MIRSIG 2020 December Webinar

Recap of the Practical Image Registration workshop

Accounting for Previous Treatments and Replans

varian

mim SOFTWARE

Quantum HEALTH GROUP

MIRADA
The Imaging Software People

MIRSIG

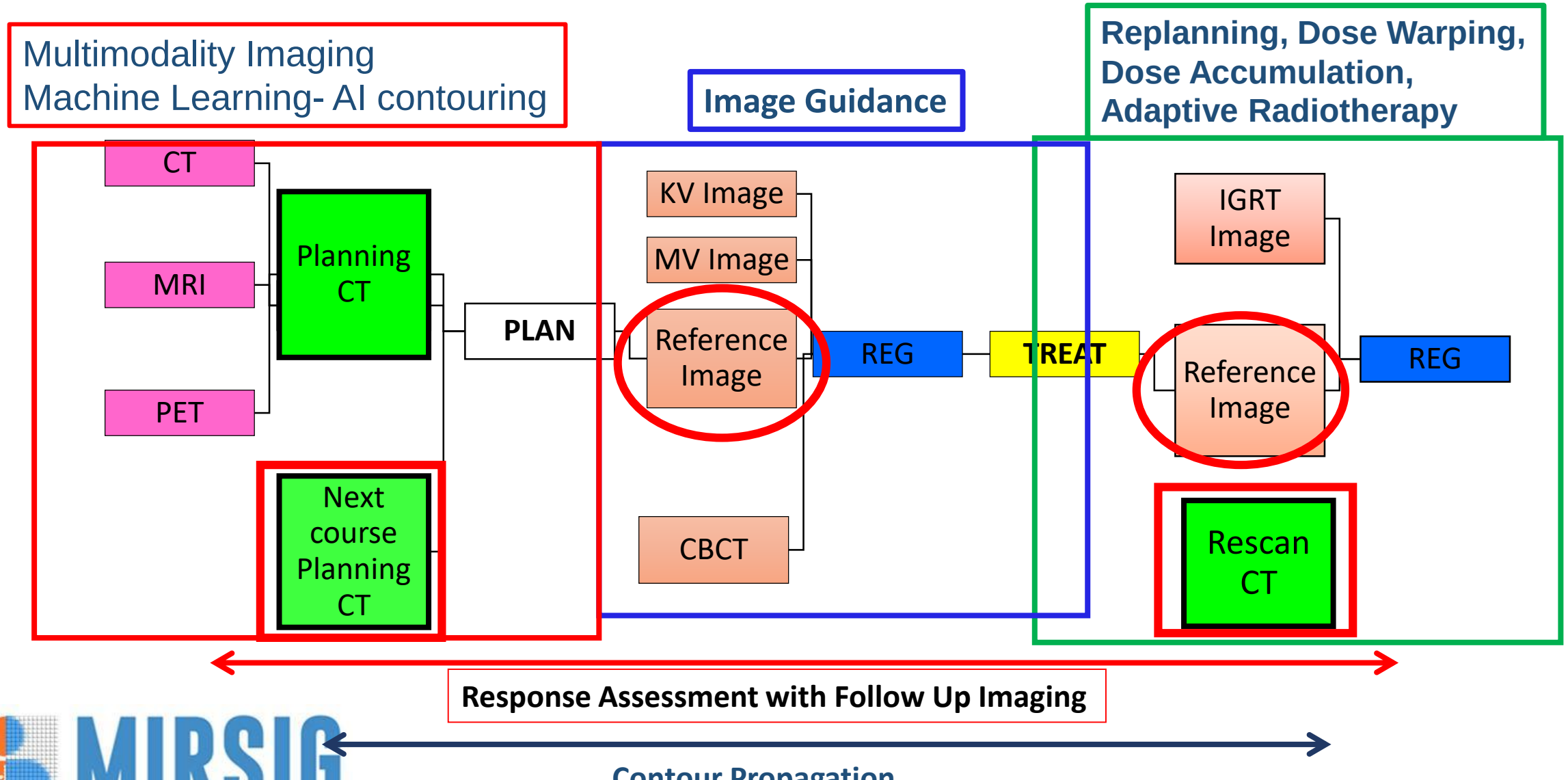
THE UNIVERSITY OF SYDNEY
School of Physics

ACPSEM
Australasian College of Physical Scientists & Engineers in Medicine

How is Image Registration part of Replanning and Re-irradiation?

MIRSIG

Image Registration in Radiotherapy

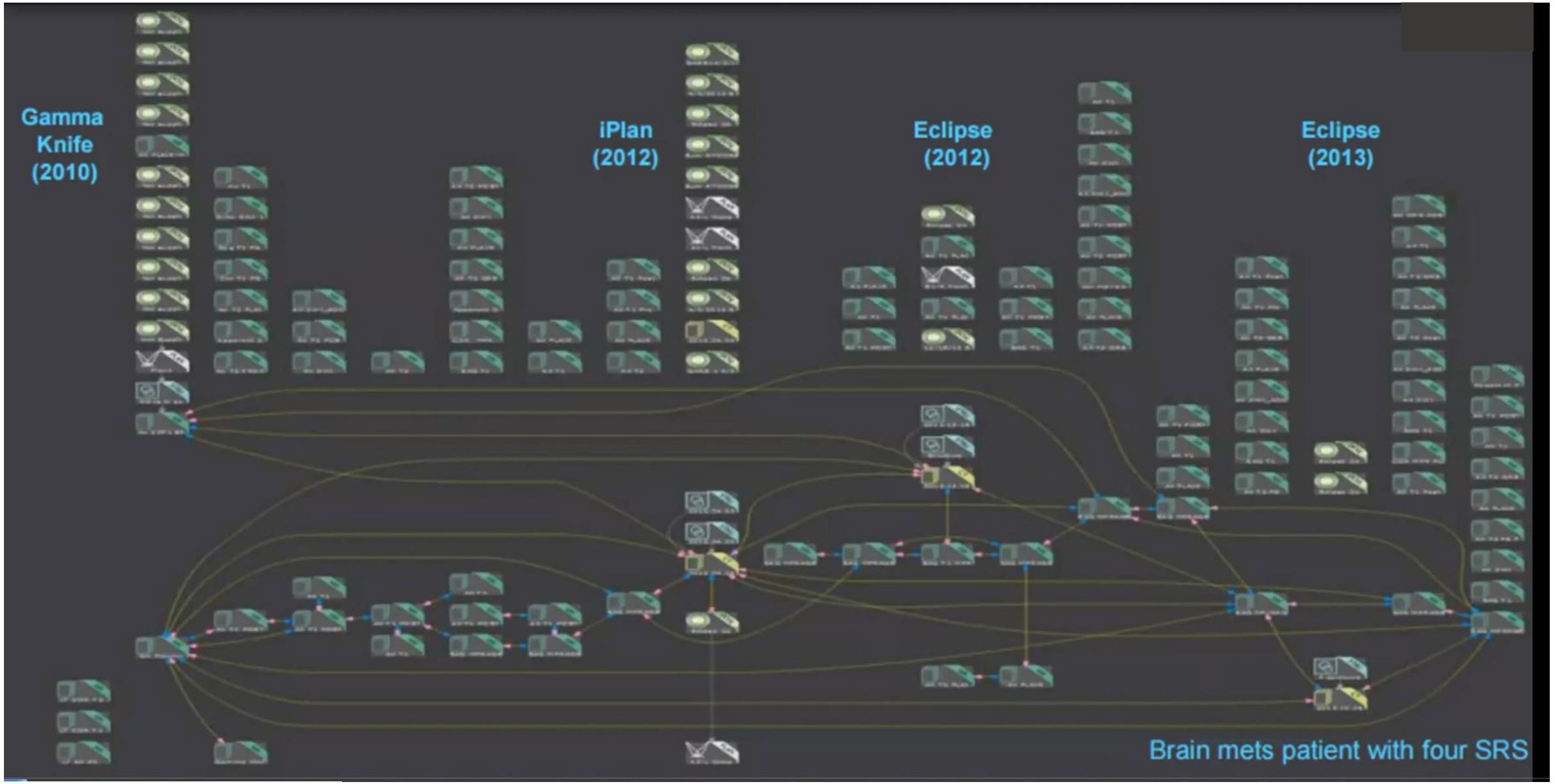


MIRSIG

The Importance of

Data Hygiene

MIRSIG


Gamma Knife (2010)
iPlan (2012)
Eclipse (2012)
Eclipse (2013)
Brain mets patient with four SRS

