Precision Motion Management in Pencil Beam Scanning Proton Therapy: With SGRT by Vision RT

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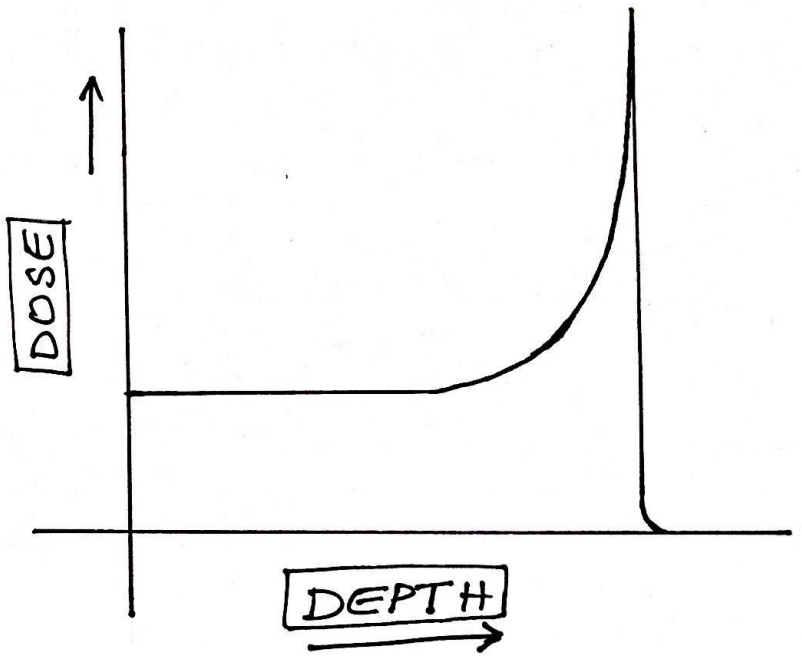
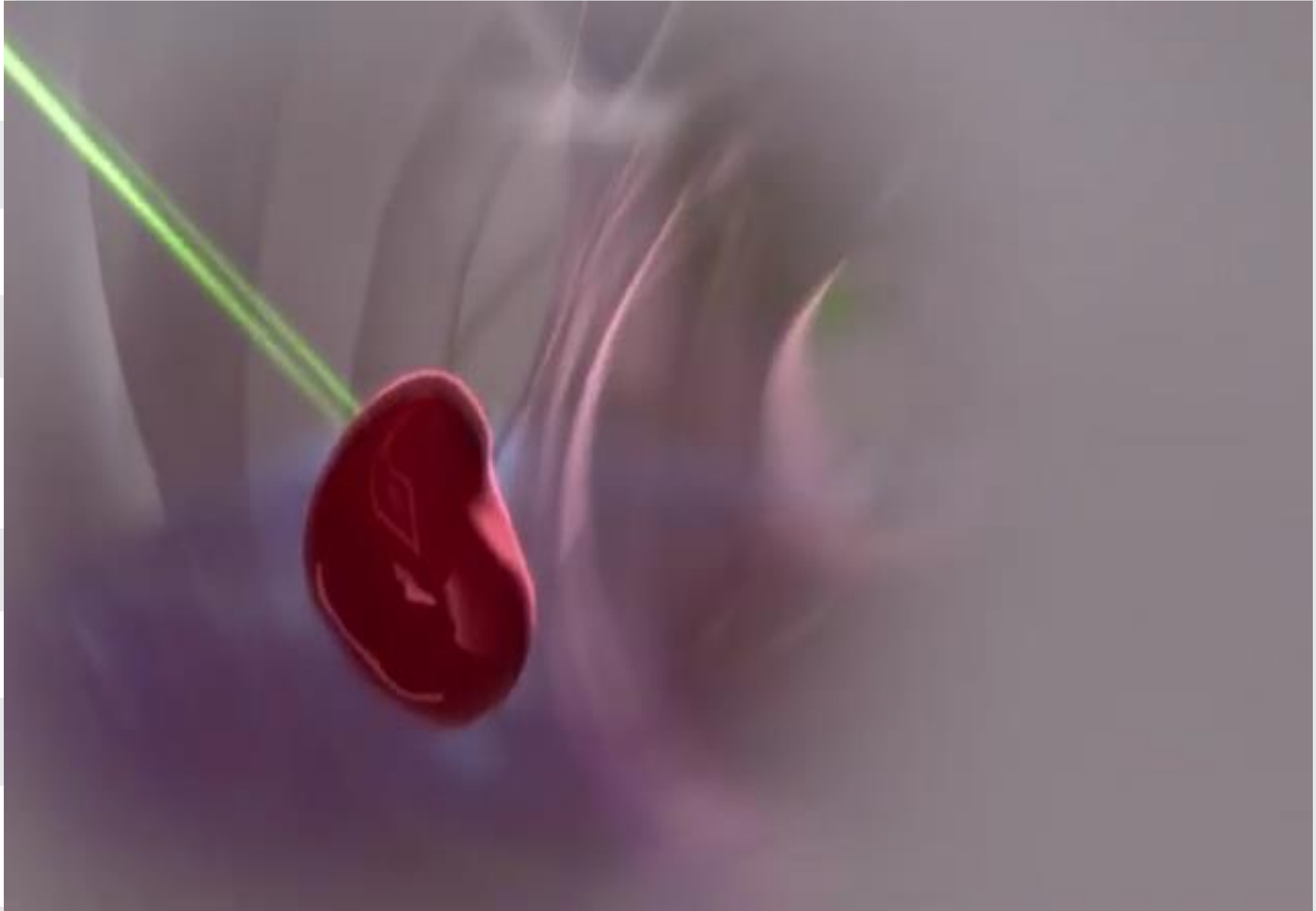
Proton - Bragg Peak



Skyrocket firework rise quickly into sky; it looses minimal fuel during its ascent & after certain height blasts with beautiful colours.

Similarly protons loose less dose while passing through tissue and Bragg peak occurs immediately before particles come to rest.



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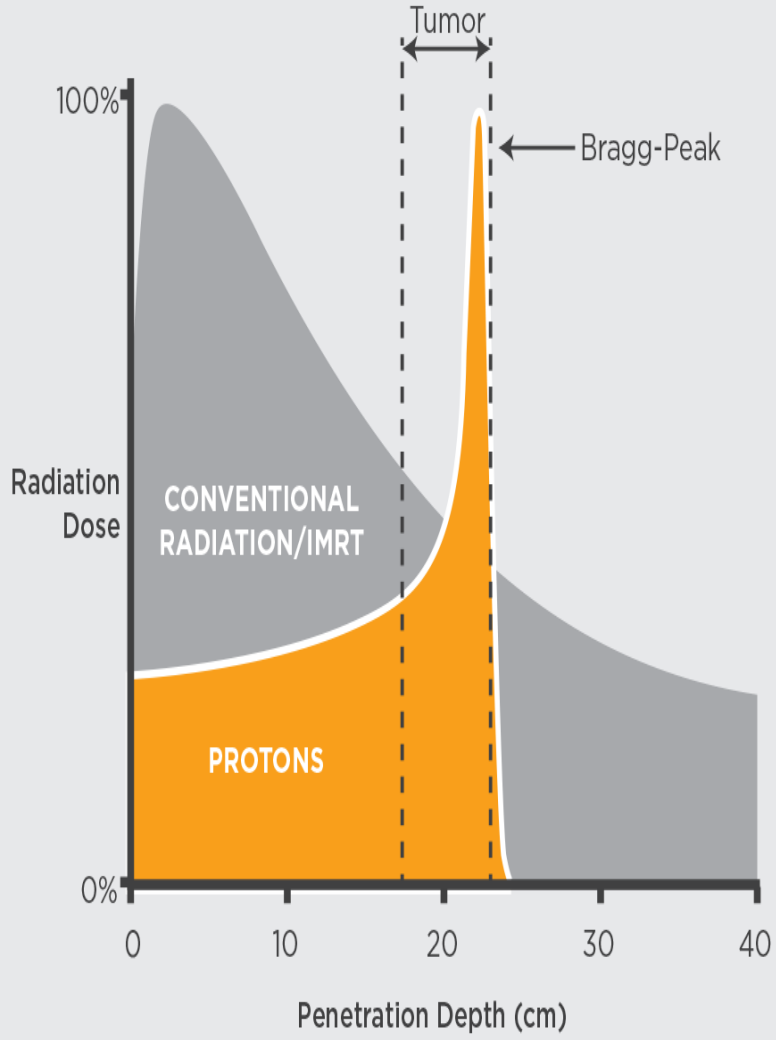
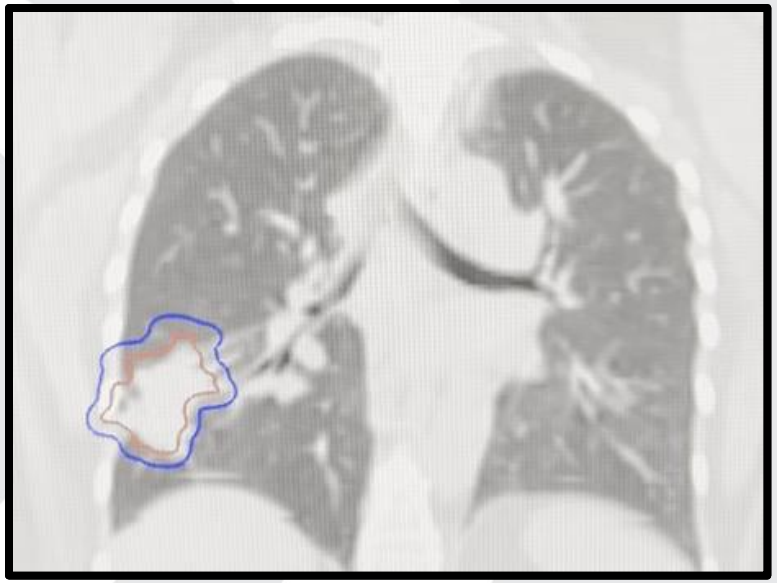
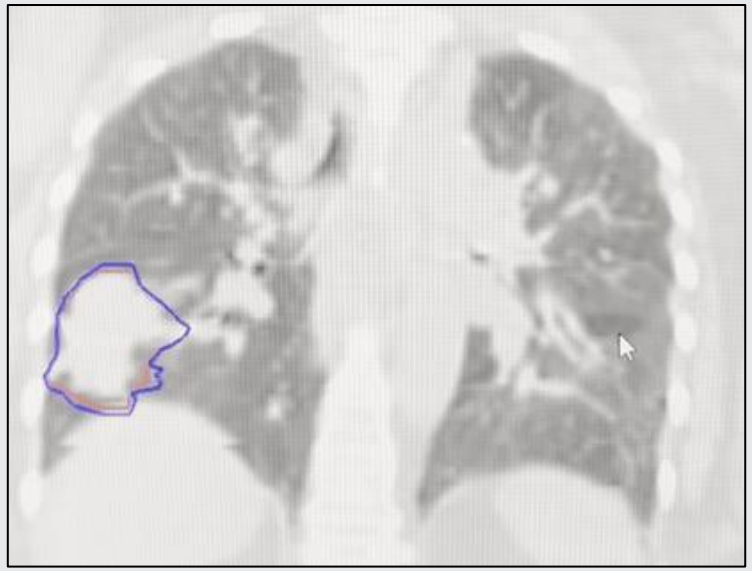
Relevance of motion management in Proton Therapy

