Australasian College of Physical Scientists & Engineers in Medicine

ACPSEM CPD Endorsed Activity

MIRSIG

ASMIRT APPROVED CPD PROGRAM
Appellation Code: SGHCCC-001544-2020

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

The **current seminar** 1200, Tue , Tue 6th October 2020, is chaired by Adam Yeo

- Talk 1: **Image registration QA for adaptive radiotherapy**

Presented by Ben Archibald-Heeren(Physics)

Webinar activities!!

-Use the "Q&A" to ask questions!

Live Poll!

Poll information will be used to confirm CPD, so it is important to participate!

Post webinar survey!

Please answer survey when email is sent

Seminar material available online!

Please see https://www.acpsem.org.au/About-the-College/Special-Interest-Groups/MIRSIG

Be more involved!

1. MIRSIG welcomes professions from all disciplines, including radiation therapists and radiation oncologists
2. Sign up to the MIRSIG mailing list (https://www.acpsem.org.au/Home , click myACPSEM, click speciality groups, tick MIRSIG)
3. Join MIRSIG as a member, email mirsig@acpsem.org.au

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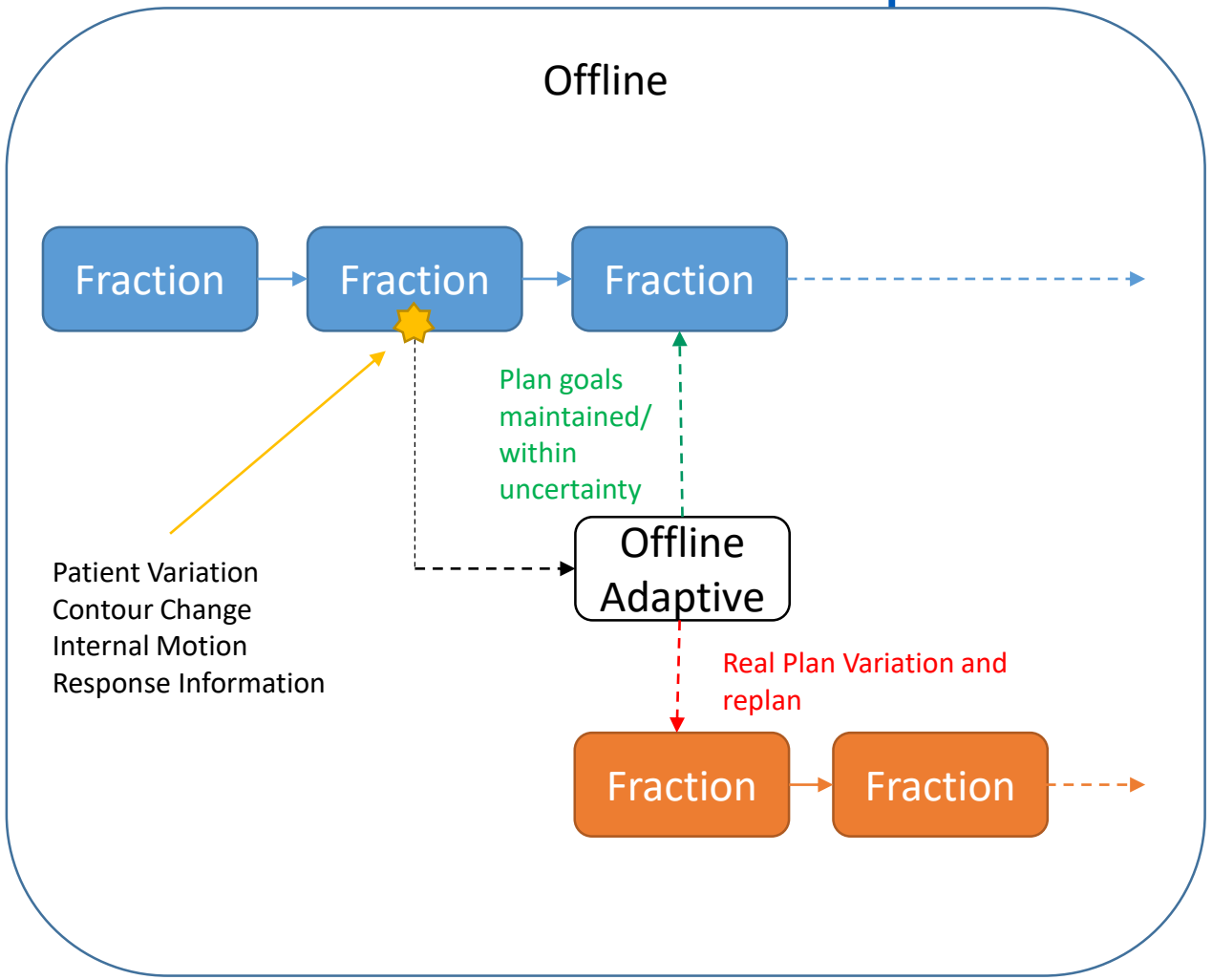
Quality Assurance for Adaptive Radiotherapy

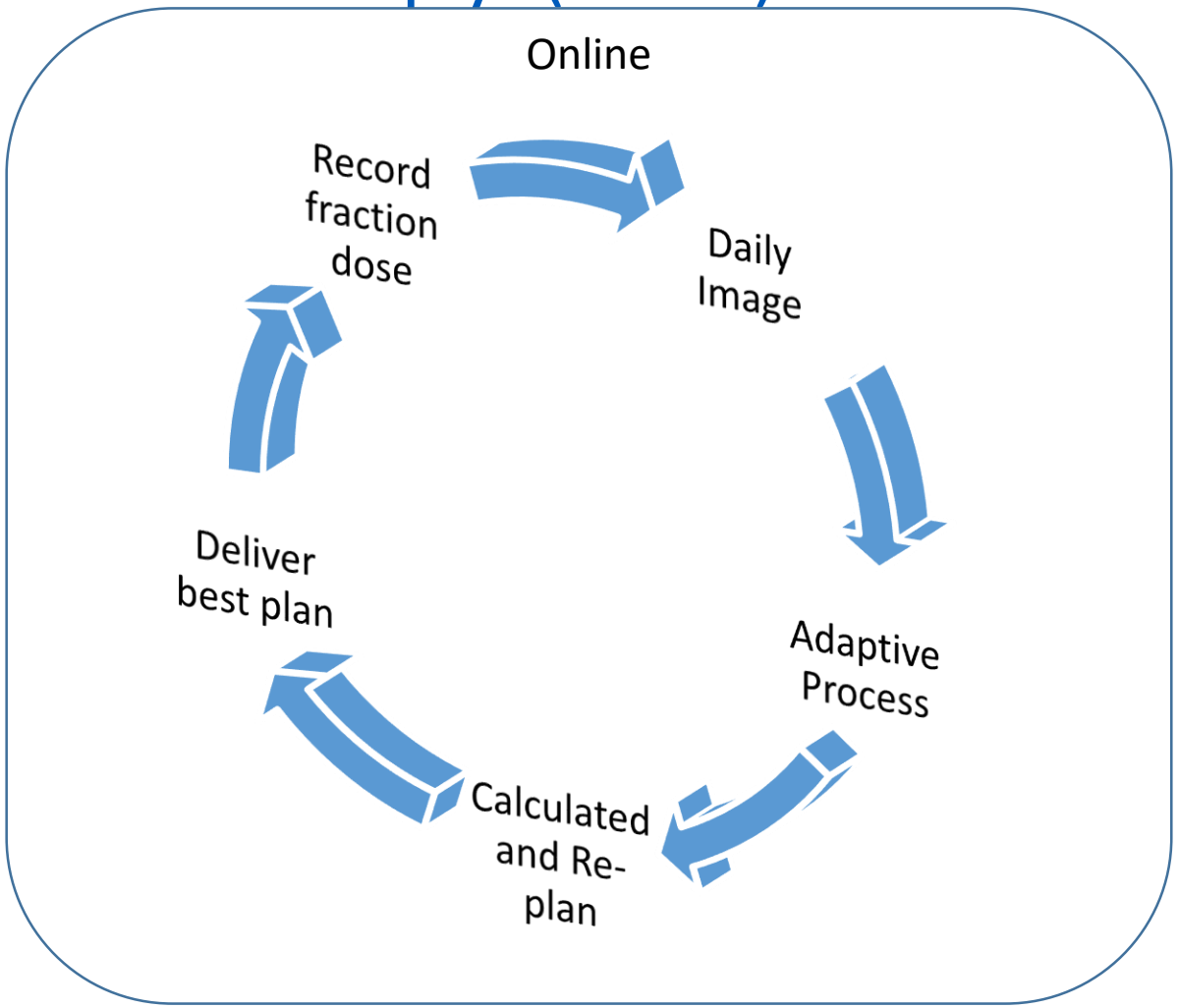
Ben Archibald-Heeren

MIRSIG Online Seminars

October 6th, 2020

Workflows of Adaptive Radiotherapy (ART)





