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

This seminar (1200, Tue 7th July 2020) is chaired by Laurel Schmidt

- Talk 1: **Current Practices in Clinical Use for Rigid and Deformable Image Registration: Survey Results and Analysis**

Presented by Johnson Yuen

- Talk 2: **Deforming to best practice: Key considerations for deformable image registration in radiotherapy**

Presented by Jeffrey Barber

**Webinar activities!!**

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

**Liver 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

# Deforming to best practice

## Key Considerations For DIR In Radiotherapy

MIRSIG Webinar June 2020

Jeff Barber

Senior ROMP, Sydney West Radiation Oncology Network

Blacktown Cancer & Haematology Centre | Crown Princess Mary Cancer Centre Westmead

# Learning Objectives

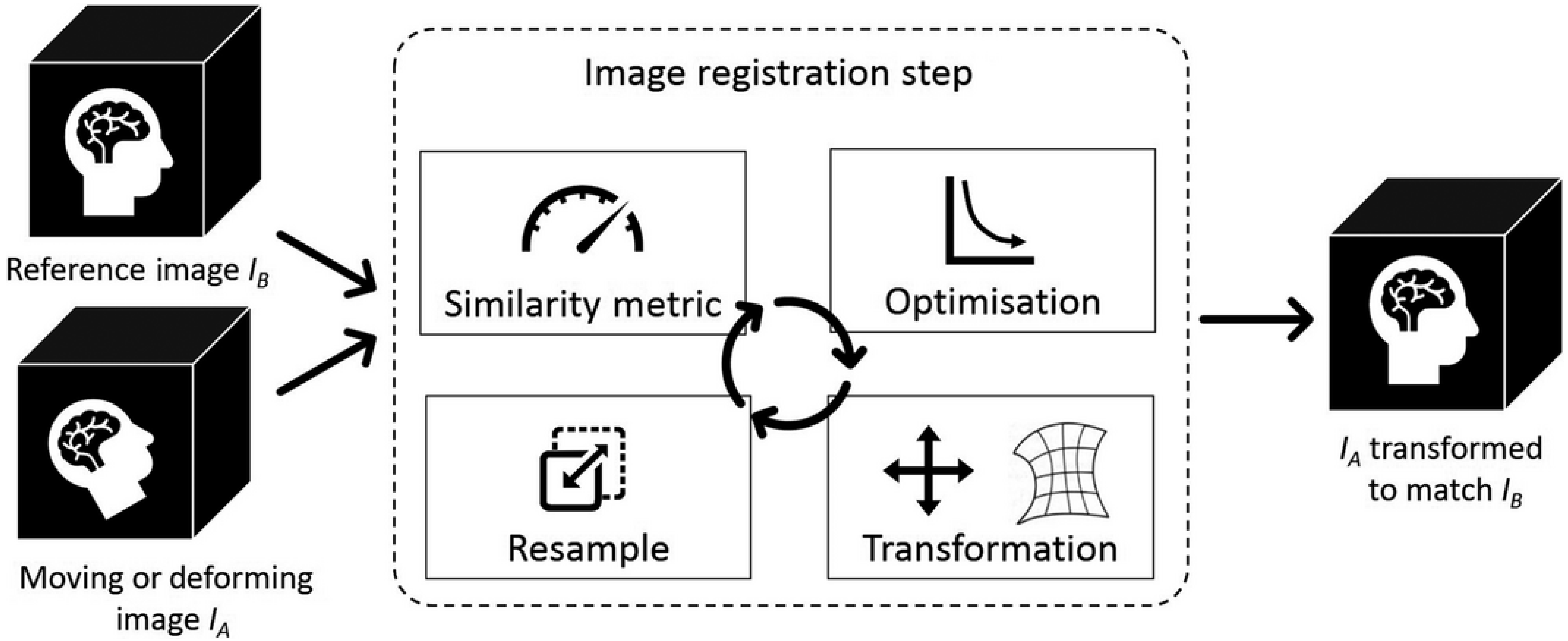
- Know strategies for evaluation and implementation of DIR in multidisciplinary radiotherapy workflows
- Appreciate limitations of DIR for applications in radiotherapy
- Apply best practice recommendations to the use of DIR in radiotherapy

Last month John Kipritidis provided an excellent summary of the AAPM TG-132 recommendations