MIRSIG

Nome

Image I
- Multi-
- Resar

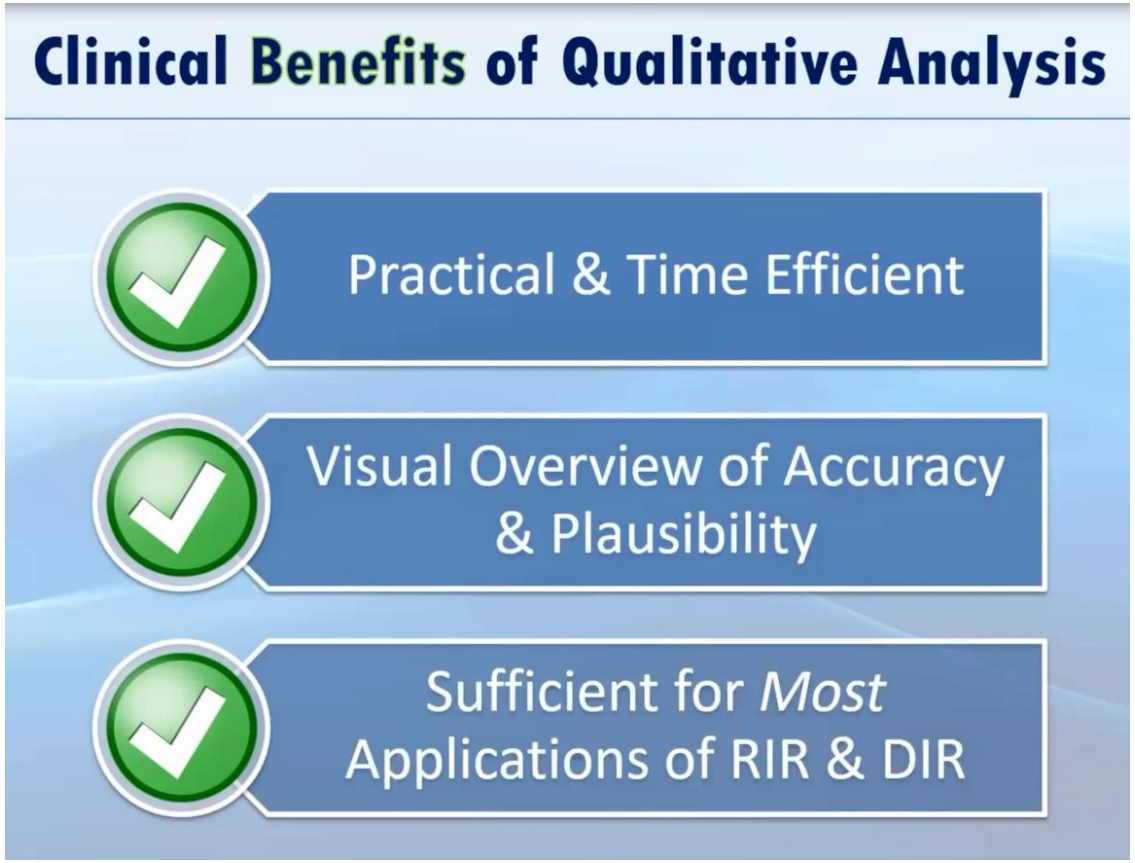
Structu
- Propa
- Defor
- Previc

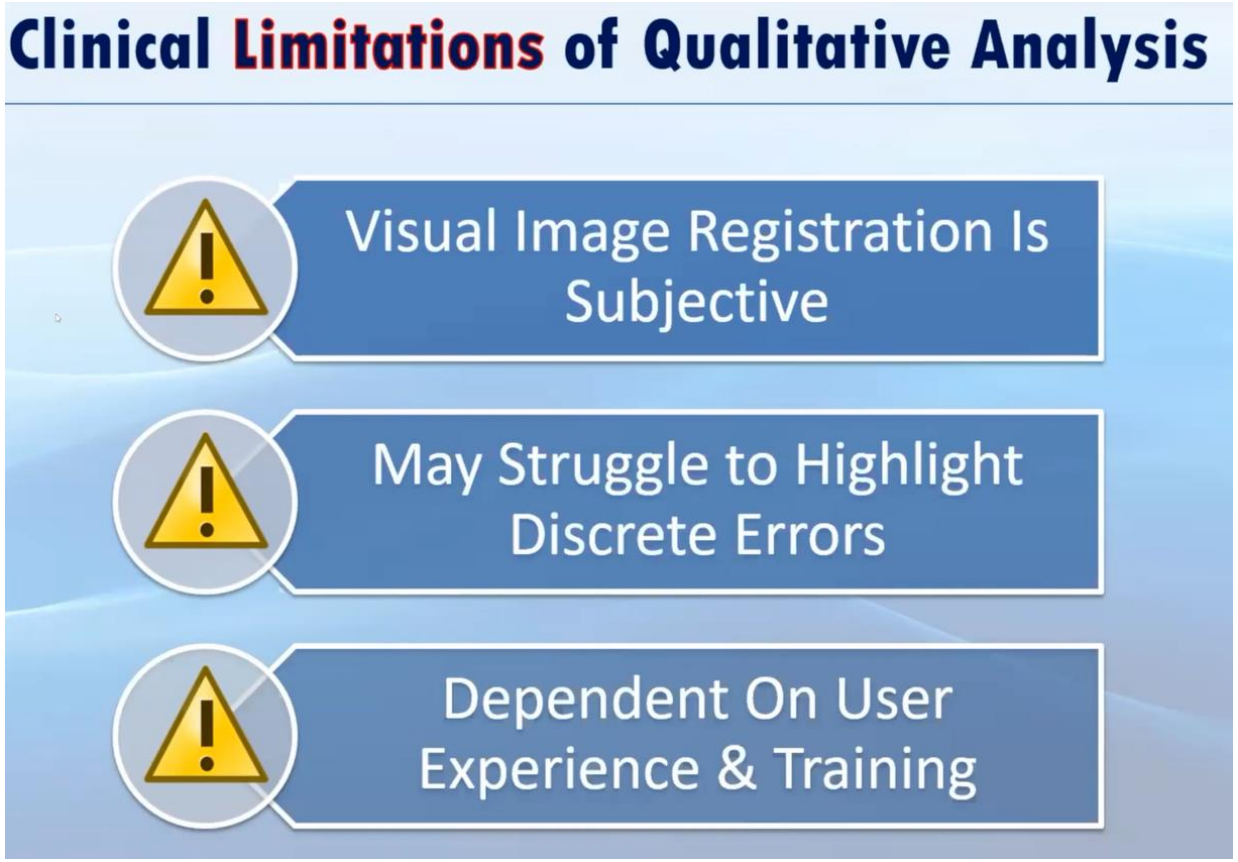
Dose Fi
- Calcu
- Warp
- Summ

Registra

ding

Qualitative Analysis of Image Registration





MIRSIG

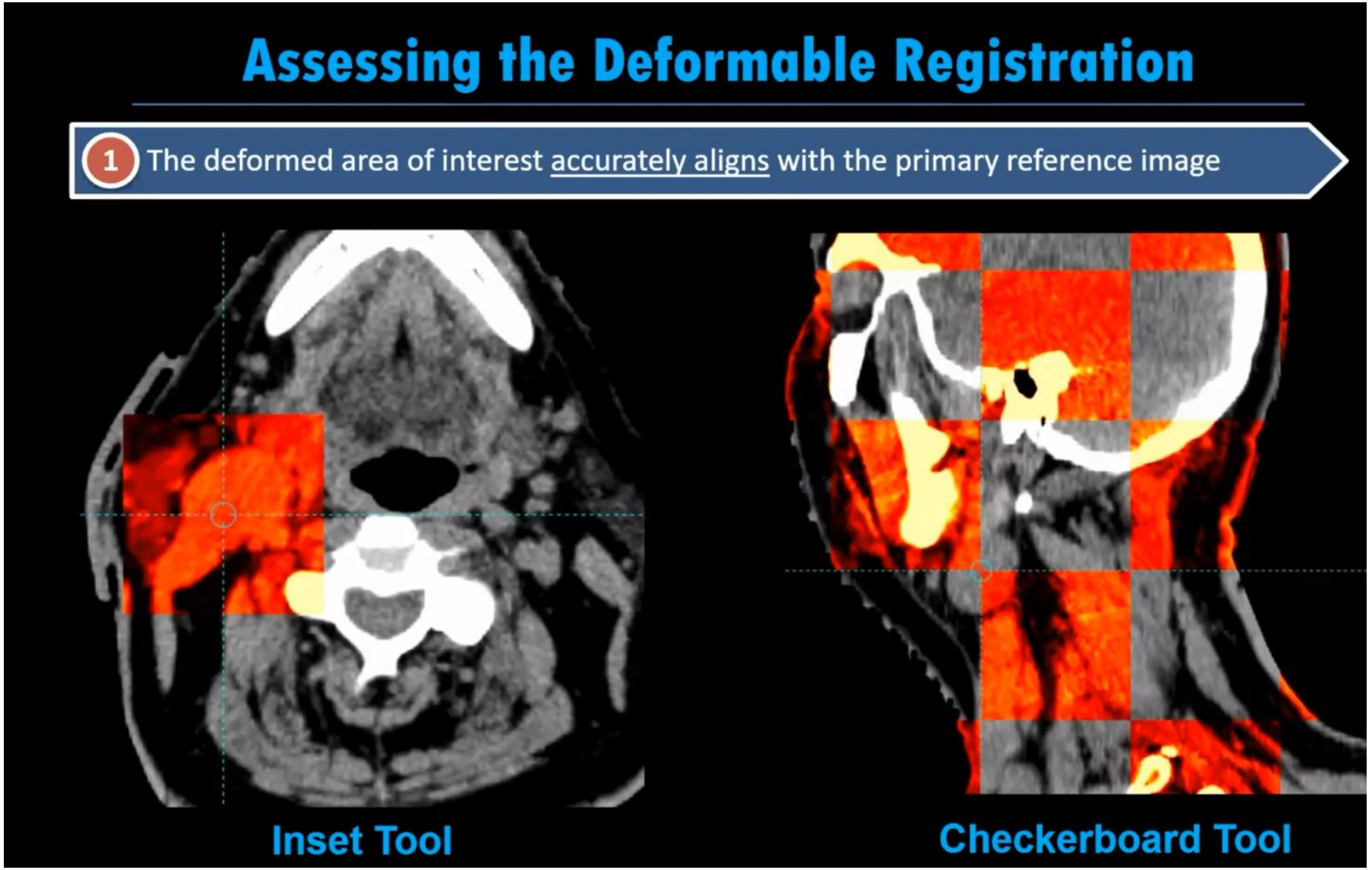
Slides by Eddie Gibbons

How Do We Qualitatively Assess DIR's?

Two criteria must be satisfied for the DIR to be suitable for clinical use:

1. The deformed area of interest accurately aligns with the primary reference image
2. The deformed area of interest is biologically plausible with a smooth deformation field

MIRSIG



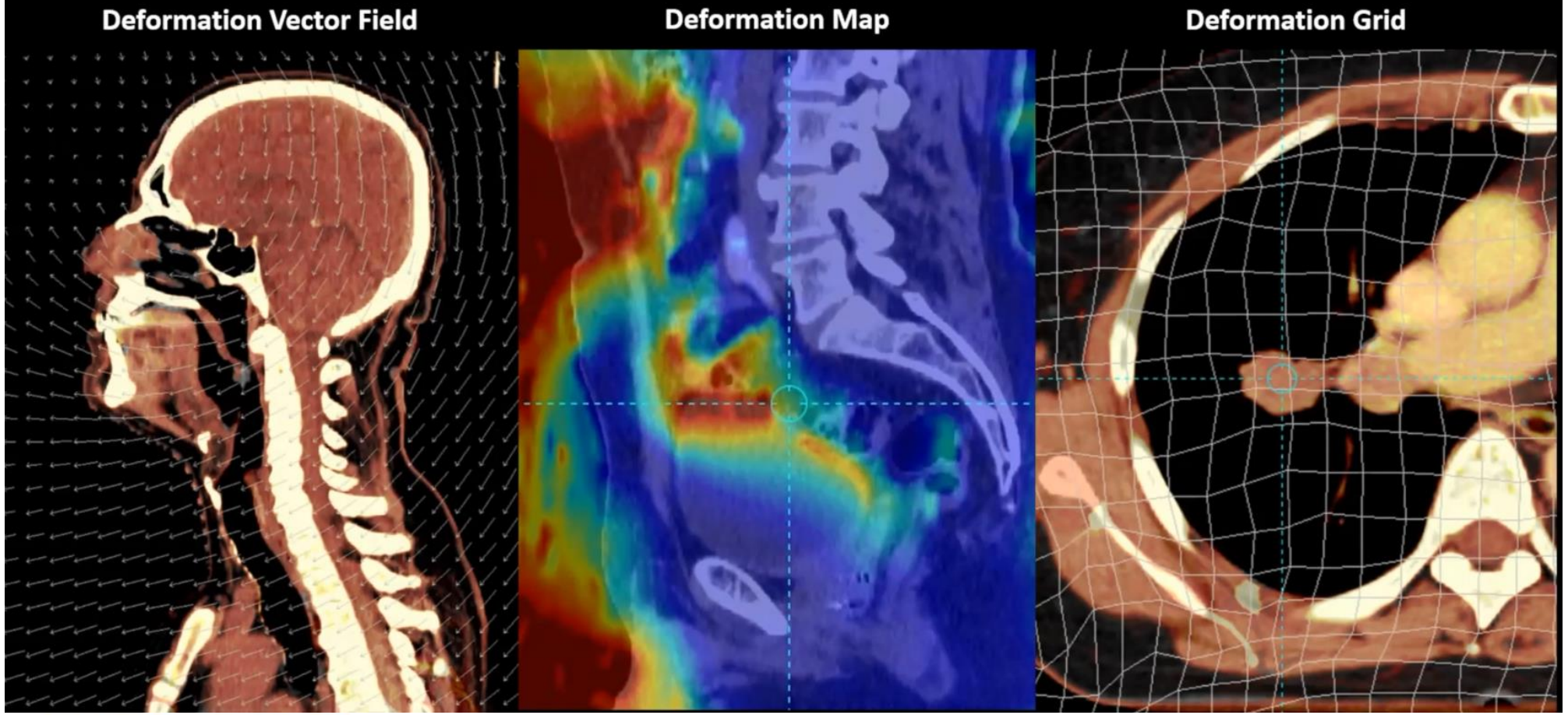
Tools for qualitative:

- Inset tool
- Checkerboard
- Blend bar

MIRSIG

Assessing the Deformable Registration

2 The deformed area of interest is biologically plausible with a smooth deformation field



MIRSIG

Data Analysis

Anatomical structures segmented into **Qualitative Ratings** (**Good**, fair & **bad**)

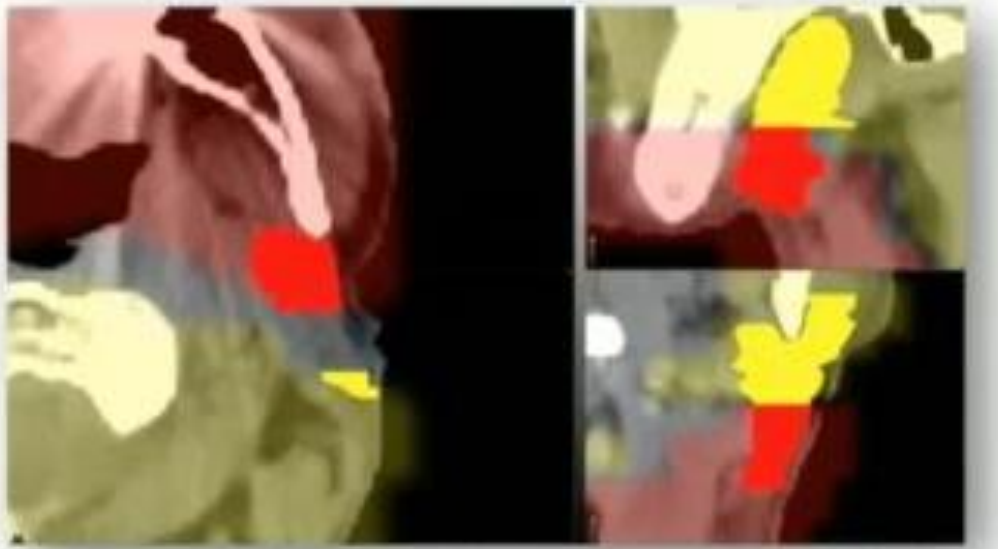


Figure 5: *Example of left parotid segmented into fair and bad ratings*

AIM 1: Quantitative Metrics

- Hausdorff Distance (HD)
- Mean Distance to Agreement (MDA)
- Dice Similarity Coefficient (DSC)
- Jacobian Determinant

AIM 2: Inter-Operator Reliability

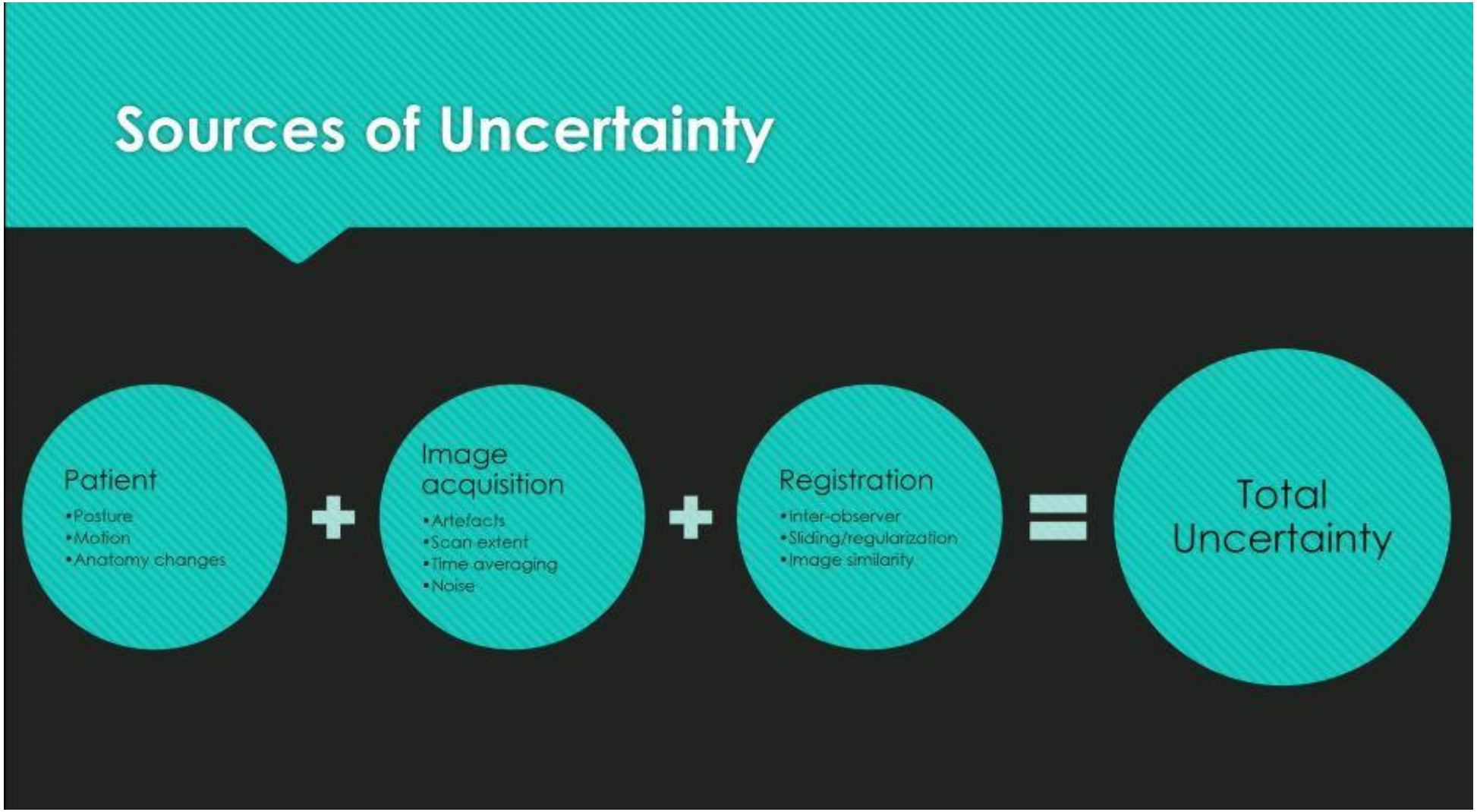
- Krippendorff's Alpha test[3]

AIM 3: Tool Efficacy

- Rating time (mins)
- Volume measures of each rating (cm^3)

MIRSIG

Evaluation of a Deformable Image Registration Quality Assurance Tool for Head and Neck Cancer Patients – Molly Mee, et al JMRS Dec 2020


Sources of Uncertainty
Patient
•Posture
•Motion
•Anatomy changes
Image acquisition
•Artefacts
•Scan extent
•Time averaging
•Noise
Registration
•Inter-observer
•Sliding/regularization
•Image similarity
Total Uncertainty

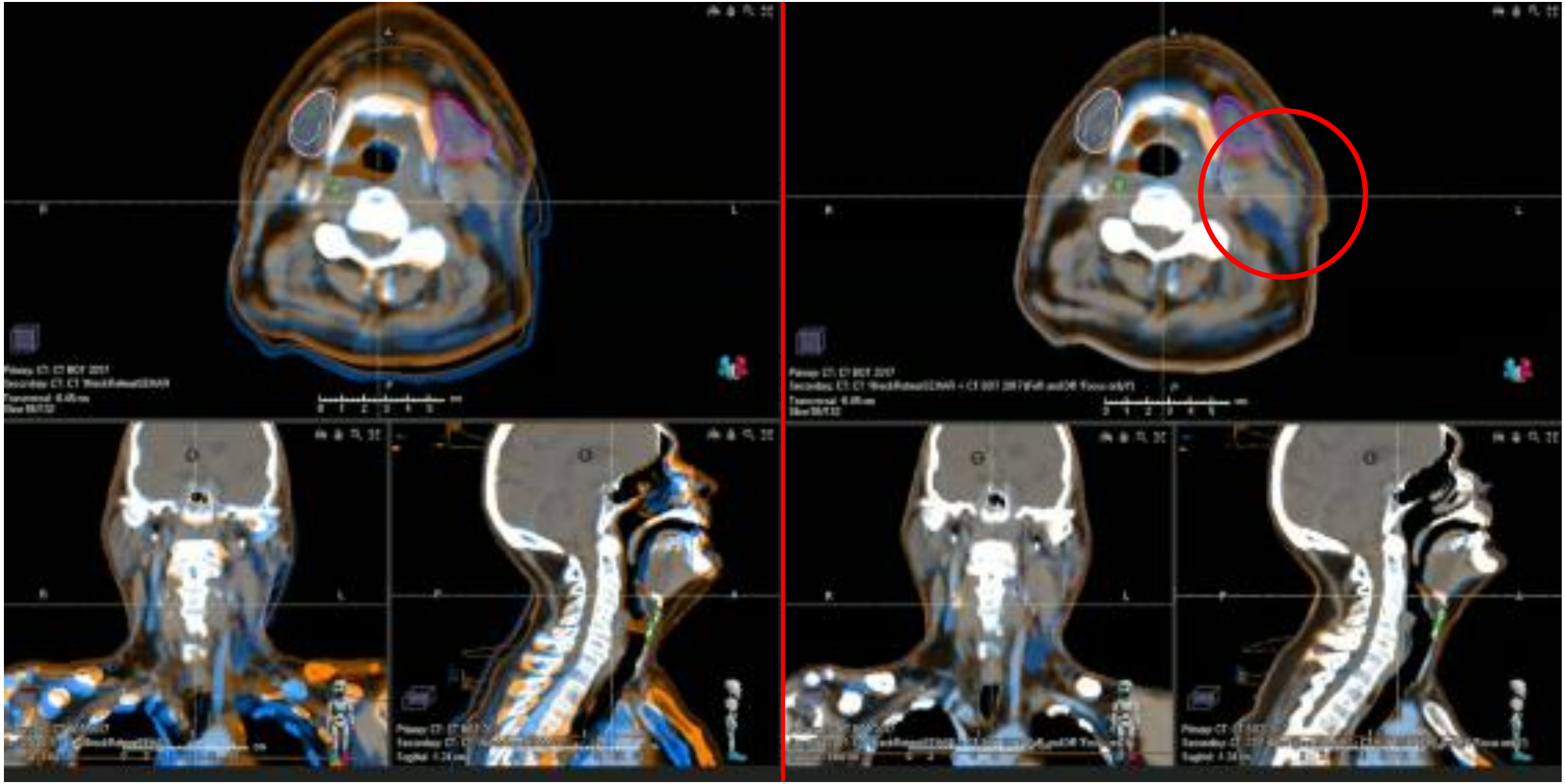
MIRSIG

MIRSIG

Postural uncertainties

- Not always possible to reproduce previous treatment positioning
  - Head/neck flexion
  - Arms up to arms down
  - Unable to tolerate position

