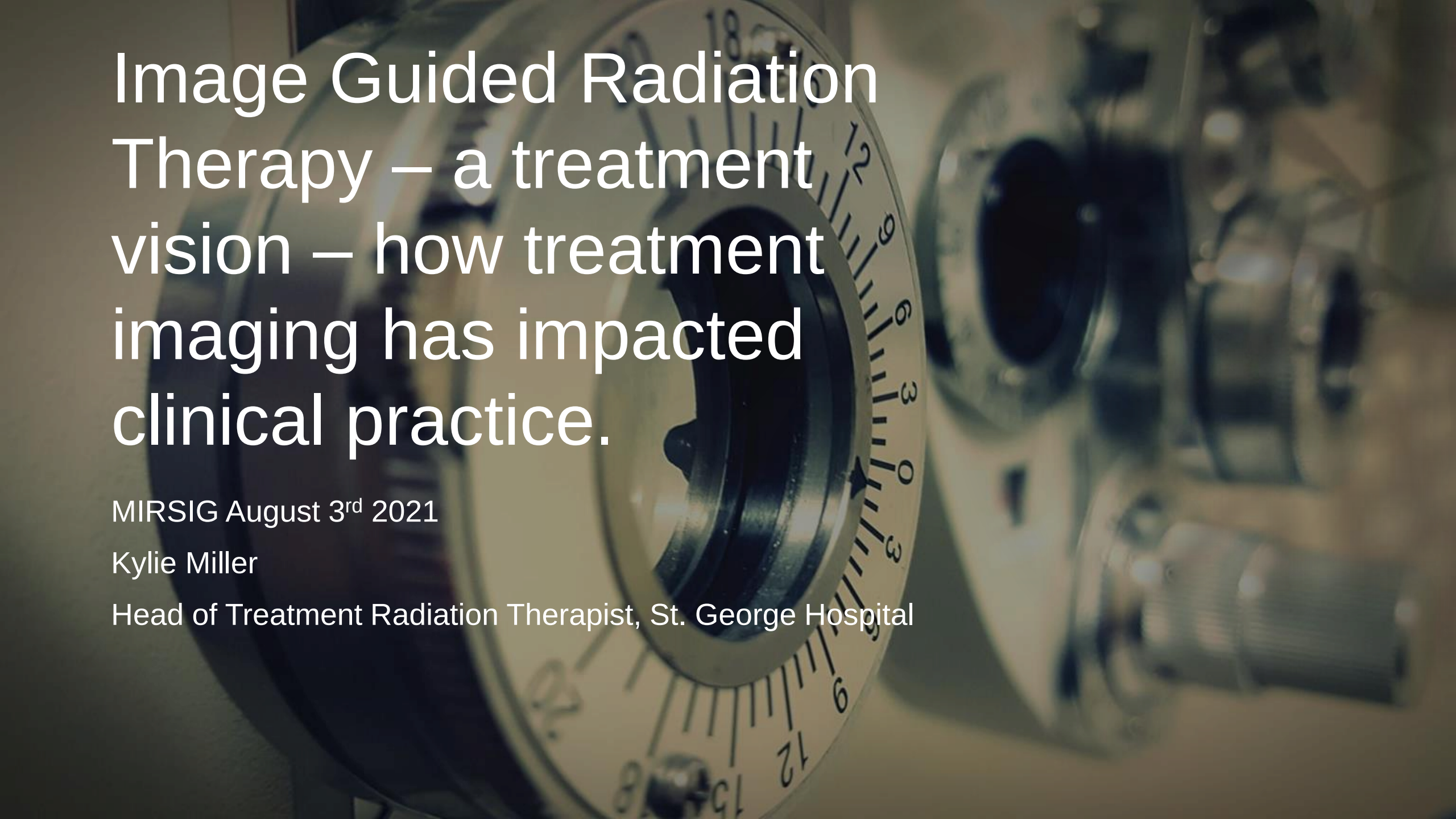

Image Guided Radiation Therapy – a treatment vision – how treatment imaging has impacted clinical practice.

MIRSIG August 3rd 2021

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Learning Objectives

1

Understand how IGRT has developed (IGRT then and now).

2

Appreciate how clinical practice has changed with advances in IGRT (a treatment perspective).

3

Understand how treatment imaging is used for dosimetric and clinical assessment and as indication for replanning.

Aims of Radiotherapy

- Safely and accurately deliver treatment maximising dose to tumour volumes while minimising dose to surrounding structures.
- Achieve the best clinical outcome possible for the patients.
- Four main advancements allowing us to do this:

    1.Image fusion – allows more accurate target delineation.

    2. Modern planning and treatment techniques – e.g. IMRT/VMAT – allowing dose to be better sculpted.

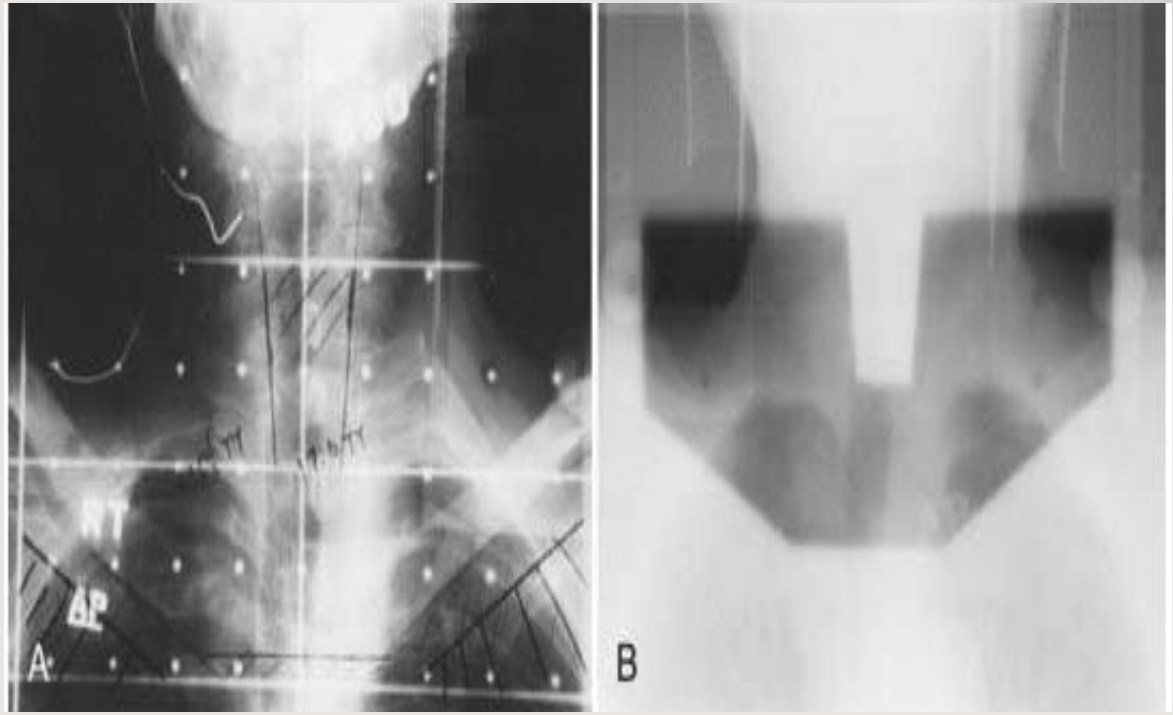
    3. Improved Quality Assurance practices.

    4. Accurate treatment due to improvements in technology including advanced imaging have allowed margin reduction and surety around plan delivery.