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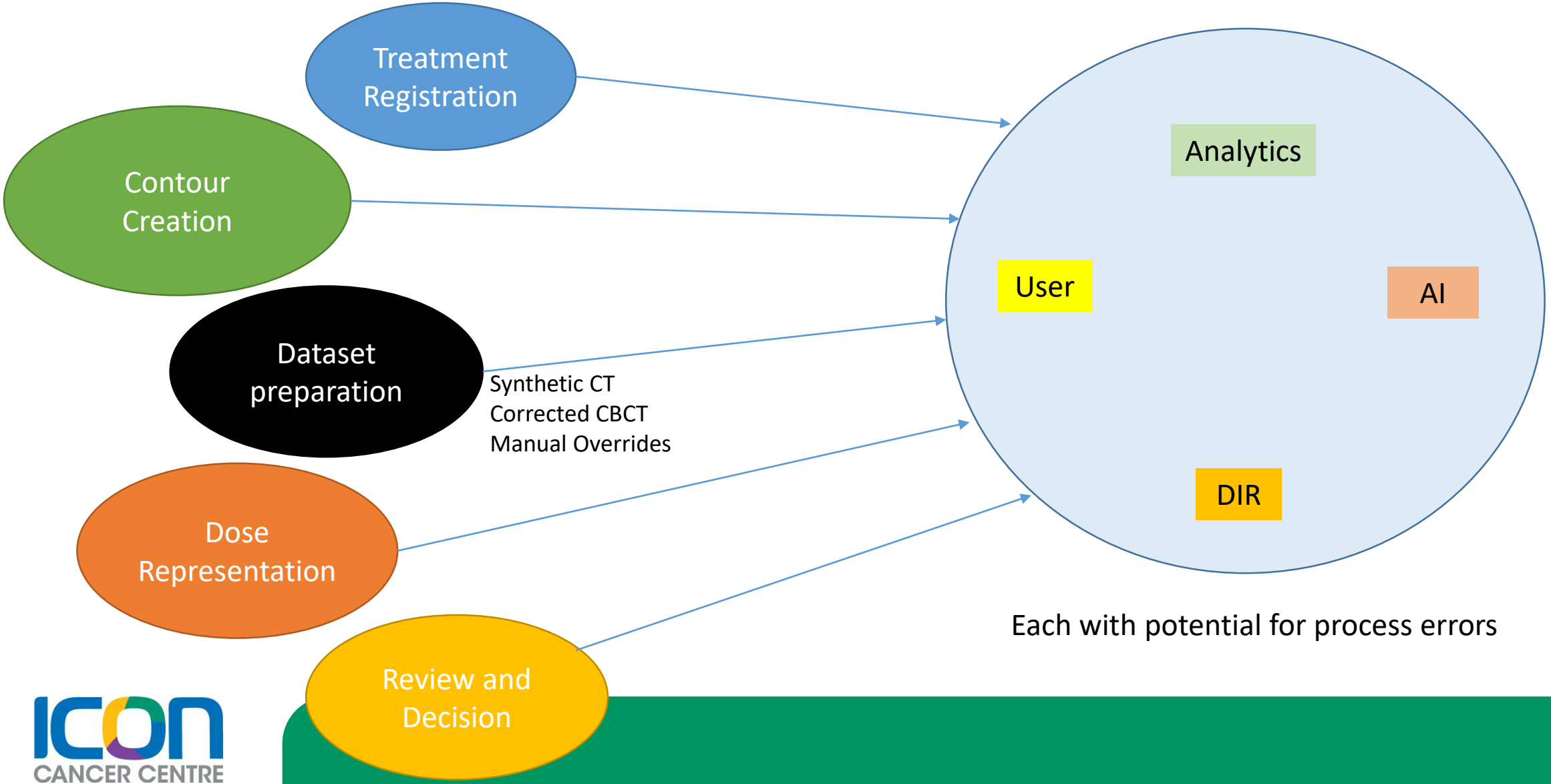
Adaptive processes and common components



Each with potential for process errors

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Risk- TG 100

$$RPN = O \cdot S \cdot D$$

The report of Task Group 100 of the AAPM: Application of risk analysis methods to radiation therapy quality management

M. Saiful Huq[a)]
Department of Radiation Oncology, University of Pittsburgh Cancer Institute and UPMC CancerCenter, Pittsburgh, Pennsylvania 15232

https://aapm.onlinelibrary.wiley.com/doi/epdf/10.1118/1.4947547

- Guideline for assessing risk of processes through failure modes and effects analysis (FMEA)
- Breaks down steps in process and possible failure modes
- Ideally implemented for any new technique or process
- Highlights areas of particular risk to focus quality assurance and methods for quality control

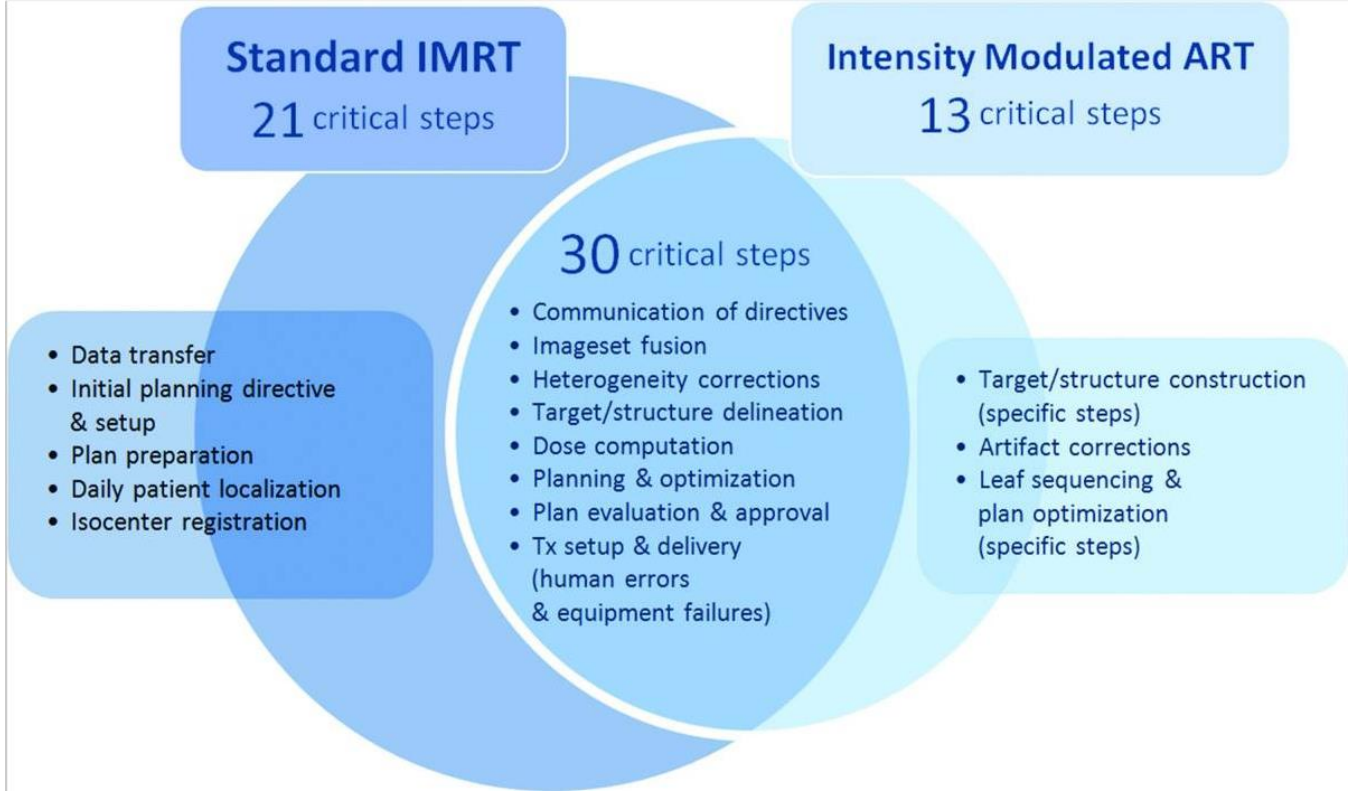
TABLE II. Descriptions of the O, S, and D values used in the TG-100 FMEA.

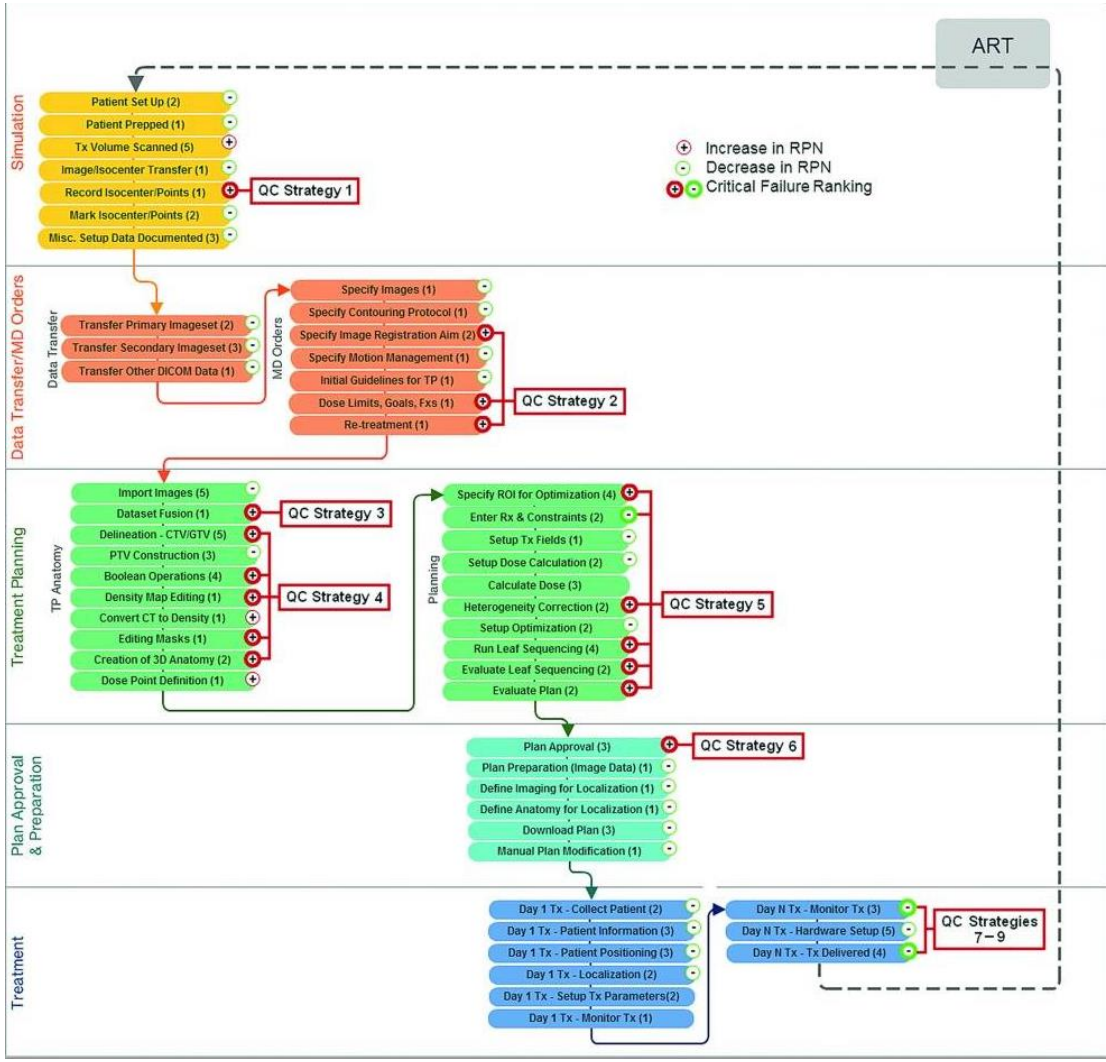
Rank	Occurrence (O)		Severity (S)		Detectability (D)
	Qualitative	Frequency in %	Qualitative	Categorization	Estimated Probability of failur e going undetected in %
1	Failure unlikely	0.01	No effect		0.01
2		0.02	Inconvenience	Inconvenience	0.2
3	Relatively few failures	0.05			0.5
4		0.1	Minor dosimetric error	Suboptimal plan or treatment	1.0
5		<0.2	Limited toxicity or tumor underdose	Wrong dose, dose distribution, location, or volume	2.0
6	Occasional failures	<0.5			5.0
7		<1	Potentially serious toxicity or tumor underdose		10
8	Repeated failures	<2			15
9		<5	Possible very serious toxicity or tumor underdose	Very wrong dose, dose distribution, location, or volume	20
10	Failures inevitable	>5	Catastrophic		>20

TABLE III. Ranking of QM tools based on the effectiveness with examples, in part following the suggestions of ISMP (Ref. 67). The lower numbers are the most effective.