MIRSIG



MIRSIG

RIR

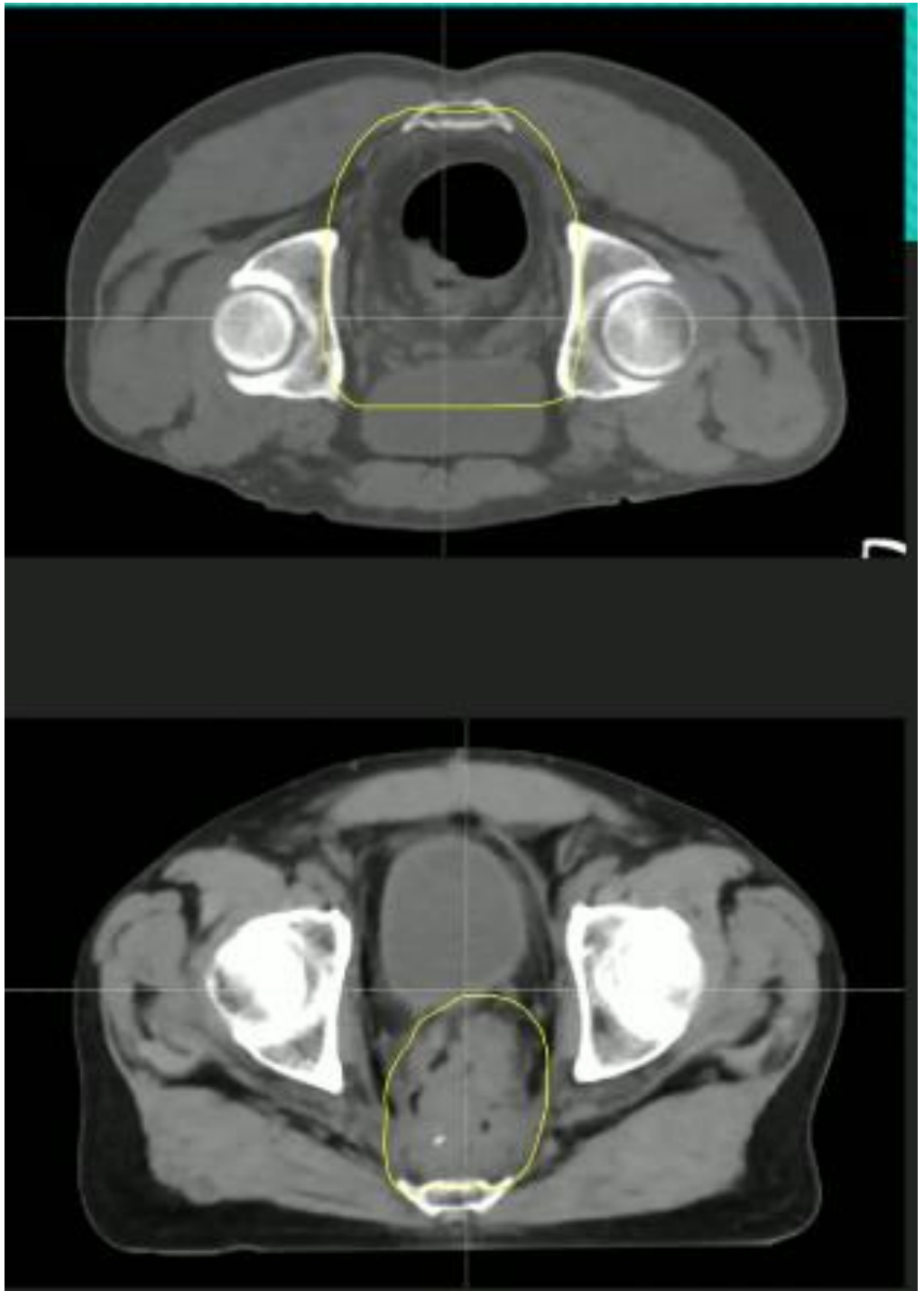
DIR

Postural uncertainties

- Rectum retreatment
- Prone vs Supine
- Presence of gas in the rectum

- RIR unable to align pelvis – Side-by-Side

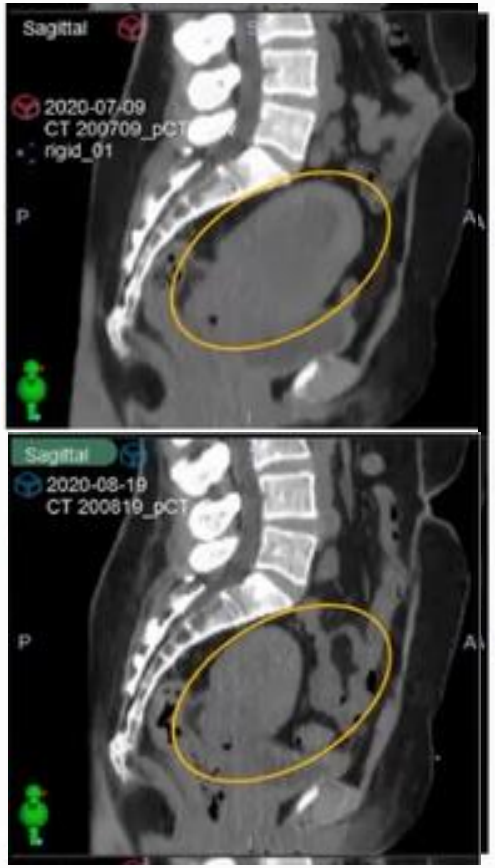
- DIR bones deformed but not able to match the soft tissue and region of tumour – use with caution

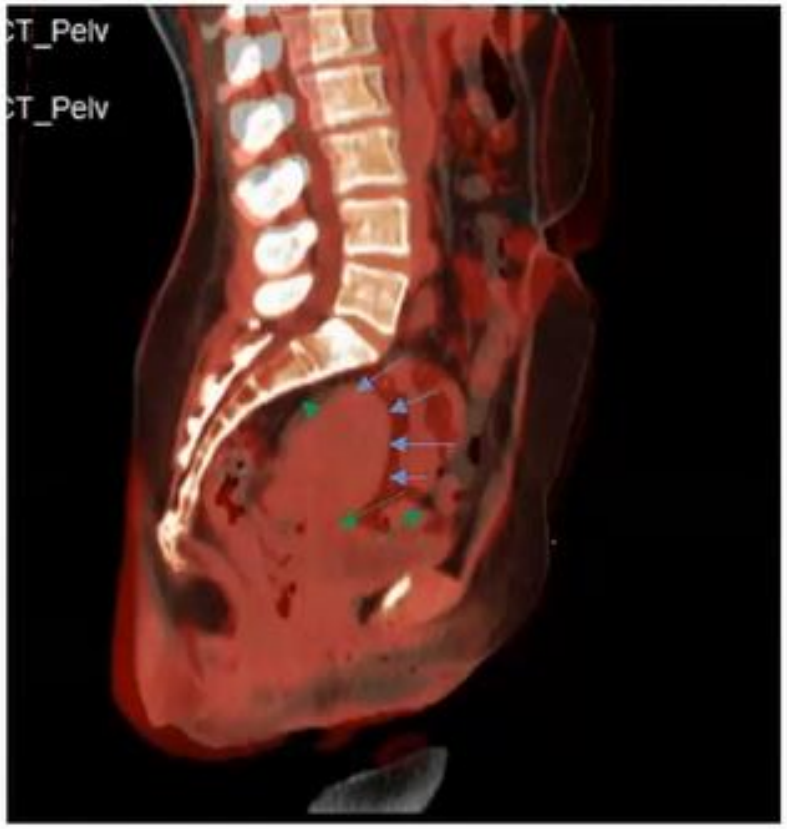


MIRSIG

DIR Challenge

Intial pCT





- Several deformation challenges
  - Large changes
  - Low contrast medium changes
  - Sliding/opposing deformation vectors
- Dose Deformation
  - Ideally accurate universal
  - Minimum accurate for some structures
  - No folding

Often unrealistic deformations and unstable grids unsuitable for dose deformation and require a thorough review of individual ROI doses to verify dose accuracy

MIRSIG

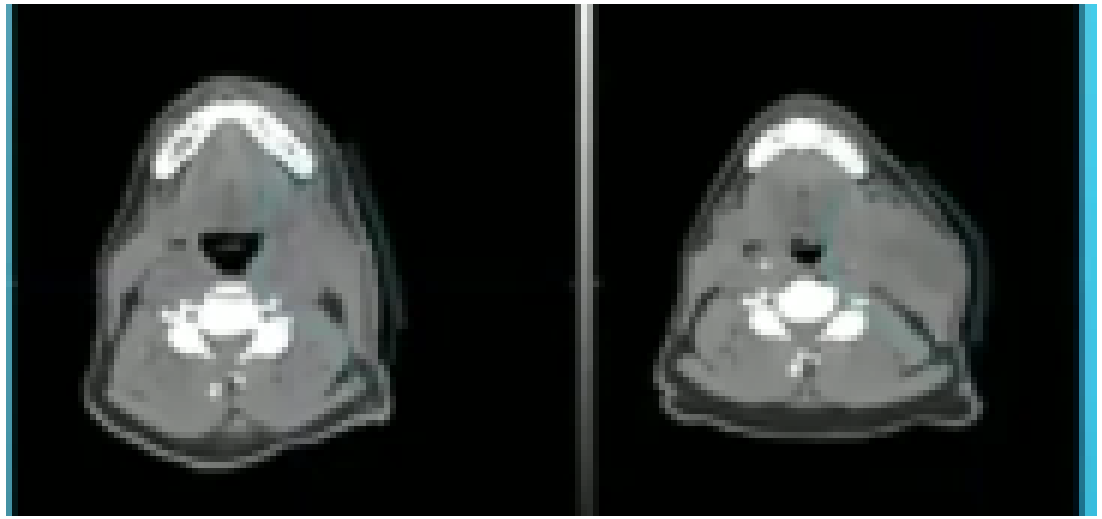
Slide from Ben Archibald-Heeren

Replanning (Adaptive RT)Workflow

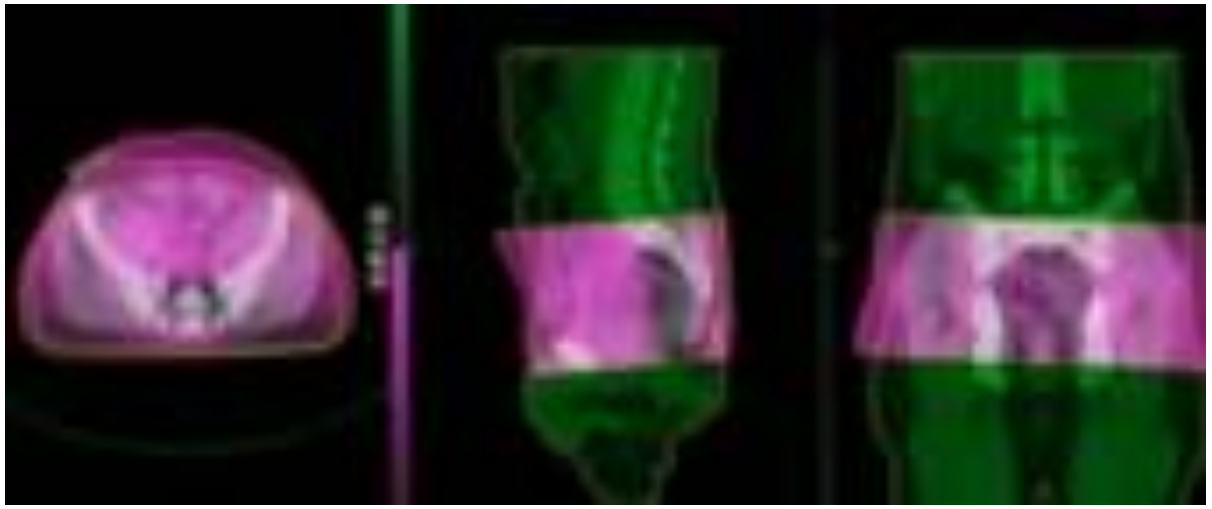
- **Monitoring of treatment –**
  - Assessment of immobilisation device
  - IGRT – OAR and PTV positions
  - Patient complaint/ unable to tolerate treatment position
- **Adaption decision**
  - Assess CBCT or Rescan against Ref Image
- **Adjusting PTVs and replan**