IGRT – the first stanza

Treatment fields marked on the patient

Simulation and Portal X-ray Images

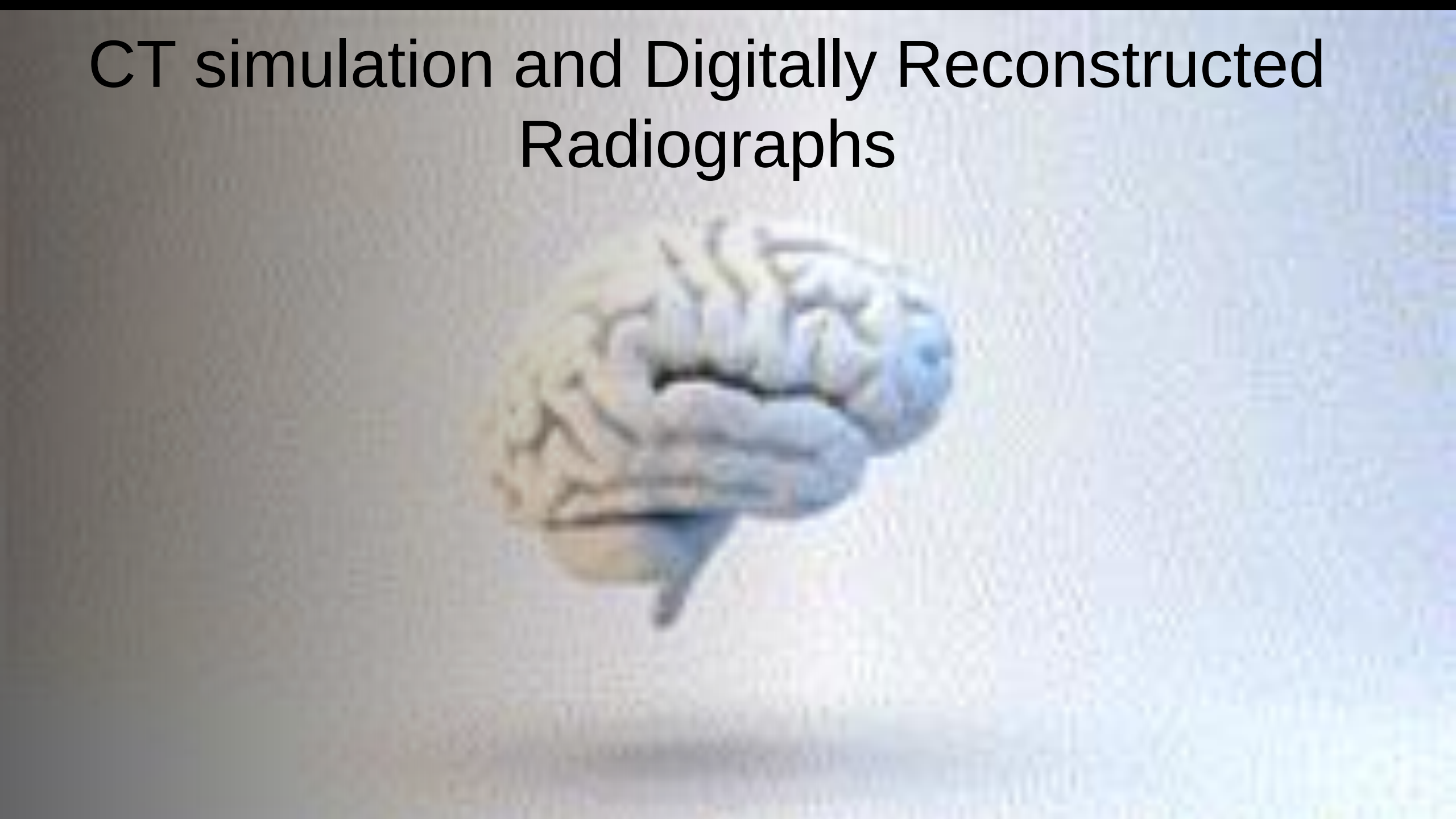


Images from - https://oncohemakey.com/cancer-of-the-oral-cavity

IGRT for treatment…… “Can you please run and process this port film” - how times have changed!

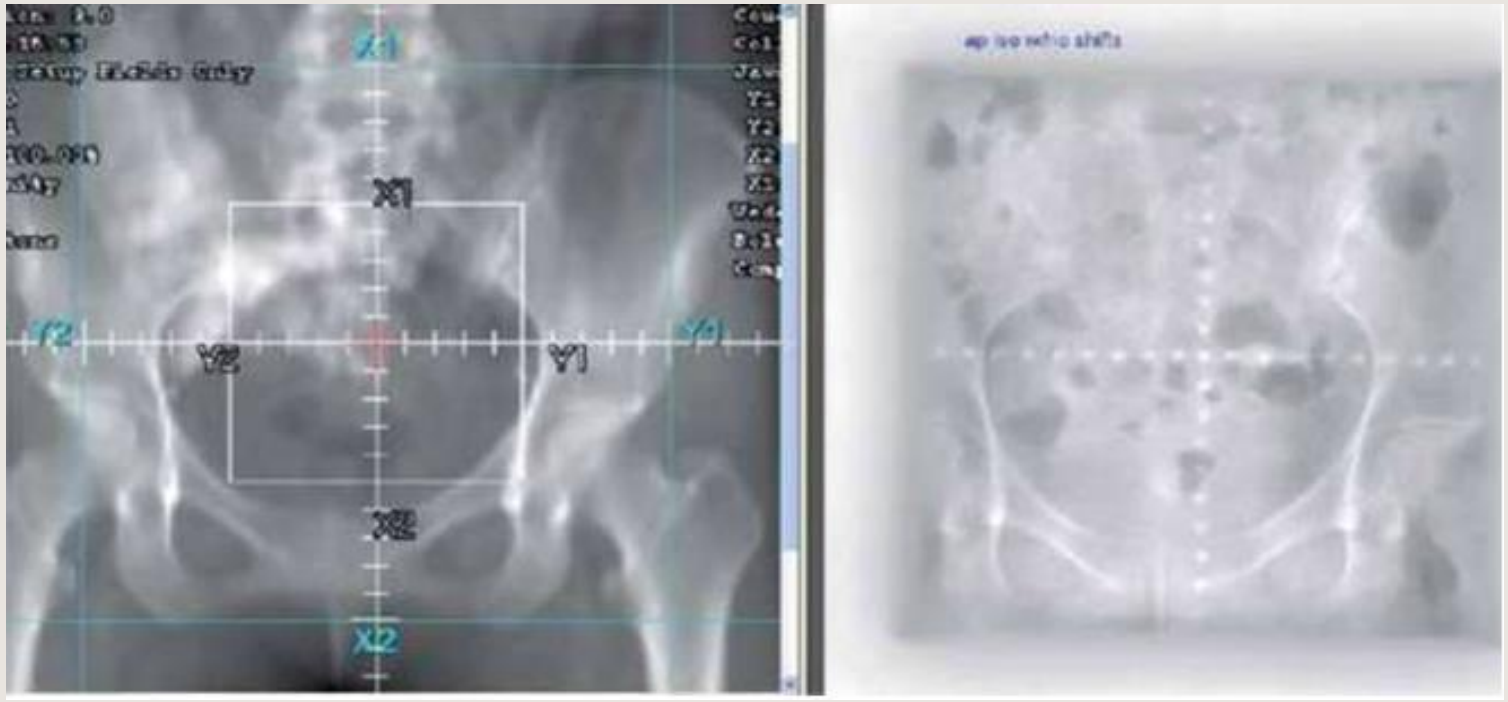
- **Simulation and Treatment Portal Films:**
  - Images manually developed.
  - Real time imaging non-existent.
  - Reduced imaging frequency.
  - Accuracy?? Magnification factors and side-by-side comparison of simulation and treatment images.
  - No true soft tissue visualization or patient contour monitoring.
  - Replans were infrequent with Tissue Phantom Ratio corrections for static fields used to account for change in external contours.
  - Higher imaging doses.

CT simulation and Digitally Reconstructed Radiographs



CT Simulation and Treatment Imaging

- Use of 3D CT data sets for treatment planning allowed generation of Digitally Reconstructed Radiographs (DRRs).
- Initially used like simulation X-ray images with side-by-side comparison with treatment images.
- CT simulation and DRRs paved the way for onboard real time imaging.



Images from - https://doctorlib.info/oncology/gynecologic-oncology-clinical-practice/19.html

On-Board (EPID) Imaging

Replaced film for treatment verification. Can be used for EPID dosimetry checks.

Early editions had no capacity to overlay images and send couch shifts but was a marked improvement in treatment imaging. Allowed development of current 2D, 3D and 4D treatment imaging techniques .

Can be MV or kV. These two modalities can be used in tandem.

Now standard on most Linear Accelerators. Online matching and ability to calculate and apply remote couch corrections adopted as standard practice.

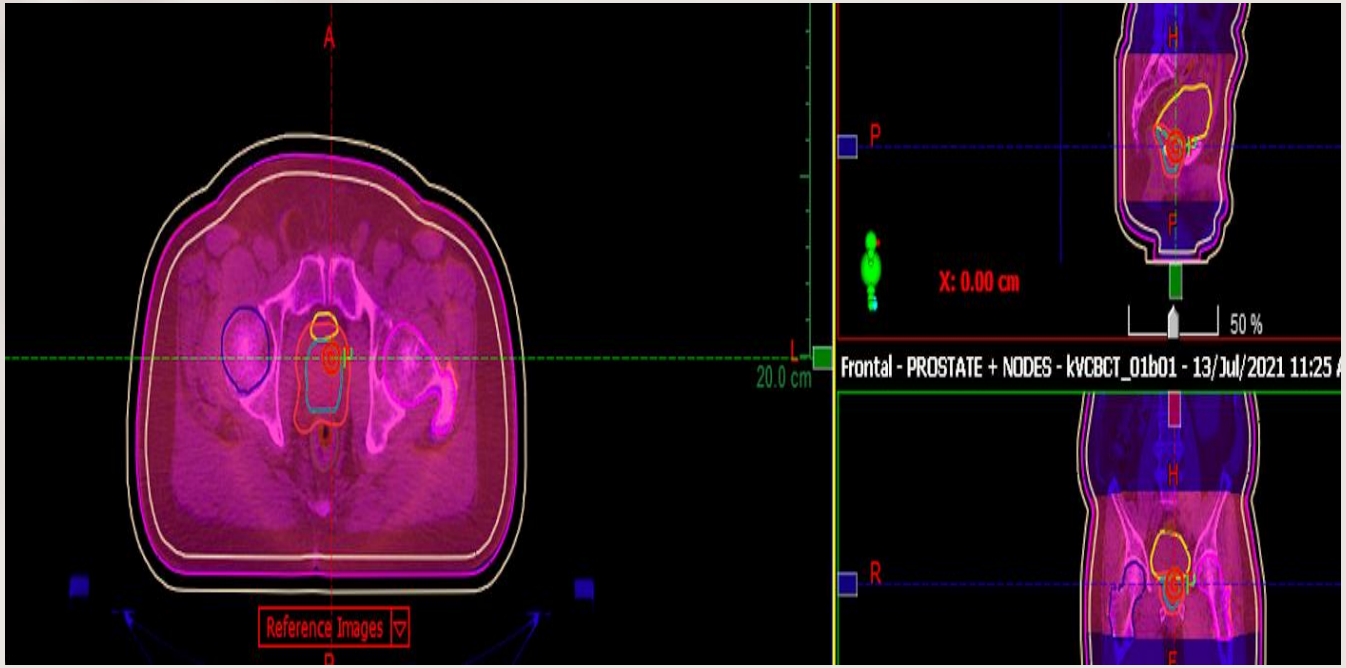
The combination of EPID and software improvements drastically improved the timeliness of image review, treatment accuracy and documentation.