- Proton therapy delivers dose with sharp distal fall-off (Bragg Peak)
- Any motion during delivery can lead to Range – uncertainty that causes target miss or critical organ overdose
- Tumor motion from breathing, heartbeat, or Gastrointestinal (GI) Motility must be managed precisely
- Pencil beam scanning is sensitive to motion due to spot-by-spot deliver



Concerns – Monitoring during treatment





Common Moving Tumor Diagnosis

🫁 Thoracic Region (Lungs & Chest)

- **Non-Small Cell Lung Cancer (NSCLC)**
- **Small Cell Lung Cancer (SCLC)**
- **Pulmonary Metastases**
- **Mediastinal Tumors**
- **Hilar Masses**
- **Thymoma**

🧠 Upper Abdomen

- **Hepatocellular Carcinoma (HCC)**
- **Liver Metastases**
- **Cholangiocarcinoma (Bile Duct Cancer)**
- **Pancreatic Cancer**
- **Gallbladder Carcinoma**
- **Adrenal Tumors**

💕 Others

- **Esophageal Cancer**
- **Gastric Cancer (particularly near diaphragm)**
- **Renal Cell Carcinoma**
- **Para-aortic Nodal Disease**
- **Diaphragm-involved tumors**

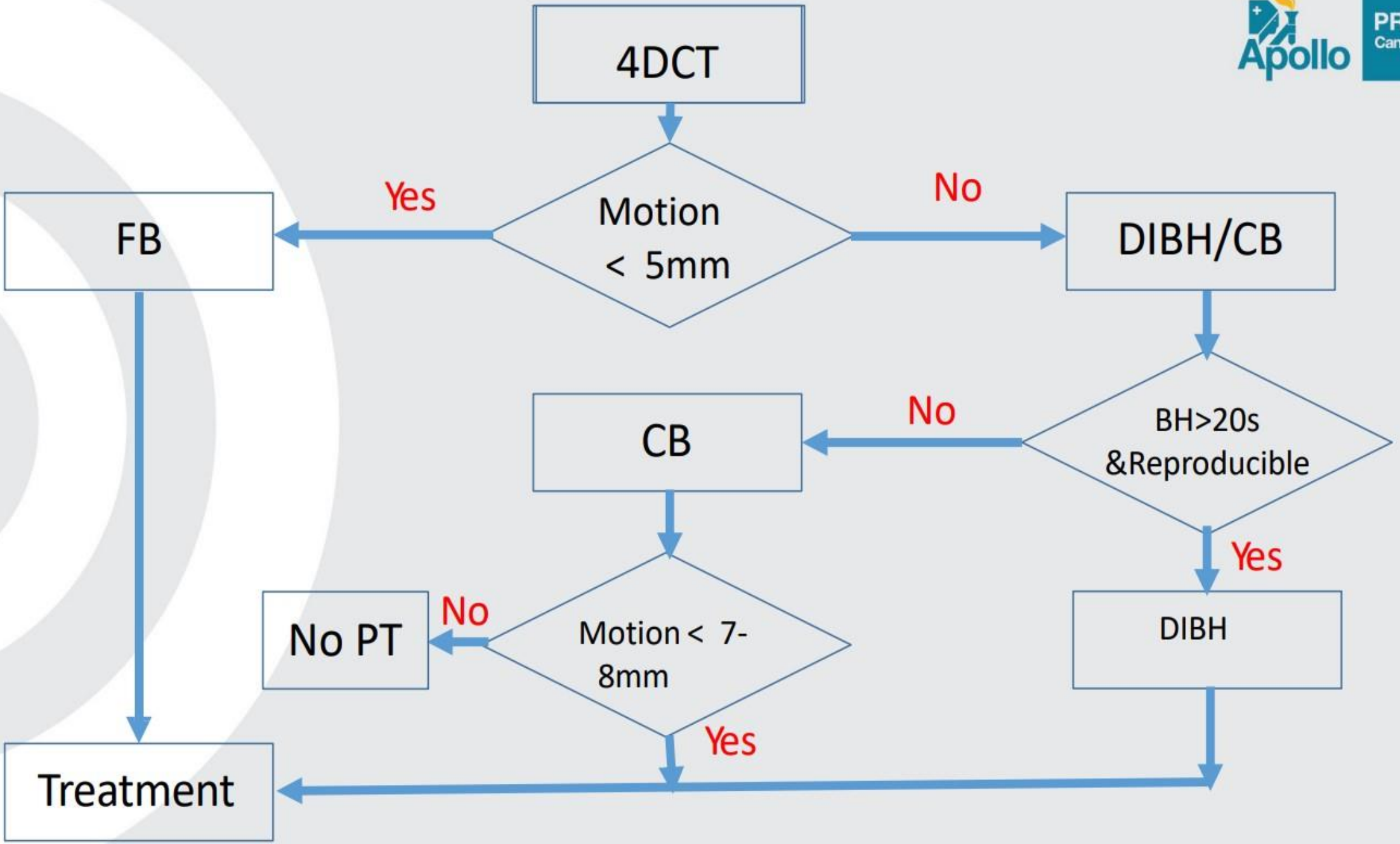
&

- Ca Breast

Challenges in Simulation\Image Acquisition

- Evaluate the motion with Imaging
- Selection of appropriate Motion mitigation Techniques
- Free Breath
- Deep Inspiratory Breath Hold
- Compression Belt
- Gating/Tracking

We can use either one of these techniques or more than one in combination for mitigating the motion



Deep inspiration breath hold(DIBH)

Coaching

- Patient educated
- Coaching with SGRT in TX room
- Minimum 20sx 5 Attempts
- Check Breath Hold -Duration, Stability, and Consistency
- Practice at Home