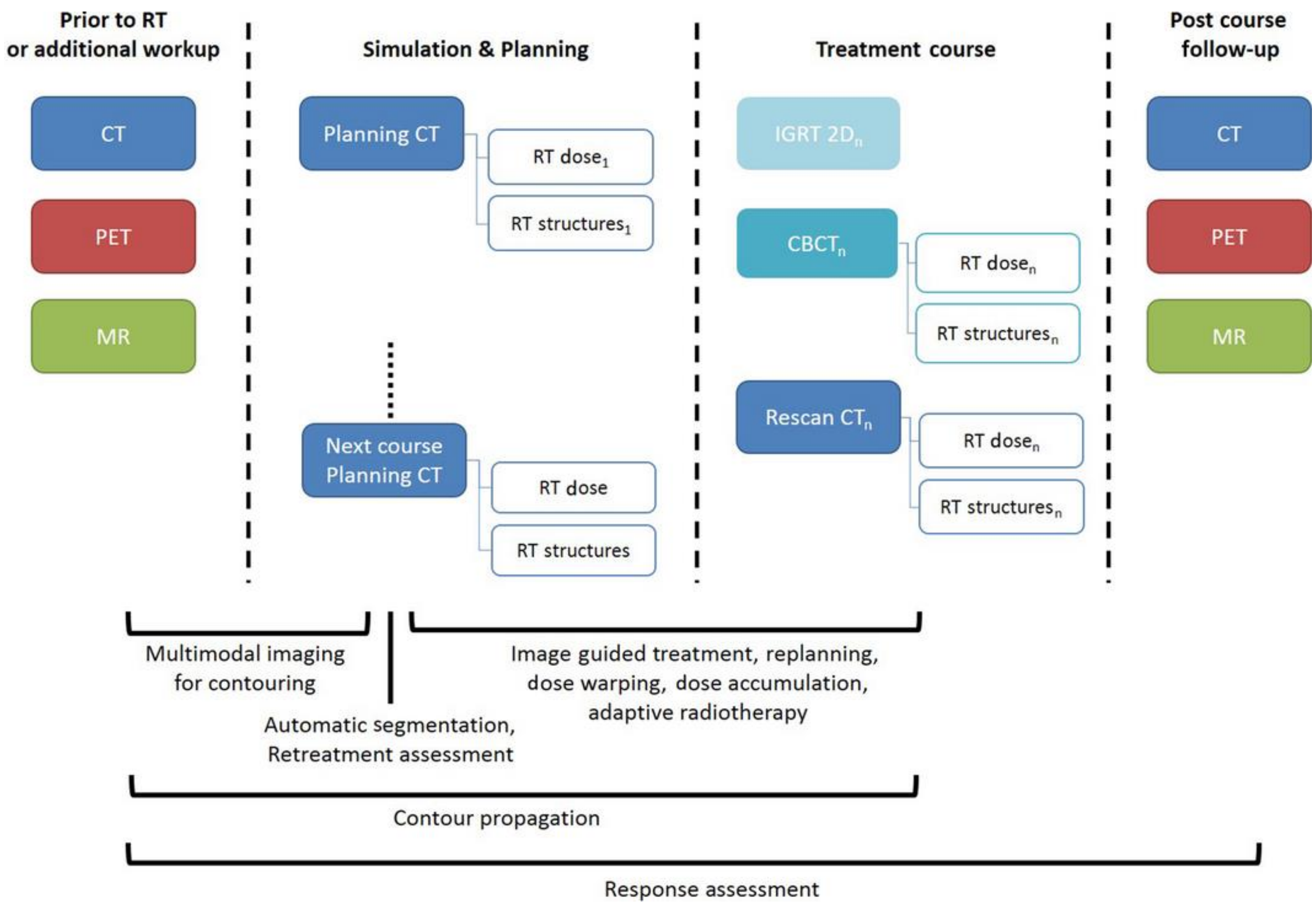
I’m going to discuss starting to move beyond TG-132…

# Poll #3

# General Image Registration Process



# Datasets along patient journey



# What does AAPM TG-132 say about DIR?

- General advice applies to rigid and deformable
- More advanced applications are beyond scope