On-Board (EPID) Imaging then and now

Image from -https://www.oncologysystems.com/

https://www.medicalexpo.com/prod/varian-oncology/product

The Arrival of Cone Beam Computed Tomography (CBCT)

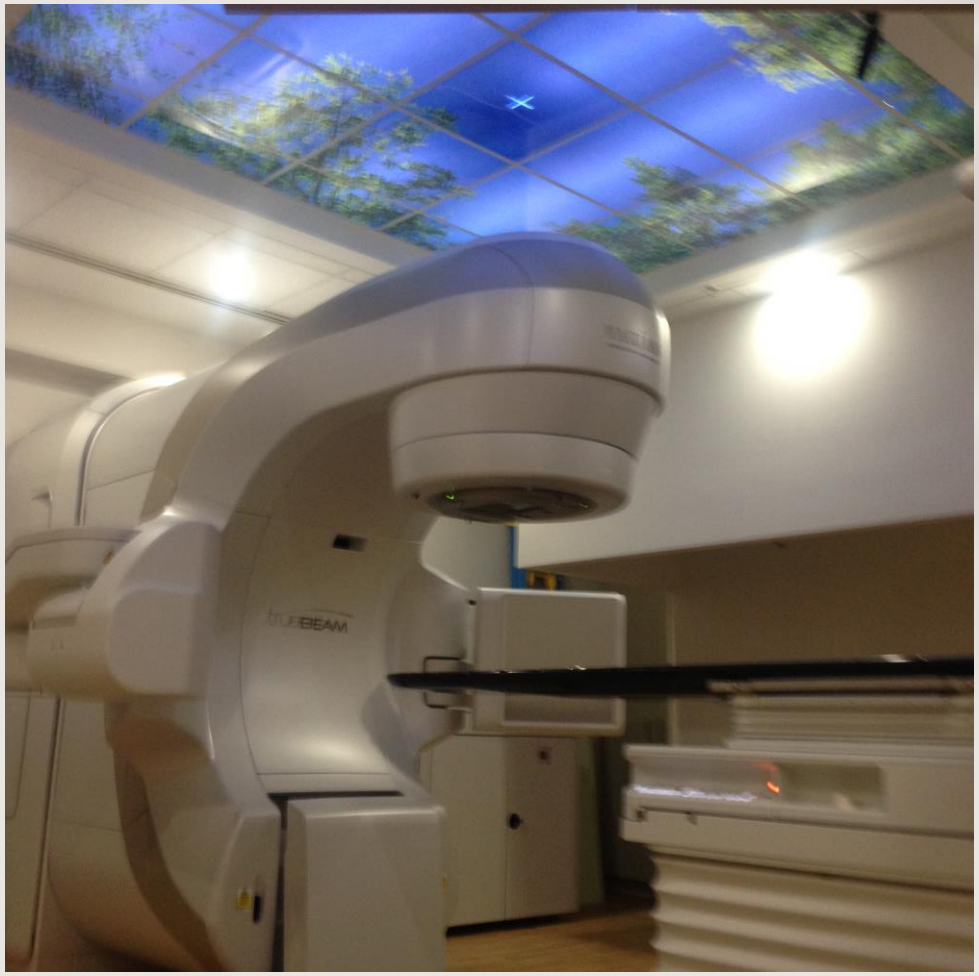


CBCT – A game changer in clinical practice

- Use of CBCT is now widely adopted as gold standard in Radiation Oncology
- CBCT has changed clinical practice through:
  - 3D visulisation of bony and soft tissue anatomy.
  - Improved treatment accuracy: target localisation, assessment of tumour volumes, OARs and patient contour.
  - 4DCBCT: online/offline visualisation of tumour motion.
  - Allowing calculation and application of couch corrections in 6DoF.
  - Timely dosimetry assessment and decision making around replanning and continuation of treatment without needing to re-CT patients.
  - Reducing re-setups and manual handling to improve treatment efficiency (factors which benefit patients, staff and the service at large).

The St. George Hospital CBCT Experience

- First Varian TrueBeam installed 2017.
- MDT focus on utilising advanced imaging and 6DoF couch capabilities.
- Initially daily CBCT with 6DoF couch corrections for Brain, Head and Neck, Prostate and SABR cases.
- Now 3 Varian TrueBeams with advanced imaging and 6DoF couch capabilities - adoption of daily CBCT with 6DoF couch correction for most sites.
- Competency based assessments for RT training.
- Image Action Thresholds and CBCT decision trees assist RTs with online decision making -the more information - the harder clinical decision making.
- Offline review for audit, contour assessment and troubleshooting.
- CBCTs fused in Eclipse - dosimetry assessment.
- Gated CBCT recently rolled out.

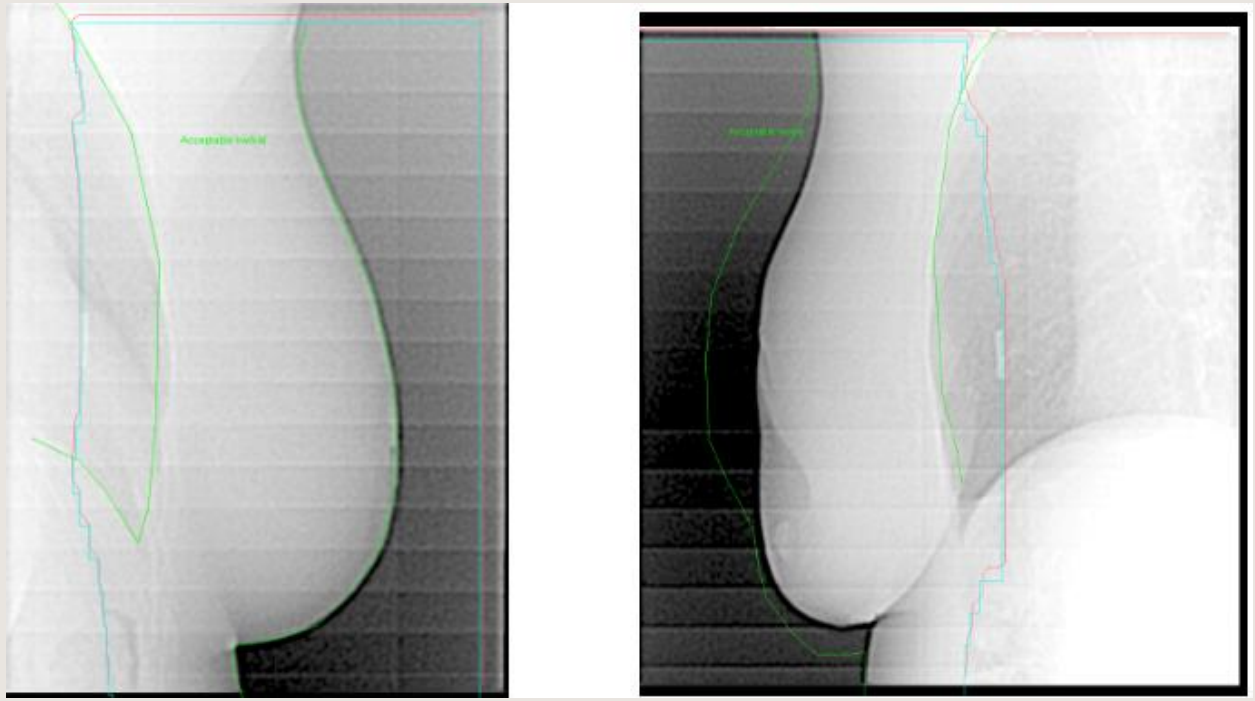


Indications for replanning seen on treatment imaging

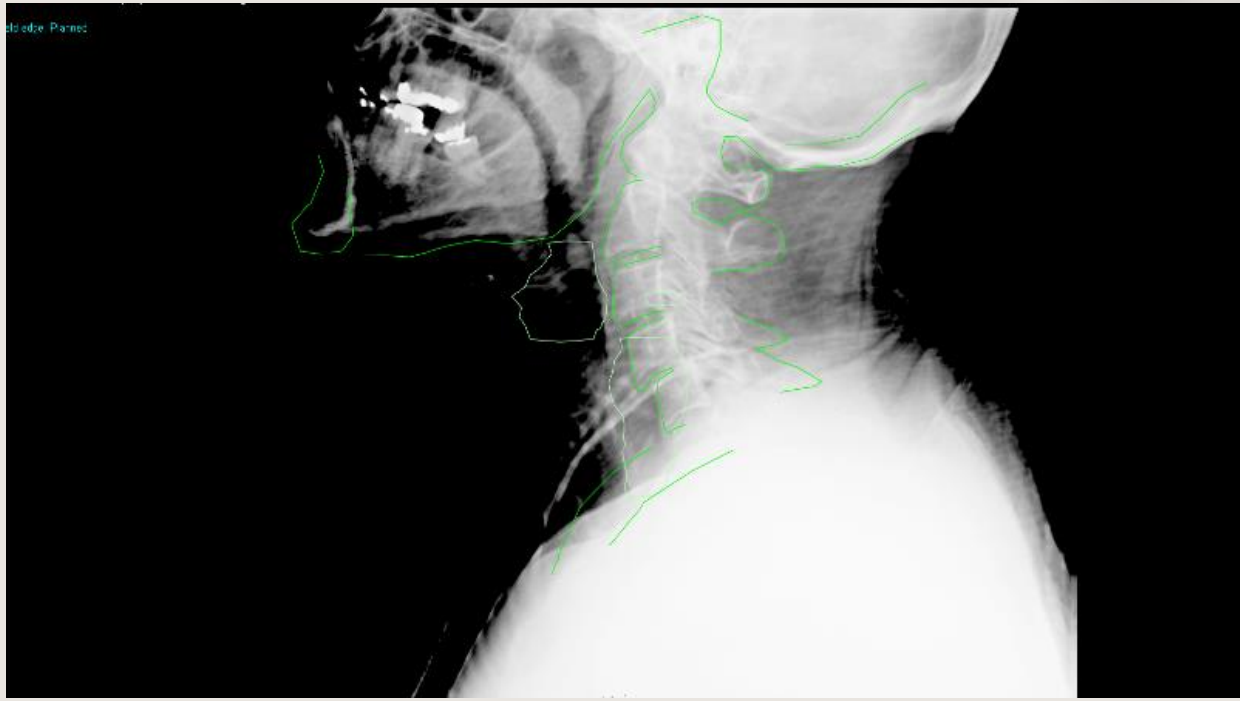
- Tissue gain/loss.
- Change in tumour volume/position.
- Change in other internal anatomy.
- Change in patient condition (requiring repositioning).
- Setup reproducibility issues.