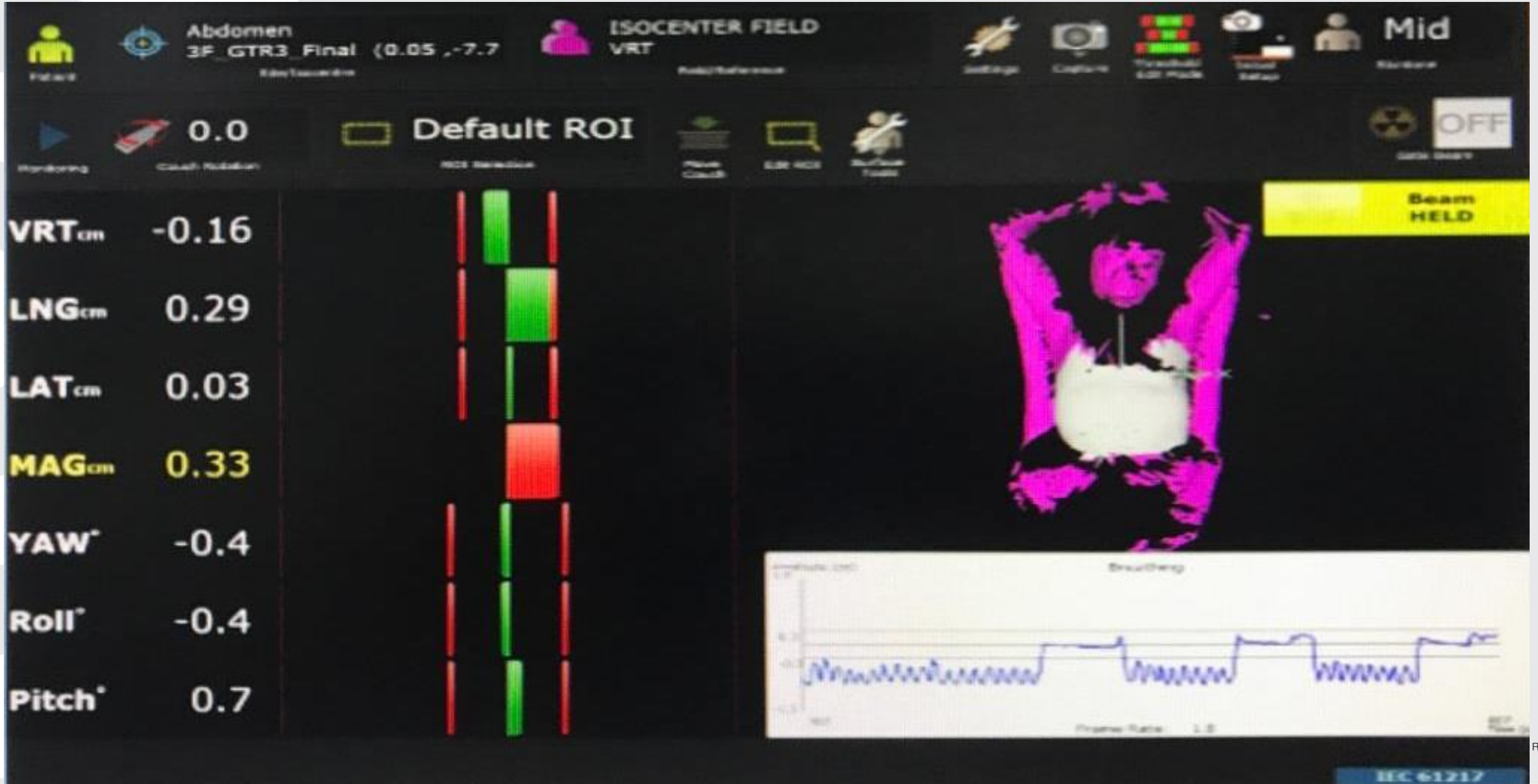
CT Scan Aquisition

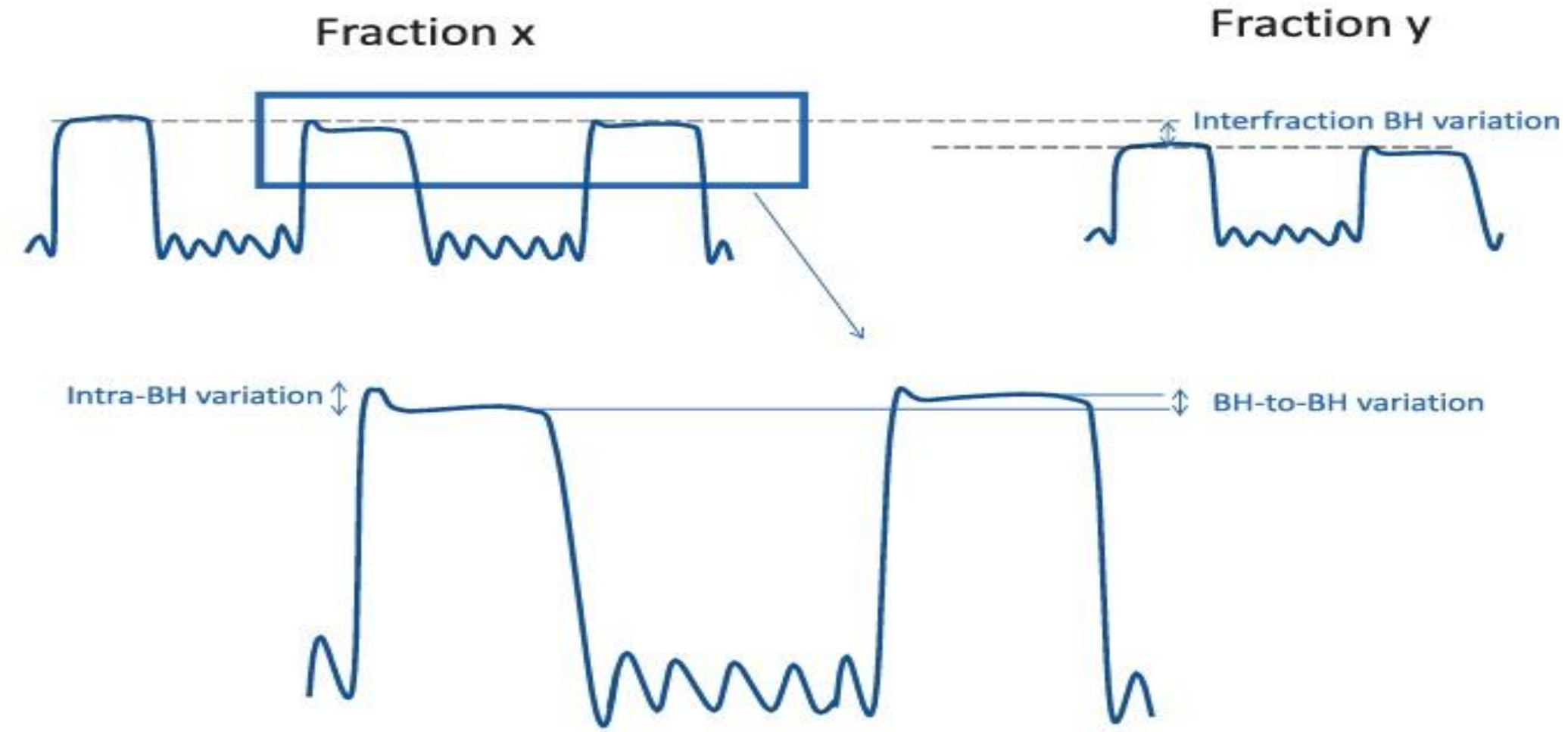
- 3 Additional CT scans in DIBH to verify motion suppression
- Detecting residual tumor motion despite breath-hold
- Selected one of the scans For contouring and further treatment planning

Treatment planning

- 1.Single field optimization(SFO)
- 2.Robust optimization to account for setup uncertainties (3 to 5 mm) and range uncertainties (3.5%).

Breath-hold reproducibility coaching





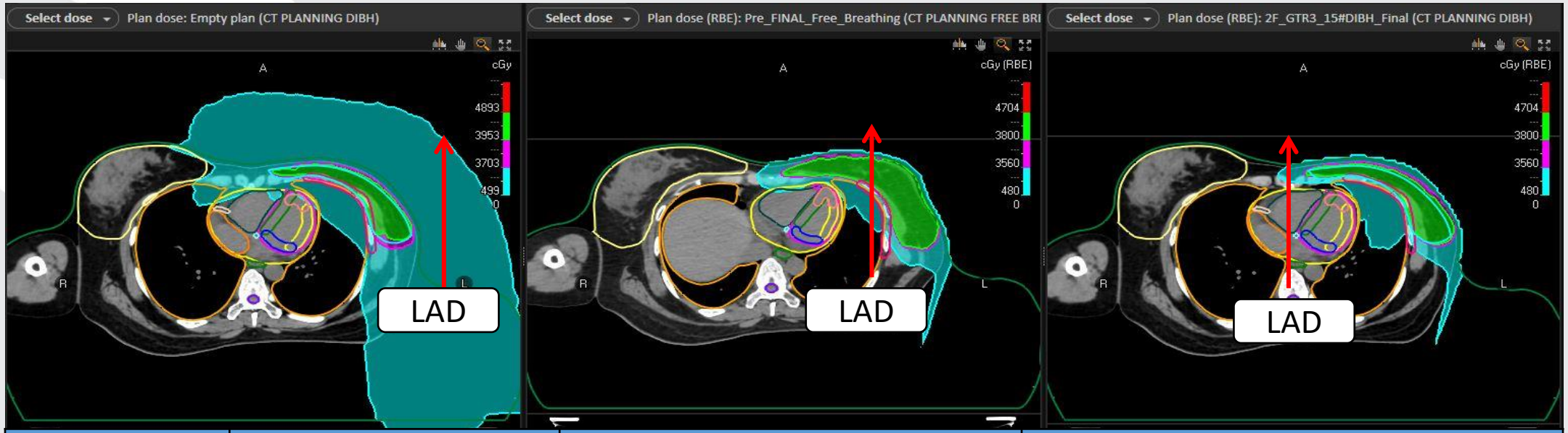
- Intra-BH variation: Variation within a single breath-hold, e.g. a "deep" inspiration becoming less "deep" within seconds. The breath-hold duration may be too long, or the patient may require direct feedback to maintain the breath-hold.
- BH-to-BH variation: Variation from one breath-hold to the next within one treatment fraction. Can be caused by fatigue, shifts in patient position as the treatment fraction is being delivered, or drifts of organs due to relaxation/gravity.