1. Forcing functions and constraints
   - Interlock
   - Barriers
   - Computerized order entry with feedback
2. Automation and computerization
   - Bar codes
   - Automated monitoring
   - Computerized verification
   - Computerized order entry
3. Protocols, standards, and information
   - Check-off forms
   - Establishing protocol/clarify protocol
   - Alarms
   - Labels
   - Signs
   - Reduce similarity
4. Independent double check systems and other redundancies
   - Redundant measurement
   - Independent review
   - Operational checks
   - Comparison with standards
   - Increase monitoring
   - Add status check
   - Acceptance test
5. Rules and policies
   - Priority
   - Establishing/clarify communication line
   - Staffing
   - Better scheduling
   - Mandatory pauses
   - Repair
   - PMI (preventive maintenance inspection)
   - Establish and perform QC and QA (hardware and software)
6. Education and information
   - Training
   - Experience
   - Instruction

TG-100 Analysis ART





Process-based quality management for clinical implementation of adaptive radiotherapy

Camille E. Noel, Lakshmi Santanam, Parag J. Parikh, and Sasa Mutic[a)]

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4119199/

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TG- 100 Analysis ART

PMC full text: Med Phys. 2014 Aug; 41(8): 081717.
Published online 2014 Jul 30. doi: 10.1118/1.4890589

TABLE III.

Mitigation strategies for ART processes with critical failures.

Failure	QC strategy	Prototypes and commercial tools
(1) Isocenter documentation	Automated isocenter capture, checklists, monitoring trends in daily patient shifts	
(2) Miscommunication of planning directives and failure to properly account for dose accumulation	Well-defined protocols, stable clinical workflow, staff training, integrated record management, electronic physician order, and whiteboard systems	Santanam (Ref. 8), Mallalieu (Ref. 9)
(3) Poor dataset fusion	Automated fusion tools, specialty training for onsite staff	
(4) Incorrect target/structure delineation and construction	Automated contour integrity verification software	ImSimQA^{contour}, StructSure (not specifically designed for ART)
(5) Poor plan optimization and or incorrect dose computation	Automated software verifying: • dose computation • leaf sequencing • plan integrity	RadCalc (LifeLine Software), IMSure (Standard Imaging), muCheck (Oncology Data Systems Imaging), Sun (Ref. 16), Xing (Ref. 24), Yang (Ref. 12)
(6) Poor plan review	Automated comparisons between planning goals and achieved goals, decision support software	Zhu (Ref. 13), Moore (Ref. 14)
(7) Incorrect interpretation of plan data for treatment delivery	Independent verification software comparing data indicated by the planning to data read by the delivery system	QAPV (IHE-RO) (Ref. 15)
(8) Failures in treatment parameter setup on treatment machine	Simulated delivery, pretreatment (running gantry rotations and MLC patterns without dose output)	Sun (Ref. 16), QUASAR™ Automated Delivery QA Software (Modus Medical)
	Retrospective MLC QA, post-treatment	
(9) Failures occurring during treatment delivery	Transmission detectors	*In vivo* EPID dosimetry, DAVID harp chamber, MatriXX^{Evolution}, investigational transmission detectors [Islam (Ref. 19), Goulet (Ref. 20), Wong (Ref. 21)]
	Real-time MLC/gantry monitoring	Jiang (Ref. 22)

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Tools to help

1. Commissioning to determine limitations of systems

Use of image registration and fusion algorithms and techniques in radiotherapy: Report of the AAPM Radiation Therapy Committee Task Group No. 132

Kristy K. Brock[a)]
Department of Imaging Physics, The University of Texas MD Anderson Cancer Center, 1400 Pressler St, FCT 14.6048, Houston, TX 77030, USA

https://aapm.onlinelibrary.wiley.com/doi/epdf/10.1002/mp.12256

Journal of Medical Radiation Sciences
Open Access
PRACTICE GUIDELINE

Deforming to Best Practice: Key considerations for deformable image registration in radiotherapy

Jeffrey Barber, MMedPhys,[1,2] Johnson Yuen, MSc,[3,5,6] Michael Jameson, PhD,[4,5,6] Laurel Schmidt, BSc,[3] Jonathan Sykes, PhD,[1,2] Alison Gray, MAppSc,[4,5,6] Nicholas Hardcastle, PhD,[7,8] Callie Choong, BScApp,[4] Joel Poder, MSc,[3,8] Amy Walker, PhD,[4,5,6] Adam Yeo, PhD,[7,9] Ben Archibald-Heeren, MSc,[10] Kristie Harrison, MPhil,[11] Annette Haworth, PhD,[2] & David Thwaites, PhD[1,2]

https://onlinelibrary.wiley.com/doi/epdf/10.1002/jmrs.417

2. QC to ensure process safety and quality

Standardised reporting templates

- Offline Adaptive Evaluation Report Public V1.1 –(DOWNLOAD XLS LINK)

This worksheet has been developed by the ACPSEM Medical Imaging Registration Special Interest Group (MIRSIG). The sheet has been created through consensus between centres experienced in deformable registration and offline adaptive techniques with two specific intents: (1) To provide a measure of guidance for centres looking to incorporate new offline adaptive techniques and (2) To drive consistency among Australasian centres in documenting process, quality assurance and outcomes of offline adaptive analysis. The sheet is designed to assist in the offline assessment of dosimetry impacts of patient changes on treatment in respect to the need for a treatment replan. As an example, this sheet may be used in assessing the need for a replan after a week 3 fraction image of a head and neck patient shows considerable weight loss.

Note that this is a public version of a template as a voluntary standard. Each institution is responsible for their clinical decisions and processes. For more guidance, please see the webinar resources linked to this template (scheduled MIRSIG October 2020 Talk)

Note that there is a MIRSIG Offline Adaptive Data Collection Sheet Public V1.0 developed by the ACPSEM Medical Imaging Registration Special Interest Group (MIRSIG) to data mine from the MIRSIG Offline Adaptive Report Template. This searches all reports in a specified directory to provide statistics on all report data. Contact mirsig@acpsem.org.au for a copy of this spreadsheet.00B

Resources

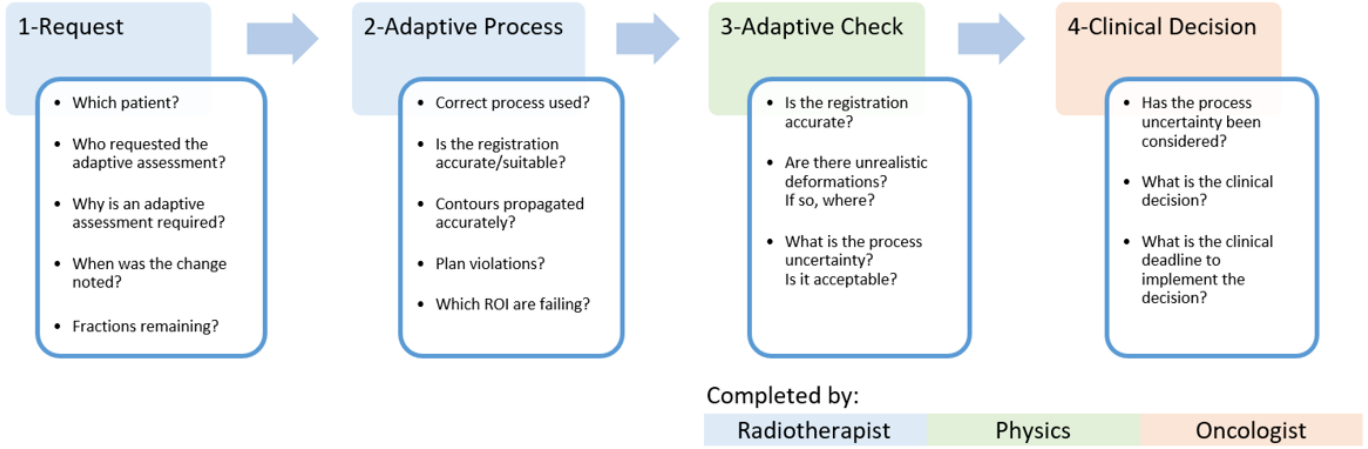
- MIRSIG list of open datasets for deformable image registration V1.2 - PDF (840KB)

MIRSIG has generated a list of open source datasets suitable for deformable image registration. The idea is to collect as many open source datasets as possible from experts in medical imaging and radiation oncology community with a primary aim of using it to validate deformable image registration (DIR) systems. The secondary aim is to identify any gaps as per clinical need (e.g. body sites). For more guidance, please see the webinar resources linked to this template (scheduled MIRSIG March 2021 Talk)