MIRSIG

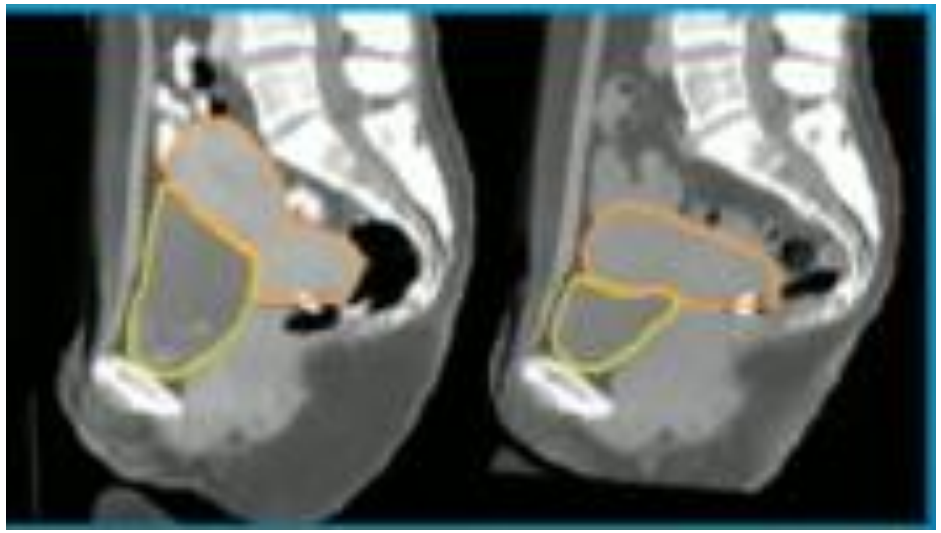
From Kate Stewart



Changes in tumour size or shape



Changes in patient geometry



Changes in size, shape and relation of surrounding OARs

MIRSIG

Slide from Kate Stewart

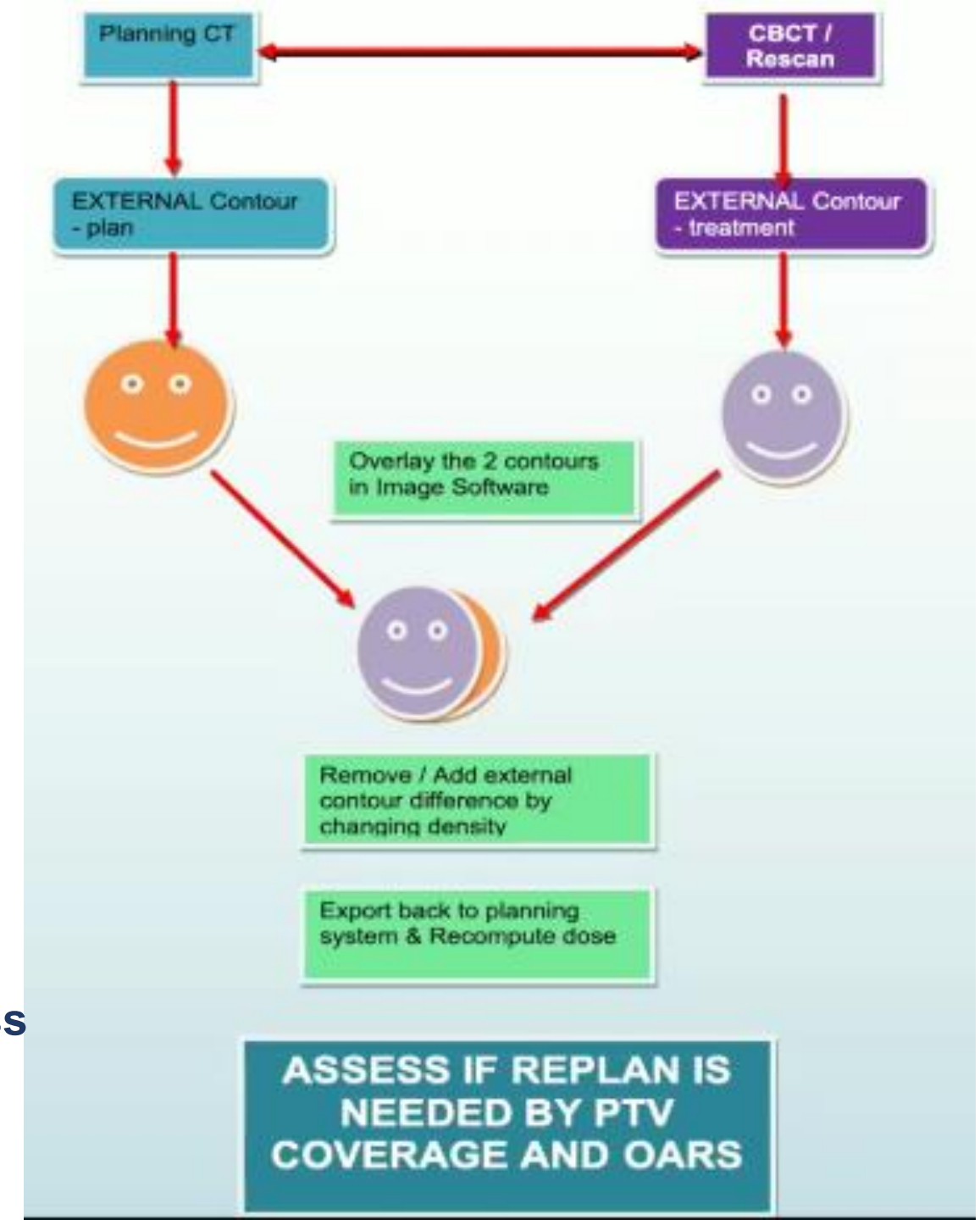
- Change in patient geometry noted
- CBCT registered offline with planning CT
- Differences in body contour – correct density (air or tissue equivalent)
- Export to TPS – recompute
- Assess PTV coverage + OARs

Pros:

- **Very easy to do**
- **Fast turn around time**
- **Quick check of PTV coverage + S/C for H&N pts**

Cons:

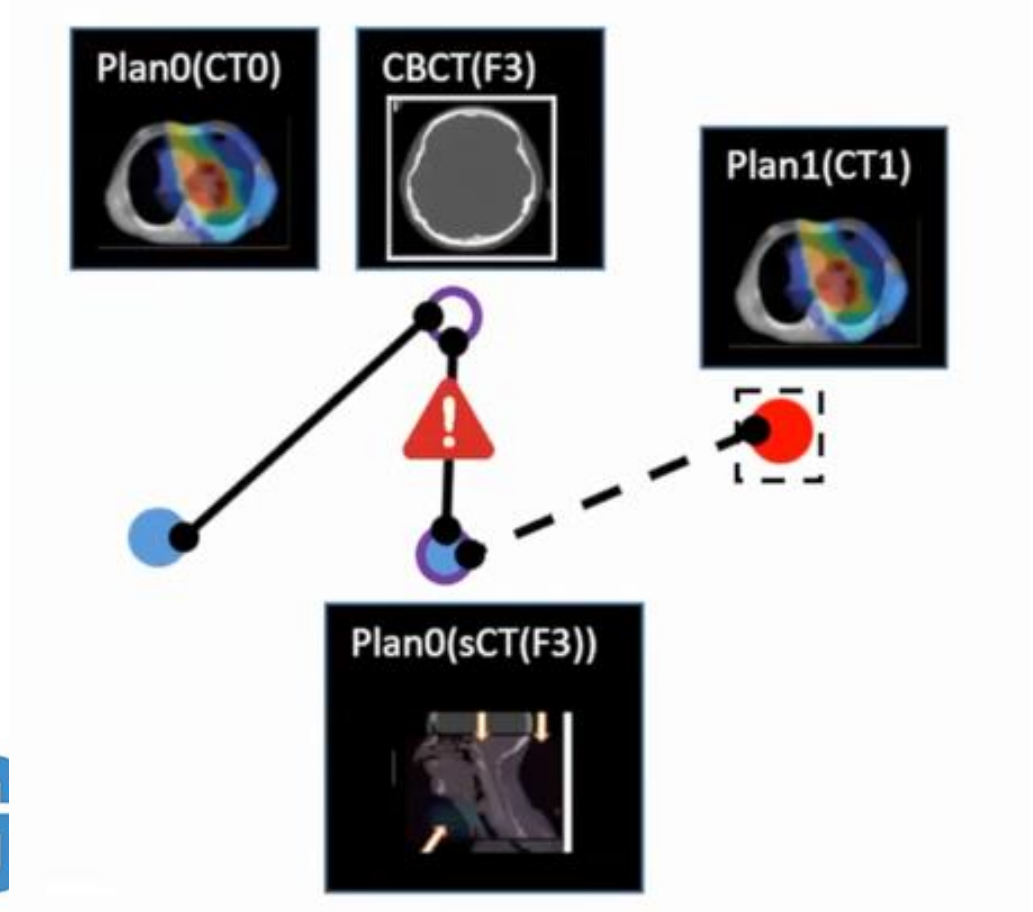
- **If other OARs have changed shape – can't assess**



MIRSIG

Decision by treatment team from observed deviation in anatomy.

- **Offline adaptive evaluation**: analysis dose on a *synthetic CT* (Hay 2020)
- **Offline adaptive replan**: as above, but also replan if required