ESTRO-ACROP guideline: Recommendations on implementation of breath-hold techniques in radiotherapy

Marianne Camille Aznara,⇑, Pablo carrasco de fezb, Stefanie Corradinic, Mirjam Mastd, Helen McNaire, Icro Meattinif,g, Gitte Perssonh,i, Paul van Haaren

SGRT System At APCC :

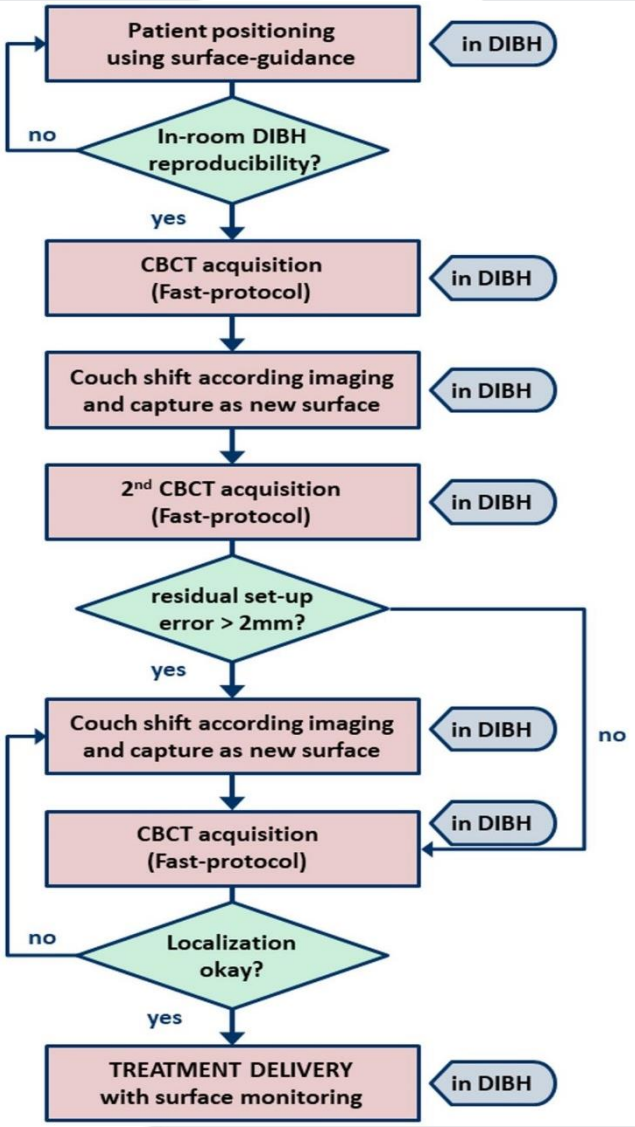
Ca LT Breast FB vs DIBH

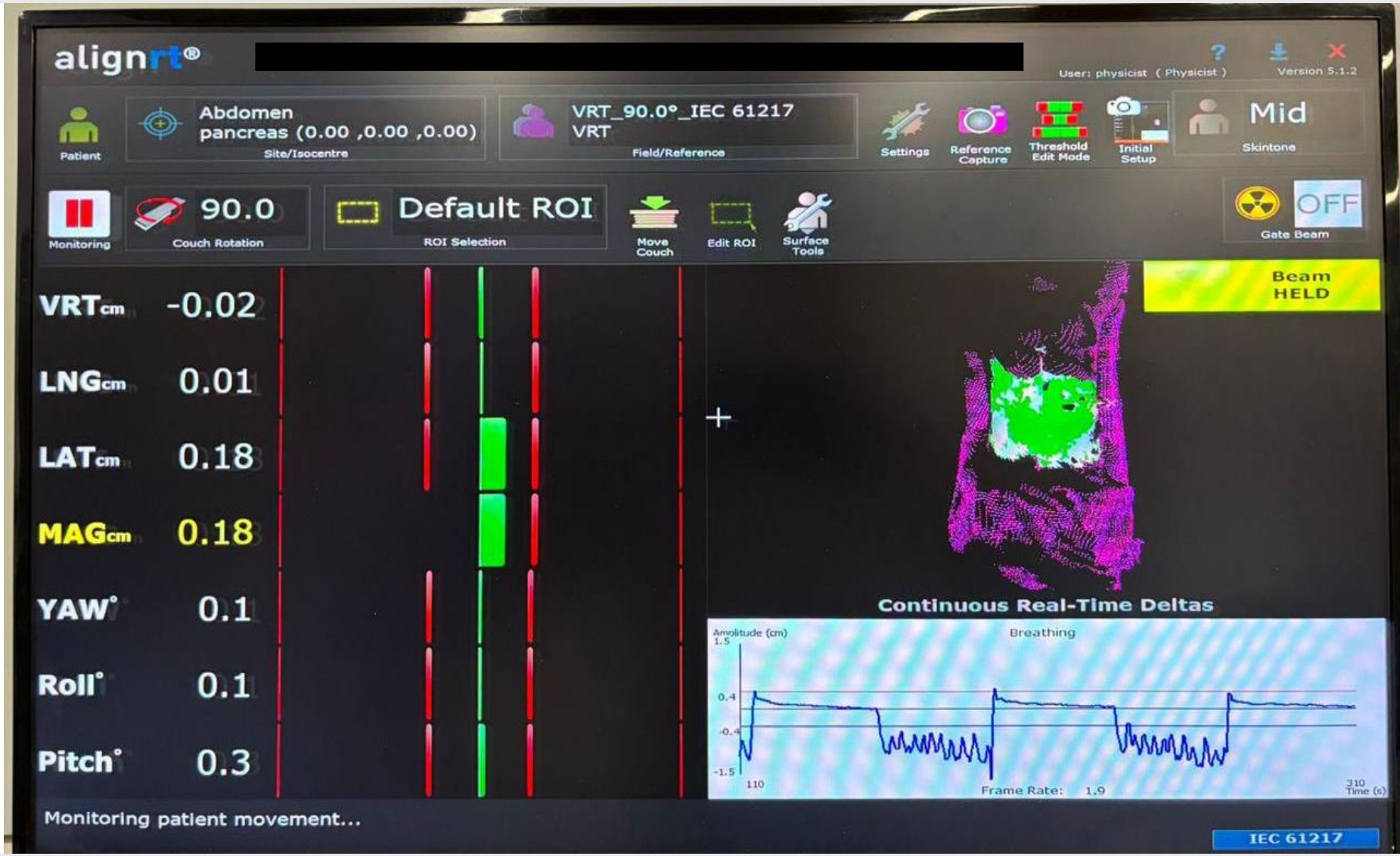


	Tomo DIBH	Proton FB	Proton DIBH
Heart Mean (GyE)	3.08	0.52	0.39
LAD Mean LAD Max (D0.03cc)	4.96 9.89	1.19 5.07	0.47 2.14
LV Mean (GyE)	2.57	0.05	0.11
Contralateral Breast (GyE)	3.03	0.14	0.14

Data Courtesy: Dr.Sapna Nangia

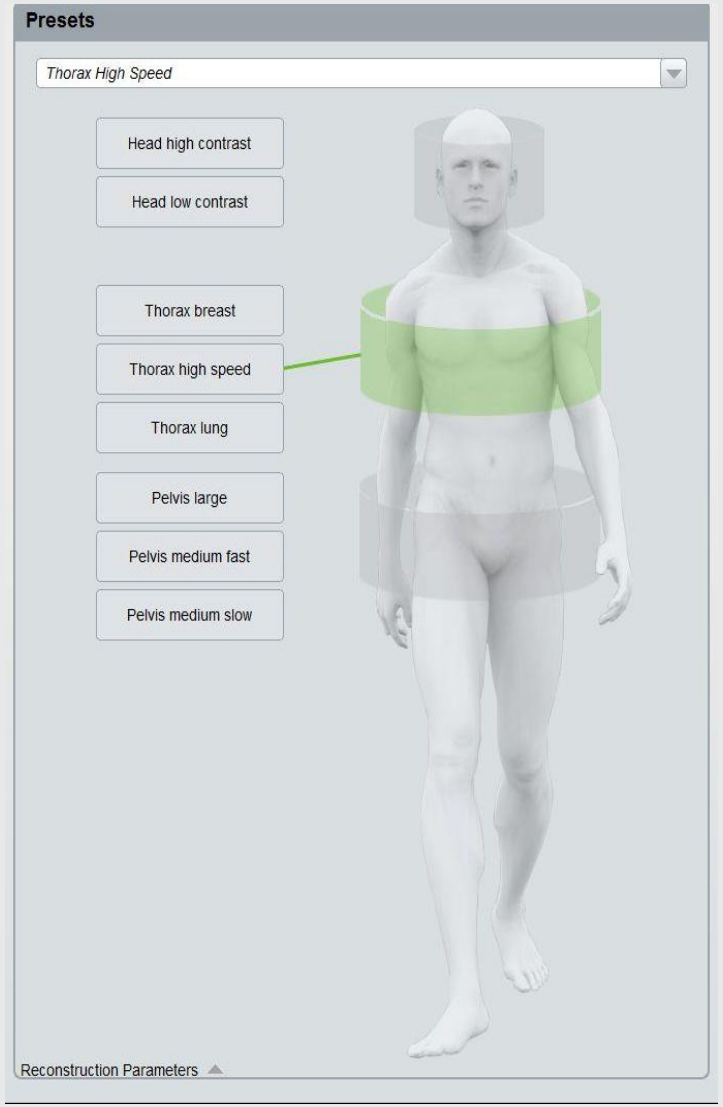
Daily Treatment Deliver SOP for DIBH Pts