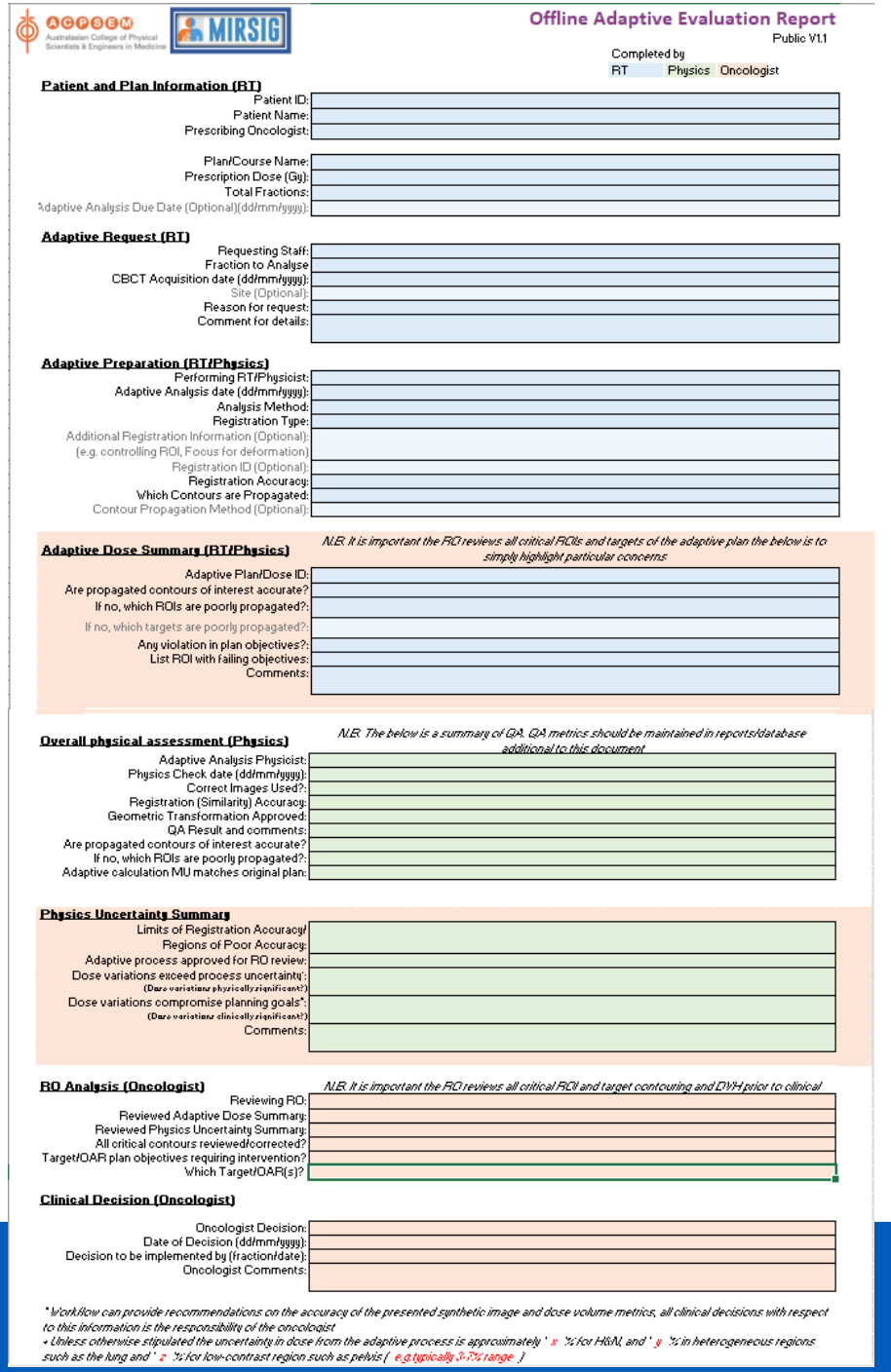
https://www.acpsem.org.au/About-the-College/Special-Interest-Groups/MIRSIG

MIRSIG Offline Adaptive Sheet

- A standardized format for assessing dose impacts of patient changes on treatment
- Developed from input from expert national sites and a nationwide survey
- Split into components



- Anonymized data for long term data collection and trends across Aus/NZ



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7 major risks – each with multiple modes of error

Communication

Image Registration

Segmentation

Plan Re-creation

Dose Determination

Interpretation

Intervention

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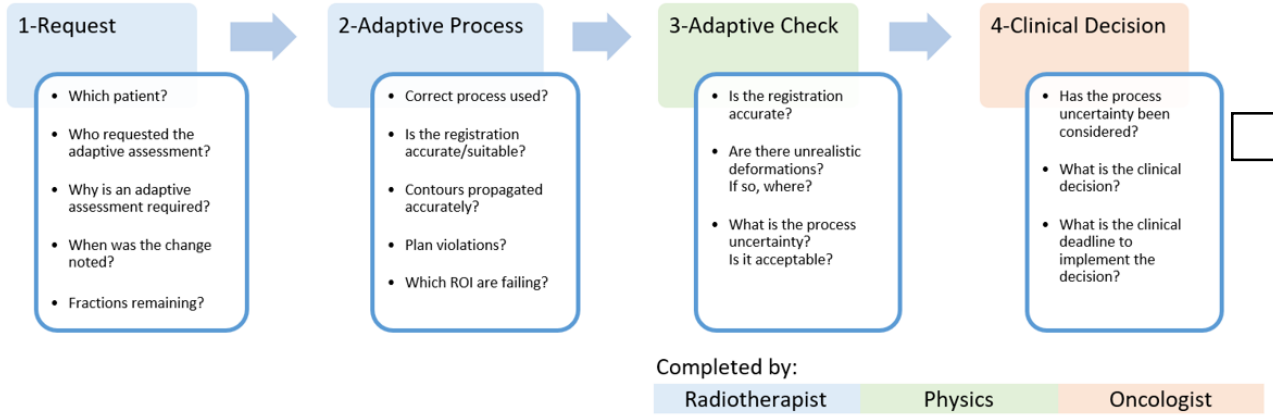
Risks- Communication

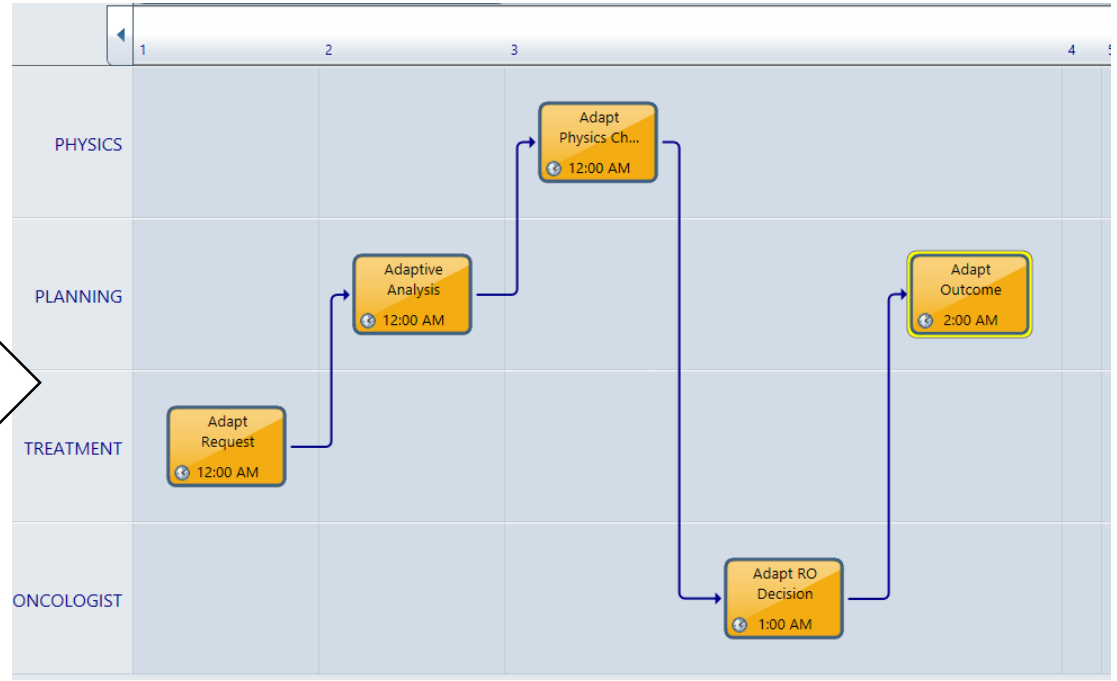
- Delays in Analysis
  - Sub-optimal treated fractions that could be avoided
  - Unnecessary changes in plans
  - Delays in patient treatment
- Clear protocols and timelines
- Workflows implemented in R&V
- Structures of implementation and Reporting

Adaptive Dose Summary (RT/Physics)

N.B. It is important the RO reviews all critical ROIs and targets of the adaptive plan the below is to simply highlight particular concerns

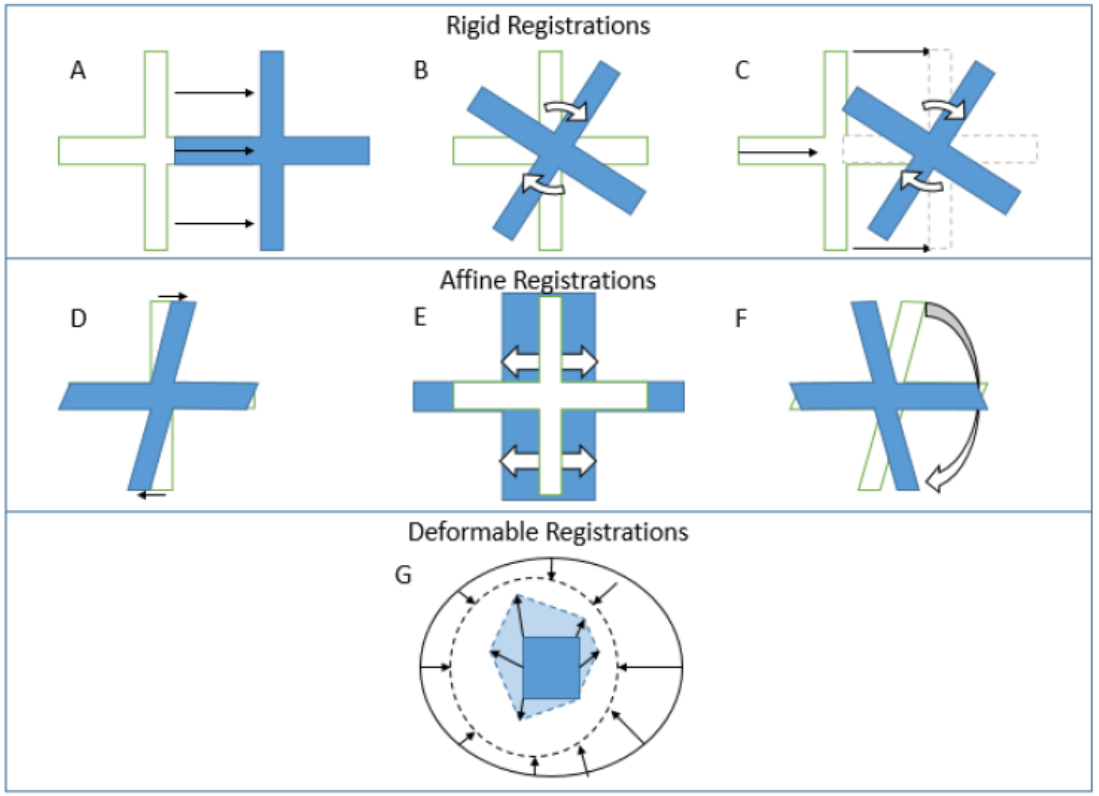
Adaptive Plan/Dose ID:	
Are propagated contours of interest accurate?	
If no, which ROIs are poorly propagated?:	
If no, which targets are poorly propagated?:	
Any violation in plan objectives?:	
List ROI with failing objectives:	
Comments:	





