Reassessing CTV to PTV margin by analysing patient motion during beam delivery of patients treated with intracranial SRS

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Conflict of Interests

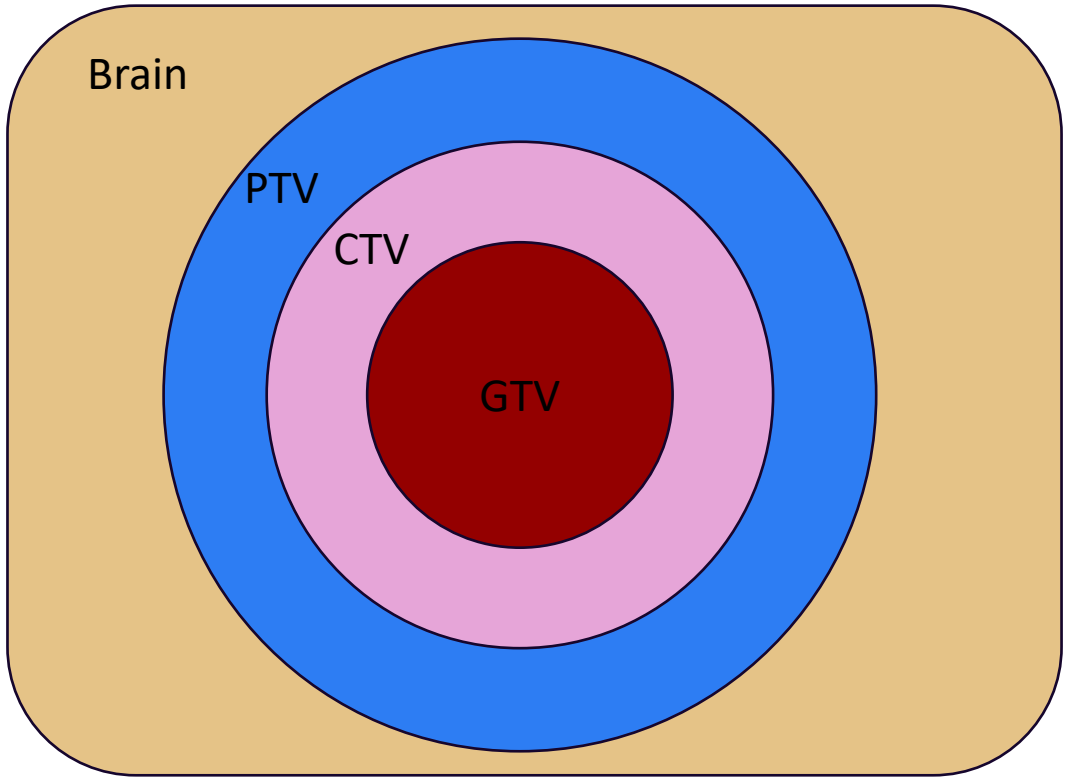
Peter Mac has an institutional agreement with VisionRT which is unrelated to this current works.

Let’s start with the basics

The CTV→PTV margin encapsulates the uncertainties to ensure coverage

The larger the margin, the more certain we are of covering the tumour

The larger the margin, the greater the volume of healthy tissue will be irradiated



For intracranial SRS there is pressure to have a small CTV→PTV margin:

- Brain (OAR) is abutting the tumour
- CTV can be small (1cm in diameter)
  - The PTV component, as a percentage of the total target volume, is large
- Our intracranial SRS delivered on TrueBeam + OBI had an initial CTV→PTV margin = 1.5mm
- Can we safely reduce this margin to spare a greater volume of healthy brain tissue?