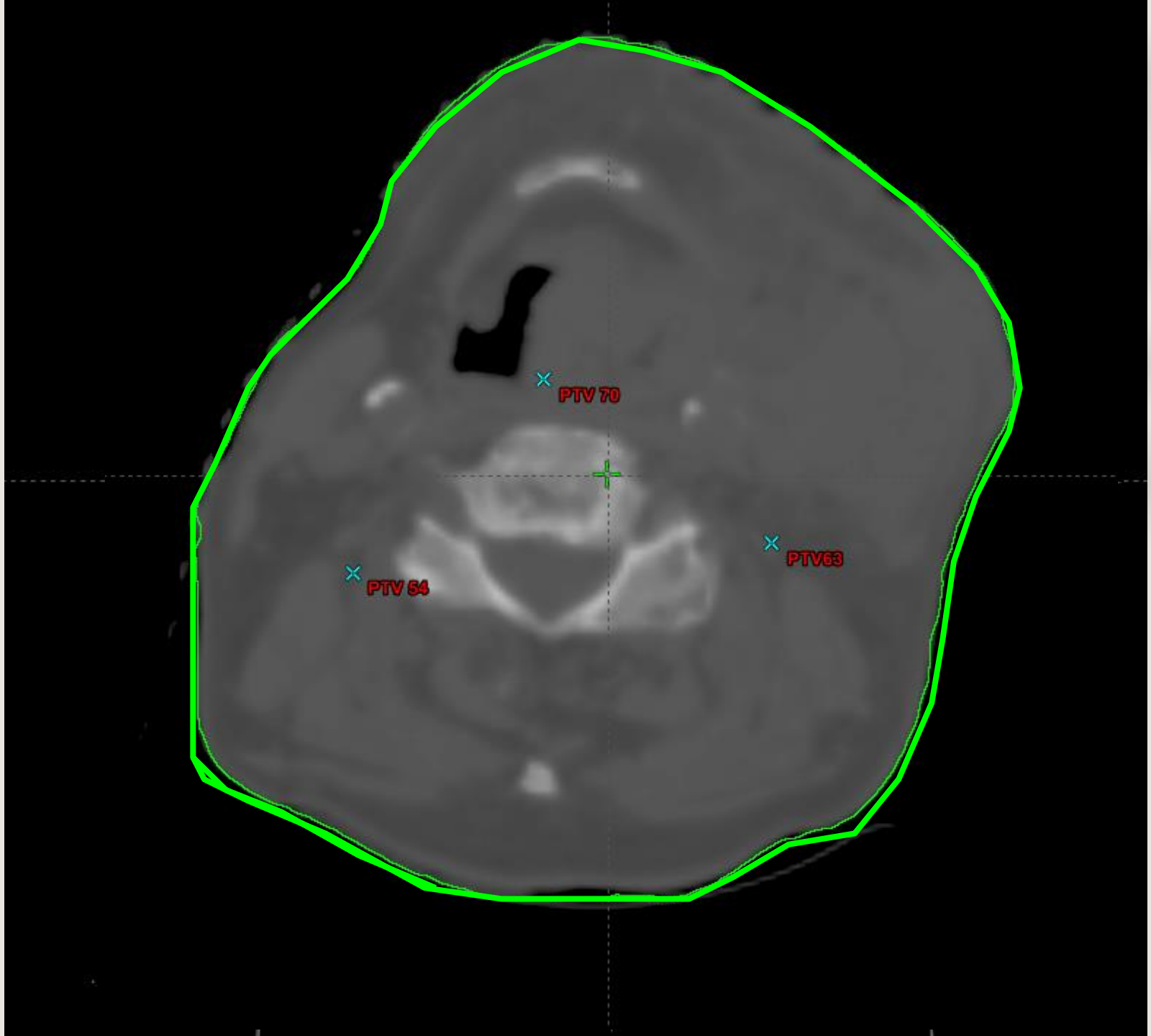
External Contour change on 2D Imaging vs 3D Imaging

2D MV Planar Treatment Portal Image showing change in patient external contour for a breast case



2D kV image for a head and neck case no soft tissues/external contour visible





Head and Neck contour change viewed on CBCT

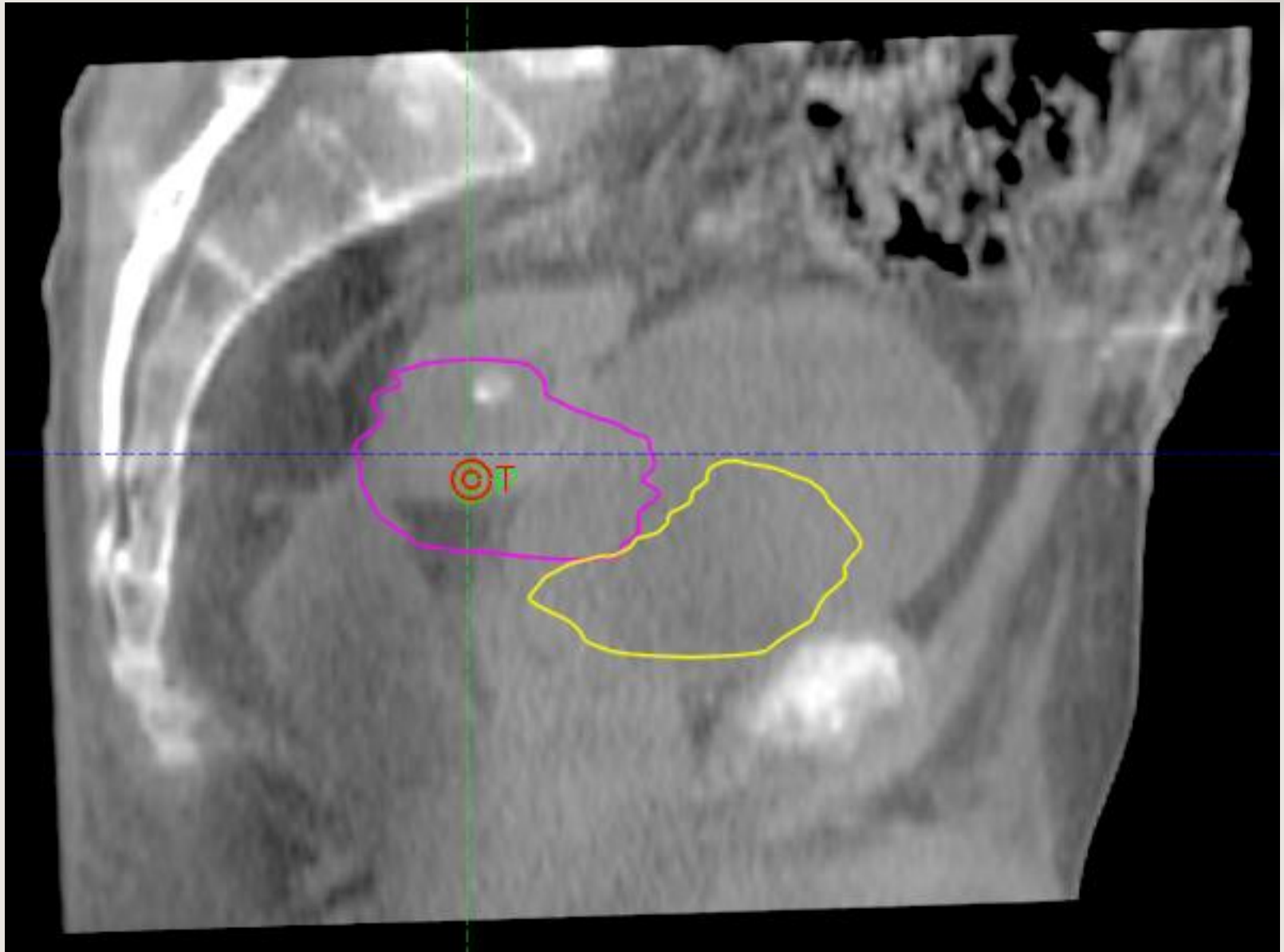
Internal anatomy and tumour changes 2D images vs CBCT

Lung lesion on 2D kV imaging – appears that lesion has moved but this is hard to quantify by how much or the dosimetric implications.

