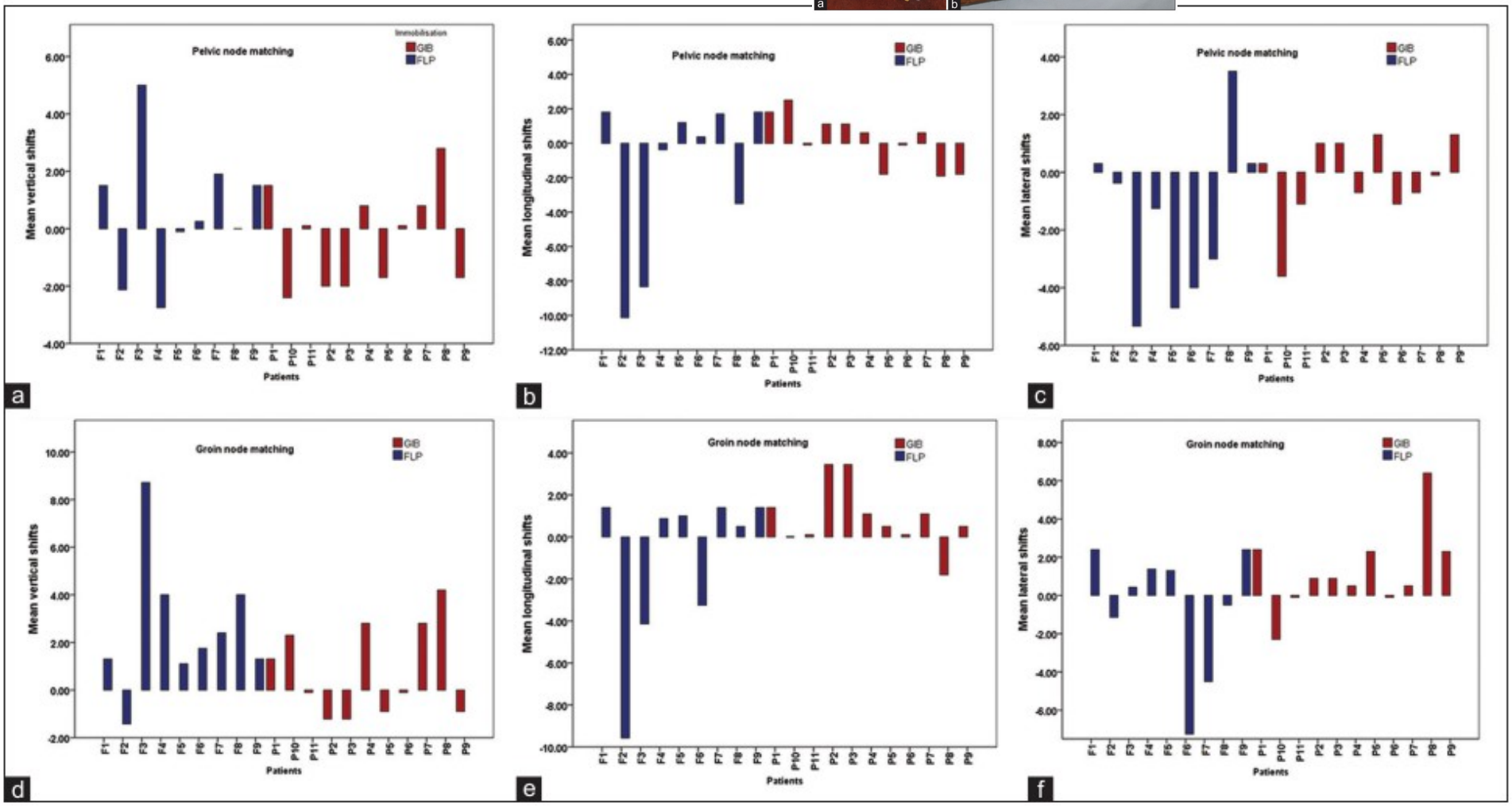


Figure 2: Pelvic lymph node mean shifts in the vertical (a), longitudinal (b) and lateral (c) directions and groin node mean shifts in the vertical (d), longitudinal (e) and lateral (f) directions using frog-leg position and groin immobilization board

Indigenous Groin Board Immobilization Reduces Planning Target Volume Margins in Groin Radiotherapy. R. Krishnatry et al, 2020