Typical Intercranial SRS at Peter Mac

Treatment Machine
TrueBeam
Standard MLC
6DOF Couch
On board imaging

Prescription
30Gy/1fx
24Gy/3fx
25Gy/5fx

Single Iso per Target

Treatment beams at
Couch 0
Couch 45
Couch 315

Prebeam Imaging
CBCT at couch 0
MVKV pair at couch kicks

IGRT Tolerance
0.5mm/0.5deg

Patient immobilisation
CDR Open Face Mask

Patient monitoring
Surface Guided AlignRT

AlignRT Tolerance
1.0mm/0.7deg

Aim

Reassess our CTV→PTV margin for intracranial SRS cases by quantifying and analysing patient motion during beam delivery

Method

Python script was created to help extract surface monitoring data from the AlignRT system for:

- A total of 42 unique patients
- A total of 134 fractions

Python script was created to calculate the systematic and random errors of patient motion during beam delivery in accordance with BIR formulation [1]

The effect of camera occlusion of the AlignRT data was briefly investigated

[1] Tudor GSJ. et al. 2020 Geometric Uncertainties in Daily Online IGRT: Refining the CTV-PTV Margin for Contemporary Photon Radiotherapy. British Institute of Radiology.

Determining CTV→PTV margin

Different ways to determine CTV→PTV margin. This presentation uses formula outlined by Tudor in British Institute of Radiology (2020) [1]

The formula for the CTV–PTV margin, M, may be expressed in general terms as:

$$M = \alpha\Sigma_{total} + \beta\left[\sqrt{\sigma_{total}^2 + \sigma_p^2} - \sigma_p\right]$$

Σ_{total} - Systematic Error

- Affects the treatment in th

σ_{total} - Random Error

- Randomly affects the treatment

Part of the attractiveness of this formula arises from its popularity over the past two decades. It provides a common standard that if adopted allows for comparison between treatments or centres in the knowledge that geometric uncertainty is unlikely to contribute significantly towards variations in control. However, the formula does not define an uncontestable "correct" margin to use clinically. The formula, especially where

	Random Error (σ)
Surrogate Error	
Matching Error	Matching
Technical Accuracy	Technical Accuracy
Intrafraction Motion	Intrafraction Motion

[1] Tudor GSJ. et al. 2020 Geometric Uncertainties in Daily Online IGRT: Refining the CTV-PTV Margin for Contemporary Photon Radiotherapy. British Institute of Radiology.

Surface Monitoring

Define a ROI on the patient

Capture a reference image

Compares the live ROI to the ROI of the reference image and logs the difference approx. every 100msec in a Real Time Delta (RTD) file.