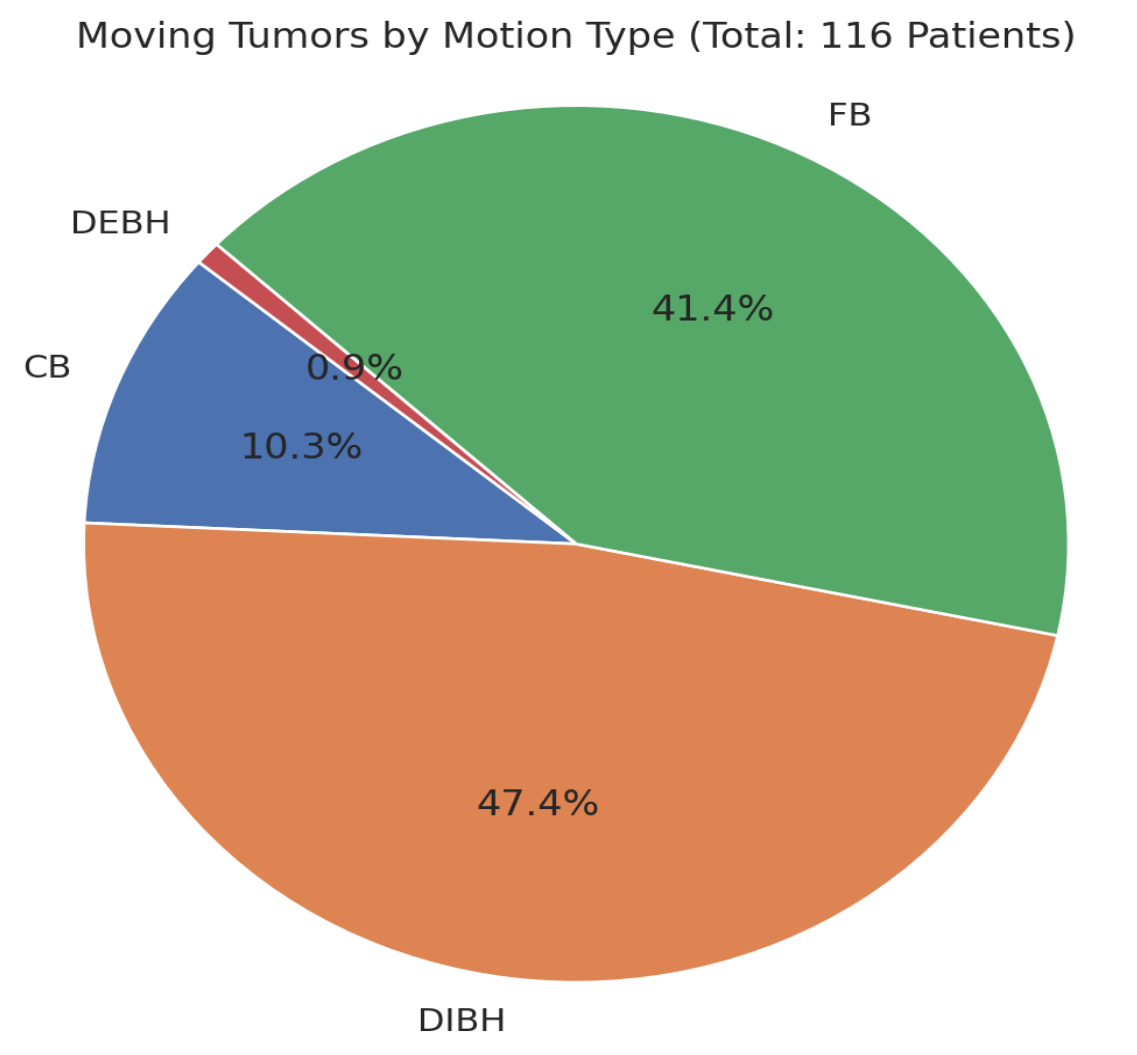


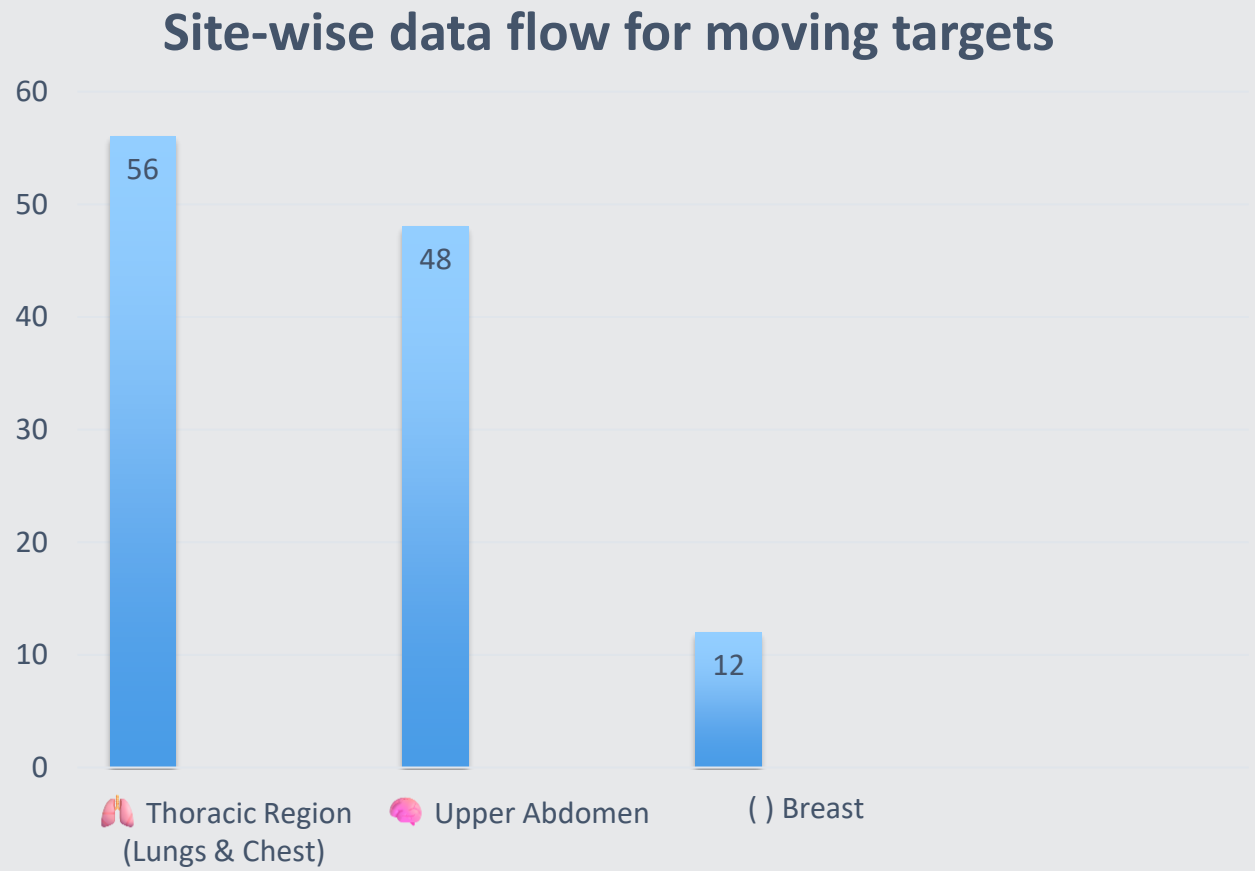
Daily Treatment Deliver SOP for DIBH Pts

- Assess the patient`s Breathing pattern,
- Capture In Surface Guidance System,
- Imaging Presets(Thorax High speed 40sec)
- 20sec interval (20+20sec)
- Reconstruction
- Manual Matching
- Apply Translational and Rotational shifts ,
- Re-Capture in SGRT (in Breath Hold Position)

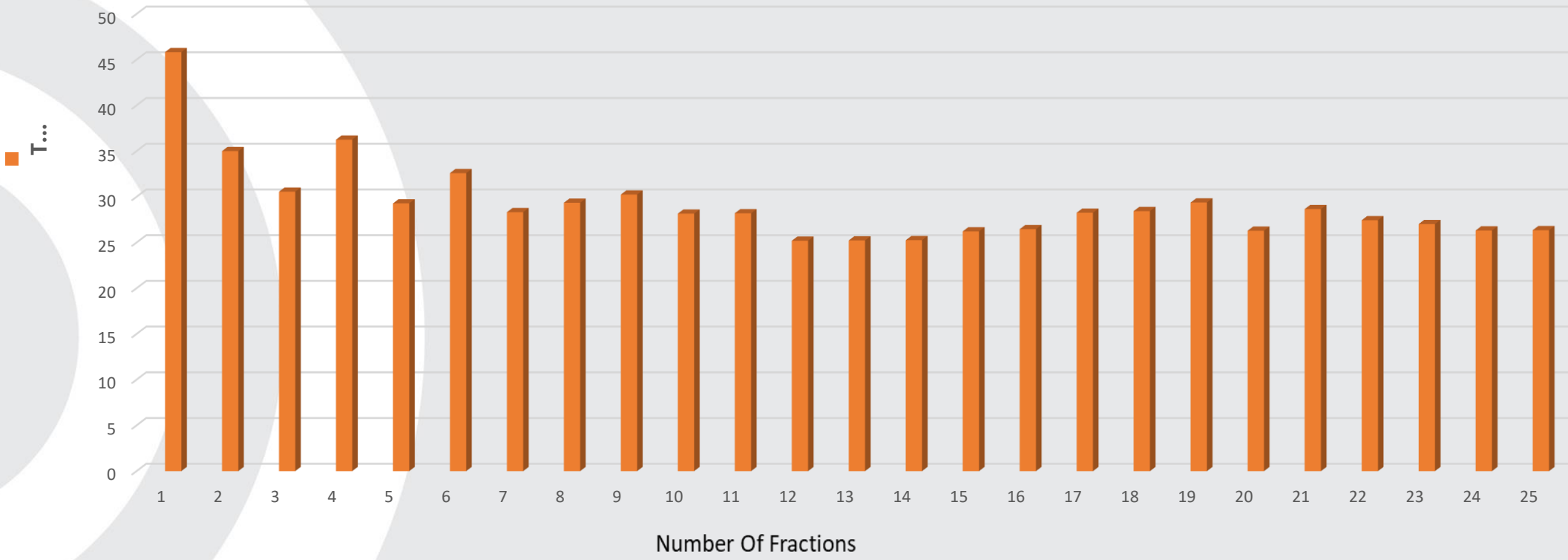


APCC Data Flow for Moving Targets (Aug 23- Mar 25)