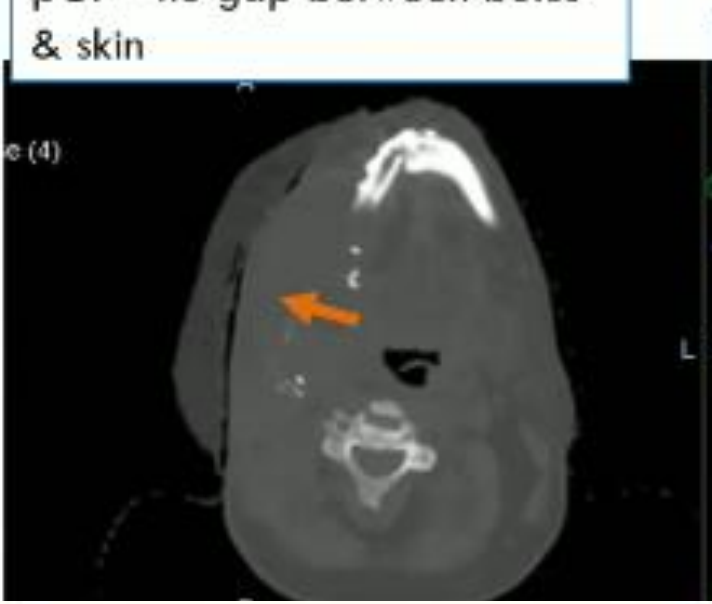
Synthetic CT = CBCT with HU correction

- Allows assessment of all OARs
- Can assess PTV coverage quickly

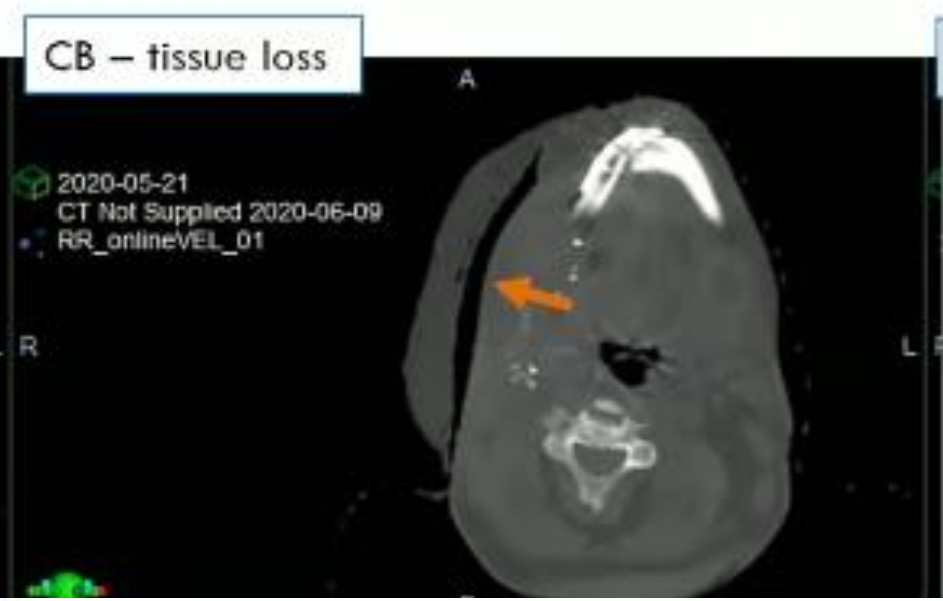
Slide from Johnson Yuen

Adaptive Planning with Synthetic CT

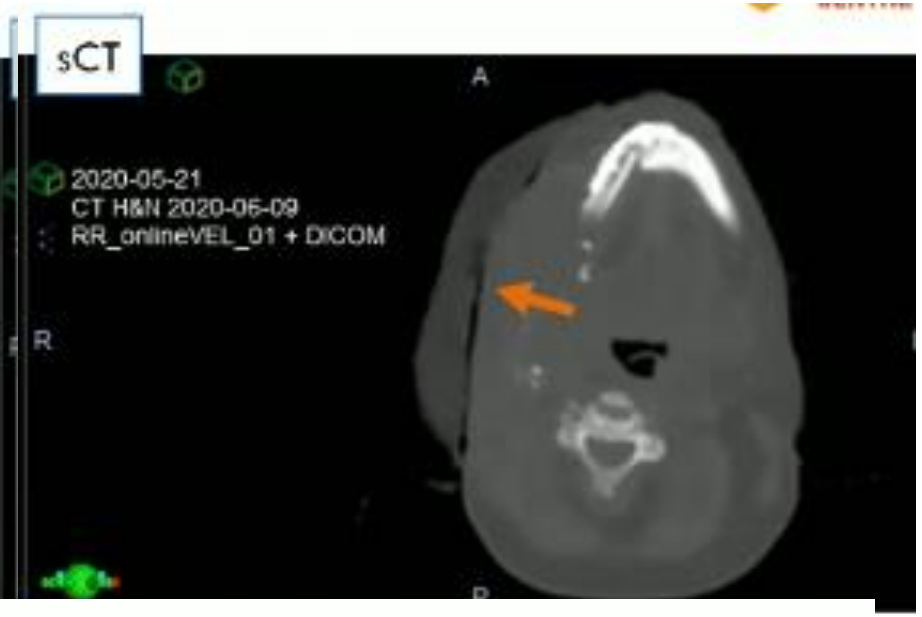
pCT – no gap between bolus & skin



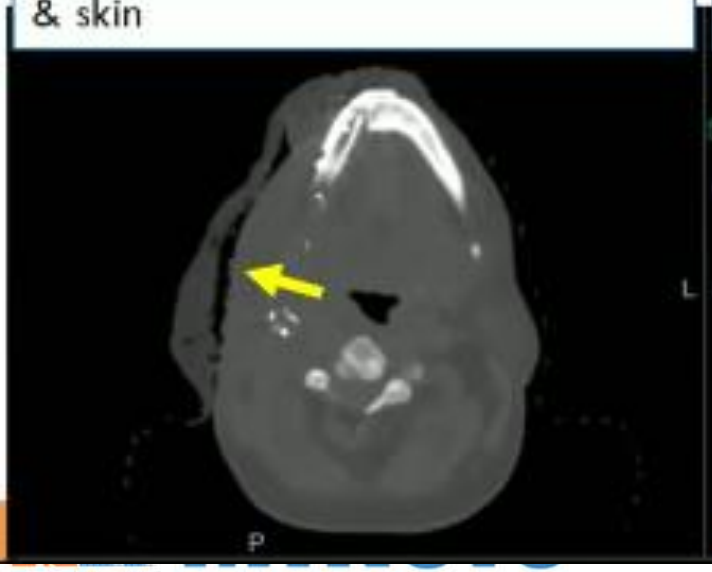
CB – tissue loss



sCT

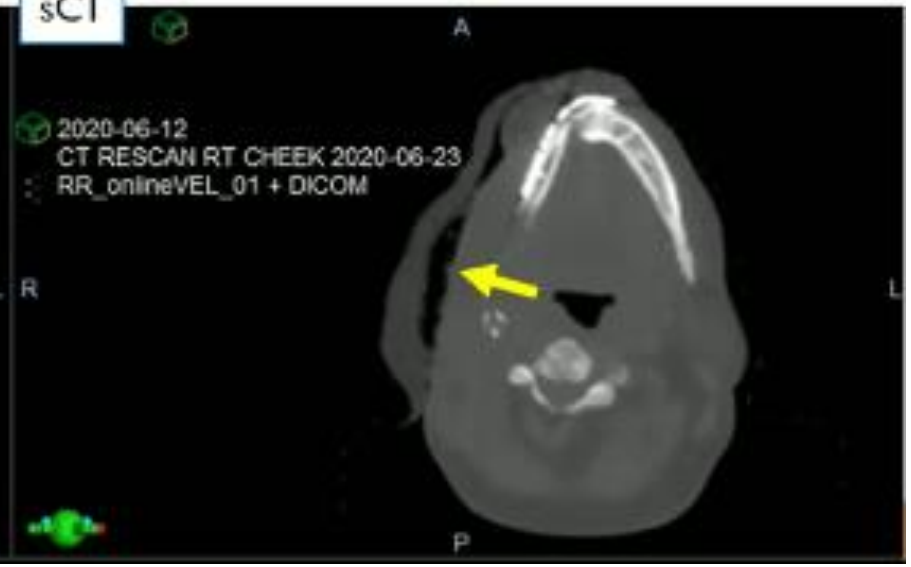


Rescan pCT – gap between bolus & skin



CB – further tissue loss

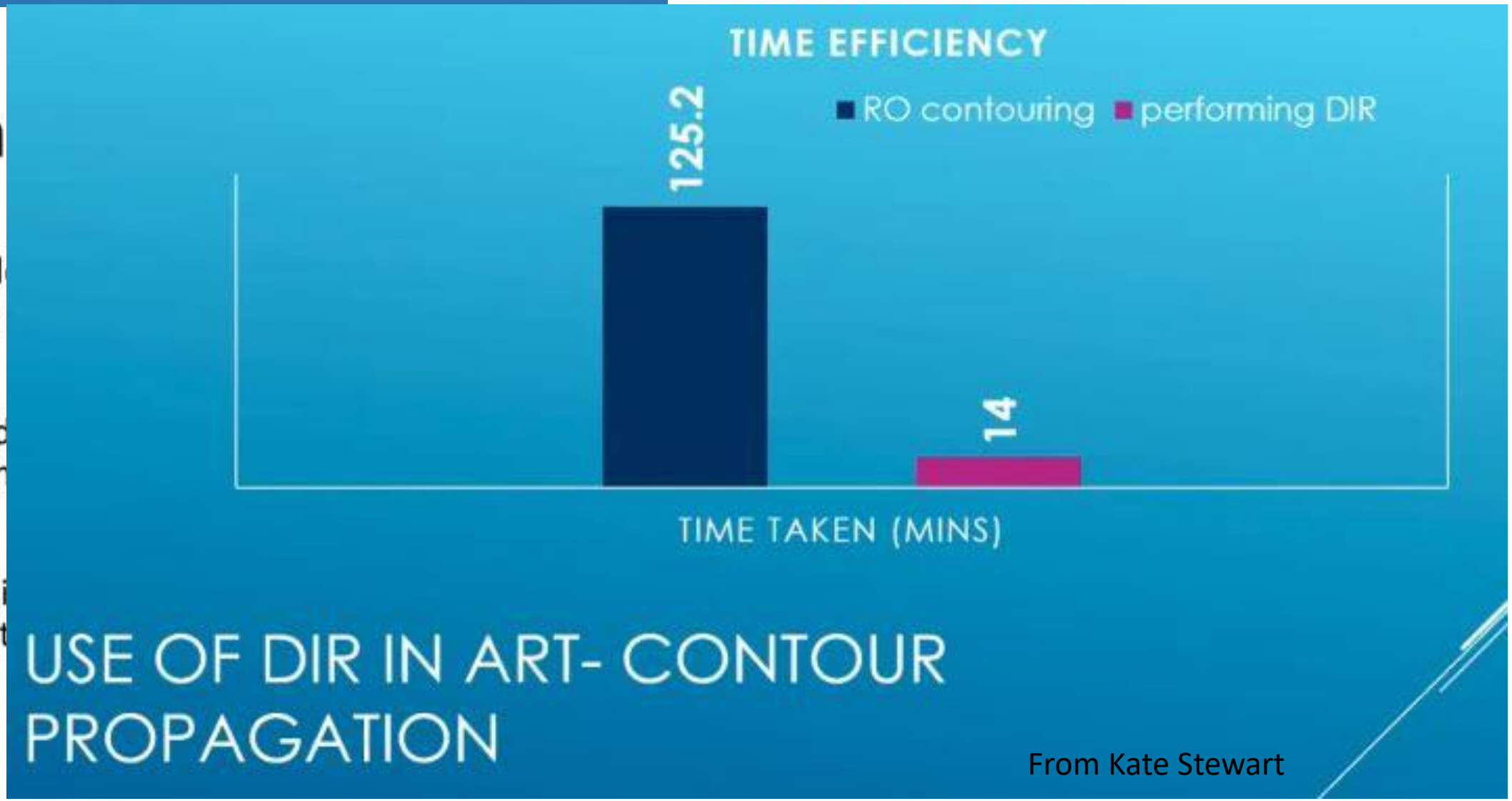
sCT



Target Delineation and Contouring

From

- Target d
process
- Can lead
with cor
- The dosi
or over t



From Kate Stewart

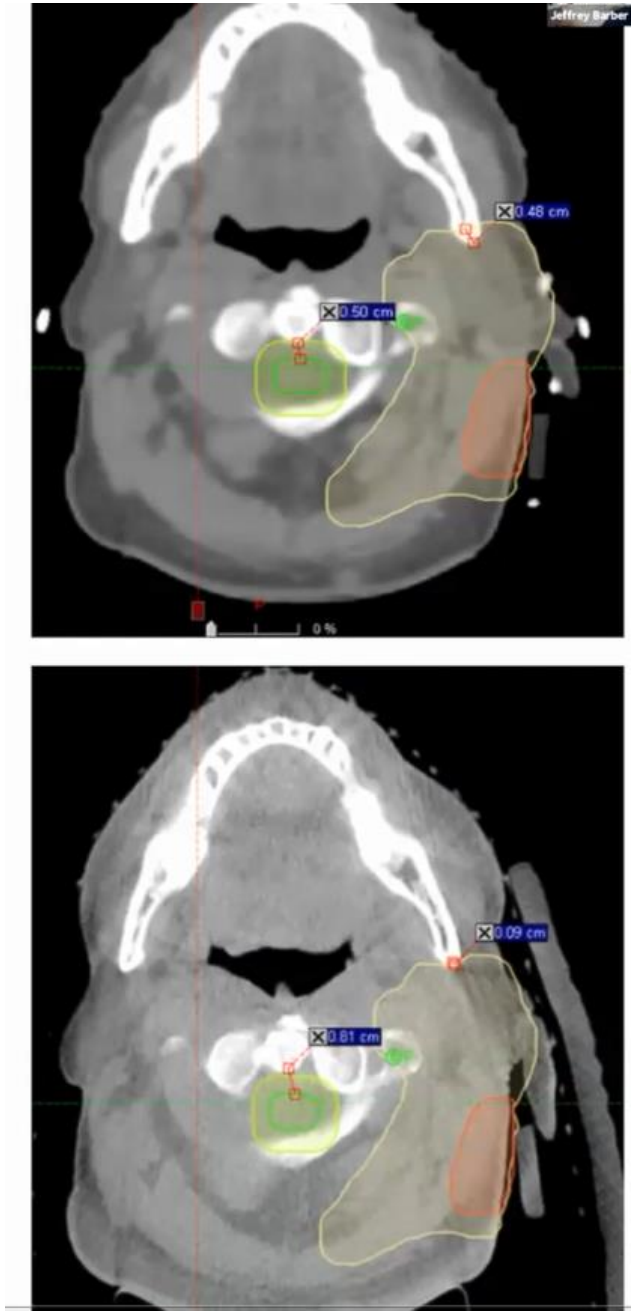
MIRSIG

Use Case: Replanning

DIR in Replanning Workflows can increase efficiency

- Improves turn around time
- Reduces the number of manual tasks –
- Ensures all staff are doing the task the same way

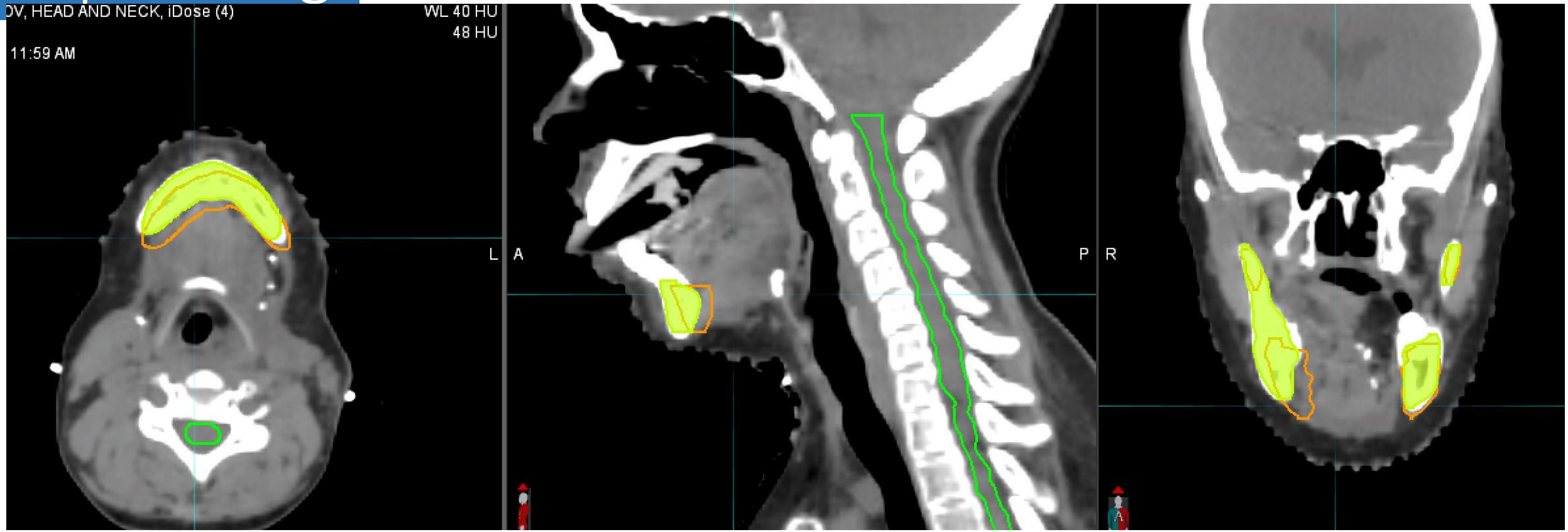
Automated DIR processes still need careful review



MIRSIG

Slide from Jeff Barber

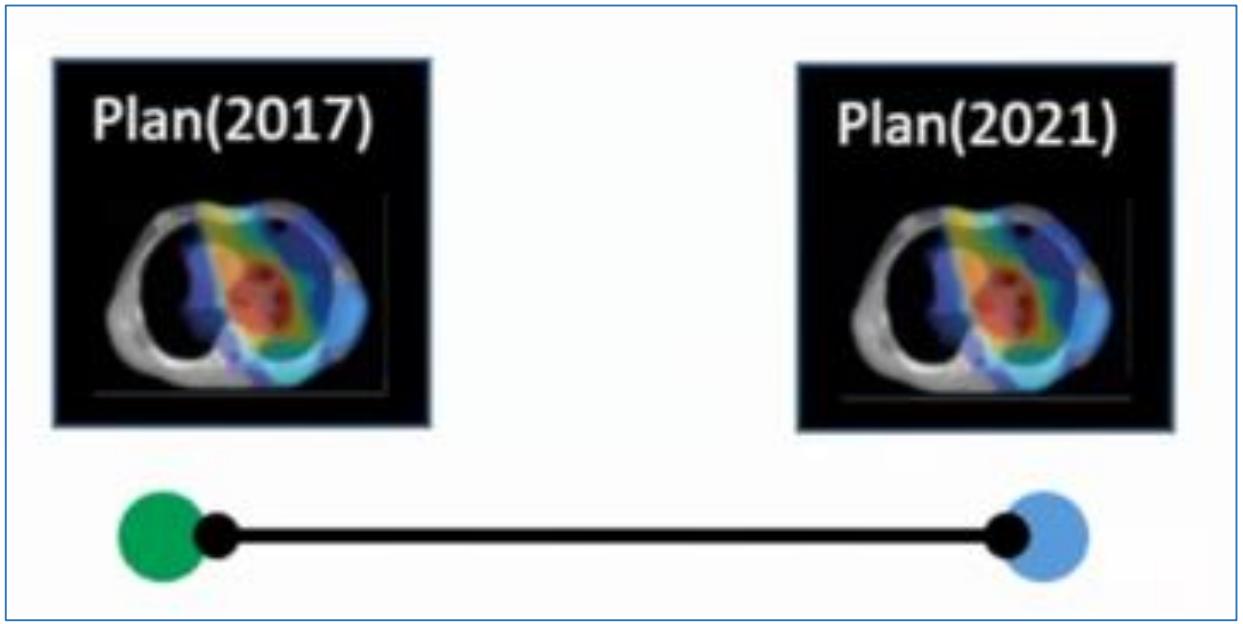
Replanning



- Deforming anatomical contours from the same patient during replanning
  - –Saves Time
  - –Safe practice as all contours checked by RO / RT
  - –**Tumour volumes then adjusted by RO**

MIRSIG

Retreatment



MIRSIG

Retreatment

- 1/10 patients present with major cancer in western society can represent with a second cancer

- **The main reasons for the above can be:**
- Continued high risk lifestyle (eg: smoking, drinking, ….)
- Genetic predisposition for cancer development
- Treatment related (Childrens are very sensitive to radiation effect 10-15 times more sensitive than adults,.....)
- Better systemic treatments and increased lifspan of cancer patients to get the second primary or loco-regional recurrence

From Dr Reza Rahbari

MIRSIG

Factors to Consider for Re-irradiation

Patient factors:

- Patient symptoms
- Patient functional status and comorbidities
- Patient wishes/urgency of treatment
- Patient life-expectancy

Disease factors:

- Primary diagnosis and prognosis, natural hsitory
- Secondary diagnosis, the same cancer recurred or is it a new primary?
- Stage of the disease

From Dr Reza Rahbari

MIRSIG

Factors to Consider for Re-irradiation

Treatment related factors:

- Previous treatment, surgery, radiotherapy
- Dose, dose per fraction , treatment technique , volume
- Time interval between the courses or radiotherapy
- Duration of effect of previous treatment
- Toxicity from previous treatment
- Type of organs and the relevant risks associated with re-irradiation

From Dr Reza Rahbari

MIRSIG

How much dose has this organ already received?
How much dose can I safely deliver to this previously irradiated organ?
How much dose in total has this organ received, and will this impact risk of side effects?

- Modern radiation oncology techniques provide ability to shape isodose lines around targets and critical organs

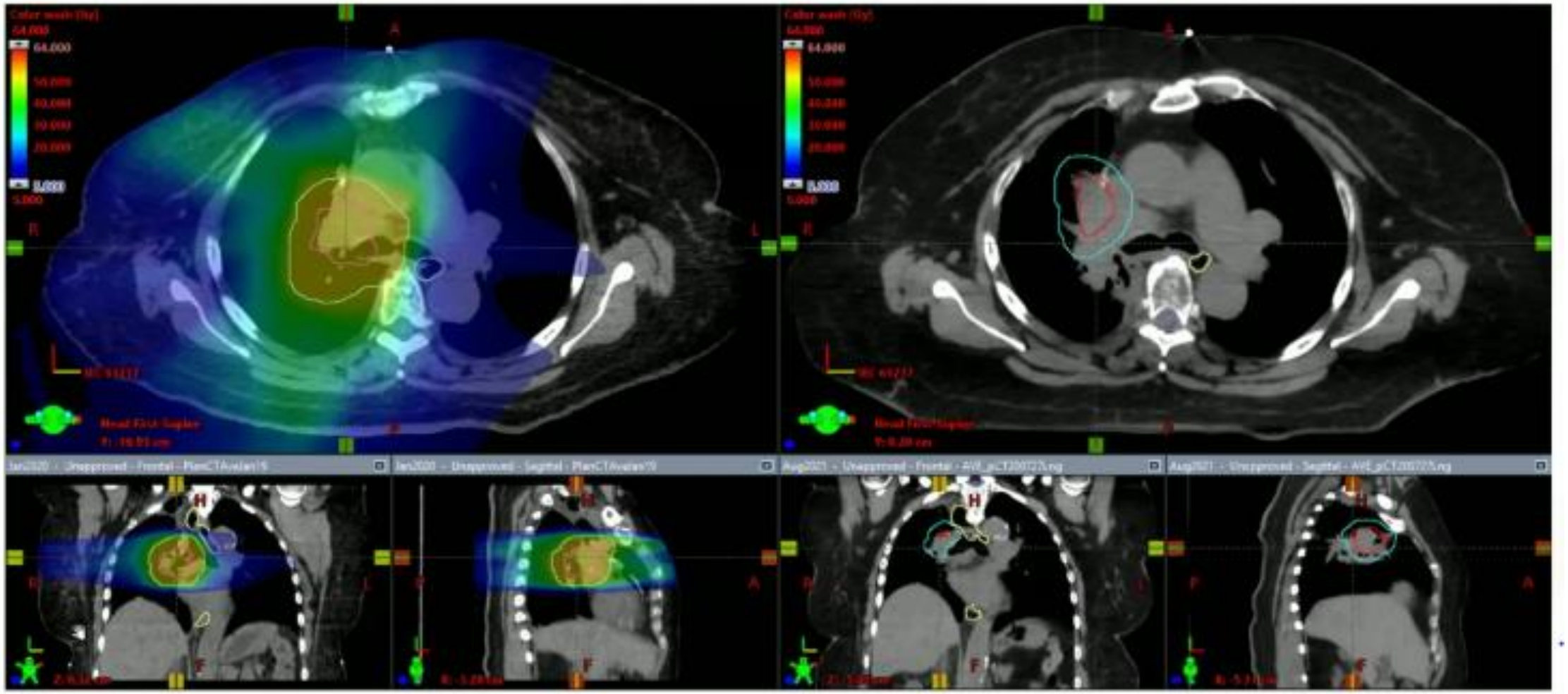
- Re-irradiation is thus feasible with modern radiotherapy treatment techniques