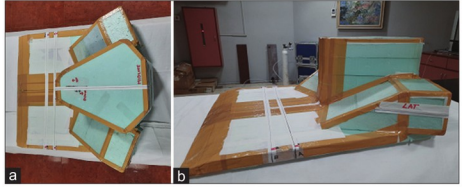


Table 2: Systematic, random errors and the required planning target volume margins (mm) in pelvis and groin matching using frog-leg position and groin immobilization board

	Pelvis to pelvis matching					
	FLP			GIB		
	Vertical (X)	Longitudinal (Y)	Lateral (Z)	Vertical (X)	Longitudinal (Y)	Lateral (Z)
Systematic error	2.8	3.1	2.9	2.0	1.8	1.7
Random error	2.6	4.1	3.1	1.6	2.3	1.5
PTV margin by Van Herk`s formula	8.9	10.6	9.4	6.2	6.2	5.2
PTV margin by Stroom`s formula	7.4	9.1	7.9	5.2	5.3	4.4
	Groin matching					
	FLP			GIB		
	Vertical (X)	Longitudinal (Y)	Lateral (Z)	Vertical (X)	Longitudinal (Y)	Lateral (Z)
Systematic error	2.9	3.9	3.85	2.01	1.3	1.9
Random error	2.7	3.6	2.1	1.8	1.8	3.5
PTV margin by Van Herk`s formula	9.2	12.2	10.9	6.3	4.7	7.2
PTV margin by Stroom`s formula	7.7	10.3	9.2	5.3	3.9	6.3

FLP: Frog-leg position, GIB: Groin immobilization board, PTV: Planning target volume

Indigenous Groin Board Immobilization Reduces Planning Target Volume Margins in Groin Radiotherapy. R. Krishnatry et al, 2020