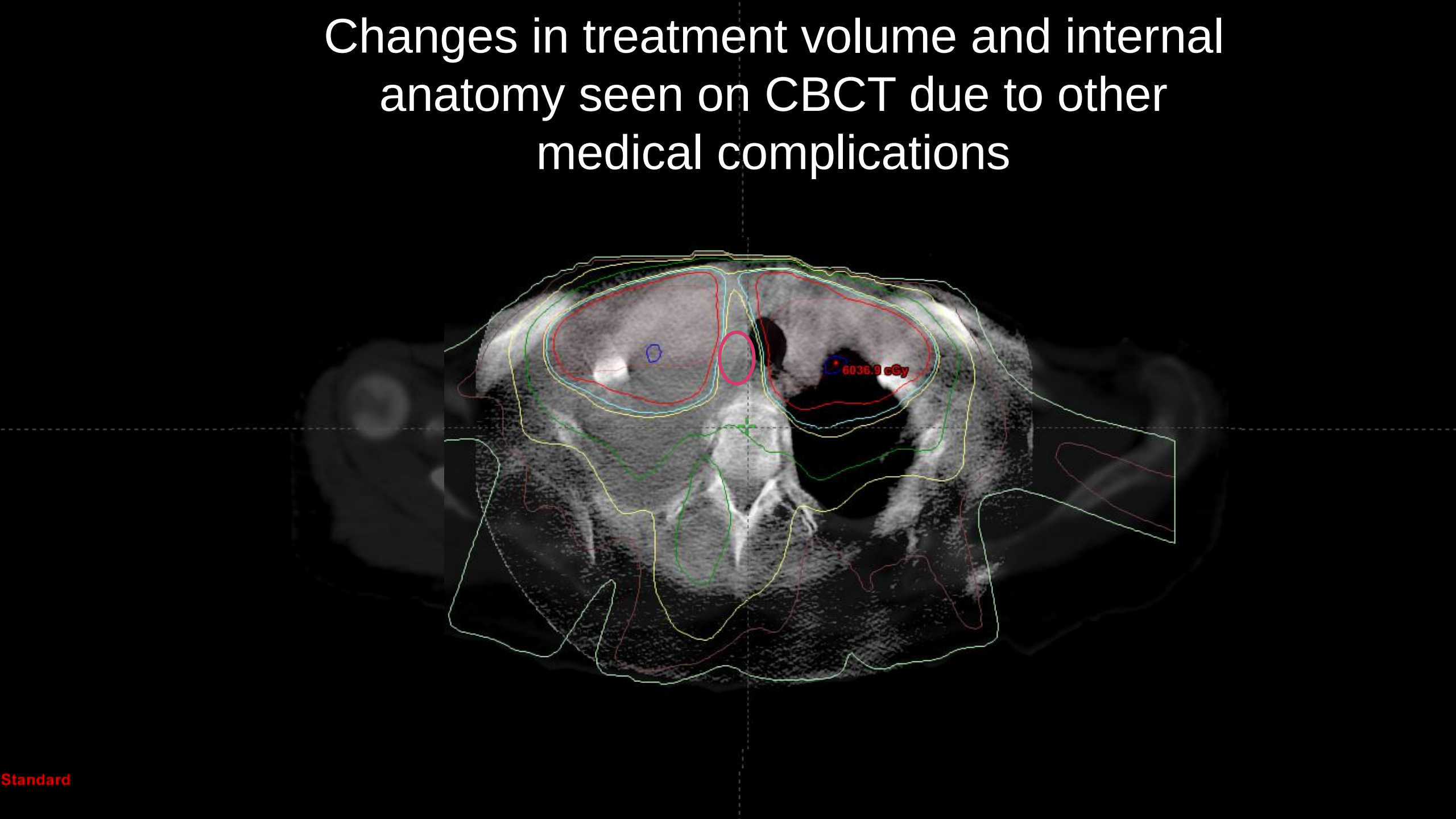
Lung lesion visualised on CBCT – indicating replan required

Tumour only partially in original PTV due to change in lesion position – resulting in replan.

Organs at Risk Displacing Tumour Volume

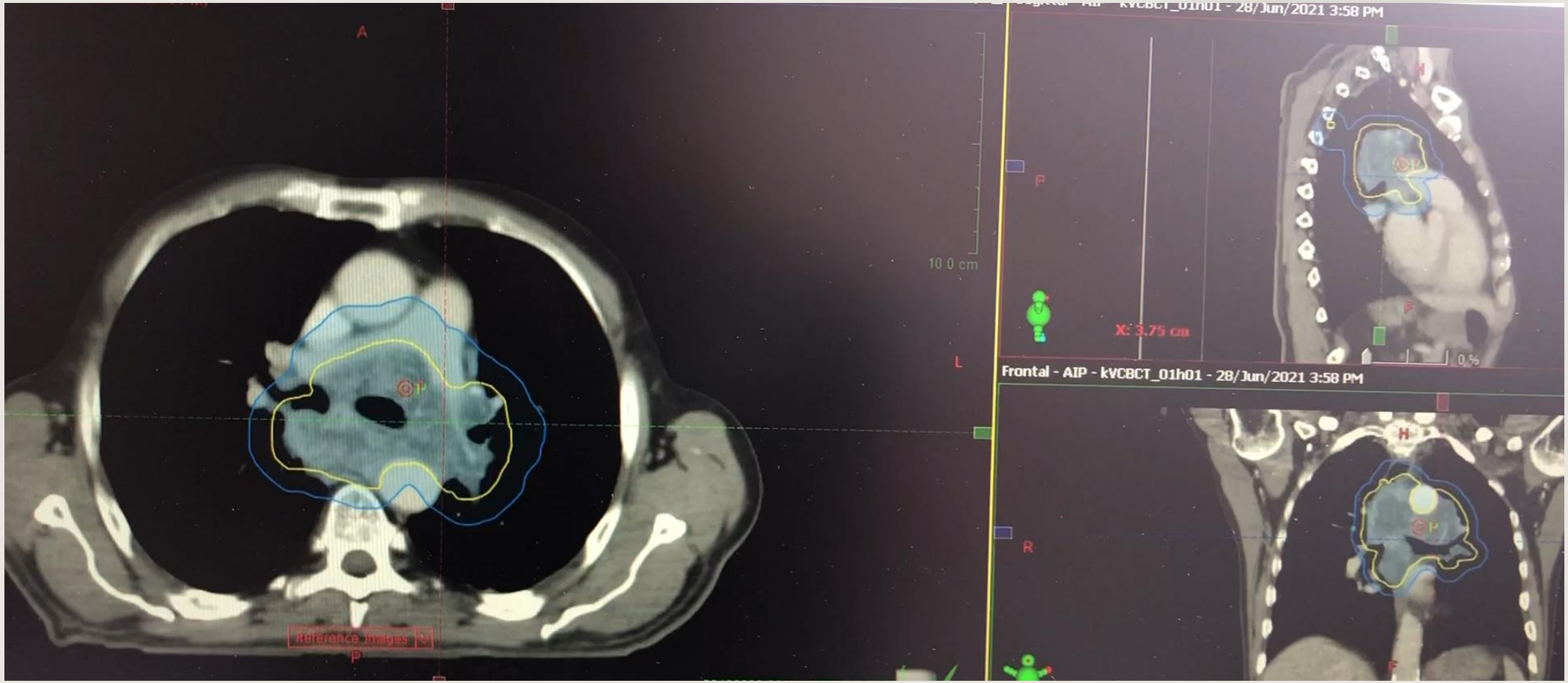


Changes in treatment volume and internal anatomy seen on CBCT due to other medical complications



Replan due to reduction in tumour volume

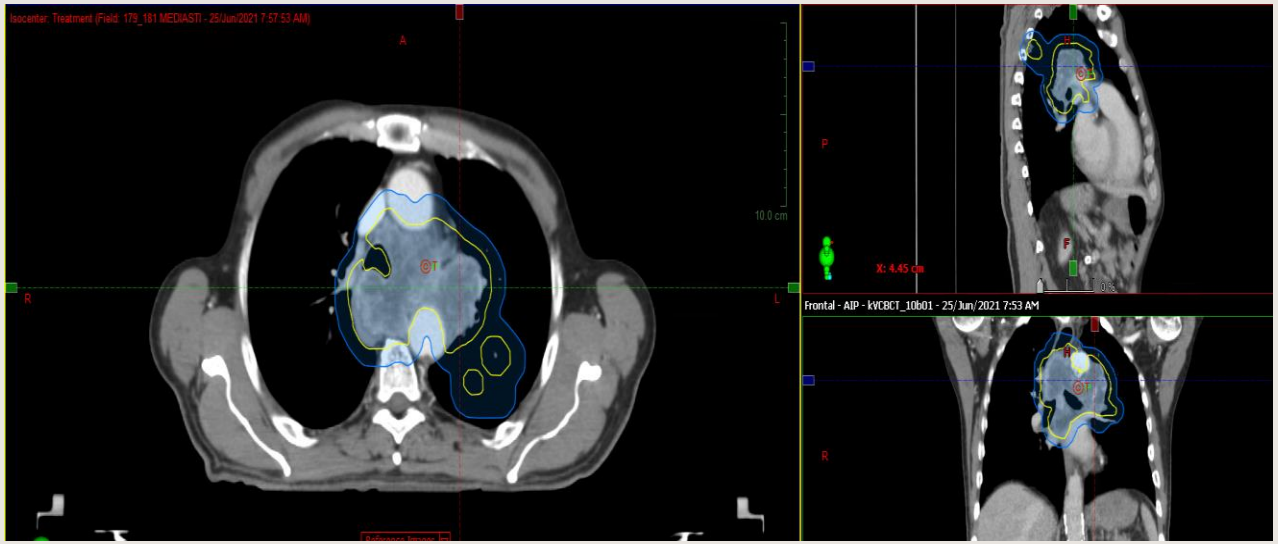
Mediastinum and left lung SCLC treated with concurrent chemo/radiation. RO asked for monitoring of tumour volume on CBCT as they wished to replan if there was significant reduction in tumour volume as they were looking to escalate dose from 45Gy/20# to 49.5Gy/22# if possible.