MIRSIG

From Nick Hardcastle

Jan 2019: 50 Gy in 25 Fx

Aug 2020: (aim for) 60 Gy in 30 Fx



Careful assessment of what dose was received by Spinal Cord and Oesophagus

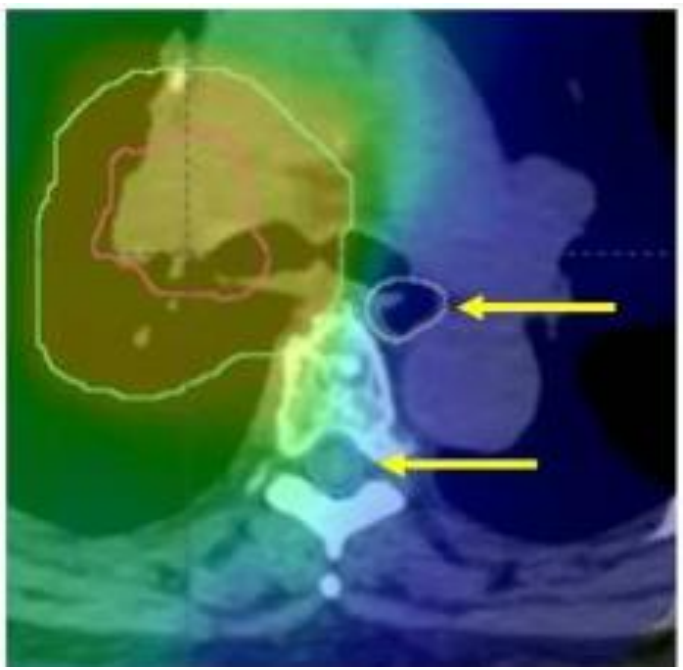
MIRSIG

From Nick Hardcastle

Structure	Metric	Original Plan Physical Dose (Gy)*	Dose limit (Gy)	Allowed dose in 2 Gy fractions (Gy)**
Spinal Canal	Max	33.8	46	12.2
Oesophagus	D0.03cc	24.3	63	38.7

*both treatment courses were delivered in 2 Gy fractions, so no EQD2/BED scaling performed

** 'forgotten dose factor' ignored for the purposes of this example



MIRSIG

Method	Structure	Metric	Original Plan Physical Dose (Gy)*
Metrics	Spinal Canal	Max	33.8
Metrics	Oesophagus	D0.03cc	24.3
RIR	Spinal Canal	Max	35.1
RIR	Oesophagus	D0.03cc	53.1
DIR	Spinal Canal	Max	33.9
DIR	Oesophagus	D0.03cc	53.2

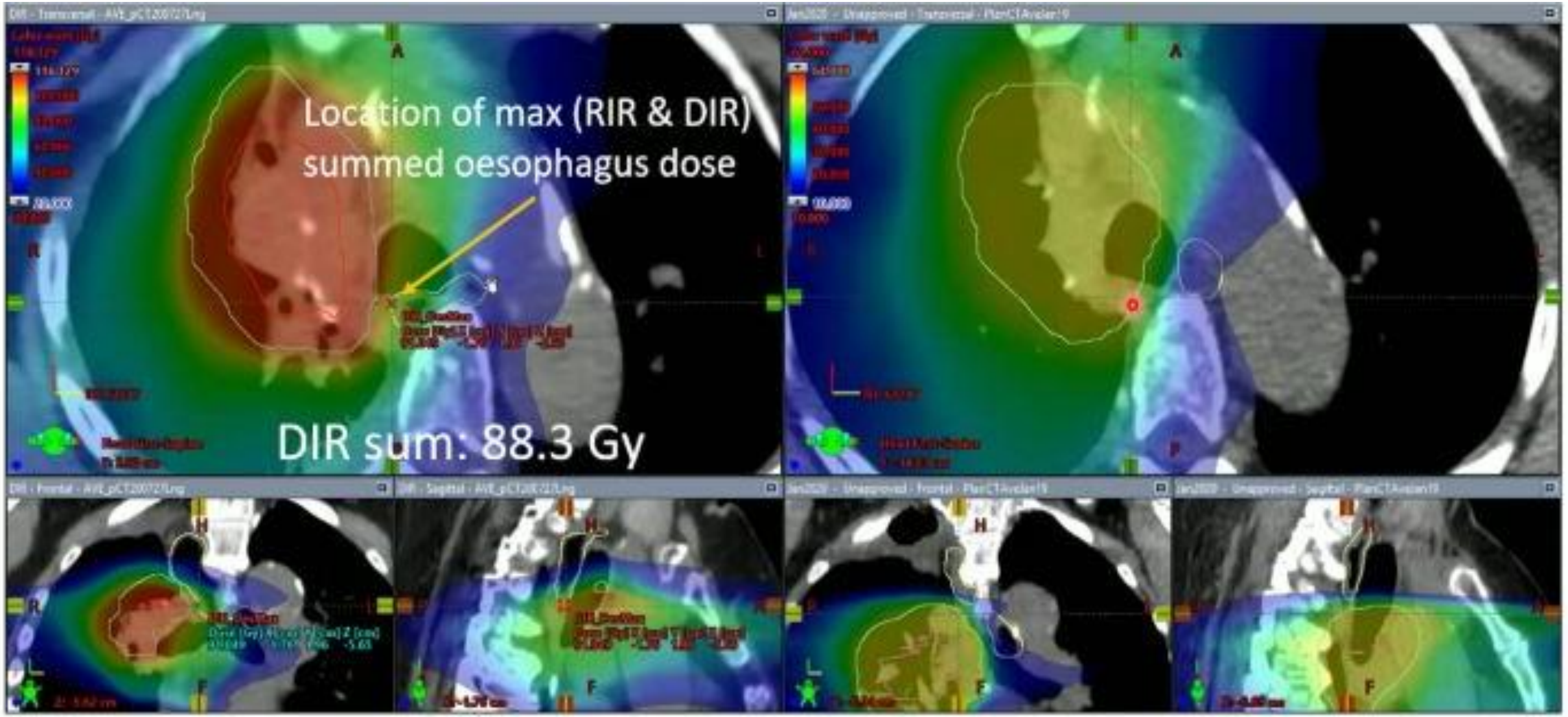
Spinal Cord:

- Bony anatomy registered well
- Near max dose can be used in retreatment

Oesophagus:

- Dose is attached to anatomy when doing registration
- Registration error for both RIR and DIR

MIRSIG



Shows a Dose-Warping Error

MIRSIG

Re-Irradiation Dose Assessment

Transferring Dose from Previous Treatment

- Convert Isodose lines to structures contour propagation to transfer to new planning CT

- Dose files transferred to new planning CT
  - RIR may preserve overall “shape” of isodose lines (more obvious with POP)
  - DIR may qualitatively appear like anatomy registered
  - ** Need to do QA + sanity check for dose warping errors

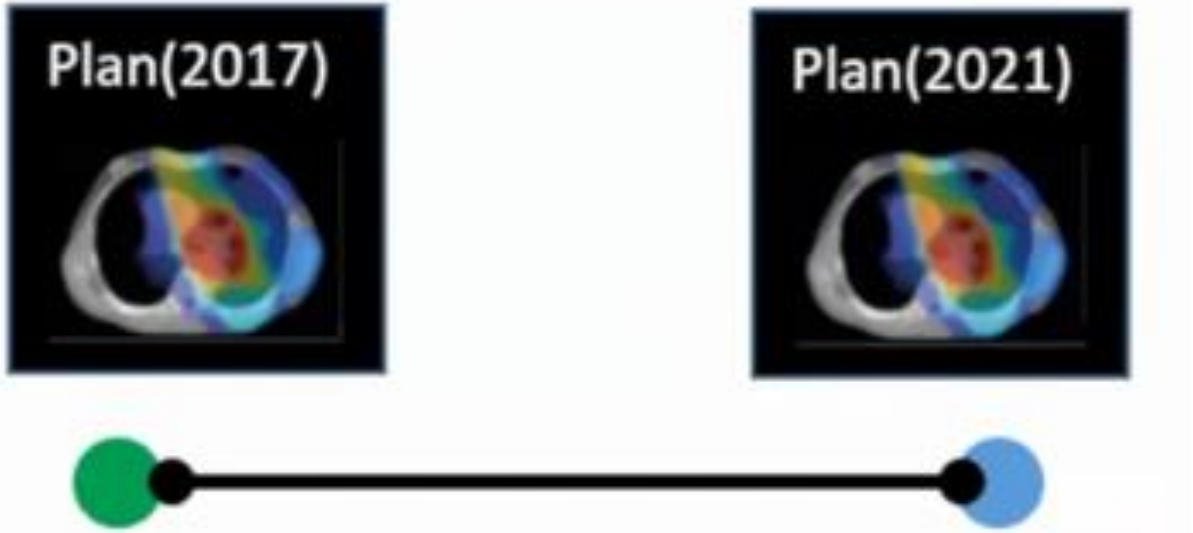
- Metric summation for OARs
  - assumes max in same location of organ
  - Most conservative approach

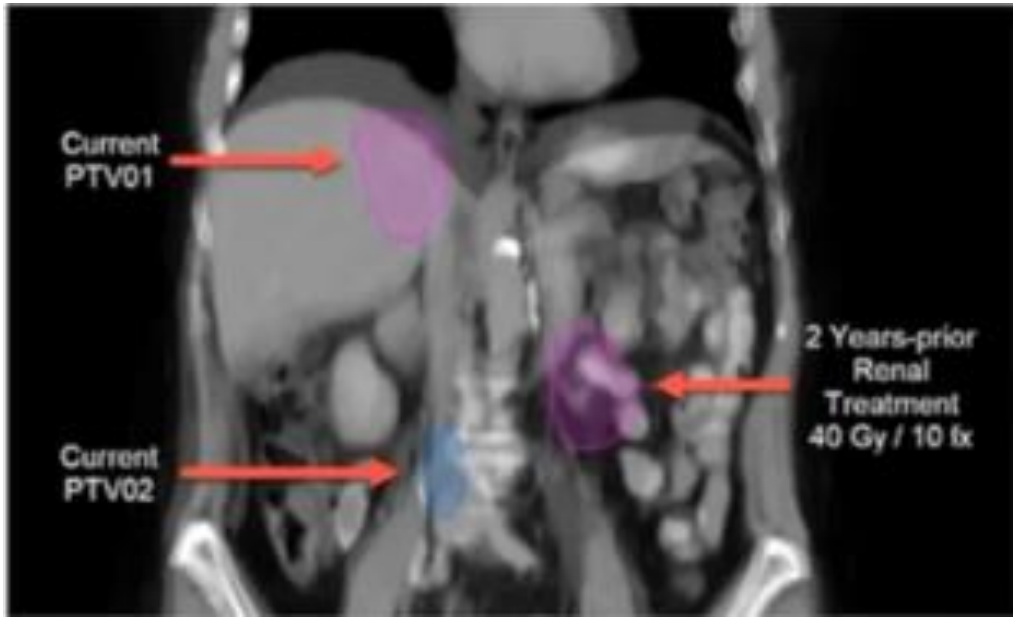
- Mean dose / volumetric dose
  - meaningless as functionality / biology of tissue changed

MIRSIG

Re-irradiation – EQD2 and BED

This may include analysis of
-treatment overlap
-cumulative radiation doses to organs at risk
(Paradis 2019).





MIRSIG

Slide from Johnson Yuen

Scientific Article

Advances in Radiation Oncology 2019 (4) 559-565

The Special Medical Physics Consult Process for Reirradiation Patients

Kelly C. Paradis PhD*, Charles Mayo PhD, Dawn Owen MD, Daniel E. Spratt MD, Jason Hearn MD, Benjamin Rosen PhD, Rojano Kashani PhD, Jean Moran PhD, Daniel S. Tatro CMD, Whitney Beeler MD, Karen Vineberg CMD, Dylan C. Smith MS, Martha M. Matuszak PhD

Scientific Article

Advances in Radiation Oncology 2021 (6)

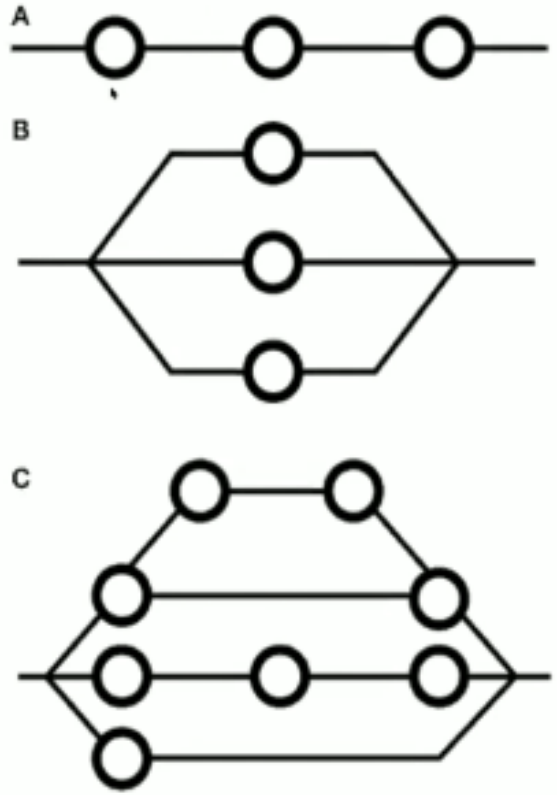
Practical Clinical Implementation of the Special Physics Consultation Process in the Re-irradiation Environment

Robert A. Price Jr, PhD,* Lihui Jin, PhD, Joshua Meyer, MD, Lili Chen, PhD, Teh Lin, PhD, Ahmed Eldib, PhD, Xiaoming Chen, PhD, Jie Liu, PhD, Iavor Veltchev, PhD, Lu Wang, PhD, CM and Charlie Ma, PhD

MIRSIG

Dose Tolerances

- Prior dose fractionation
- Volume treated
- Serial VS. Parallel FSU
- Time since last treatment
- Tolerance doses generally calculated based on EQD2 and BED



eg Spinal cord

eg Lungs

eg Liver

From Dr Reza Rahbari

MIRSIG

Spinal Cord Re-irradiation

Table 1: Risk score for development of radiation myelopathy

	Factors									
	0	1	2	3	4	5	6	7	8	9
Cumulative BED (Gy2)	≤120	120.1-130	130.1-140	140.1-150	150.1-160	160.1-170	170.1-180	180.1-190	190.1-200	>200

Interval <6 months

One BED course >102

~4.5

Table 2: Risk group for development of radiation myelopathy

Risk group	Score	Myelopathy (%)
Low risk	≤3	0
Intermediate	4-6	33
High	>6	90

From Dr Reza Rahbari

EQD2

Paradis paper has a list of EQD2 values for various organs that are used in their practice

Work out what dose was given in EQD2
What dose discounting can be applied
Allowable dose for OAR for replan

Paradis *et al* ARO 2019 https://doi.org/10.1016/j.adro.2019.05.007
Supplement Appendix E2

	OAR Name	α/β (Gy)	Dose limit Max to 0.1cc (EQD2) (Gy)	For >3 years, 50% discount suggested			
				< 3 mo	3-6 mo	6 mo - 1 yr	1 - 3 yrs
☐	Bladder	2.5	85	0	10	25	50
☐	Brachial Plexus	2.5	70	0	10	25	50
☐	Brainstem	2.5	64	0	10	25	50
☐	Cauda Equina	2.5	60	0	10	25	50
☐	Chest Wall	2.5	100	0	10	25	50
☐	Colon	2.5	70	0	10	25	50
☐	Duodenum	2.5	54	0	0	10	25
☐	Esophagus	2.5	70	0	10	25	50
☐	Great Vessels	2.5	100	0	10	25	50
☐	Heart	2.5	70	0	10	25	50
☐	Kidneys	2.5	ALARA	0	0	0	0
☐	Optic Chiasm	2.5	54	0	10	25	50
☐	Optic Nerve	2.5	54	0	10	25	50
☐	Rectum	2.5	80	0	10	25	50
☐	Retina	2.5	50	0	10	25	50
☐	Sacral Plexus	2.5	70	0	10	25	50
☐	Small Bowel	2.5	54	0	0	25	25
☐	Spinal Cord	2.5	50	0	10	25	50
☐	Spinal Cord (when < 2mm from target)	2.5	55	0	10	25	50
☐	Stomach	2.5	54	0	0	25	25
☐	Trachea/Bronchus	2.5	70	0	10	25	50
☐	Liver	2.5	NTCP limited	0	0	50	100
☐	Lungs	2.5	Customized per case	0	0	25	50