Incertidumbre Tipo B

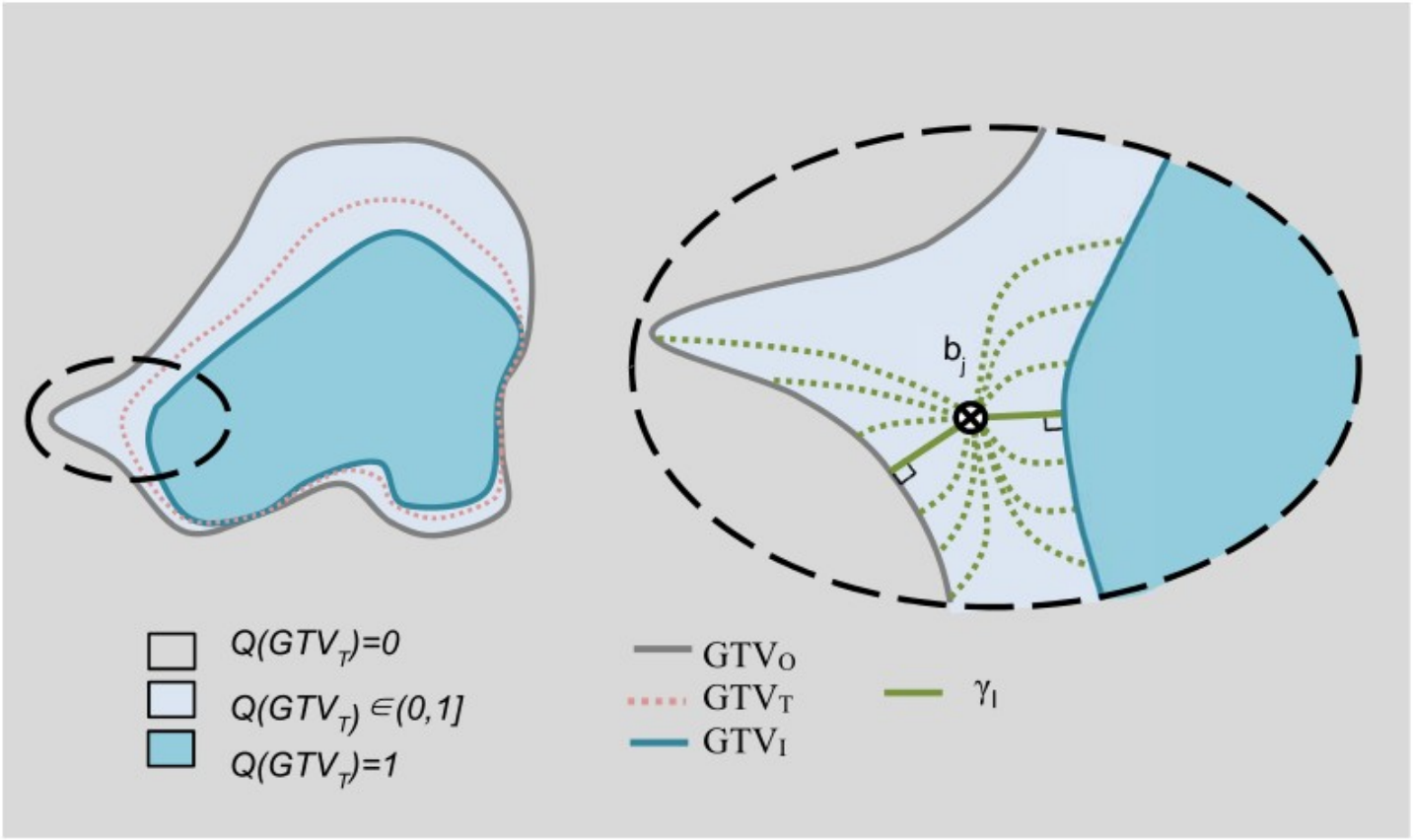


Figure 1. Left: an illustration of the containment limits and associated probabilities Q. Right, a close up illustration of the left dashed sector. Each dotted green curve illustrates a potential curve from the surface of GTV_I through the point b_j to the surface of GTV_O. The shortest curve from GTV_I through b_j to GTV_O, γ, is given by the solid green curve.

New target volume delineation and PTV strategies to further personalise radiotherapy. D. Bernstein et al, 2021

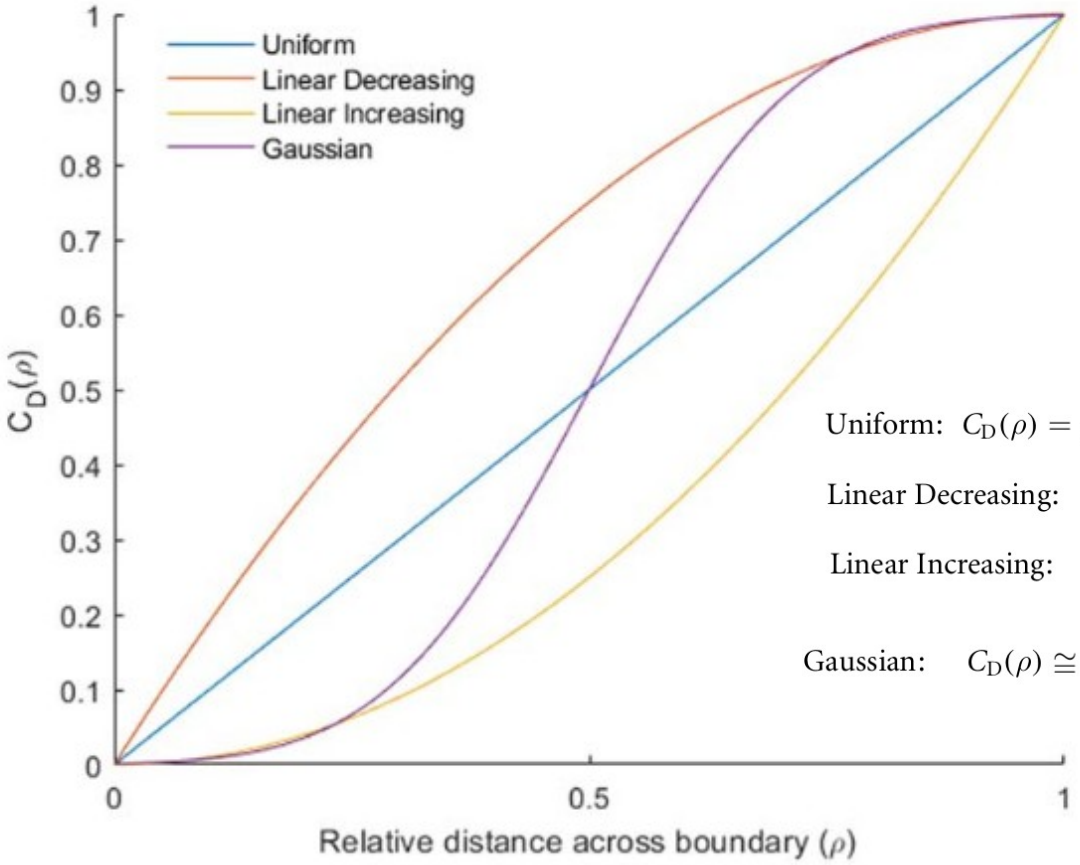


Figure 2. Coverage probability, C_D, of covering GTV_T by the prescribed isodose as a function of the position of the shell in terms of relative distance, ρ.