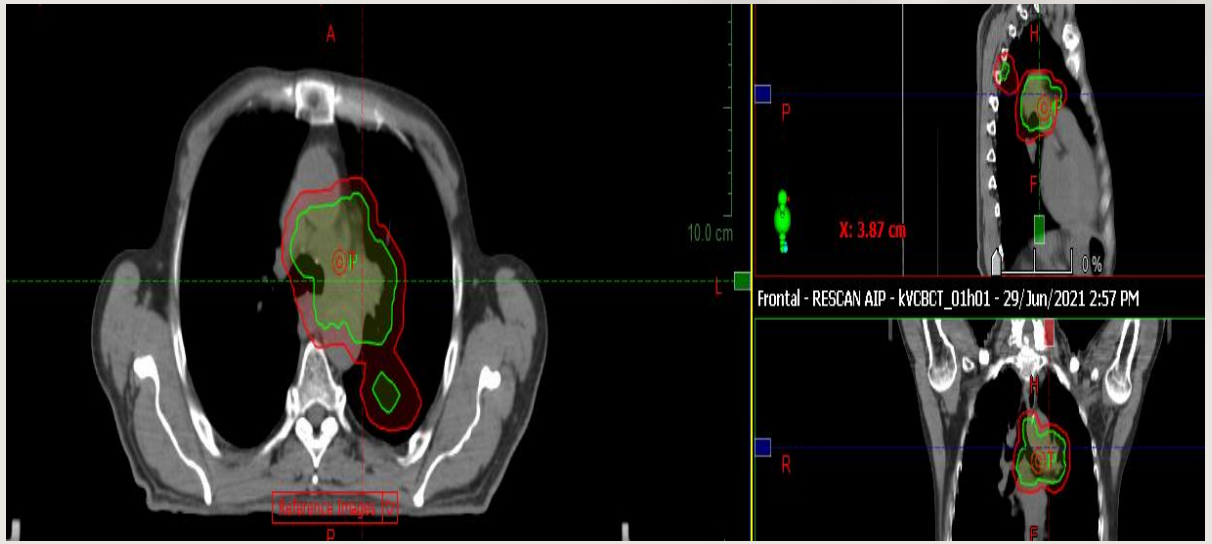


Difference in new PTV allowing for dose escalation

Original Planning CT – PTV 875.77cm3

Rescan Planning CT after 9 fractions – PTV – 453.1cm3



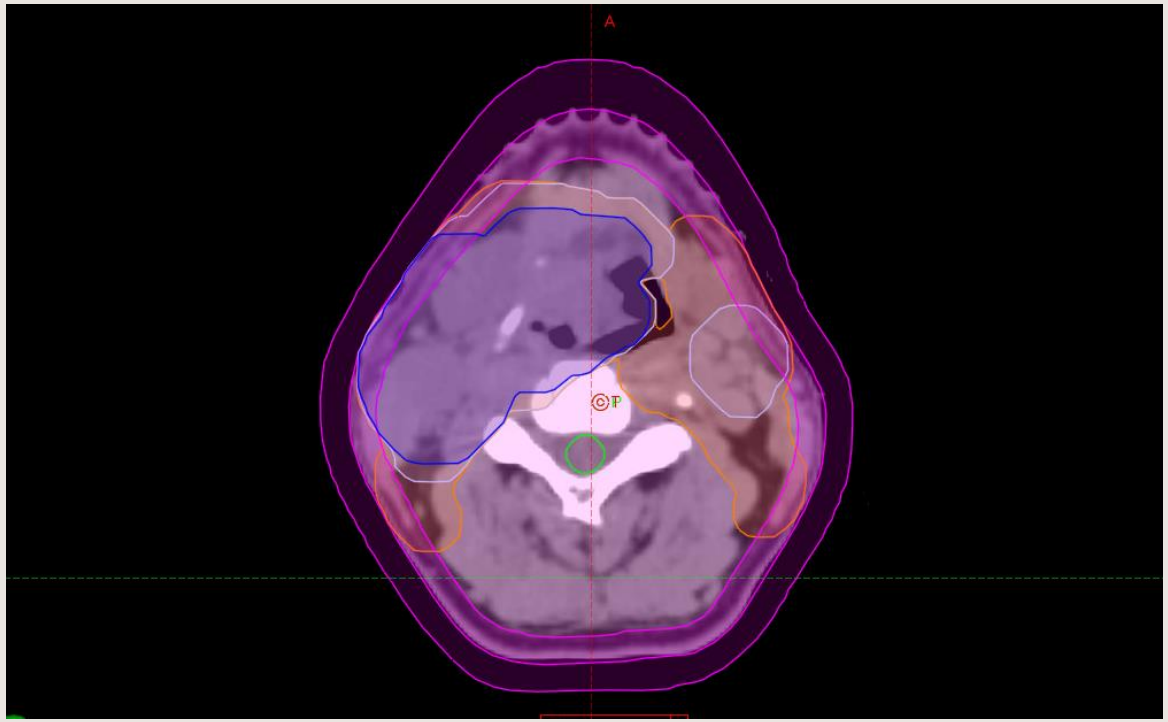


Using CBCTs for dosimetry assessment and determining requirement for replanning

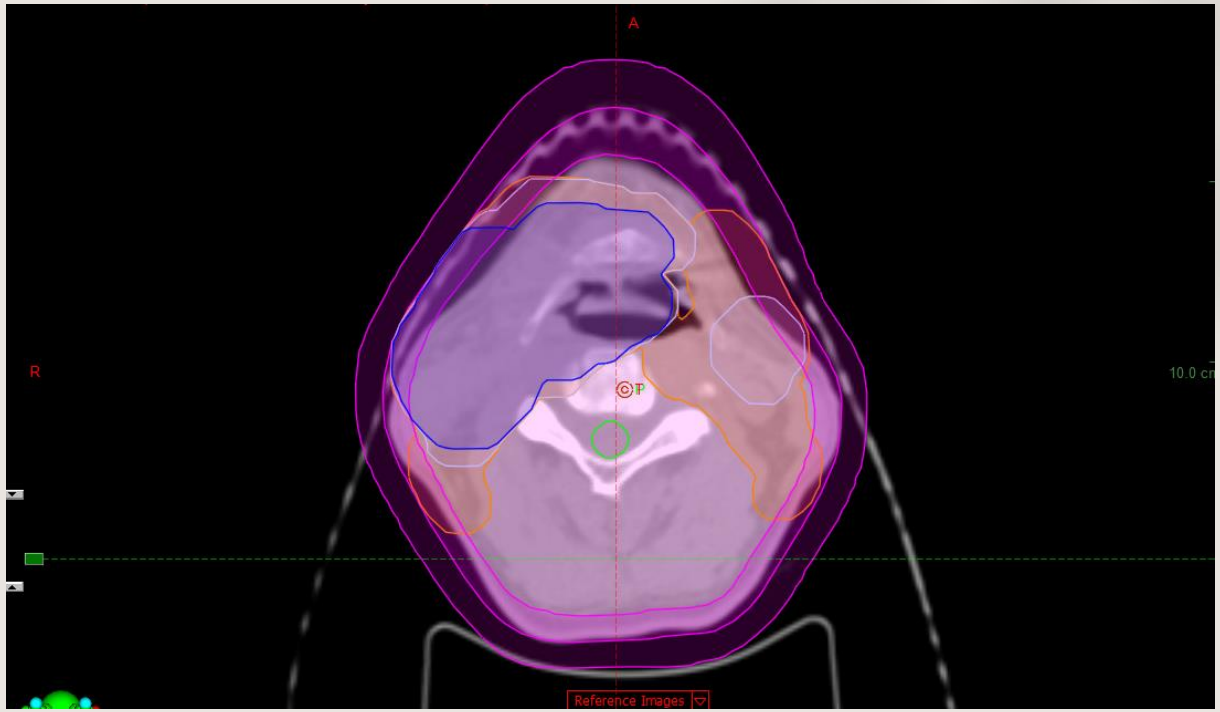
- At St. George we monitor contour changes daily on CBCT and we have created FSD tolerance structures to indicate need for assessment of dosimetry changes due to external contour difference.
- We have developed a CBCT Dose Overlay Process where the CBCT is registered with the planning CT in the Eclipse TPS.
- New external contour created using CBCT external contour. Plan recalculated to assess PTV coverage and OAR dose.
- Process approximately 20mins - a quick way of determining if a replan is required. If required may be completed numerous times during treatment (especially for head and neck cases).
- This process replaced a “Mid Treatment CT” which was acquired at an arbitrary point in a treatment course. Eliminates excess dose to the patient and reduced burden on CT resources.
- If there is a marked change in other internal anatomy for example parotids then we can use a synthetic CT and contour propagation for dose assessment.
- If replanning is required contours are populated onto the new planning scan using MIM software, adjusted and checked by RO’s and RTs. This has expedited turnaround times of replans.
- A change in the external contour does not always mean a change in the tumour volume or OAR positions. Slight changes in dosimetry is not reason to delay treatment even if the current plan is continued for a few fractions until replan is ready.