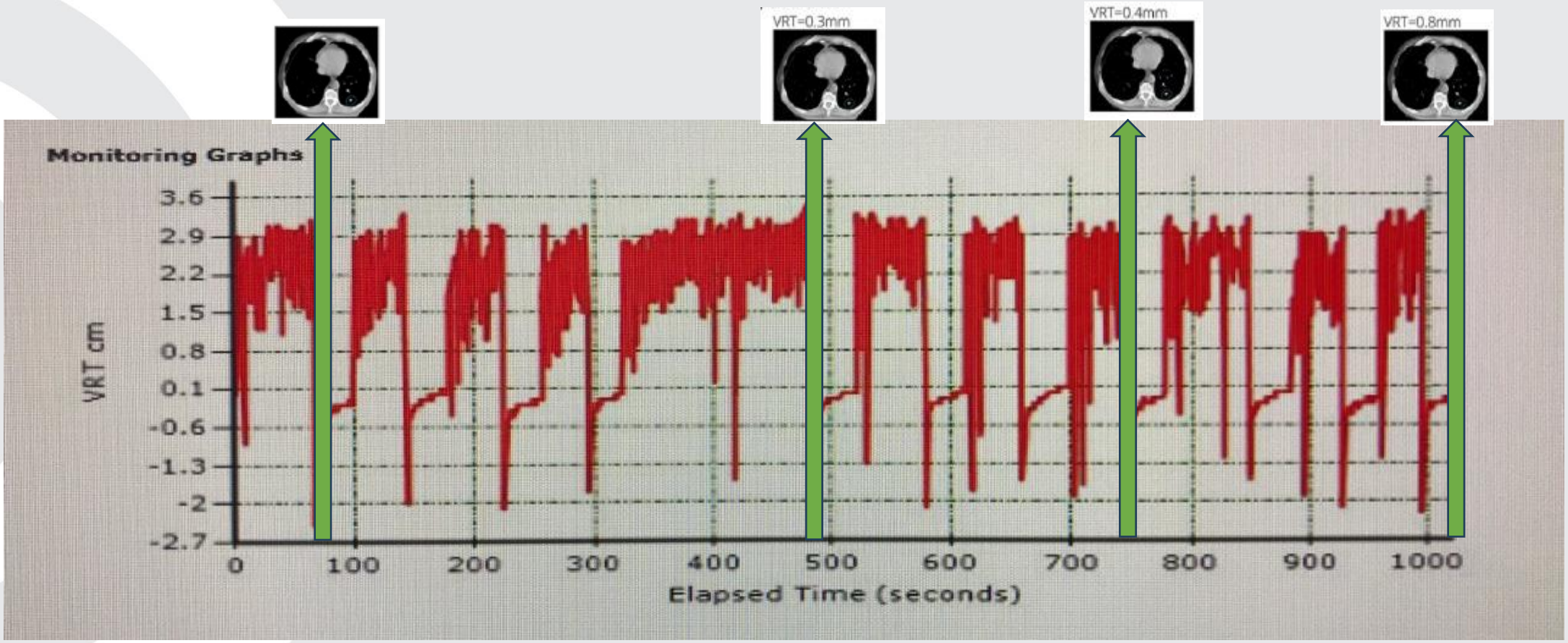
Time Metrics Across 18 Deep Inspiration Breath-Hold (DIBH) Patients using SGRT



******Data includes beam-on time, patient setup, and delays due to breath-hold readiness and beam waiting

- **Average Breath-Holds per Fraction**: 12–15 (including (CBCT)imaging)
- **Gap Between Breath-Holds**: 30–40 seconds
- **Average Number of Beams**: 4–5 (excluding repainting)

Correlation of SGRT Vs IGRT



kV-CBCT apneas

- Respiratory motion information in the VRT direction in the function of time of one session,

Setup Variations

Population of 32 patients(Aug 2023 - Mar 2025) in each motion management technique

DIBH-18

	X	Y	Z	ROLL	PITCH	YAW
Systematic	0.1	0.2	0.2	0.3	0.3	0.4
Random	0.3	0.4	0.3	0.4	0.5	0.5

COMPRESSION BELT-6

	X	Y	Z	ROLL	PITCH	YAW
Systematic	0.3	0.2	0.4	0.5	0.6	0.6
Random	0.3	0.4	0.3	0.6	0.6	0.5

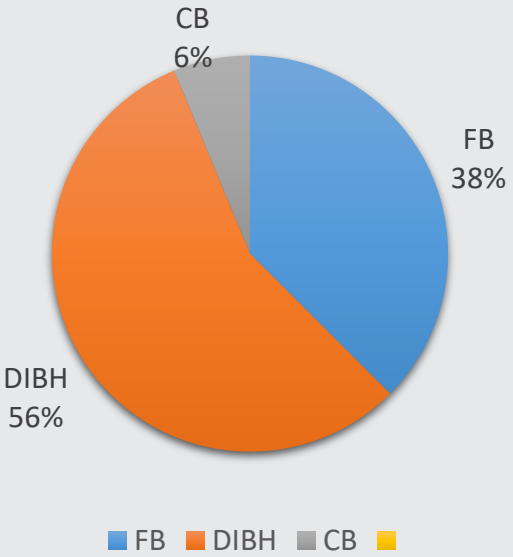
FREE BREATHING-8

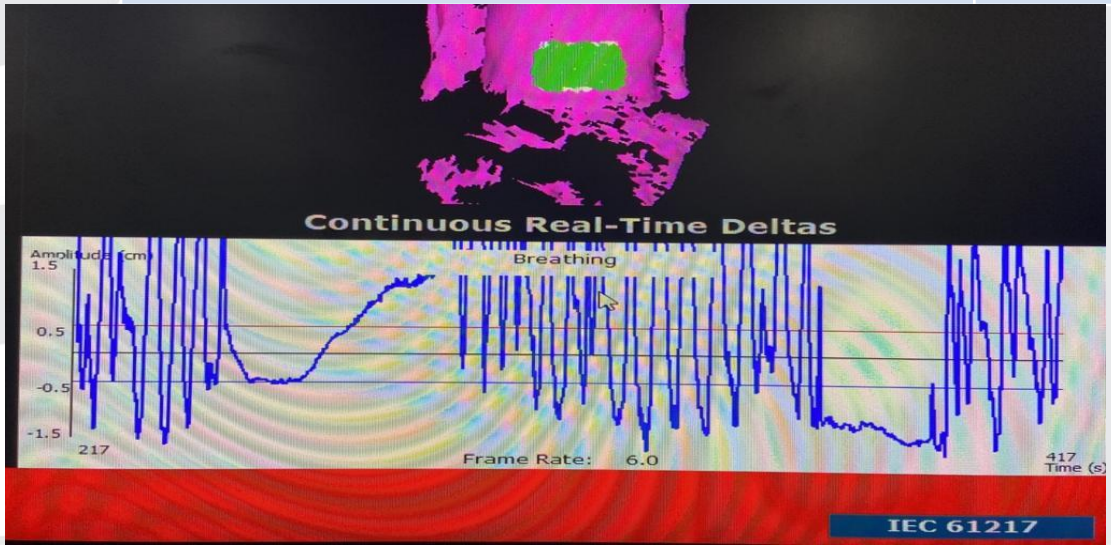
	X	Y	Z	ROLL	PITCH	YAW
Systematic	0.2	0.2	0.2	0.3	0.2	0.3
Random	0.2	0.3	0.3	0.4	0.4	0.5

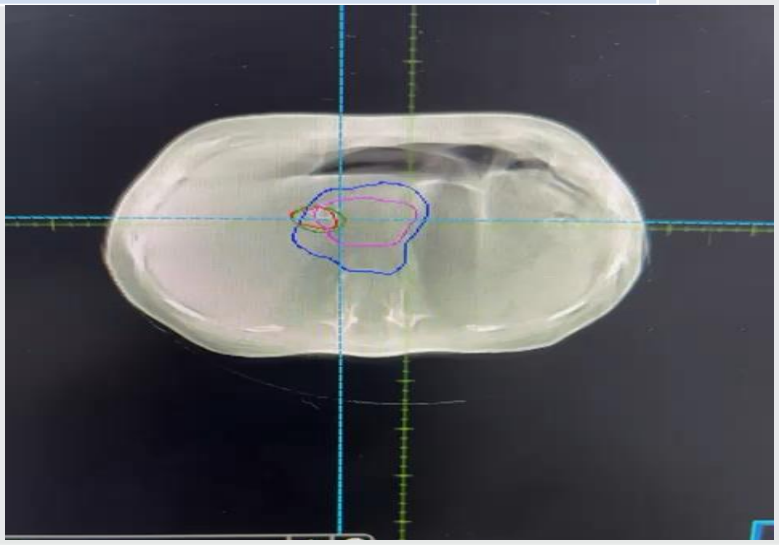
Triggers with DIBH,FB,CB using SGRT,

- Data of (12FB+18DIBH+2CB=32) patients since Jul-23
- Using SGRT, observed variability in breath-hold depths and anatomical changes over the treatment course,