MIRSIG

Dose Discounting

Table 2 Percentage repair applied to calculations of equivalent dose at 2 Gy per fraction

	<6 mo	6 mo to 1 y	>1 y
Repair, %	0	25	50

Price *et al* ARO 2021 https://doi.org/10.1016/j.adro.2020.09.027

MIRSIG

Dose Assessment for Re-irradiation

- Summing doses on different CTs is complex
- DVH metrics – are an estimate only – volumetric analysis not accurate due to differences in size / shape and function of OARs post prev XRT
- Dose voxel correspondence between images isn't always the same
- Near max dose most meaningful for reporting
- Careful review of contour
- Physics quantitative metrics assessment very useful for uncertainties

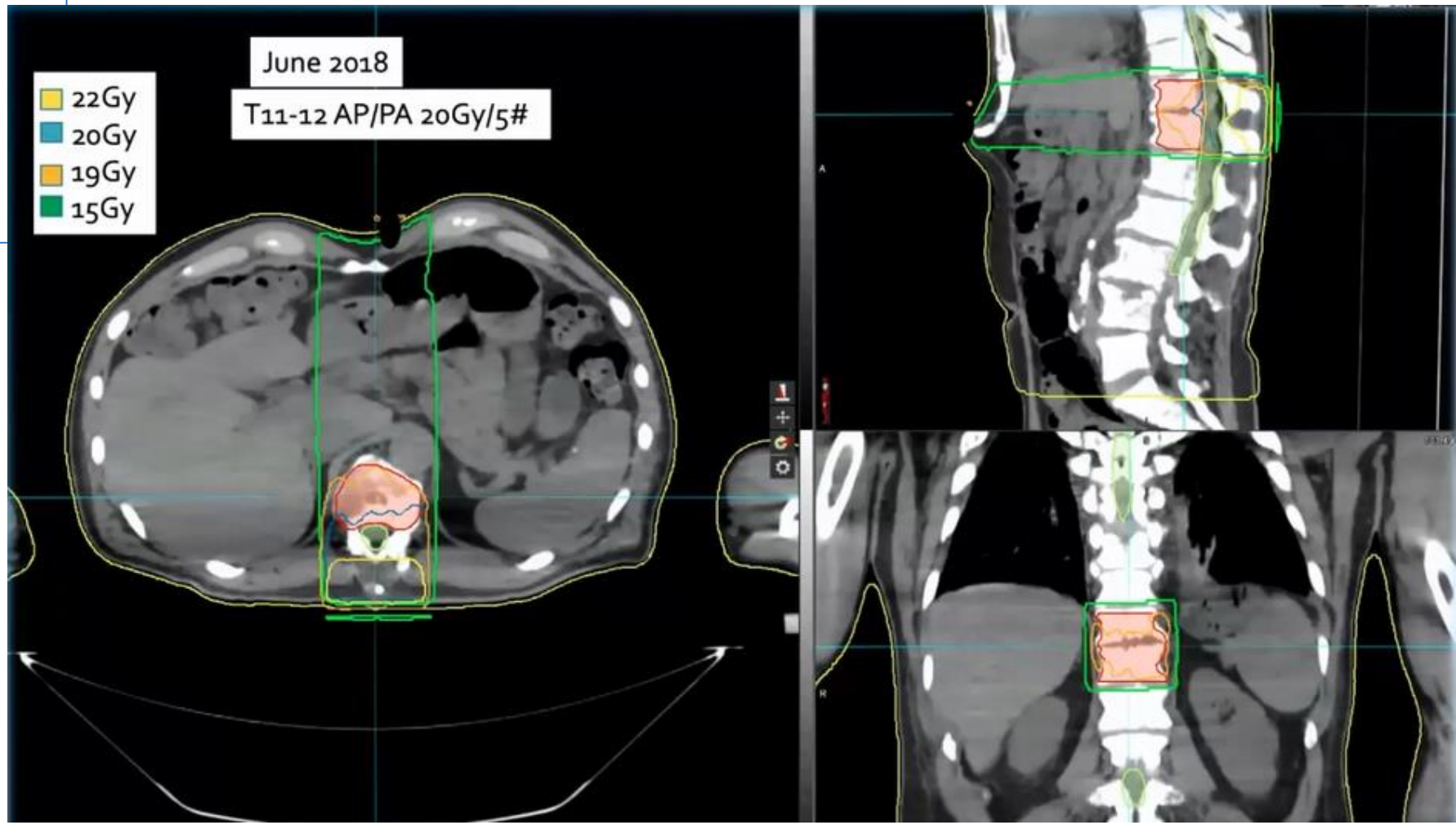
MIRSIG

Clinical examples of Re-irradiation

MIRSIG

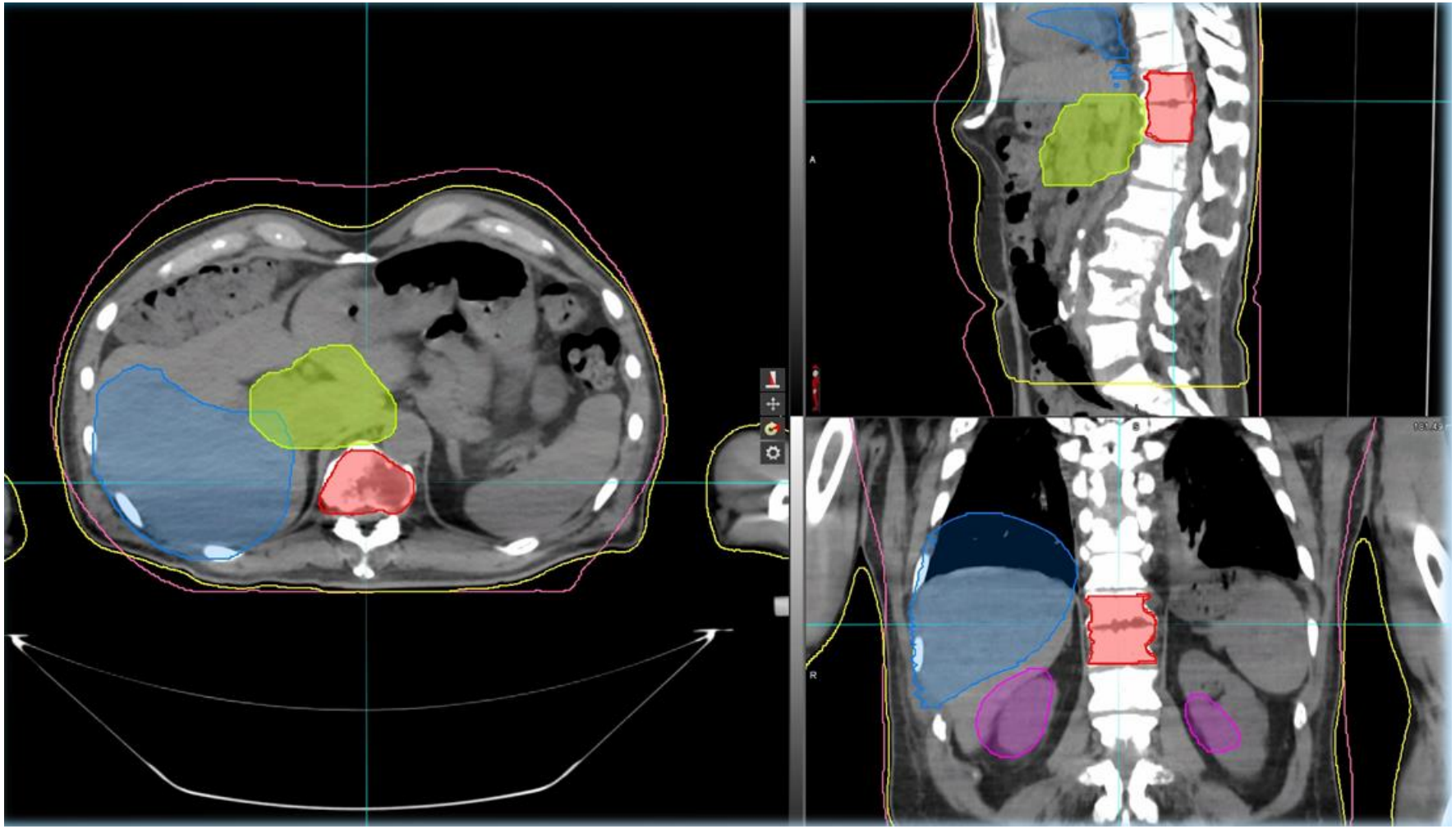
Patient with multi-level cord compression in 2018

Emergency EBRT 20Gy/5# AP/PA



MIRSIG

Pancreatic Adenocarcinoma diagnosed in 2019



Pancreas planned at GenesisCare, Prince of Wales and St George

Possible Solutions

- **Prince of Wales**
  - SABR treatment following the TROG 18.04 trial – MASTERPLAN
    - MASTERPLAN = SABR Pancreas 40Gy/5#, every second day
- **GenesisCare**
  - VMAT plan of 45Gy/ 20#
    - Constraints per EviQ
- **St George**
  - VMAT plan of 35Gy/ 15#
    - Constraints per EviQ

MIRSIG

Tissue Recovery

"Do you acknowledge tissue recovery from the previous course?"

Prince of Wales	GenesisCare	St George
We assume a 50% recovery on the Spinal Cord after 12 months. If SC received 30Gy EqD2 in 2018 we took that as 15Gy dose delivered after 12 months. New SC tolerance is approximately 17Gy for pancreas plan.	Acknowledge that recovery of 12 months could be 50% but conservatively assume 30%. Either way this is easily achieved in the new plan.	We would accept 10% in this case but up to 50% in other parts of the body Pt had prev multiple cord comp + patient's health was declining rapidly

MIRSIG

Plan Comparison

	Prince of Wales	GenesisCare	St George
Prescription	**30Gy in 5# every 2nd day**	**45Gy in 20#**	**35Gy in 15#**
Bowel Constraint	30Gy to 1.5cm^3 10Gy to 15%	44.5Gy to 0.01% 22.4Gy to 15%	36.5Gy Max 17.5Gy to 15%
Spinal Cord Constraint	12.1Gy	10.9Gy 11.6Gy to +5mm	12.1Gy

MIRSIG

Accumulated Dose Scenario

- **Patient History:**
  - **Diagnosis**
    - 1) Left Breast Infiltrating ductal Ca diagnosed April 2014 – *mastectomy*
    - 2) Presented in 2017 with metastatic disease to liver, lung and T12
  - **Summary**
    - Commenced Letrozole which supressed symptomatic T12 pain
    - Represented with symptomatic bone pain in Sep 2018 and prescribed EBRT
      - Oct 2018 – Cx 1 – Left Pelvis/Iliac (20Gy in 5#)
      - Feb 2019 –Cx 2 – Cspine (20Gy in 5#)
      - Jun 2019 – Cx 3 – Rt Humerus (30gy in 10#)
      - Oct 2019 – Cx 4 – Right Sacroiliac/hip (20gy in 5#) & T spine (20Gy in 5#)
      - Jan 2020 – Cx 5 – Sternum (20gy in 5#) & Mandible (20Gy in 5#)
    - Represented with cord compression in Feb 2020, prescribed **8Gy in 1#**
      - **Direct volume overlap with Cx 4**
      - Treated at same level as Cx 3 and Cx 5

MIRSIG

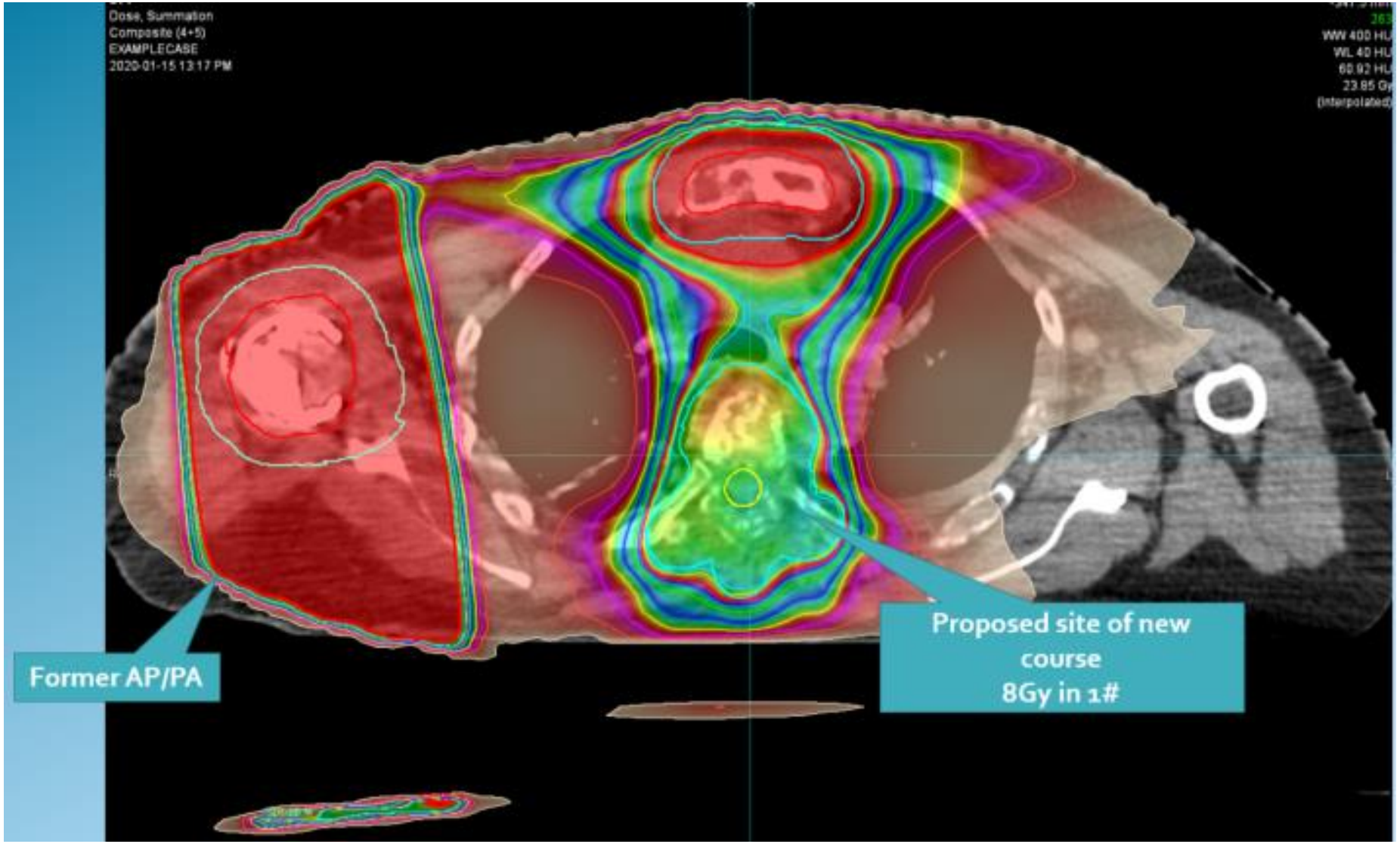
Considerations

- Modelling the Accumulated dose
- Recalculating/Recreating previous courses?
  - Limitations of machine parameters
  - Forcing/scaling MUs – *old school*
- Registration of Previous datasets?
  - Rigid/DIR