Risks- Image Registration

- Online review needs to be used to ensure accurate plan re-creation
- Two major risks
  - Poor initial match
  - Adaptive processes applies a different match to the online registration
    - Incorrect image
    - Incorrect translation



Analysis Method:	2: Calculate on treatment image
Registration Type:	1: Rigid
Additional Registration Information (Optional): (e.g. controlling ROI, Focus for deformation)	
Registration ID (Optional):	Online Treatment Registration
Registration Accuracy:	2: Locally aligned (targets)

Adaptive Analysis Physicist:	
Physics Check date (dd/mm/yyyy):	
Correct Images Used?:	

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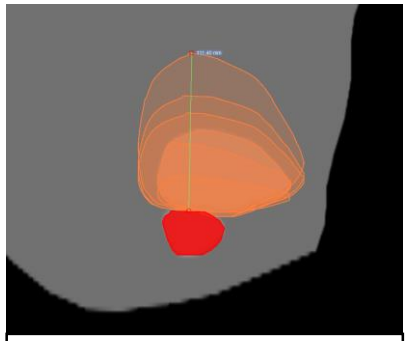
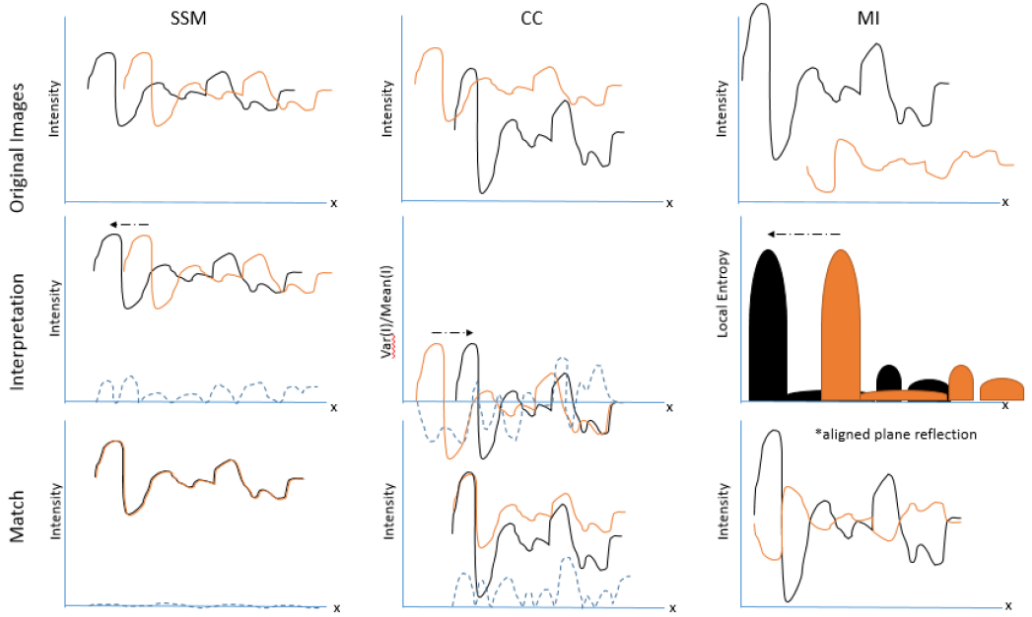
DIR- Commissioning

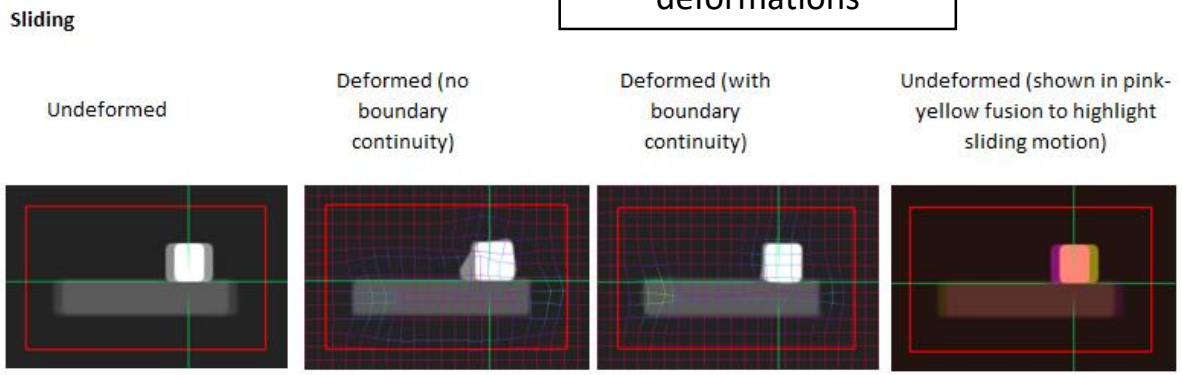
- Know your algorithm
  - Limitations- TG132 digital phantoms (Table V)
    - Performance in low contrast- CT vs CBCT
    - Magnitude limitations- transform constraints
    - Focus Region effects
    - Structure guided
    - Sliding geometries
    - Consistency
    - Voxel effects



ImSimQA synthetic deformations



SSM= Sum of Square Metric CC= Correlated Coefficient MI= Mutual Information



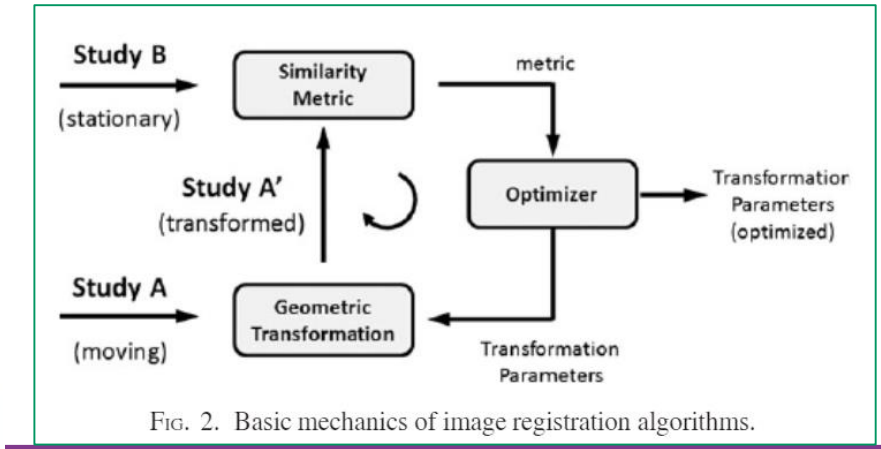


FIG. 2. Basic mechanics of image registration algorithms.

https://aapm.onlinelibrary.wiley.com/doi/epdf/10.1002/mp.12256

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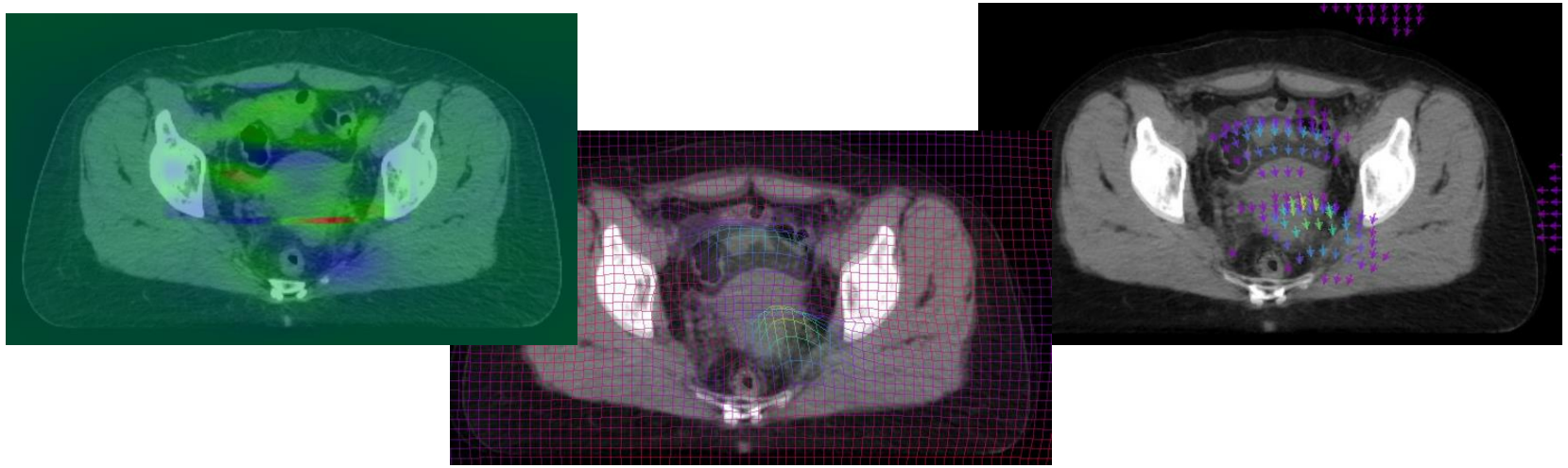
Risks- DIR Patient Specific