Example of Dose Overlay for Head and Neck case with decrease in external contour

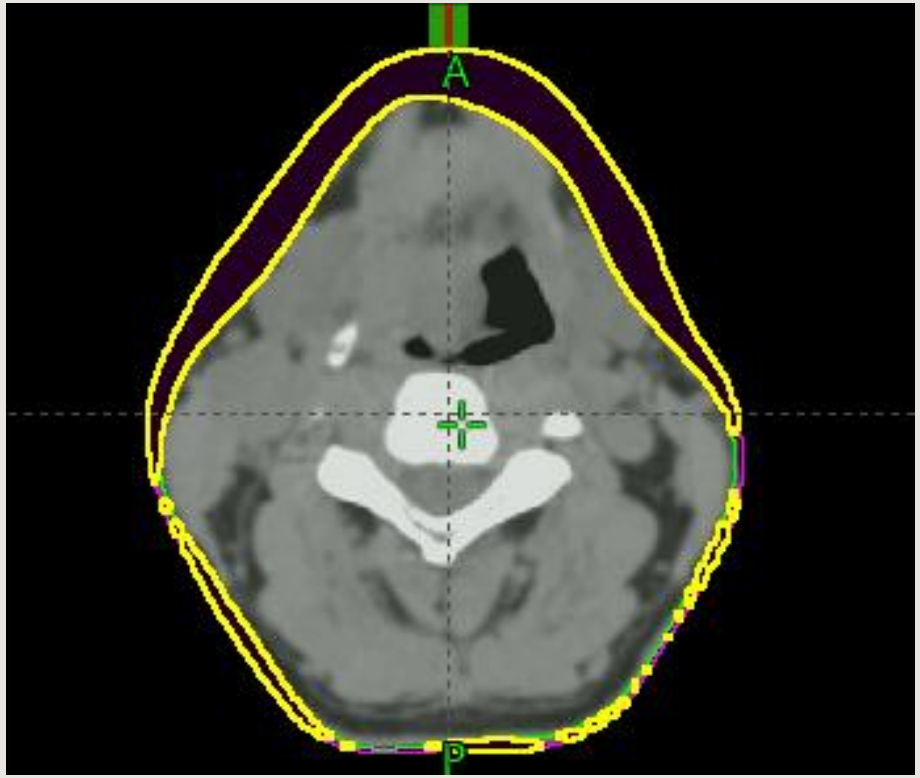
Planning CT



CBCT Acquired at Fraction 19/35

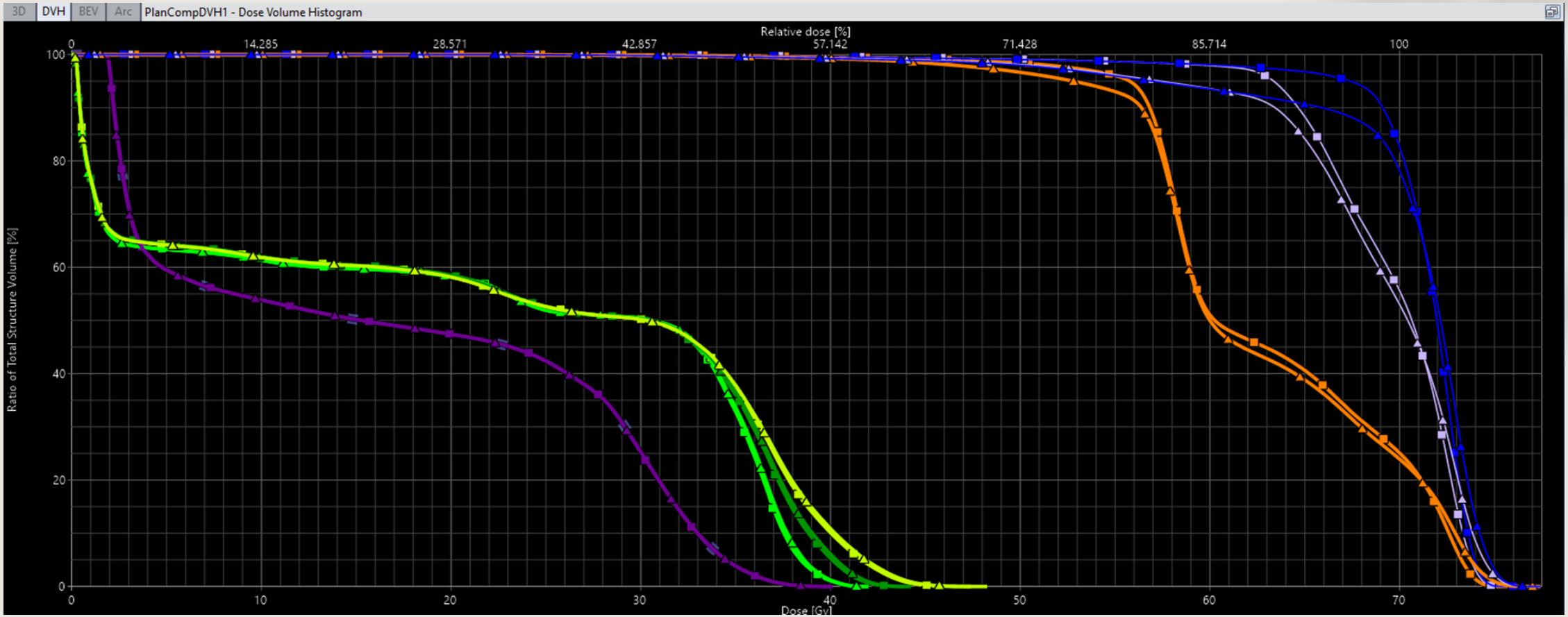


Dose Overlay with New “Current” External Contour



New contour called “Tissue Lost” created using CBCT contour and given 0 density. Plan then recomputed.

Comparison DVH: Original Plan vs Dose Overlay Plan

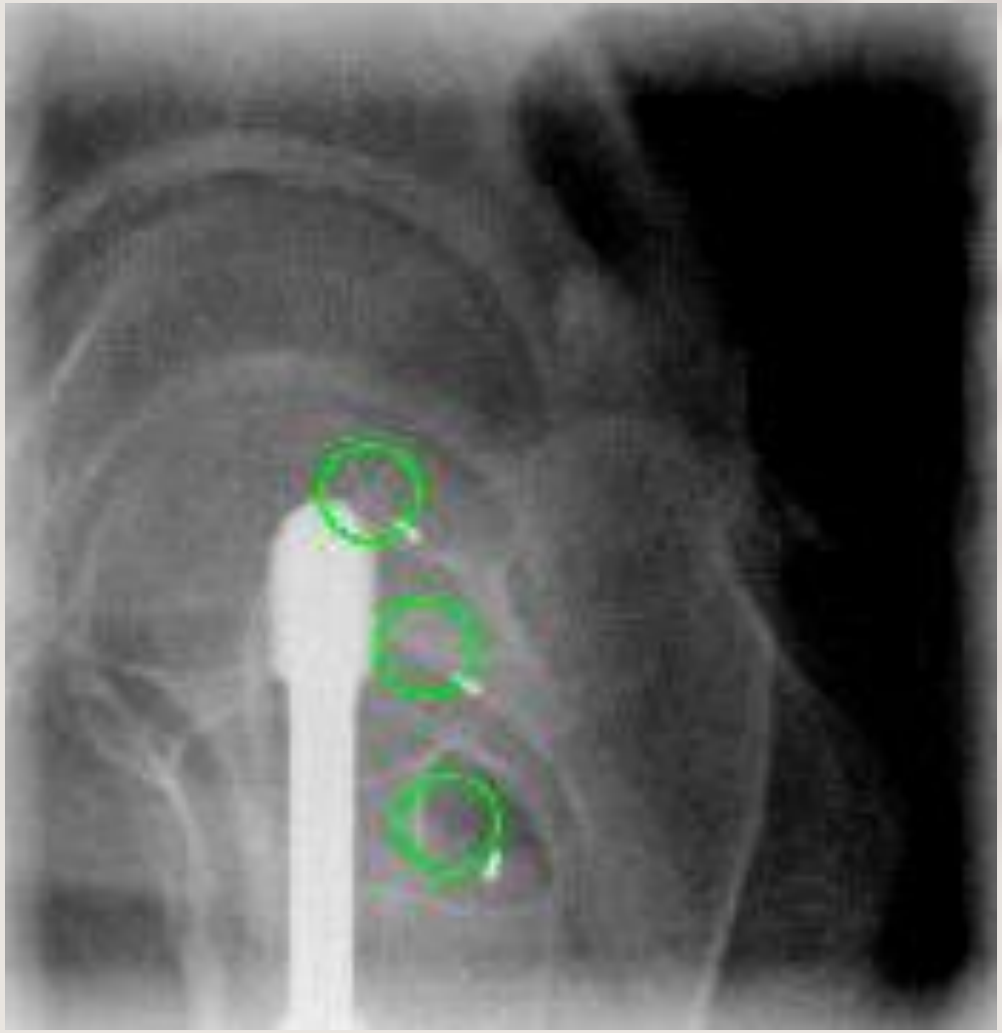


Show DVH	Structure	Approval Status	Plan	Course	Volume [cm³]	Dose Cover.[%]	Sampling Cover.[%]	Min Dose [Gy]	Max Dose [Gy]	Mean Dose [Gy]
☑	Brain_Stem	Approved	Bilat Neck	Course1	20.8	100.0	100.2	1.834	40.138	16.703
☑	SC+3mm	Approved	Bilat Neck	Course1	68.6	100.0	100.1	0.086	43.969	21.381
☑	SC+5mm	Approved	Bilat Neck	Course1	106.7	100.0	100.1	0.079	47.419	21.675
☑	Spinal_Cord	Approved	Bilat Neck	Course1	25.7	100.0	100.1	0.095	41.996	20.853
☑	Spinal_Cord	Unapproved	DoseOverlay	C1 DoseOverlay	25.7	100.0	100.1	0.095	42.068	20.913
☑	SC+5mm	Unapproved	DoseOverlay	C1 DoseOverlay	106.7	100.0	100.1	0.079	48.308	21.743
☑	SC+3mm	Unapproved	DoseOverlay	C1 DoseOverlay	68.6	100.0	100.1	0.086	44.321	21.444
☑	Brain_Stem	Unapproved	DoseOverlay	C1 DoseOverlay	20.8	100.0	100.2	1.807	40.083	16.688

- In this case the RO deemed it safe to continue on the original plan for 4 fractions to allow time for the replan and QA processes to be completed.
- For cases such as head and necks it is clinically worse to have a treatment interruption due to accelerated cell repopulation than to have slight deviation in the planned dosimetry, providing it is safe to do so from a tumour coverage and OAR dose perspective.
- Treatment interruptions or delays in commencement should be minimised. Clinical significance of dosimetry changes should be carefully considered.
- Bese et al (2007) reported that in particular for cancers of the head and neck for which the evidence is the strongest, even a 1-day interruption resulted in a decrease in the local control rate by 1.4%.
- Gonzalez Ferreira et al (2015) reported that there is “a strong significant relationship” a delay in Overall Treatment Time (OTT) can result in an average loss of Locoregional control ranging from as low as 1.2% per day to as high as 12–14% per week.
- The Dose Overlay process is a quick way to quantify if it clinically appropriate to continue on the original plan.
- We have found that there is not a linear relationship between contour change and dosimetry. VMAT techniques to be more robust in terms of dosimetry changes.