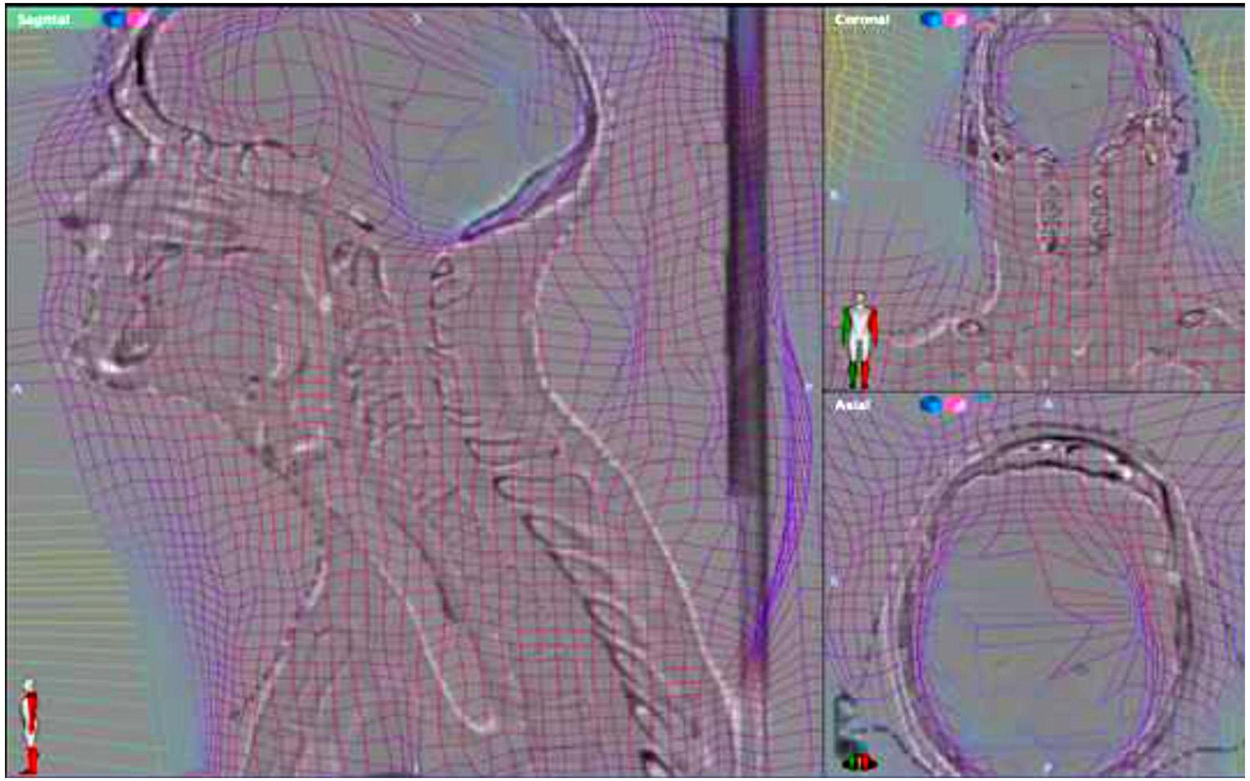
use of the registration to accumulate the dose. However, it is important to note the use of deformable registration to accumulate dose has additional demands on accuracy compared to the use of deformable registration for contour propagation. For dose accumulation, the correspondence of every voxel receiving significant dose should be accurately aligned, whereas for contour propagation the accuracy is most important at the boundary of the organ. The use of deformable registration for dose accumulation and subsequent adaptive replanning is outside of the scope of this task group. It is recommended that these issues be addressed in a subsequent task group. Protocols should be defined to guide the process for each treatment site, accounting for expected uncertainties and ensure detection of unexpected levels of uncertainties. In addition, when

# Problems with DIR

- DIR
  - is a tool
  - a mathematical process to transform voxels
  - only knows what we give it as inputs (GIGO)
  - little/no representation of physical constraints and characteristics
  - little/no free variables for user to control