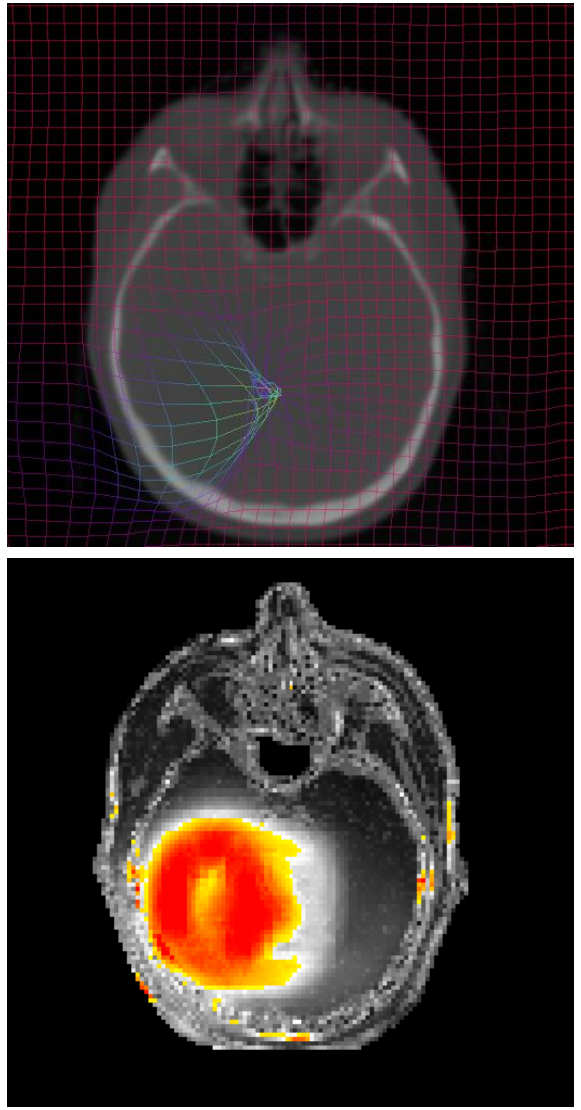
Overall physical assessment (Physics)

N.B. The below is a summary of QA. QA metrics should be maintained in reports/database additional to this document

Adaptive Analysis Physicist:	
Physics Check date (dd/mm/yyyy):	
Correct Images Used?:	
Registration (Similarity) Accuracy:	
Geometric Transformation Approved:	
QA Result and comments:	
Are propagated contours of interest accurate?	
If no, which ROIs are poorly propagated?:	
Adaptive calculation MU matches original plan:	

- Jacobians, TRE, Grid Review, Vectors, Other



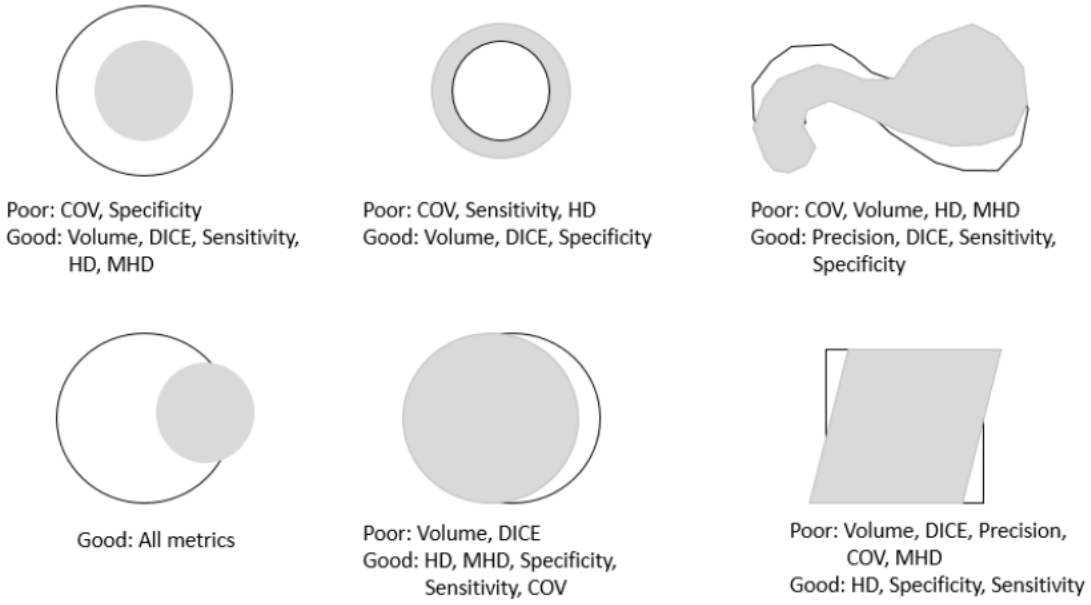


- Different QA standard for different processes-
  - propagation vs synthetic CT vs dose deformation

Mikel Byrne- 2019

Risks- Segmentation Commissioning

- Systematic Commissioning
  - Typically performed using pre-contoured gold standard datasets
  - DIR ROI propagation analysed against gold standard contours



$$\mathrm{DSC} = \frac{2\,|S_{(gold)} \cap S_{(var)}|}{S_{(gold)} + S_{(var)}}$$

$$Prescision = \frac{S_{(gold)} \cap S_{(var)}}{S_{(gold)} \cup S_{(var)}}$$

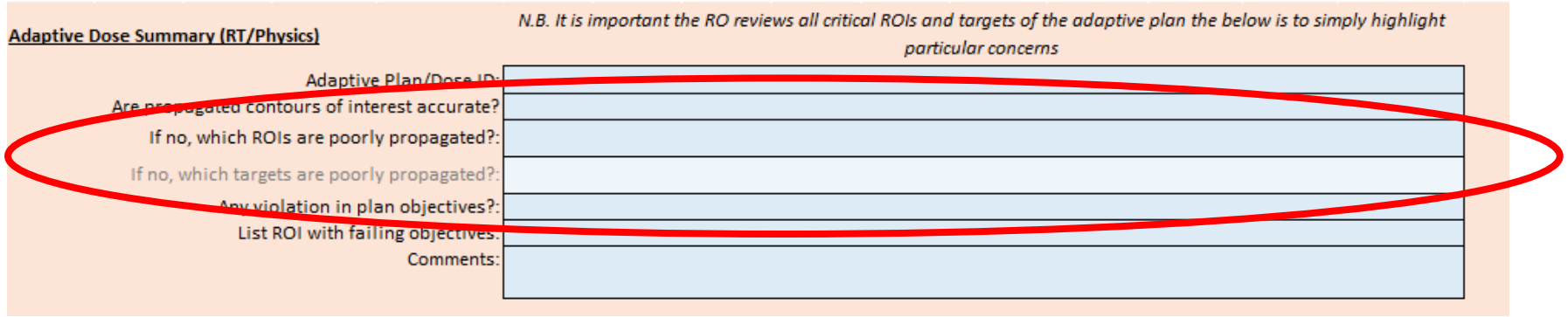
$$Sensitivity = \frac{S_{(gold)} \cap S_{(var)}}{S_{(gold)}}$$

$$Specificity = 1 - \frac{|\,S_{(var)}{}^{\sim} \cap S_{(gold)}|}{S_{(gold)}}$$

$$HD = d_H(X,Y) = max\{sup_{x \in X} inf_{y \in Y}\, d(x,y), sup_{y \in Y} inf_{x \in X}\, d(x,y)\}$$

Risks- Propagated Segmentation Patient Specific

- Propagation
  - Patient specific typically qualitative



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Any violation in plan objectives?:	
List ROI with failing objectives:	
Comments:	

  - Contours are checked at multiple stages
    - Adaptation
    - Check
    - RO
  - Contours are adjusted where necessary
  - Structure guided deformations can be performed with corrected ROI
  - Poor performing structures are recorded to highlight regions of poor accuracy over historical data

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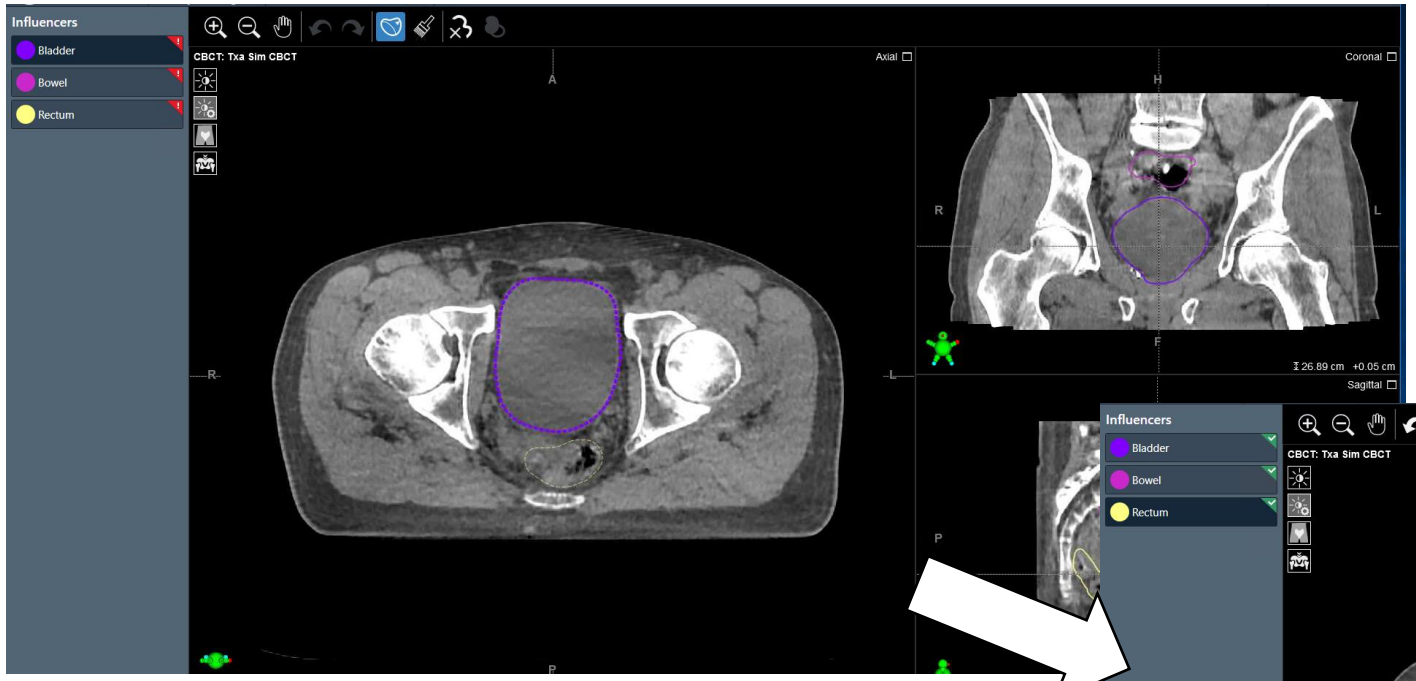
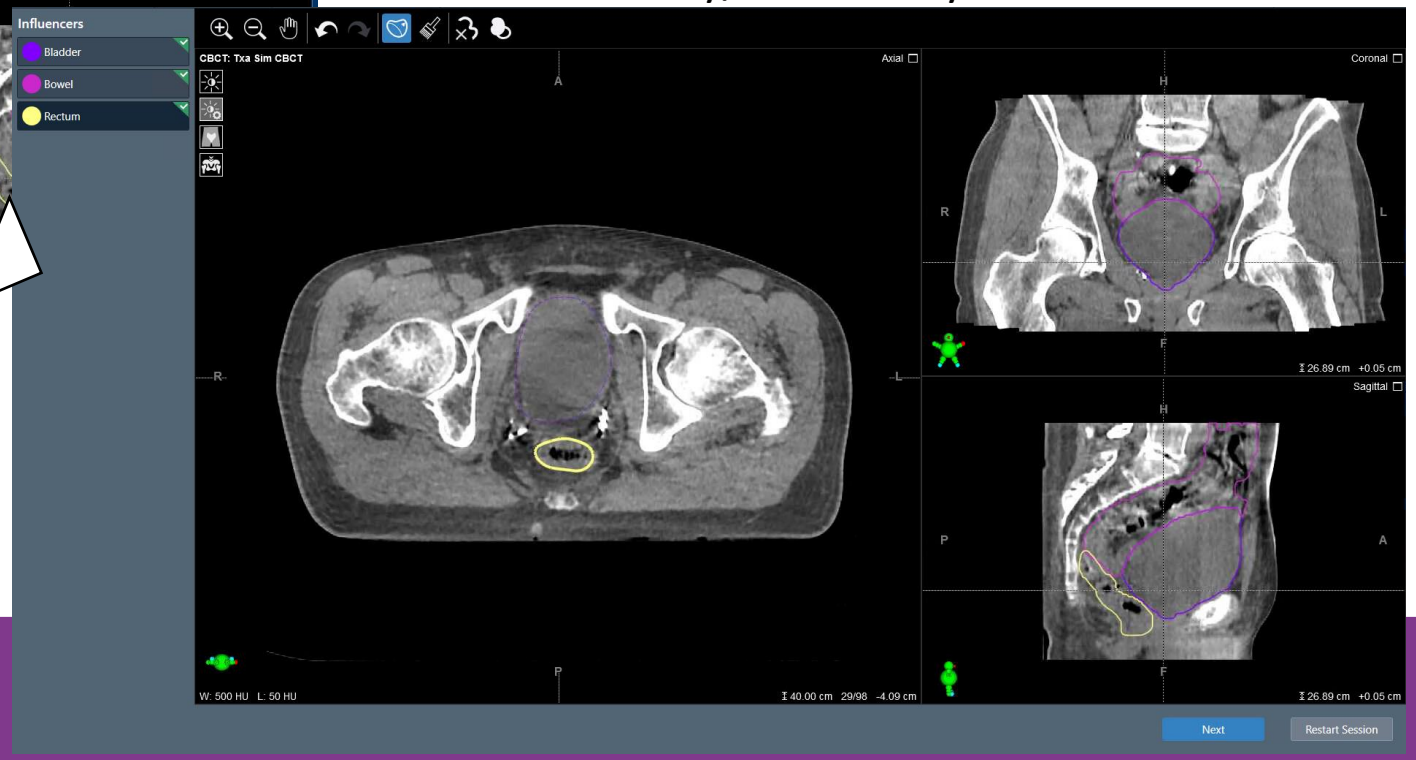
Risks- AI Segmentation