Example of triggered imaging (seed tracking) allowing safer treatment delivery

- Paraplegic patient presented with high-risk prostate cancer for EBRT.
- Had uncontrolled leg spasms even when legs secured with straps (per patients request).
- Use of daily triggered imaging was the only safe way to deliver treatment as spasms caused displacement of pelvis and target as seen on triggered imaging.



Advanced imaging does it solve every clinical problem?

In simple terms – No!

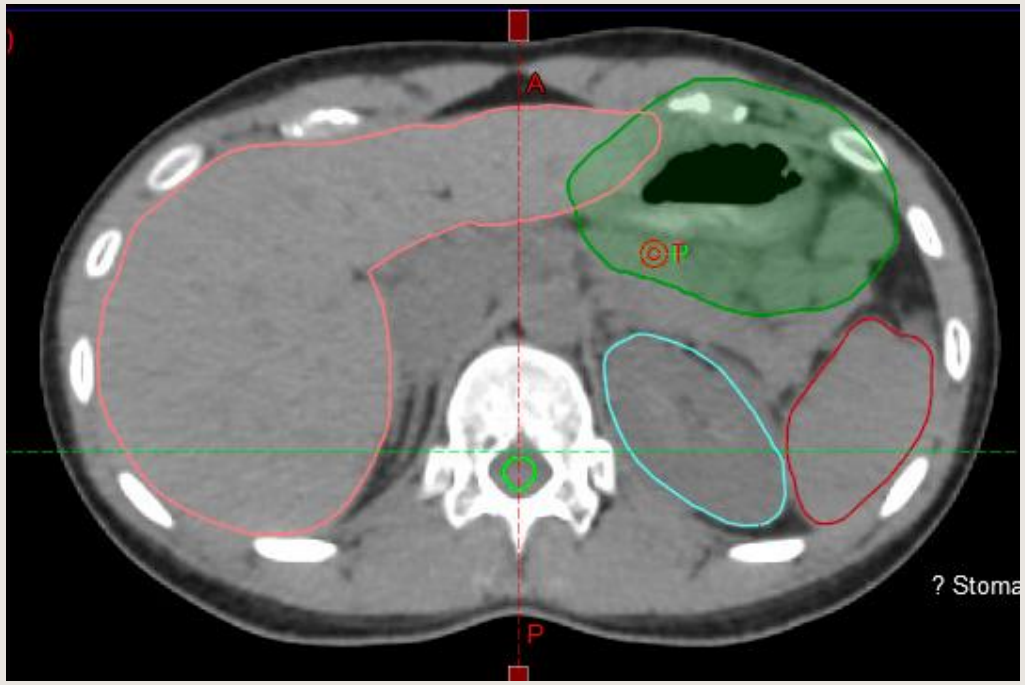
Despite marked improvements advanced imaging has not solved every issue.

An example of this is was a recent lymphoma stomach case.

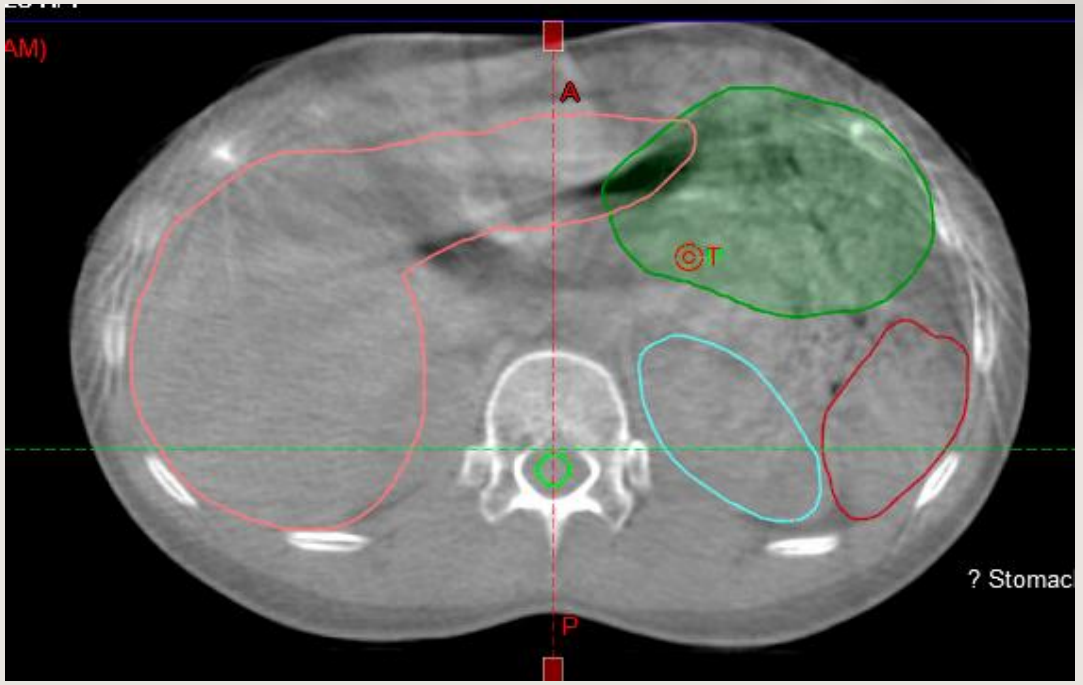
- Previously kV planar imaging used for target localisation.
- Ambiguity of target size/motion - large open fields used for treatment.
- CBCT has allowed for IMRT/VMAT techniques to now be used for these cases, improving conformity and reducing OAR dose.
- CBCT image quality in the abdomen region is often poor due to artefact caused by motion and air.

Is that stomach? Is that bowel? Is that duodenum?

Planning CT



CBCT



Advances in Radiation Oncology:

Advanced imaging techniques key to improving patient treatment options, accuracy and outcomes

- Precise target localisation and ability to see internal anatomy has allowed for surety that treatment plans are being accurately delivered and reported OAR dose is correct. This has also allowed for margin reductions.
- Techniques such as SABR for lung, liver and prostate cases would not be safely deliverable without the ability to see soft tissue on CBCT - Improved accuracy in target delineation and soft tissue matching.
- Adaptive planning and treatment e.g. Bladder.
- Improved assessment of effect of contour change on dosimetry, reduction on unnecessary replans and breaks in treatment and faster turn-around of replans.
- Intra-fraction imaging- improved surety of accurate treatment delivery and indication for intra-fraction corrections.
- New technologies such as the MR Linac – further improving soft tissue delineation and online adaptive planning.
- Dose calculation on MR and CBCT data sets.

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- https://www.oncologysystems.com/

Questions?

ACPSEM
Australasian College of Physical Scientists & Engineers in Medicine

MIRSIG

ACPSEM CPD Endorsed Activity

The ACPSEM Medical Image Registration Special Interest Group (MIRSIG) Online Webinars

Questions and Answers from the August 2021 Webinar Chaired by Laurel Schmidt (Talk 1 by Kylie Miller on IGRT)

Question 1: What are the thresholds for replanning?
Answers:

In the first instance the FSD tolerance levels assessed online on CBCT are 0.7cm for Head and Neck cases and 1cm for other sites. If they fall outside these tolerance this triggers the Dose Overlay process in the first instance prior to any re-simulation or replan.

In terms of the dose overlay assessment, PTV position and coverage and OAR position and doses are assessed by the treating RO. If the position of the PTV volume remains the same and dose coverage remains acceptable as well as the OAR positions remaining correct and falling within prescribed tolerances then treatment is continued on the current plan. If there is variation in the above then the patient will be re-scanned, re-contoured and replanned.

Question 2: Do you have a limit on the 6DOF rotations that you use?
Answers:

We allow for 3 degrees of correction for pitch, roll and rotation. We felt that the options were; we either accept a potential inherent positional error if we limited the correction or accept that there may be a small amount of patient motion caused by the application of the couch corrections.

When rolling out the technology, if there were large couch corrections we did repeat a set of orthogonal kV images post application of the couch correction to ensure that we had not introduced positional error by applying the couch correction. We found that it was rare to see a significant change. Larger patients were the cohort we observed some potential movement post couch corrections (where the couch correction may not have been the only contributing factor). If we have concerns regarding this in our current practice we will perform a kV orthogonal pair post the CBCT corrections being applied but this practice is not common as this is not often observed.