# Differences between Algorithms & Regularisation

**Fluid Deformable**




**Elastic Deformable**

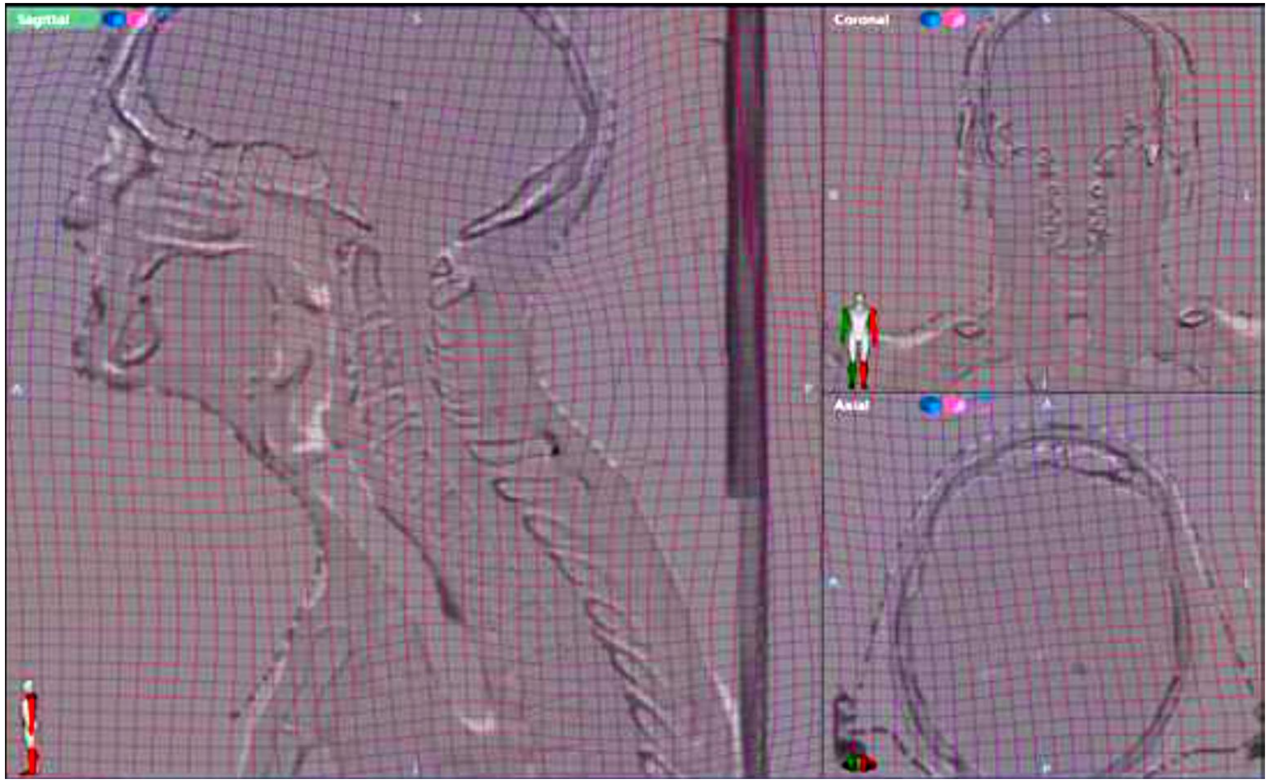
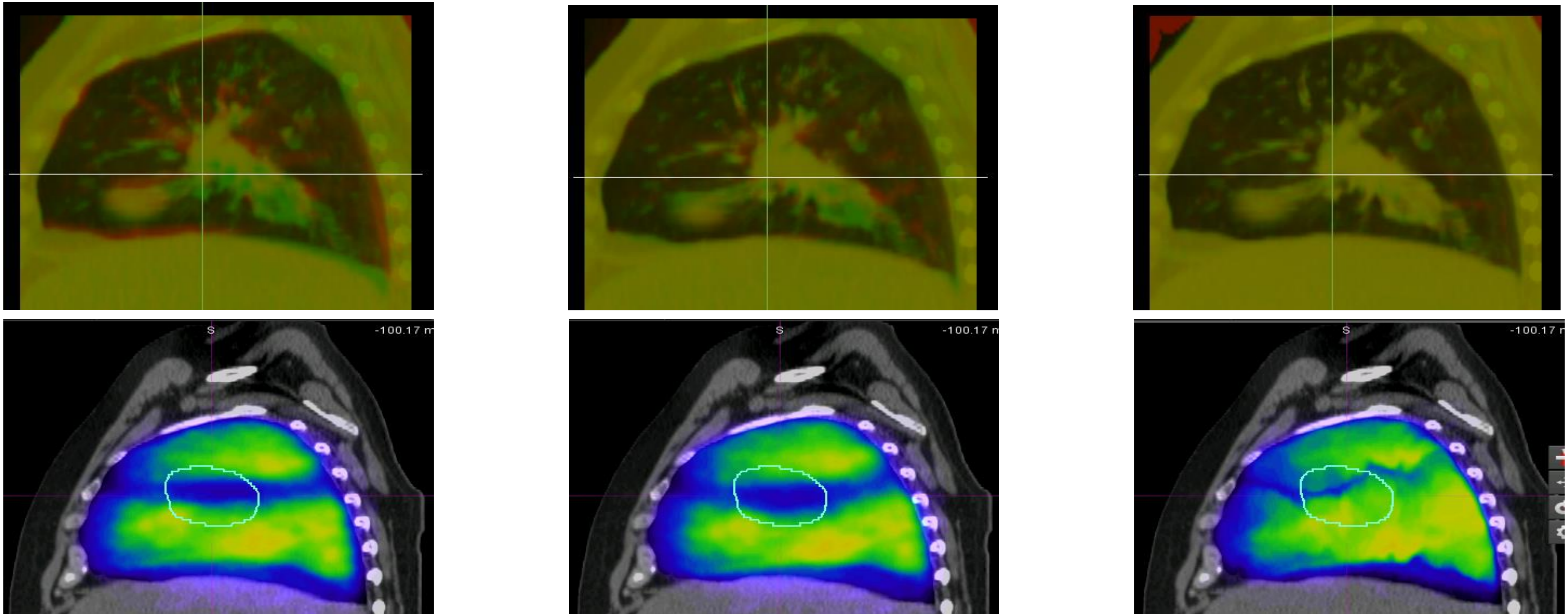