- Ethos AI generated “Influencers”
- Software integration requiring slice by slice review of contours
- User reviews/adjustment
- Protocol guidelines for contouring extents to ensure accuracy/consistency

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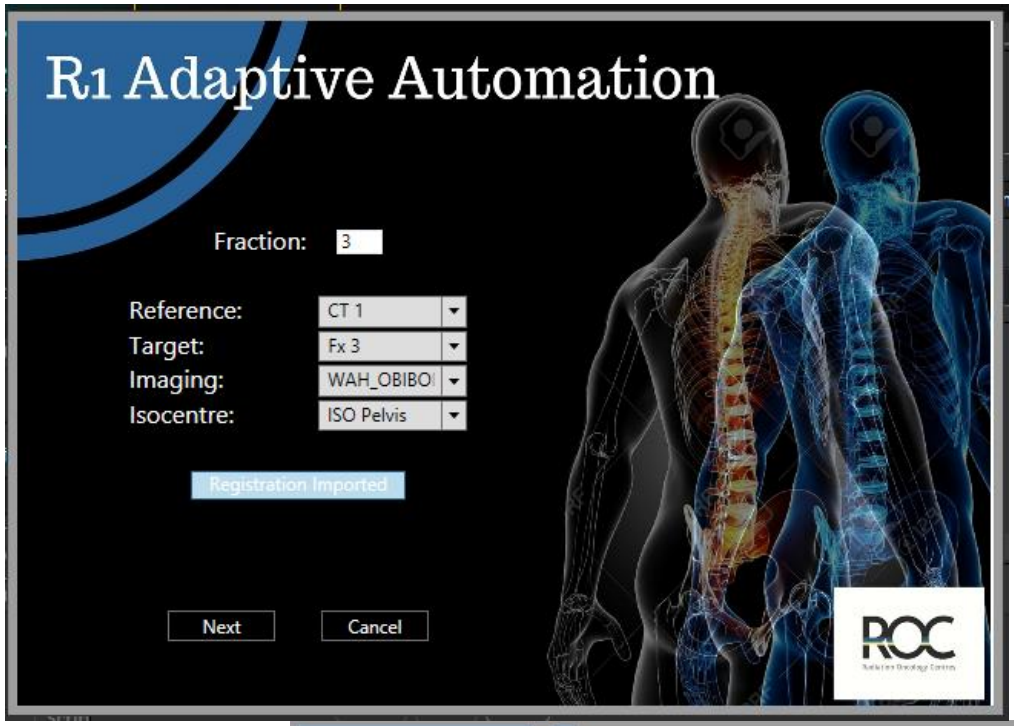
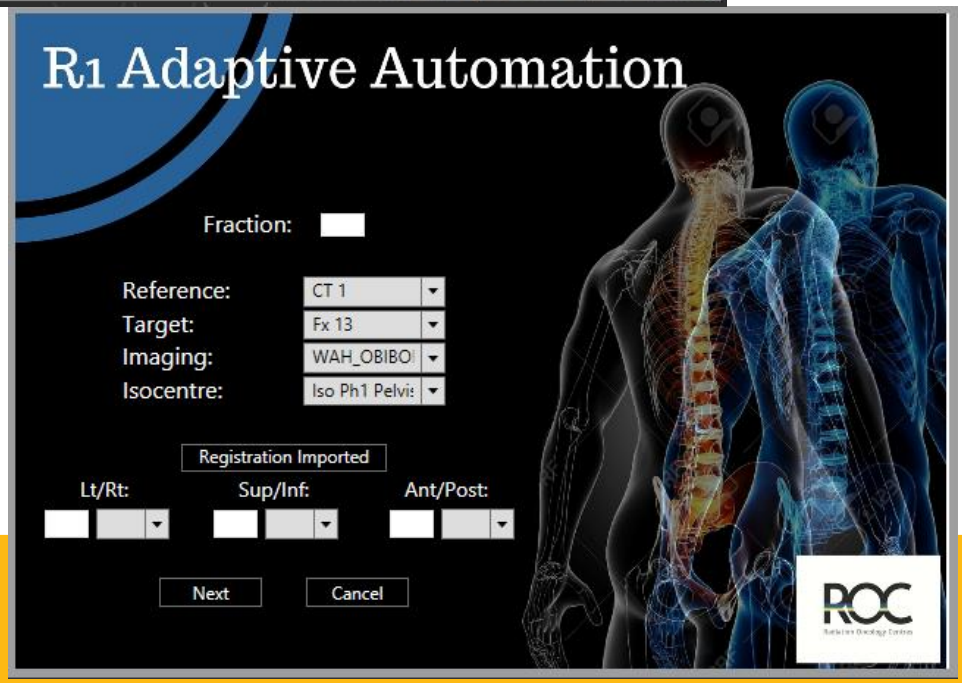
Risks- Plan Re-creation

- Isocentre re-creation
  - Translated through DICOM registration
    - Lower risk- visual check in process
  - Manually entered shifts on couch
    - Greater risk
    - Multiple human checks of input should be considered
- Beam re-creation
  - Segments re-created correctly
  - MU consistent
  - Use of scripts
  - Initial TPS verification may be sufficient other than basic checks
- As per TG-100, automation (once validated) allows for the consistency in these processes as well as efficiency
- Online Adaptive Only-
  - Deliverability
  - Optimization





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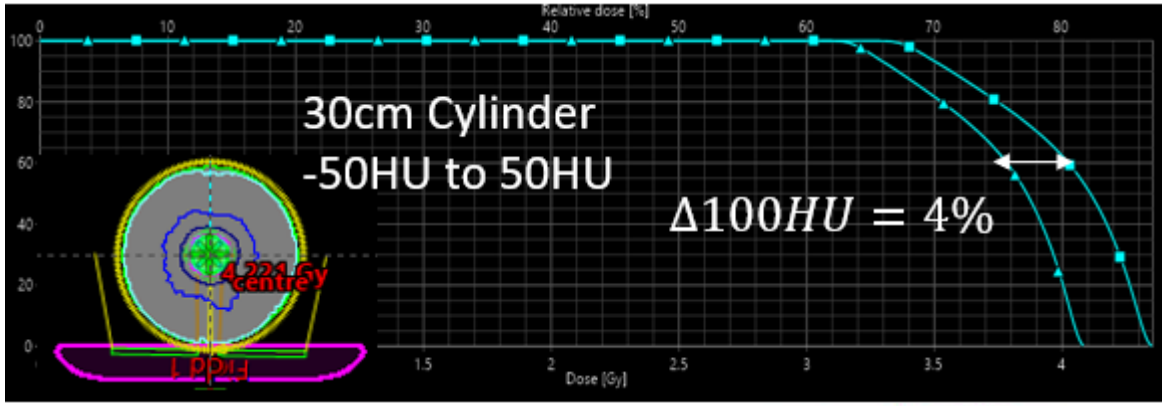
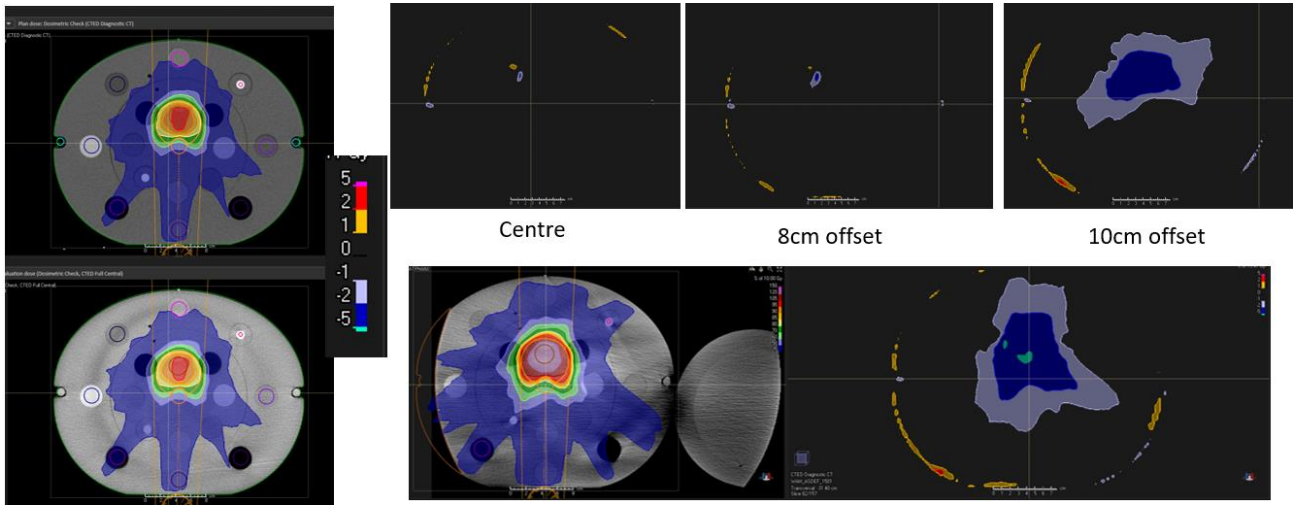
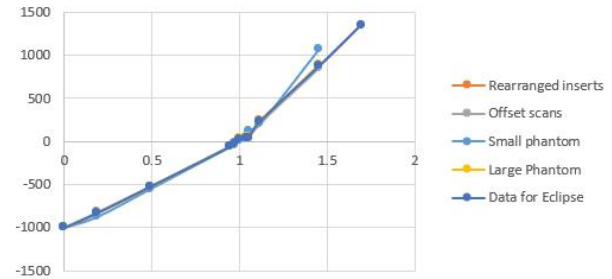
Risks- Dose Calculation