Triggered Events	Number of times
QACTs	74
Adaptive plannings	12
Re-Simulations	8



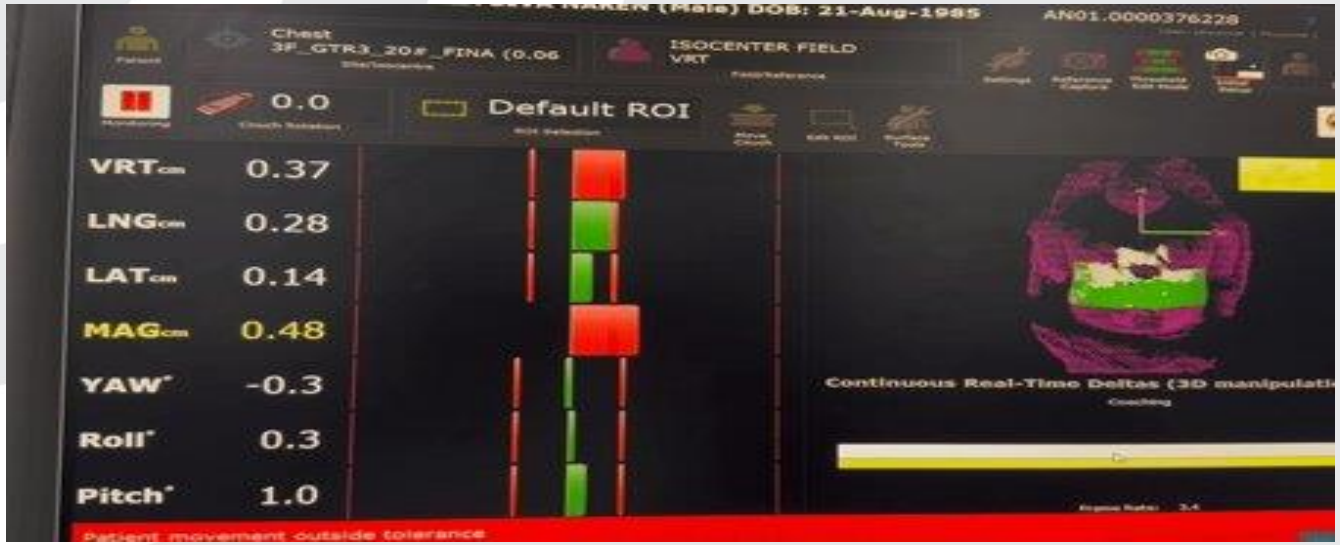


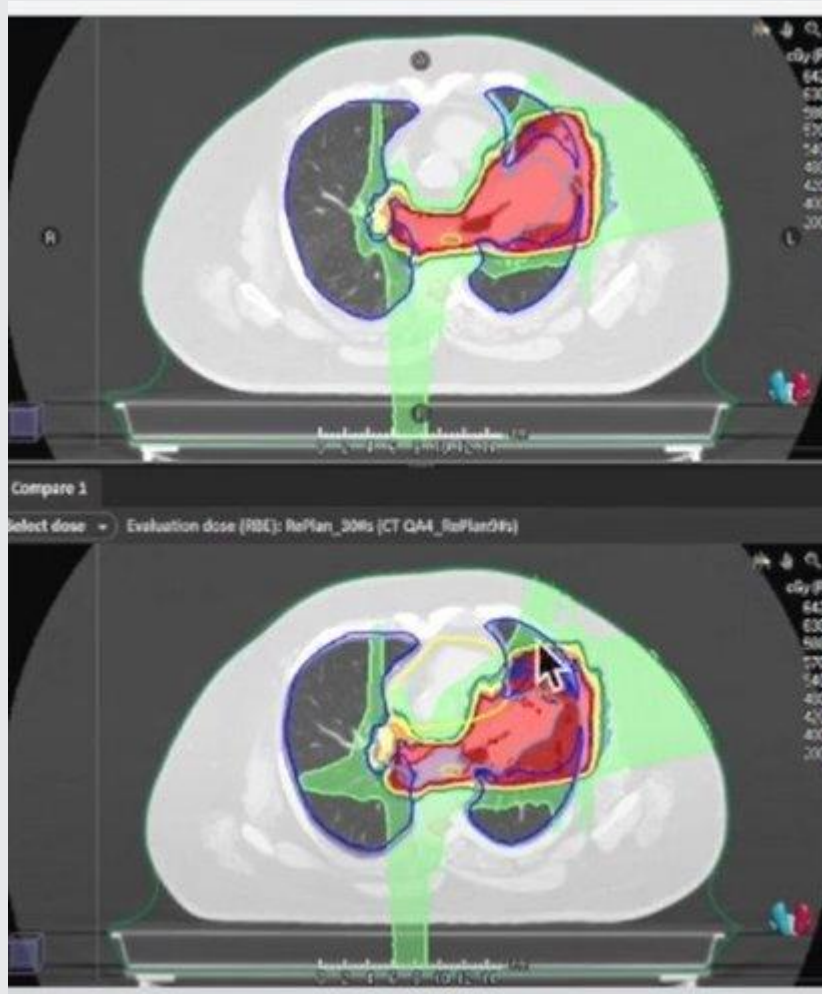


Ca Lung with DIBH

➢QACTs- 74

- Periodic QA CTs (weekly or biweekly)
- QACTs also triggered immediately upon noticing any significant patient anatomical , setup change or amplitude Variations,
- Detecting anatomical shifts, tumor regression
- ROI adjustments in SGRT



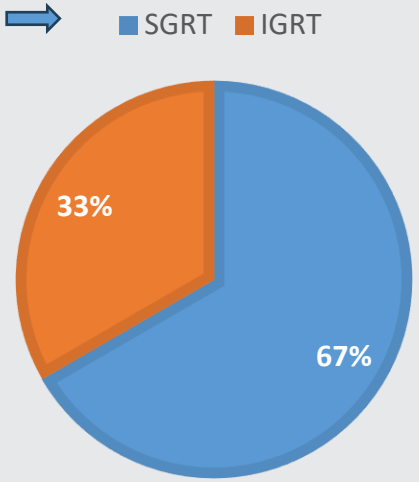


Ca Lung with DIBH

➢Adaptive planning – **12**

- Adaptive planning is particularly important in proton lung patients, where tumor shrinkage or density changes from atelectasis resolution or inflammation can significantly alter proton beam path and necessitate replanning to preserve Dosimetric integrity,