New target volume delineation and PTV strategies to further personalise radiotherapy. D. Bernstein et al, 2021

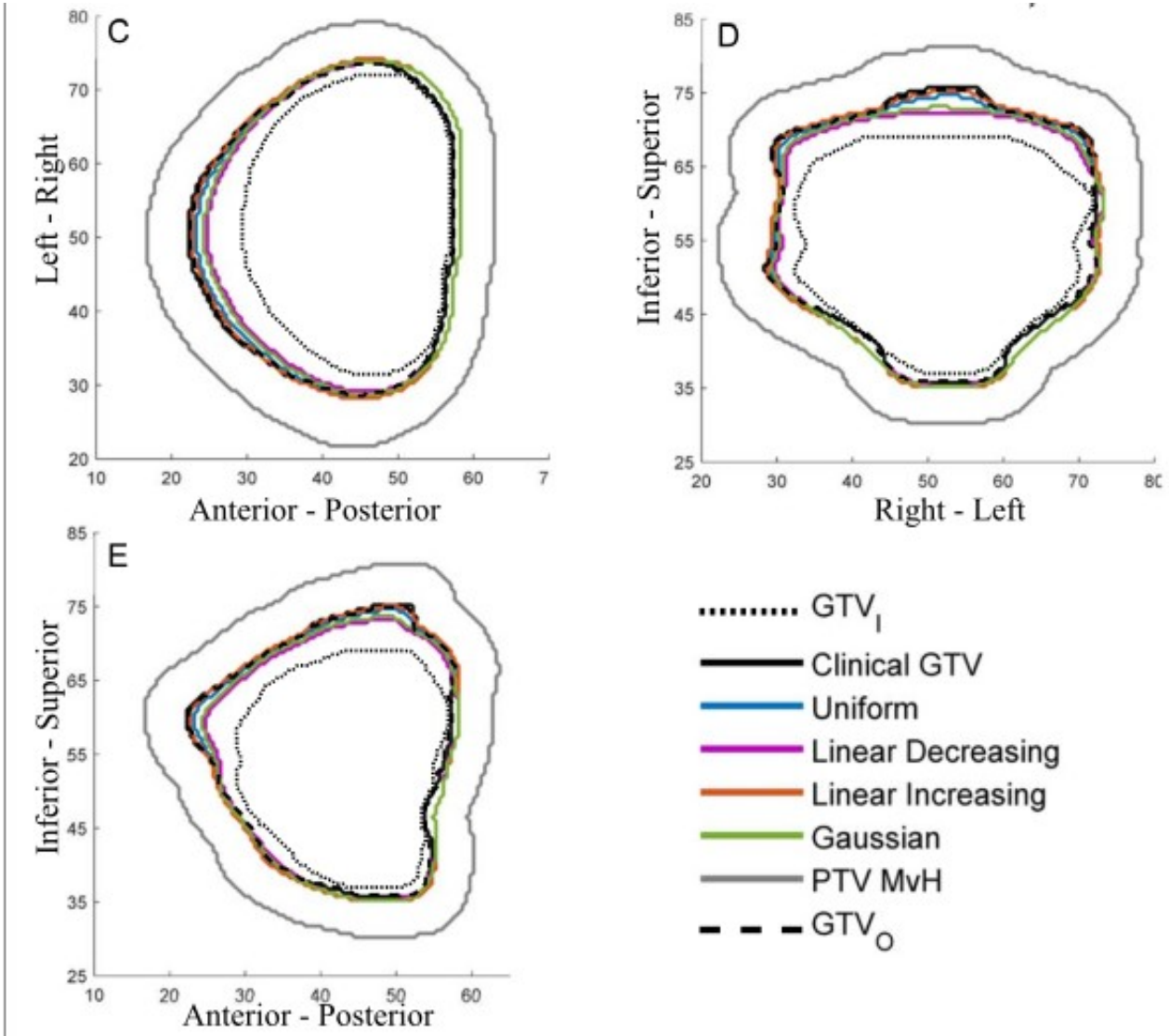


Figure 4. Clinical prostate example. (A) 3D rendering of GTV_I (yellow), the clinical GTV_C (black) and GTV_O (light blue). Note that GTV_C and GTV_O coincide over the majority of the surface. (B) 3D rendering of PTV_B (pink), using the Gaussian PDF, the clinical GTV_C (black) and