AlignRT Real Time Delta (RTD) Files

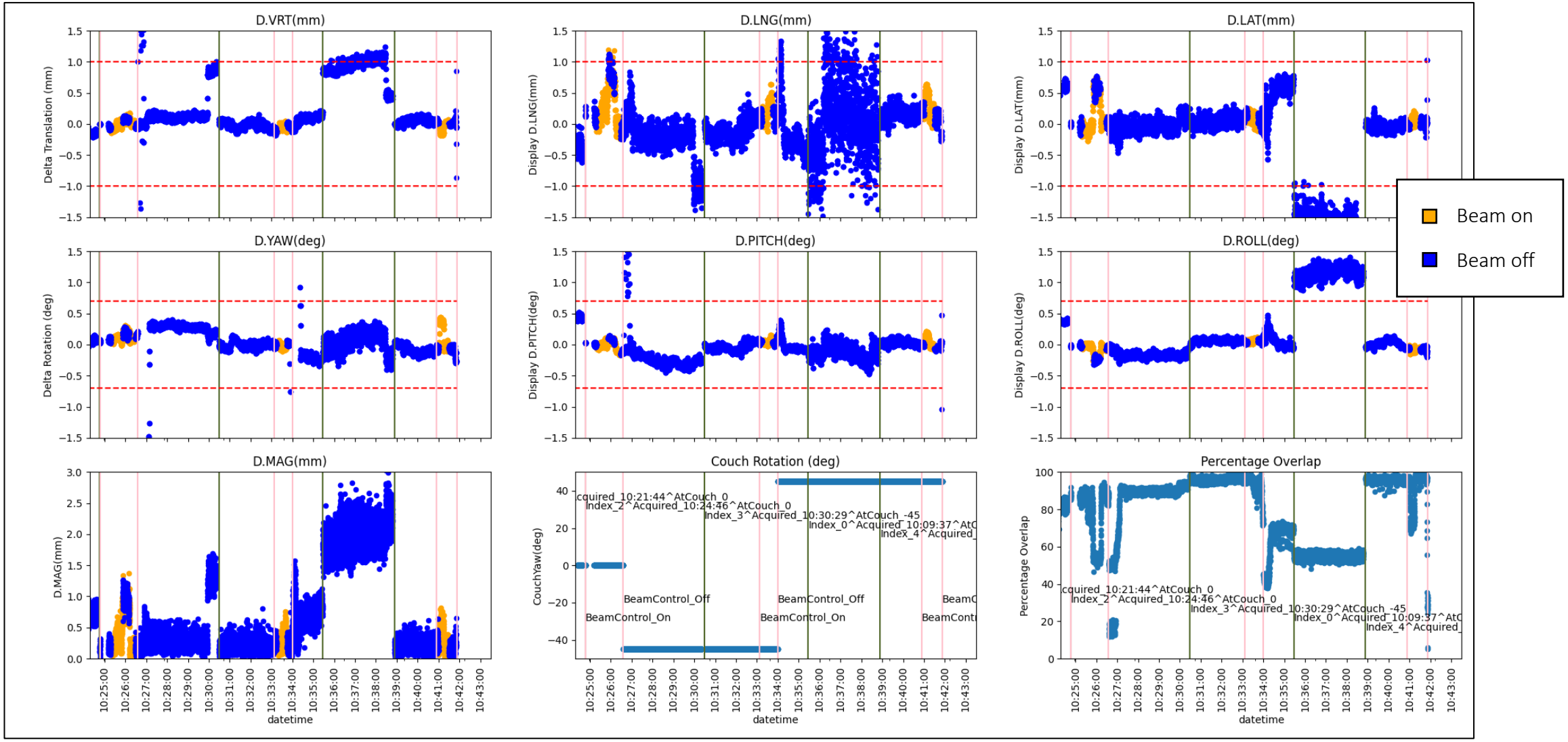
This data can be