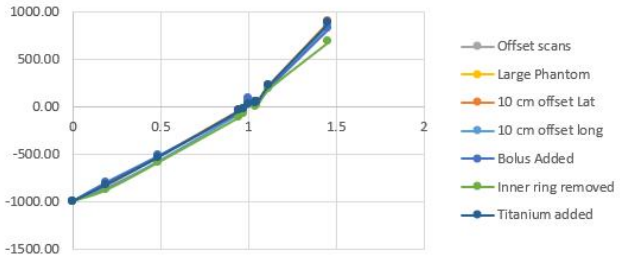
- Commissioning
  - CBCT calculations
    - Dose Uncertainty
    - Impacts of offsets
    - Scatter condition changes



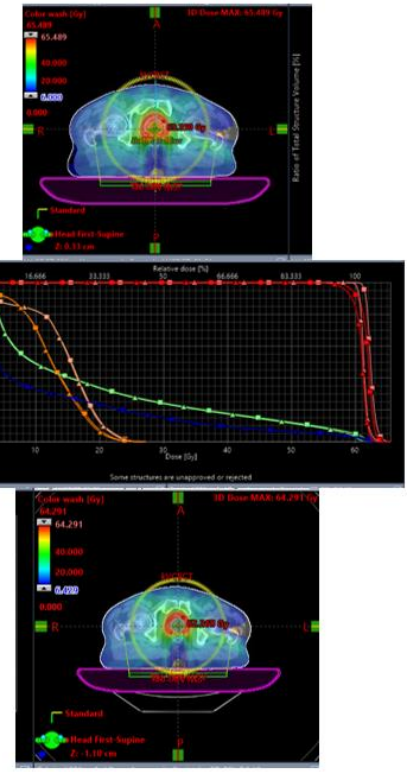


iCBCT





- Talia Jarema, ICON, 2019



Risks- Dose Calculation- System Specific

- CBCT
  - Dataset length- overrides or stitching
  - Artefacts
- Synthetic CT
  - Removes the HU curve uncertainty
  - Sensitive to DIR errors- focus on high/low densities
  - Issues with dealing with large contrast changes
  - Mass conserving
- HU Corrected CBCT
  - Corrections for CBCT HU performed by deforming CT to CBCT and determining HU bin corrections ratios
    - E.g. Average muscle in CT = 100 HU, CBCT = 50 HU, factor = 2.0 and applied to all voxels in the muscle range
  - Reliant on deformation accuracy

Risks- Analysis/Decisions within Uncertainty

- Physics role is to advise on the uncertainty
- On deformation and it's effects
  - On synthetic CT
  - Contour accuracy
- On the dose calculation
  - Uncertainty in dose for calculation method
    - CBCT- anatomy specific and impact of processes (stitching/overrides)
    - Synthetic CT- deformation specific
    - HU corrected CBCT
    - Uncertainty should be quantified
- RO role is to understand these uncertainties in making their clinical decision

Physics Uncertainty Summary

Limits of Registration Accuracy/ Regions of Poor Accuracy:	Registration is accurate about the CTVp and rectum, significant errors at the superior bladder
Adaptive process approved for RO review:	1: Yes
Dose variations exceed process uncertainty+: (Dose variations physically significant?)	2: No
Dose variations compromise planning goals*: (Dose variations clinically significant?)	2: Yes (borderline) - consider replanning, adjusting treatment or continued monitoring
Comments:	Variation in max dose is 4%, within process uncertainty of +/- 5%

RO Analysis (Oncologist)

N.B. It is important the RO reviews all critical ROI and target contouring and DVH prior to clinical decisions

Reviewing RO:	
Reviewed Adaptive Dose Summary:	1: Yes
Reviewed Physics Uncertainty Summary:	1: Yes
All critical contours reviewed/corrected?	1: Reviewed with no edits required

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** Workflow can provide recommendations on the accuracy of the presented synthetic image and dose volume metrics, all clinical decisions with respect to this information is the responsibility of the oncologist*

+ Unless otherwise stipulated the uncertainty in dose from the adaptive process is approximately 'x'% for H&N, and 'y'% in heterogeneous regions such as the lung and 'z'% for low-contrast region such as pelvis (e.g.typically 3-7% range)

Risks- Intervention

- Clear documentation and reporting of each process in the offline adaptive workflow
- Decision should be clearly determined with dates for intervention

Clinical Decision (Oncologist)

Oncologist Decision:	6: Re-sim and replan
Date of Decision (dd/mm/yyyy):	05/Oct/20
Decision to be implemented by (fraction/date):	Fx 15
Oncologist Comments:	Considerable bladder changes sustained over multiple fractions. Re-sim and re-plan required by Fx15

- Historical tracking of results correlated to changes can allow for more efficient processes/flag higher risk patients

Poll Questions

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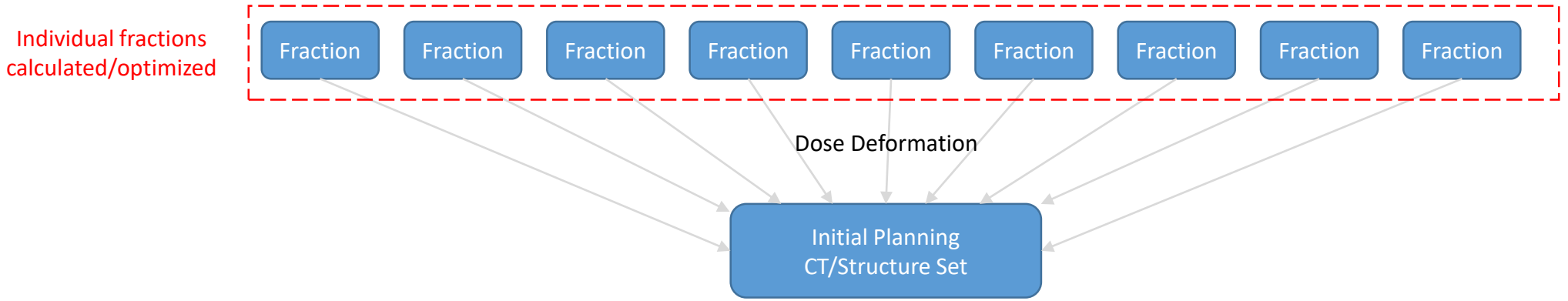
Risks- Dose Accumulation

- Long term goal, such as with systems like Ethos is daily online adaptive with dose accumulation.
- This allows for the potential for more accurate dose reporting, morbidity correlation and more accurate response models
- Not currently implemented by any Ethos users (to my knowledge) due to difficulties of assessment of dose deformation and accumulation



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

Questions and Answers from the October 2020 Webinar Chaired by Adam Yeo (Talk 1 by Ben Archibald-Heeren)

Question 1: How much of DVH accuracy by ART would translate into Clinical outcomes? What tolerance to apply ART or no ART?

Answers:

The question of DVH accuracy really depends on the processes you implement and their uncertainties. In pelvic cases with our specific iCBCT imaging we have validated the dose calculations to be within +/- 2%. This then forms the absolute minimum deviation in clinical goals that we would consider "real" and thus considered for adjusting. Further considerations need to then take place as to the likely consistency of the change and the oncologists decision on the clinical significance. Two common examples we see changes in are a) relative breast change with respect to Ph2 sites and b) bowel doses with respect to bladder filling. These cases can result in replan triggers with dose variations of < 5% if the change is consistent. Clinical outcomes are somewhat outside the scope of this presentation and will require long term clinical trials to determine.

Question 3: In addition to offline adaptive assessment, what is the potential of standardised reporting with the MIRSIG spreadsheets for other applications such as re-treatments and dose accumulation?

Answers:

The intent was to release the offline adaptive sheet first as it was perceived to provide the greatest unmet need in the current environment. If the sheet proves beneficial to the community follow up sheets will be developed with priority given on consensus from the ANZ community

Question 2: How would the MIRSIG offline adaptive assessment take feedback from ANZ centres into considerations, and how could it be integrated into oncology information systems?

Answers:

Our hope is that the spreadsheet act as a tool to sites across ANZ. The sheet itself provides email contact details for feedback. After the initial 6 month period comments and feedback will be collected from all the sites using the sheet. MIRSIG will look to invite those reviewing parties to contribute in the changes to a revised version of the sheet which will then be released through the MIRSIG site.

We welcome any sites interested to use the sheet and provide feedback.