Image from Varian Medical Systems

# DIR for Image Warping – Associated image sets

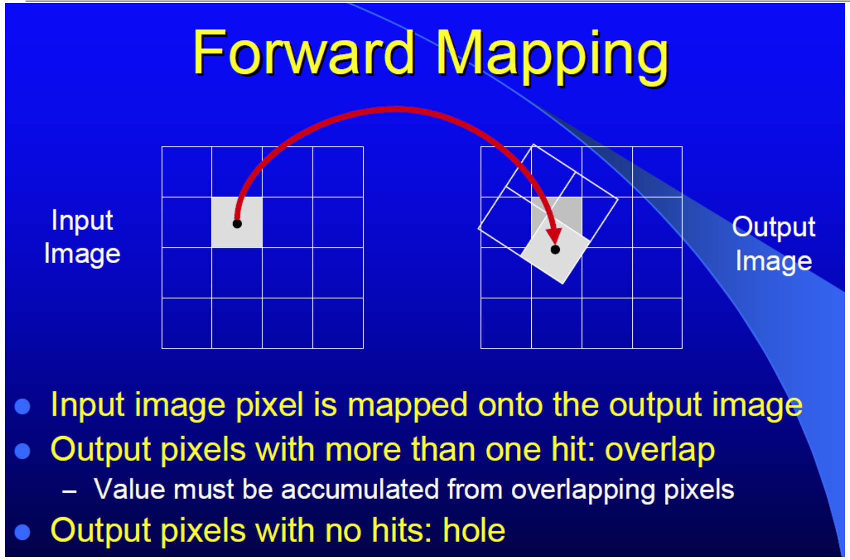
**Rigid registration** **B Splines** **Demons**

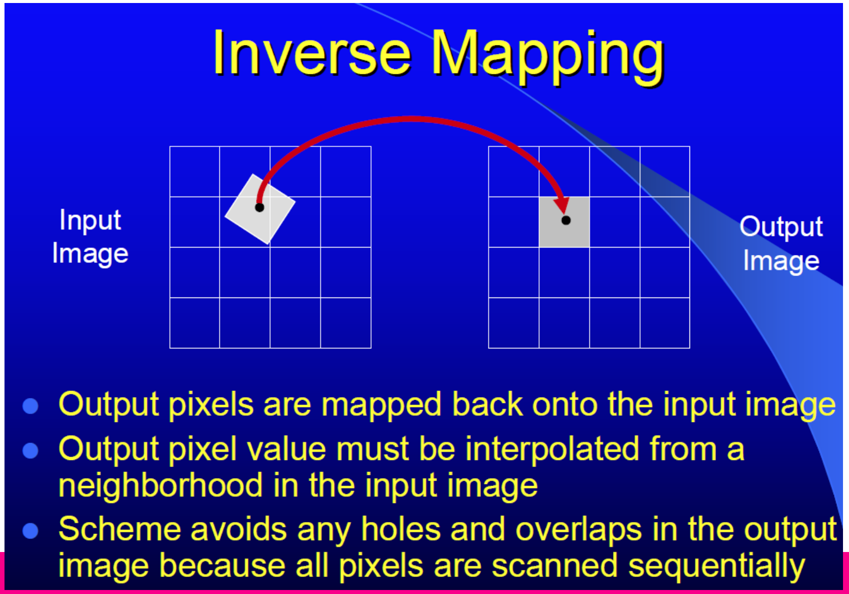


Warping of images data for good result may not be appropriate for linked functional data