PTV_{MvH} (green). (C)–(E) GTV_I and GTV_O contours, PTV_B and PTV_{MvH} boundaries through central axial, coronal and sagittal slices respectively. Axes are in mm.

New target volume delineation and PTV strategies to further personalise radiotherapy. D. Bernstein et al, 2021

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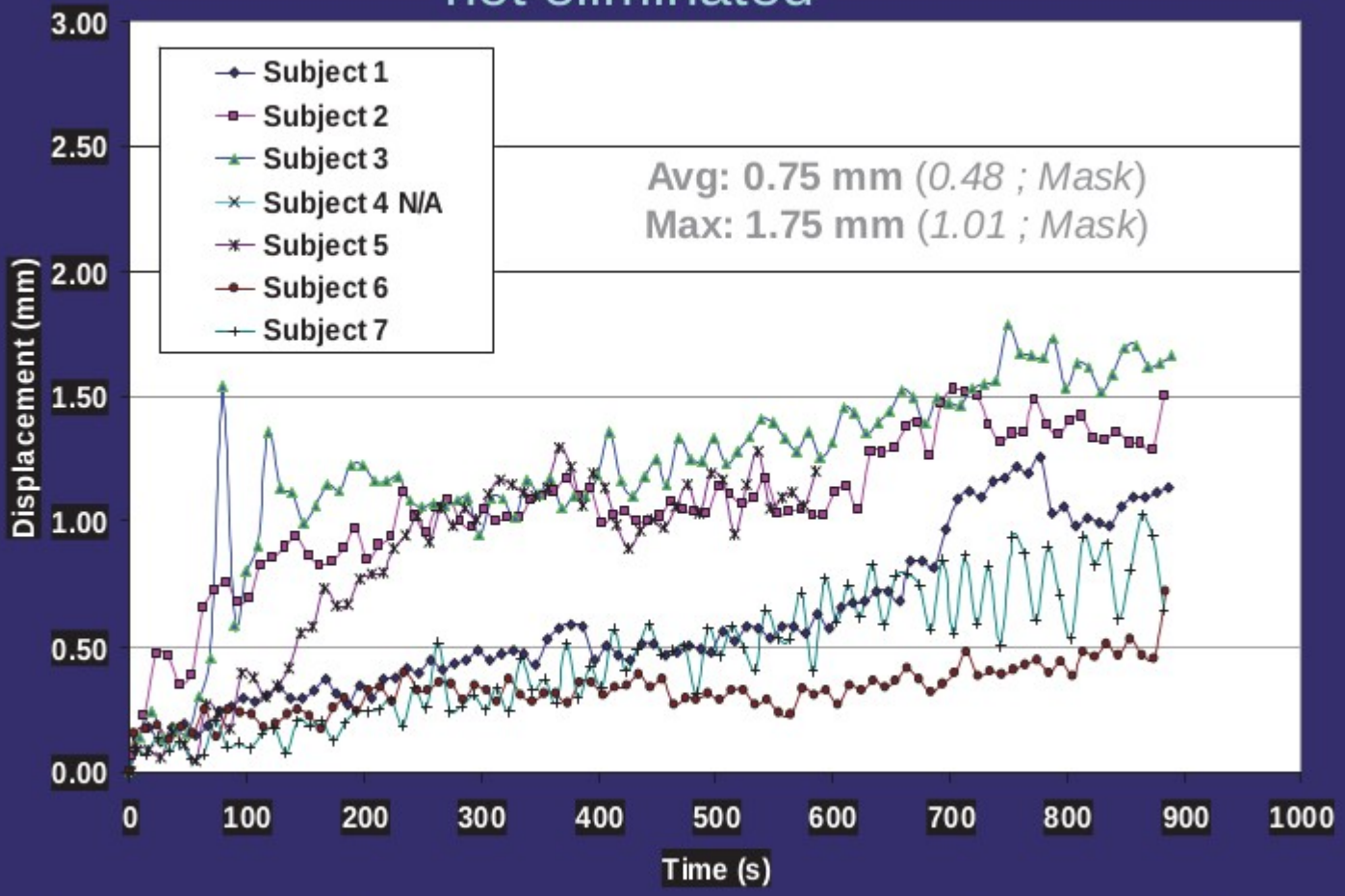
Intra-Fraction Patient motion can only be minimized but not eliminated