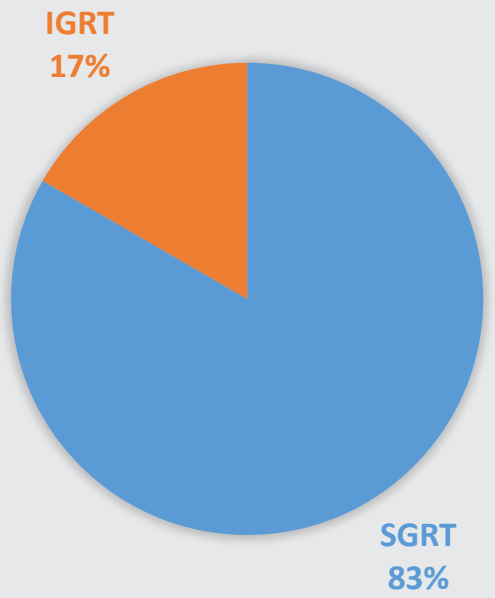
Adaptive planes triggered with ⇨



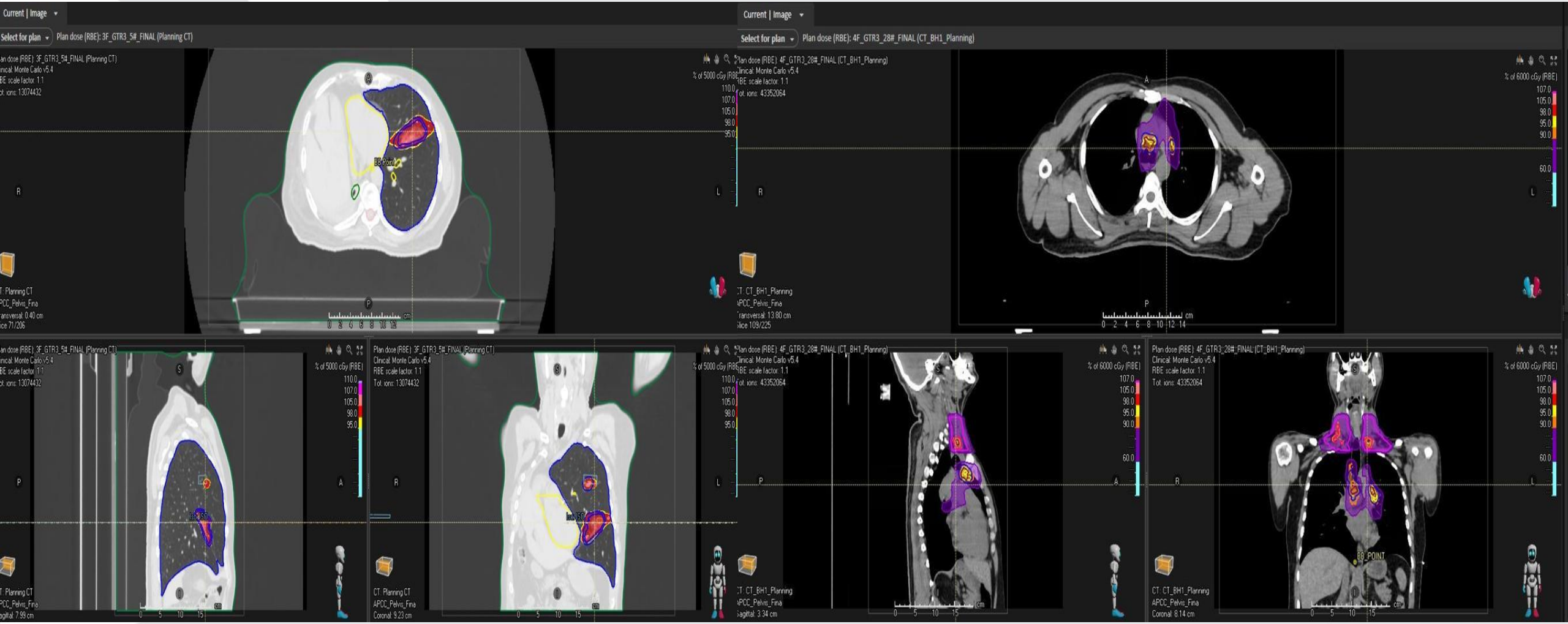
Re-Simulations

- Intrafraction uncertainties such as intra- and BH-to-BH variations
- Systematic changes in BH levels may be detected during the first three treatment fractions,
- Surrogate structures can be delineated during treatment planning

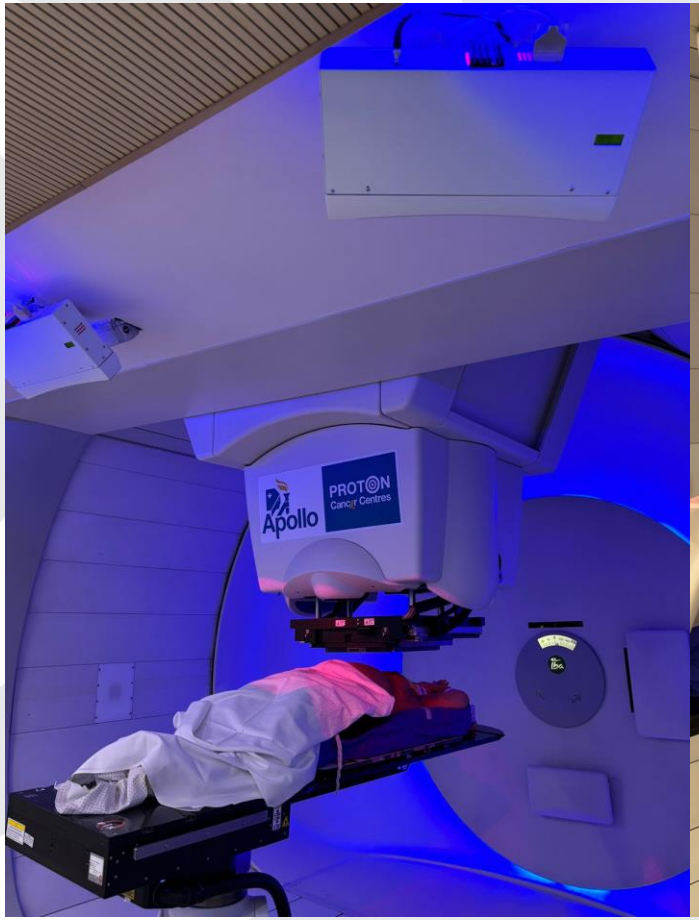
Re-Simulations Triggered with

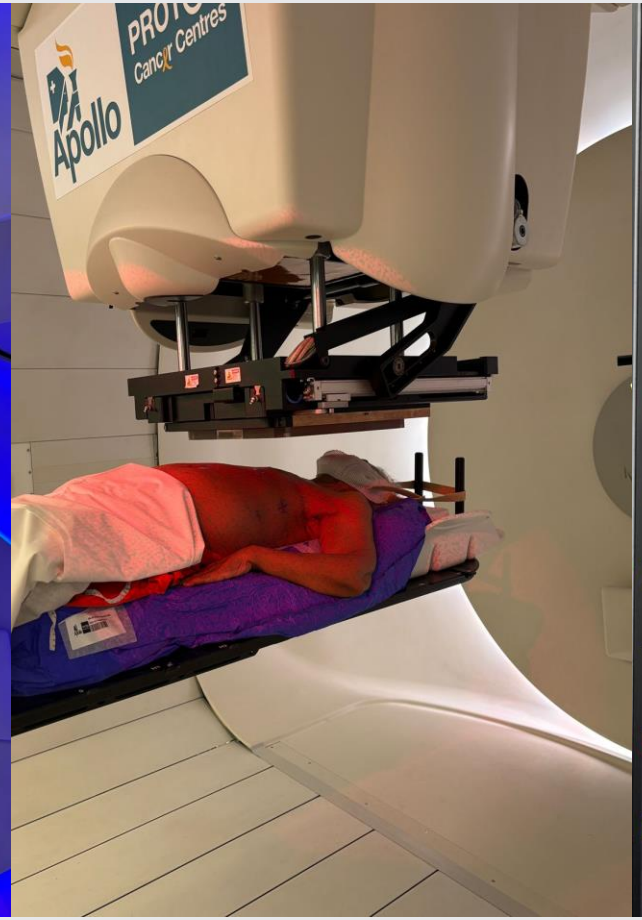


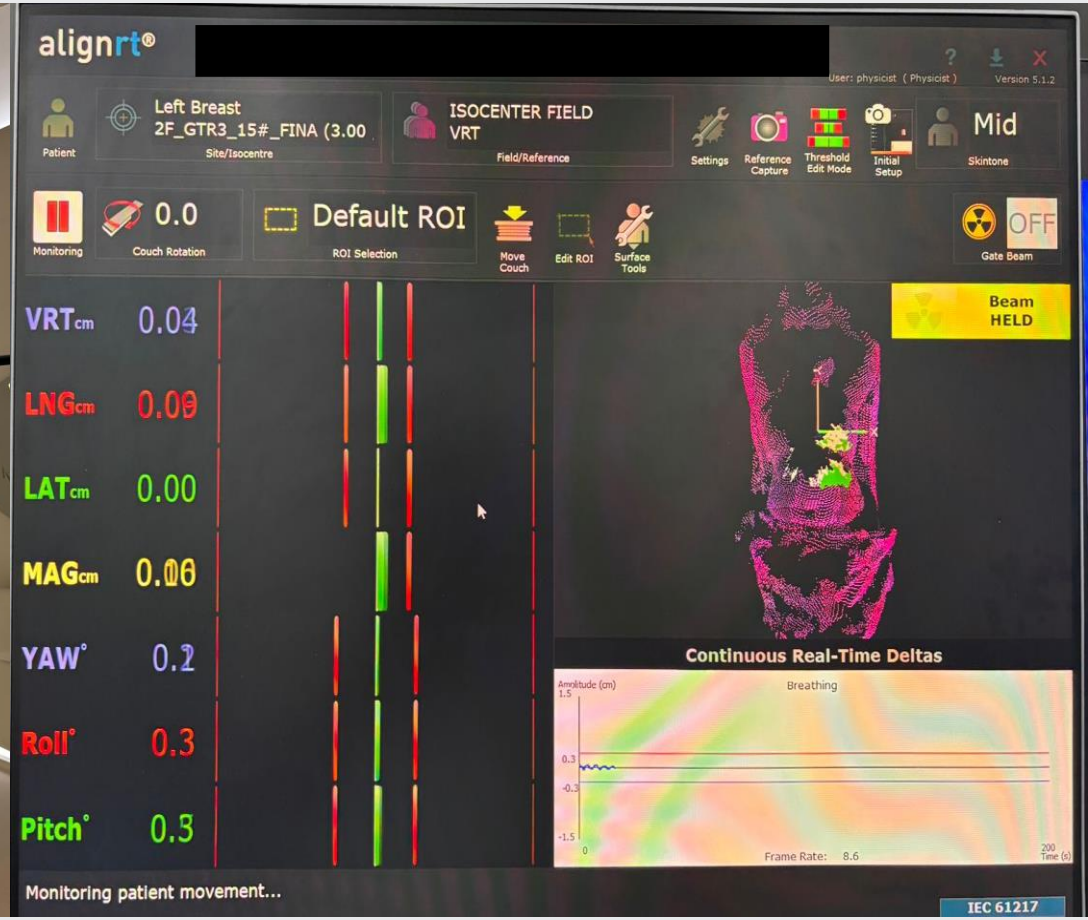
DIBH with multi-lesions



Challenges with SGRT for Proton Therapy Unit:







Summary & Takeaways

- Based on our experience, the integration of SGRT systems with tight thresholds in all 6 degrees of freedom (DoF) allows reproducible DIBH and precise tumor positioning during Moving tumour treatments with pencil beam scanning proton therapy.
- Daily imaging for the verification of the position of the target in BH as well as verification of the BH level (if necessary to ensure consistency in OAR sparing)
- Target-related intra-fraction (intra-BH and BH-to-BH) monitoring should perform
- Ability to re-image and re-plan the patient if any change of breathing pattern is suspected
- Time and resources for each institution to carry its own quality assurance programme to assess interfraction and (ideally) intrafraction uncertainties .

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