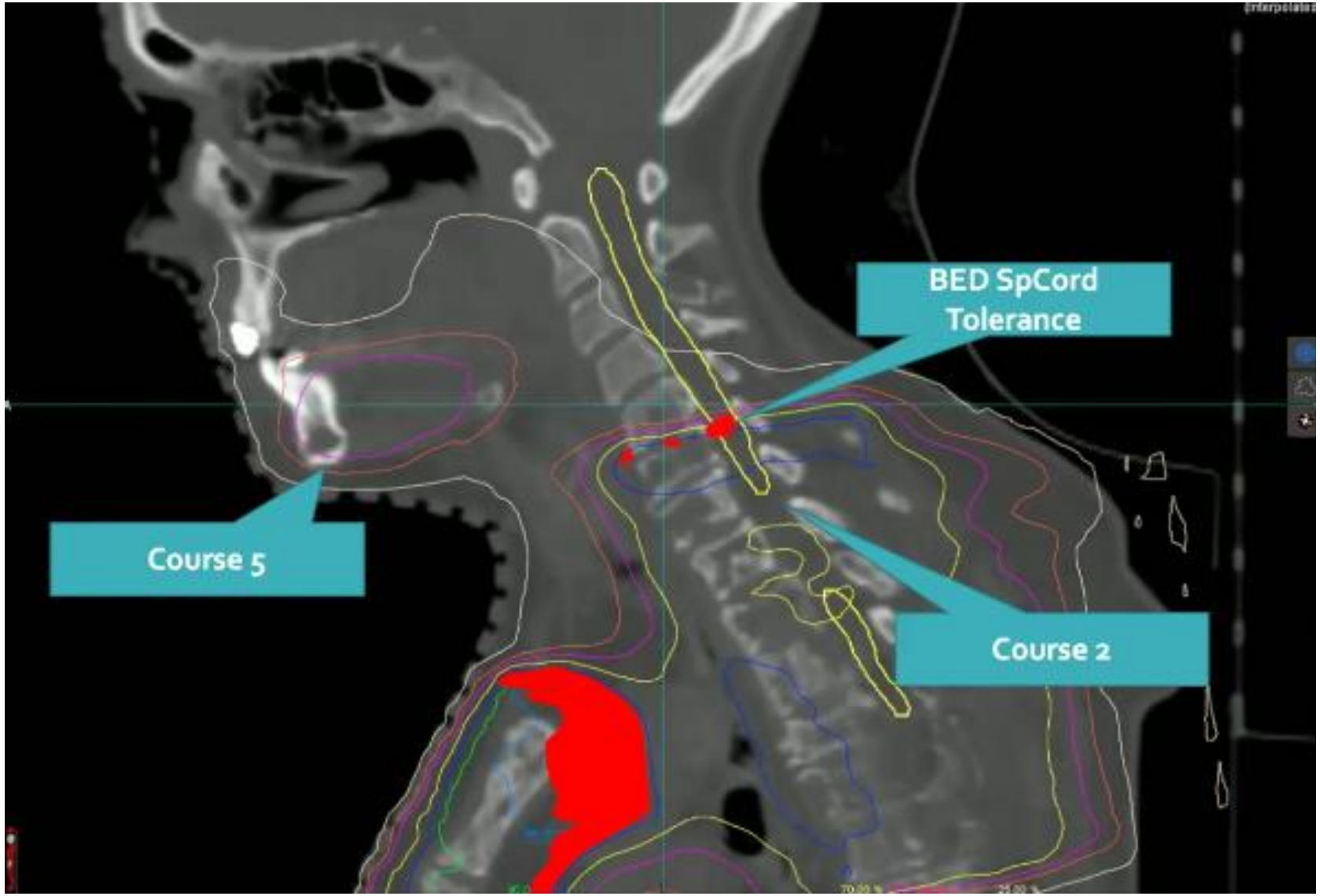
Impact on separation & positional changes

- Biological Equivalent modelling
  - Accurate tissue tolerance modelling?
  - Forgotten dose/recovery?

MIRSIG

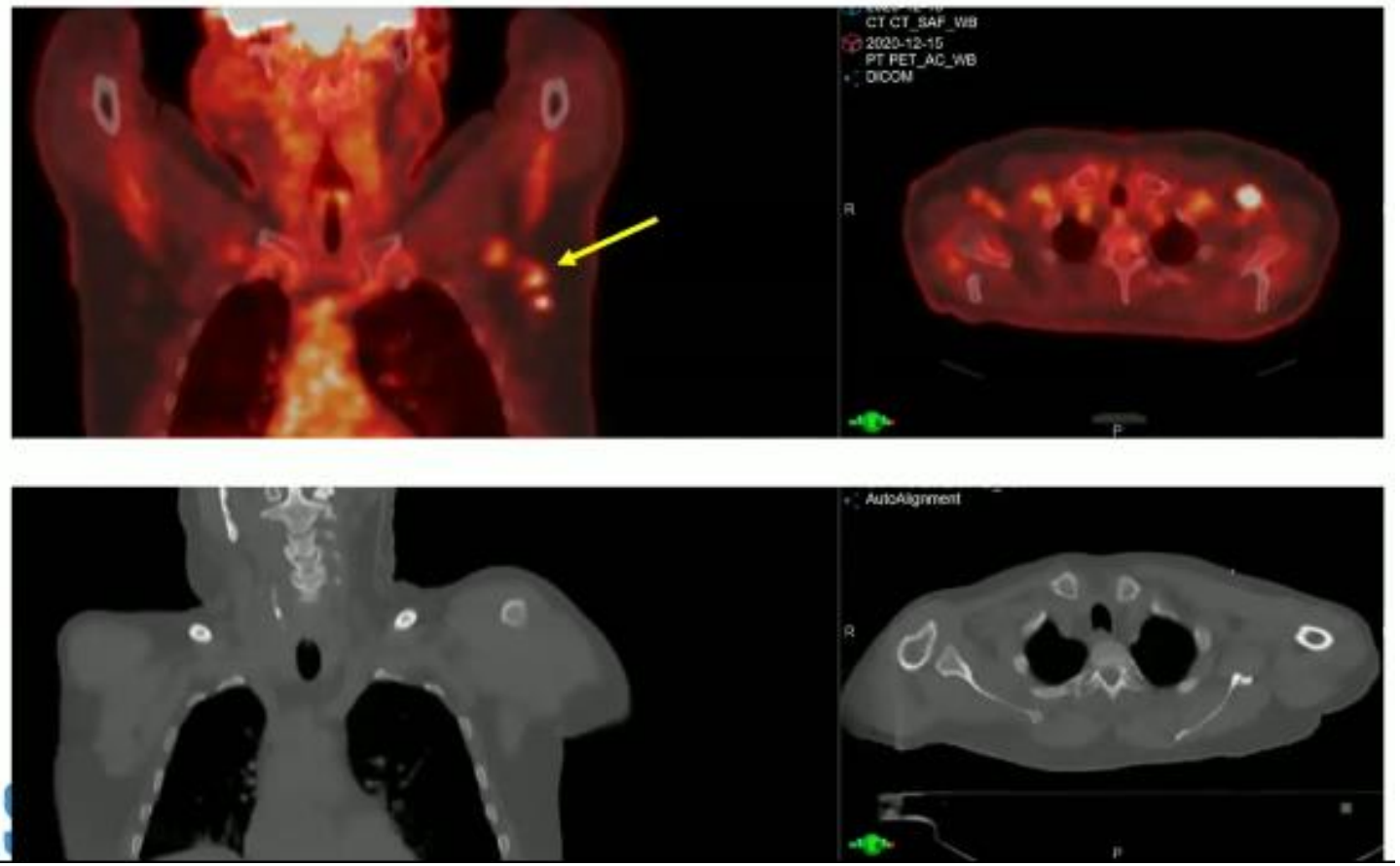

Dose, Summation
Composite (4+5)
EXAMPLECASE
2020-01-15 13:17 PM
Former AP/PA
Proposed site of new course
8Gy in 1#

MIRSIG



MIRSIG

MDT Panel Discussion



- PET avid axillary nodes – arms up
- Planning CT – couldn't raise arms

- How do you use this information to be able to delineate the target volume?

RO – contour on planning CT and try to outline PET avid nodes – in this case can visualise nodes easily on planning CT – side-by-side

ROMP – ideally use DIR, but this case will produce large areas of uncertainty due to poor deformation

RT – RIR – a couple of different registrations would try DIR, but agrees it would be difficult

MIRSIG

How do you review doses for overlap in a retreatment case?

RT

- recreate patient position for 2nd pCT
- Transfer contours and isodose lines to new pCT
- RIR for dose – but if possible DIR for dose

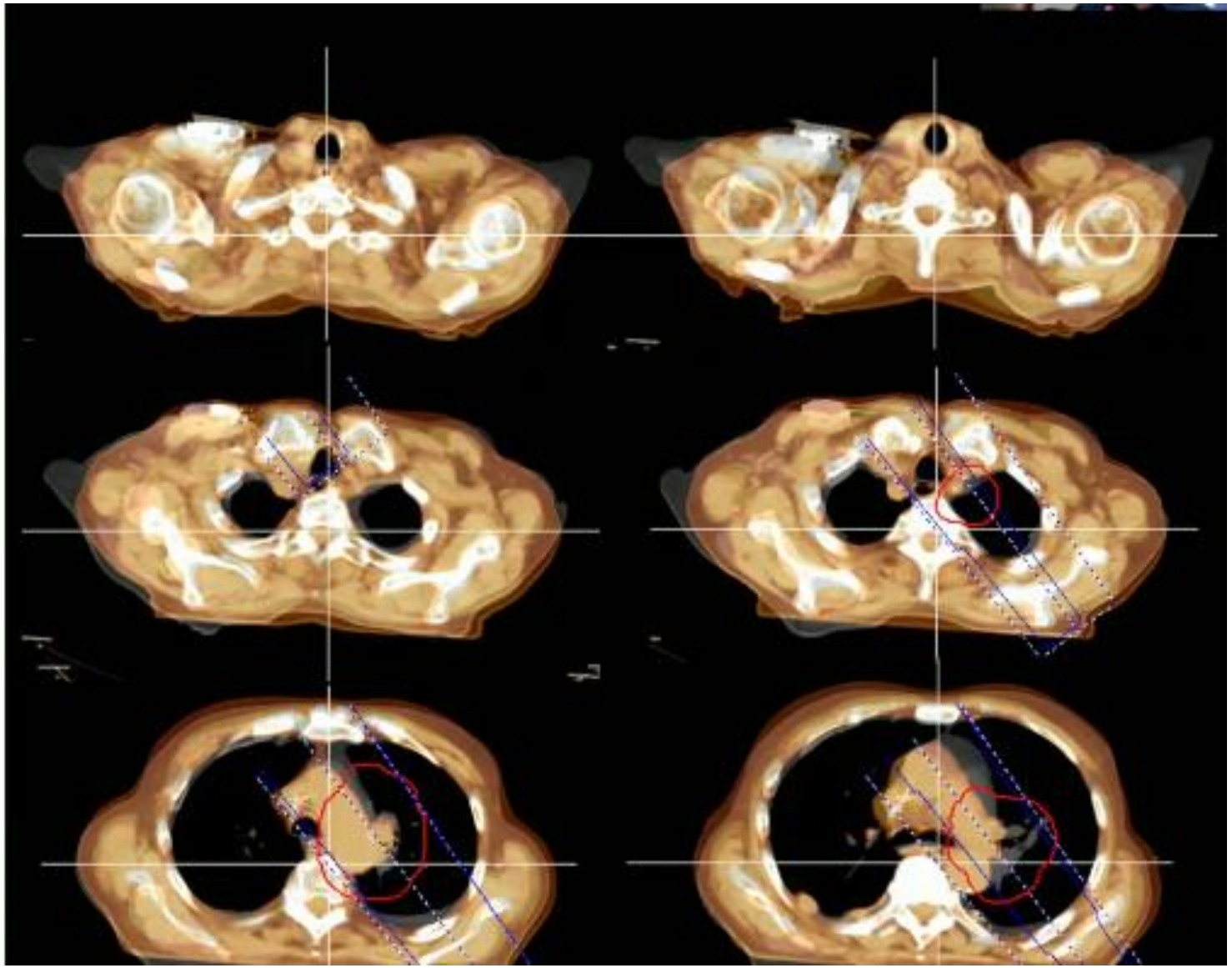
Audience:

- Transfer contours and isodose lines
- Summing of dose on fused datasets

MIRSIG

Pacemaker

- Each individual plan is getting < 2 Gy to device
- But matching to the pacemaker changes the overlap, total 3.5 Gy → increases risk category per local protocol, monitoring, IVD



MIRSIG

Dose Discounting

RO

- need to consider time between XRT treatment

- Also consider other treatments – chemo – immune therapy - surgery
- Is the benefit greater than the risk?

- Dose discounting – 30-50% with a year between treatment – case-by-case

- Dose discounting the same amount doesn’t apply to multiple times a patient presents for further treatment

MIRSIG

Last Session of the Workshop

Pre and post survey of audience

- A little test of the audience's knowledge around image registration

Clinical trials registration problems

- TROG-IR formed to address these problems

DIR challenge

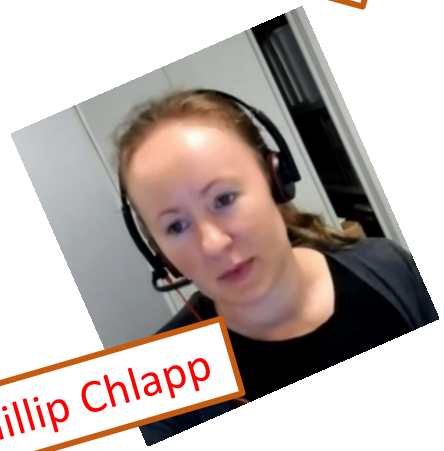
- Head and neck datasets
- looked at assessing DIR and seeing the variation between departments
- Also which system used and experience of user

Open discussion for next steps for Radiotherapy community

MIRSIG

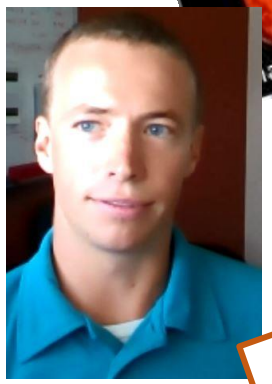
Practical Image Registration Workshop

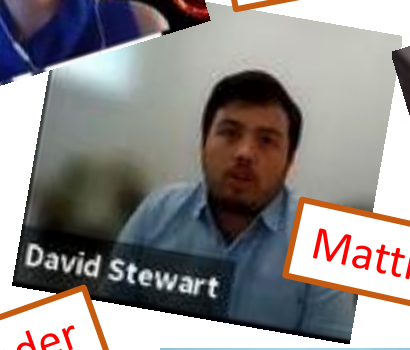
Alison Gray

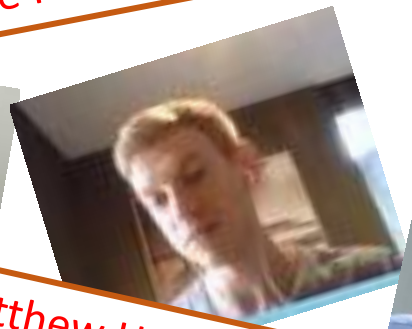


Annette Haworth

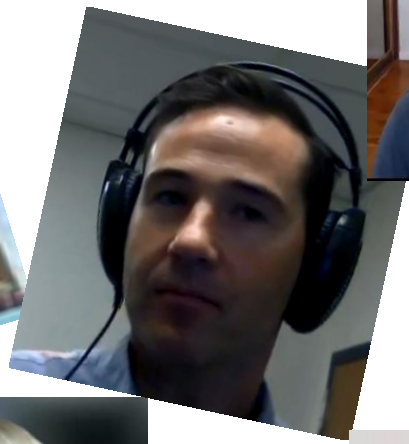
Phillip Chlapp

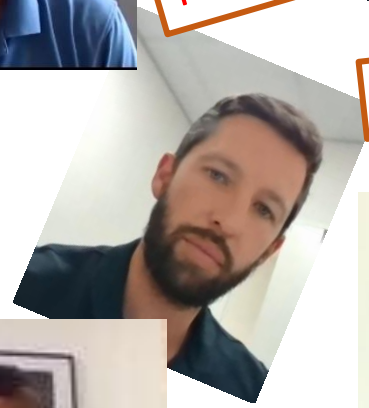






Matthew Hoffman

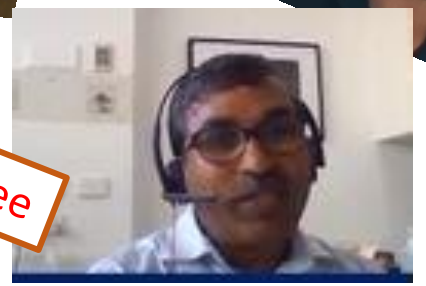




Andrew Hodgson

Joel Poder

Molly Mee



MIRSIG

Any questions?

MIRSIG