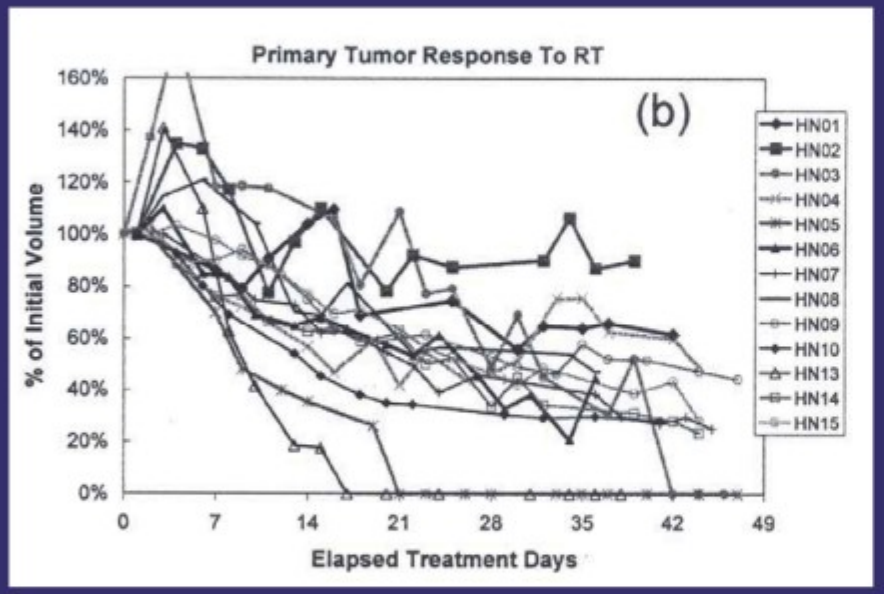
"Patient motion increases as treatment time gets longer"

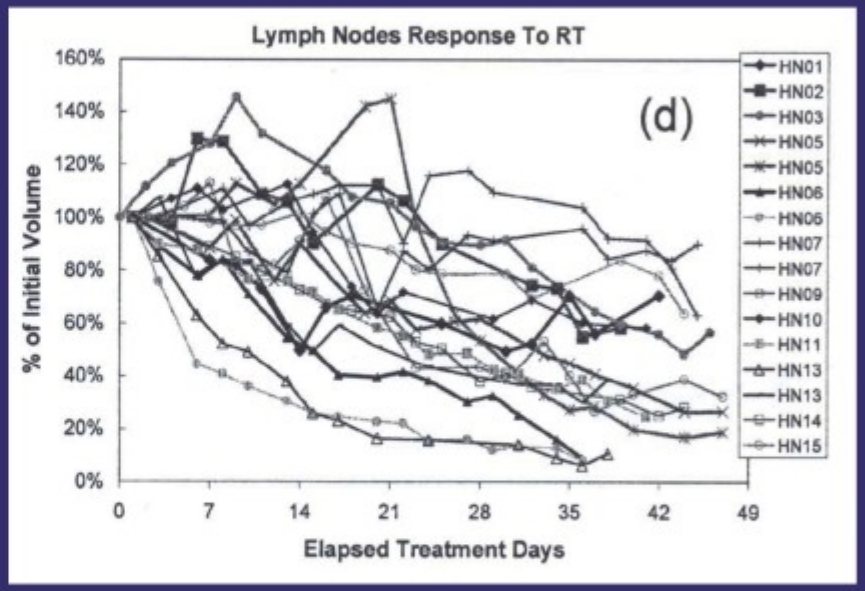
S.Kim et. al., IJROBP, 2003

How to deal with the physiological changes/deformation?

Barker (2004): 14 H+N patients, 13-20 repeat CT, in-room CT

Observation of tumor regression





Barker *et al.* , IJROBP, 59, pp 960, 2004

Can potentially result in grave consequences (overdose of critical structures and/or geographical miss) that must be evaluated on site by site basis