extracted from the AlignRT software

All anonymised

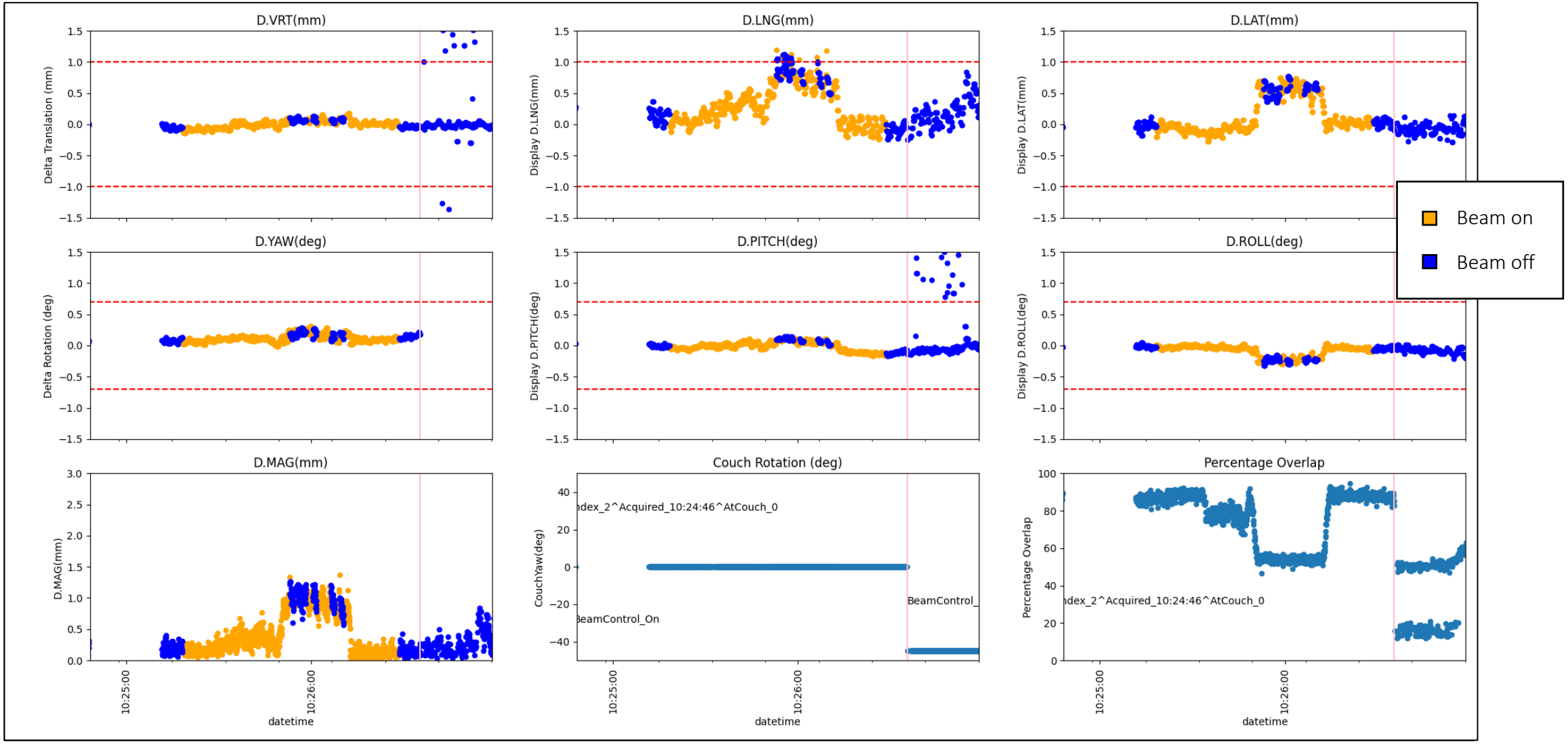
Includes:

- Date Time (ms)
- Reference Surface SurfaceID(GUID)
- CouchYaw(deg)
- Threshold High and Low Values (mm/deg)
- Delta Patient Movement (mm/deg)
- Percentage Overlap
- Is BeamControl Enabled
- ReportedBeamState

Patient motion from a single fraction



Patient motion from a single beam on event



Calculating Systematic and Random errors of Intrafraction Motion

For each patient we calculated for the patient motion during beam delivery:

- Individual Systematic Error (Σ_patient motion during beam delivery) = Average displacement when the beam was on
- Individual Random Error (σ_patient motion during beam delivery) = Standard deviation of the displacement when the beam was on

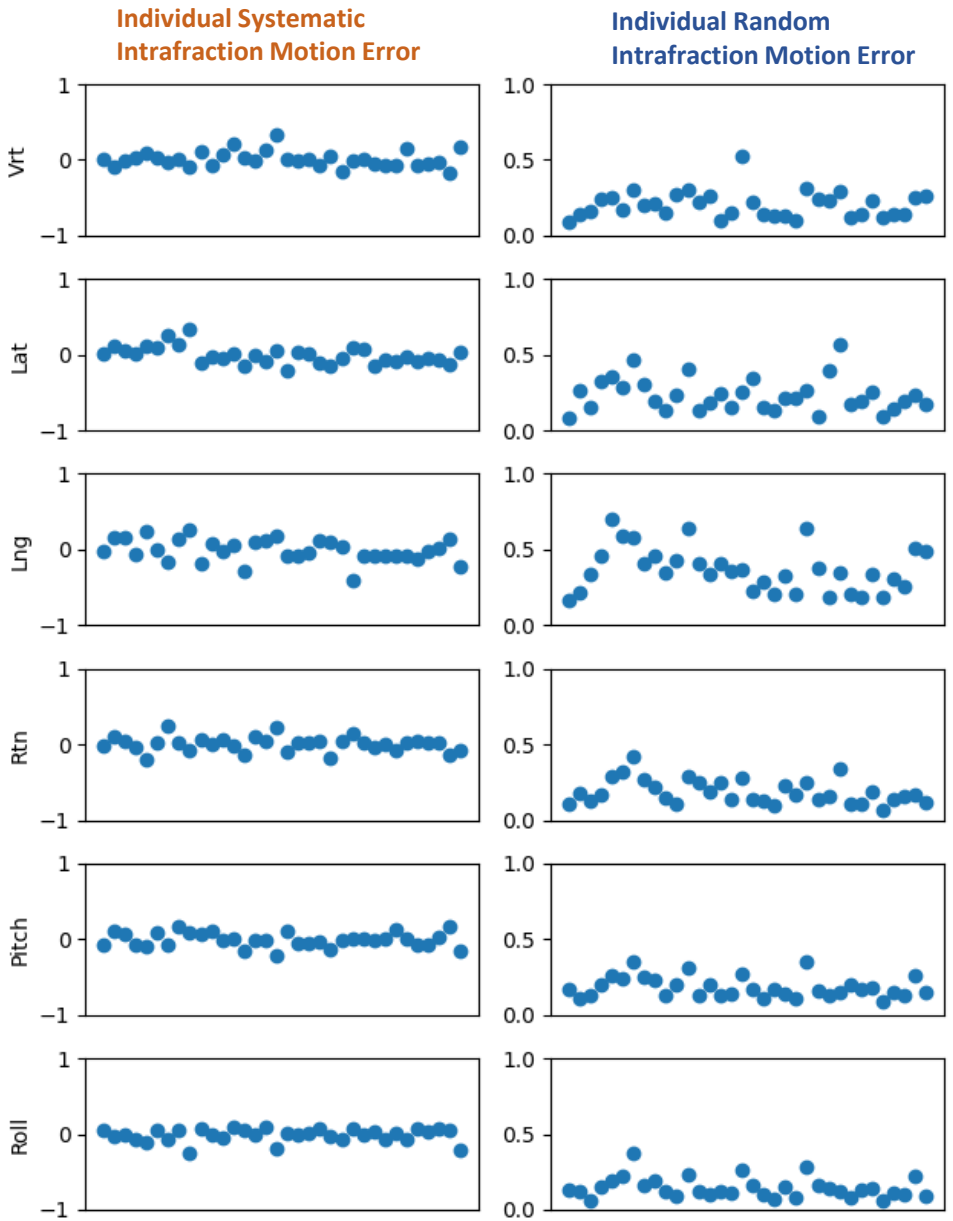
For the cohort:

- Cohort Systematic Error (Σ_patient motion during beam delivery) = Standard deviation of the Individual Systematic Error
- Cohort Random Error (σ_patient motion during beam delivery) = Standard deviation of the Individual Random Error

> Where the number of fractions analysed per patient is representative of the number of treatment fractions delivered, the systematic error, Σ can be calculated (using the techniques of sections 3.5.1.1 and 3.5.1.2) as the standard deviation of the mean values for each patient, typically with a separate calculation along each cardinal axis.
>
> Likewise, the random error can be calculated for each patient as the standard deviation of each value of interest within the treatment course. The measured random error from each patient can be combined using the method in section 3.5.1.3.

[1] Tudor GSJ. et al. 2020 Geometric Uncertainties in Daily Online IGRT: Refining the CTV-PTV Margin for Contemporary Photon Radiotherapy. British Institute of Radiology.

Patient motion during beam delivery



Patient motion during beam delivery		
	Cohort Systematic Error	Cohort Random Error
Parameter	STD(**Ind. Systematic Error**) (mm/deg)	STD(**Ind. Random Error**) (mm/deg)
Vrt	0.10	0.09
Lat	0.11	0.11
Lng	0.15	0.14
Rtn	0.10	0.08
Pitch	0.09	0.07
Roll	0.08	0.07

- Only analysing when the beam is delivered
- Ignoring times when beam is held

Cohort Systematic Error and Random Error for patient motion during beam delivery

	Patient motion during beam delivery					
	Cohort Systematic Error (Σ)			Cohort Random Error (σ)		
Percentage Overlap Threshold (%)	Vrt (mm)	Lat (mm)	Lng (mm)	Vrt (mm)	Lat (mm)	Lng (mm)
0	0.10	0.11	0.15	0.09	0.11	0.14
50	0.10	0.11	0.15	0.09	0.11	0.14
80	0.09	0.12	0.14	0.07	0.11	0.13
90	0.08	0.10	0.15	0.08	0.09	0.14

Margin Calculations - Caveats

- Iso is placed in the middle of the target.
- Target is registered locally on the MRI → CT dataset
- Prebeam OBI

Neuro SRS	Systematic Error (Σ)			
	X (mm)	Y (mm)	Z (mm)	Comment
Delineation - MR Dist	0.0	0.0	0.0	Assume neglible for local registration
Delineation - CT to MR Fusion	0.2	0.2	0.2	Estimation
Delineation - inter observer contouring	0.2	0.2	0.2	Estimation
Target Deformation	0.0	0.0	0.0	Assume neglible due to tight turnaround of MRI and pCT to treatment
Rotational	0.0	0.0	0.0	Assume neglible for cohort of small spherical, single iso, single target
Surrogate Error	0.0	0.0	0.0	Assume neglible - matching skull to the target (unmoving)
Matching Error	0.1	0.1	0.1	Observer variablilty of alignment of planning image to verif (estimation)
Technical Accuracy - tx beam to kv igrt	0.2	0.2	0.2	
Technical Accuracy - mech uncert MLC	0.0	0.0	0.0	Assume neglible
Technical Accuracy - mech uncert couch after move	0.0	0.0	0.0	Doing verif images so couch uncert doesn't play a part
Technical Accuracy - rad iso size	0.3	0.3	0.3	
Σ_(total sans intrafraction motion)	0.4	0.4	0.4	
	Random Error (σ)			
	X (mm)	Y (mm)	Z (mm)	
Rotational	0.0	0.0	0.0	Assume neglible for cohort of small spherical, single iso, single target
Matching	0.1	0.1	0.1	Observer variablilty of alignment of planning image to verif (estimation)
Technical Accuracy - mech uncert MLC	0.1	0.1	0.1	
σ_(total sans intrafraction motion)	0.1	0.1	0.1	

Margin Calculations

The formula for the CTV–PTV margin, M, may be expressed in general terms as:

$$M = \alpha\Sigma_{total} + \beta\left[\sqrt{\sigma_{total}^2 + \sigma_p^2} - \sigma_p\right]$$

Intracranial SRS	Vrt	Lat	Lng
Σ_(total sans intrafraction motion) (mm)	0.4	0.4	0.4
σ_(total sans intrafraction motion) (mm)	0.1	0.1	0.1
σ_p (mm)	7.6	7.6	7.6
β	0.8	0.8	0.8
α	2.5	2.5	2.5

With discussion with our RO and RT colleagues we decided to move to 1.0mm margin

	Patient motion during beam delivery								
	Cohort Systematic Error (Σ)			Cohort Random Error (σ)			Total Margin (mm)		
Percentage Overlap Threshold (%)	Vrt (mm)	Lat (mm)	Lng (mm)	Vrt (mm)	Lat (mm)	Lng (mm)	Vrt	Lat	Lng
0	0.10	0.11	0.15	0.09	0.11	0.14	1.1	1.1	1.2
50	0.10	0.11	0.15	0.09	0.11	0.14	1.1	1.1	1.2
80	0.09	0.12	0.14	0.07	0.11	0.13	1.1	1.1	1.2
90	0.08	0.10	0.15	0.08	0.09	0.14	1.1	1.1	1.2

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Conclusion

- Patient motion during beam delivery of 42 patients was analysed
- Systematic and Random error due to patient motion during beam delivery was <= 0.15mm
- CTV→PTV margin was calculated to be [1.1 mm, 1.1 mm, 1.2 mm] for the vertical, lateral, longitudinal directions.
- Alongside discussion with ROs, the CTV→PTV margin reduced to 1.0mm with the criteria:
  - Iso placed in the target
  - Target is registered locally on the MRI → CT dataset
  - Pre-beam OBI
- Camera occlusion did not significantly affect final margin calculation

Thank you.