Slide courtesy of Nick Hardcastle

# Problems with DIR – holes/overlap; missing info





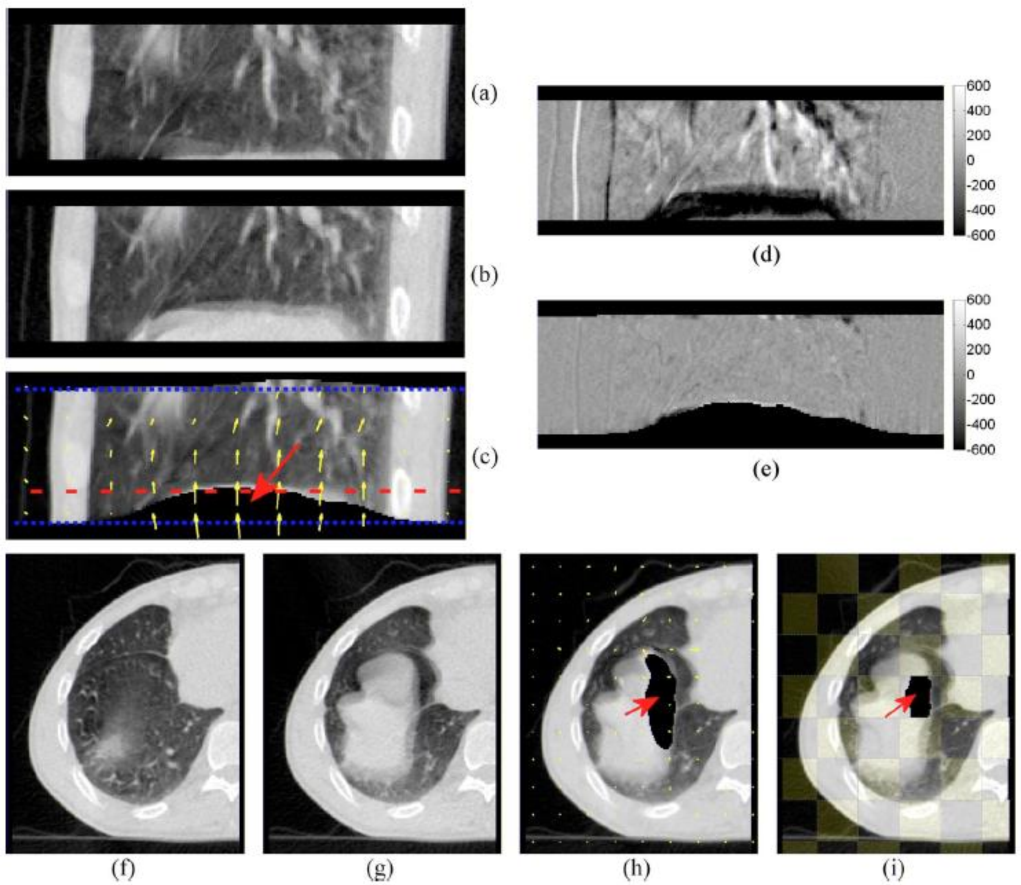
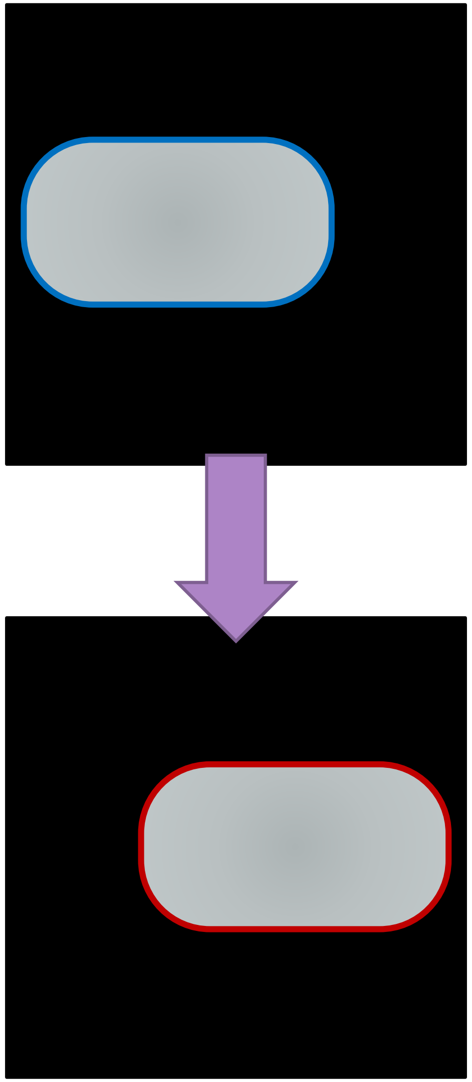
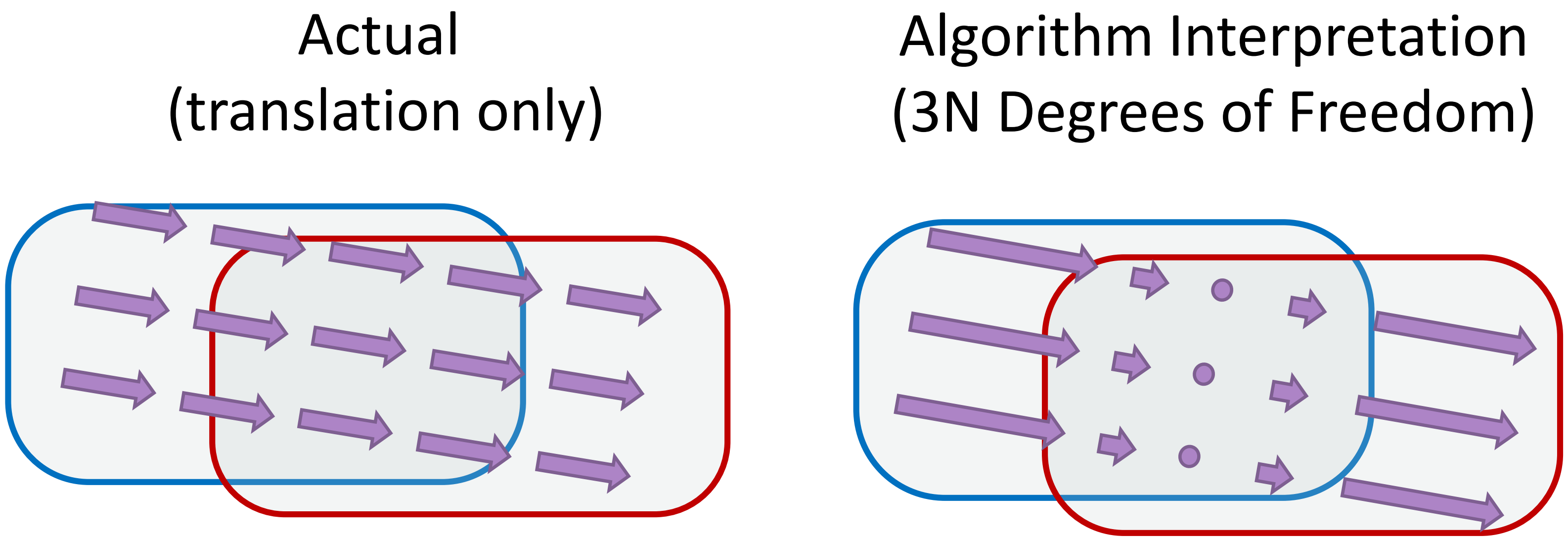




FIG. 3. New registration results using the NaN voxel extension. Both CT scans are extended in the superior-inferior and lateral directions with NaN voxels. (a) and (f) are the moving image. (b) and (g) are the fixed image. (c) and (h) are the deformed moving image. The dotted lines in (c) mark the original CT scan boundary before NaN voxel extension. (d) is the different image before registration. (e) is the different images after registration. (i) is the checkerboard image after registration. The arrows in (c), (h), and (i) indicate the deformed NaN voxels. The transverse slice shown in (f) to (i) is marked by the dashed line in (c).

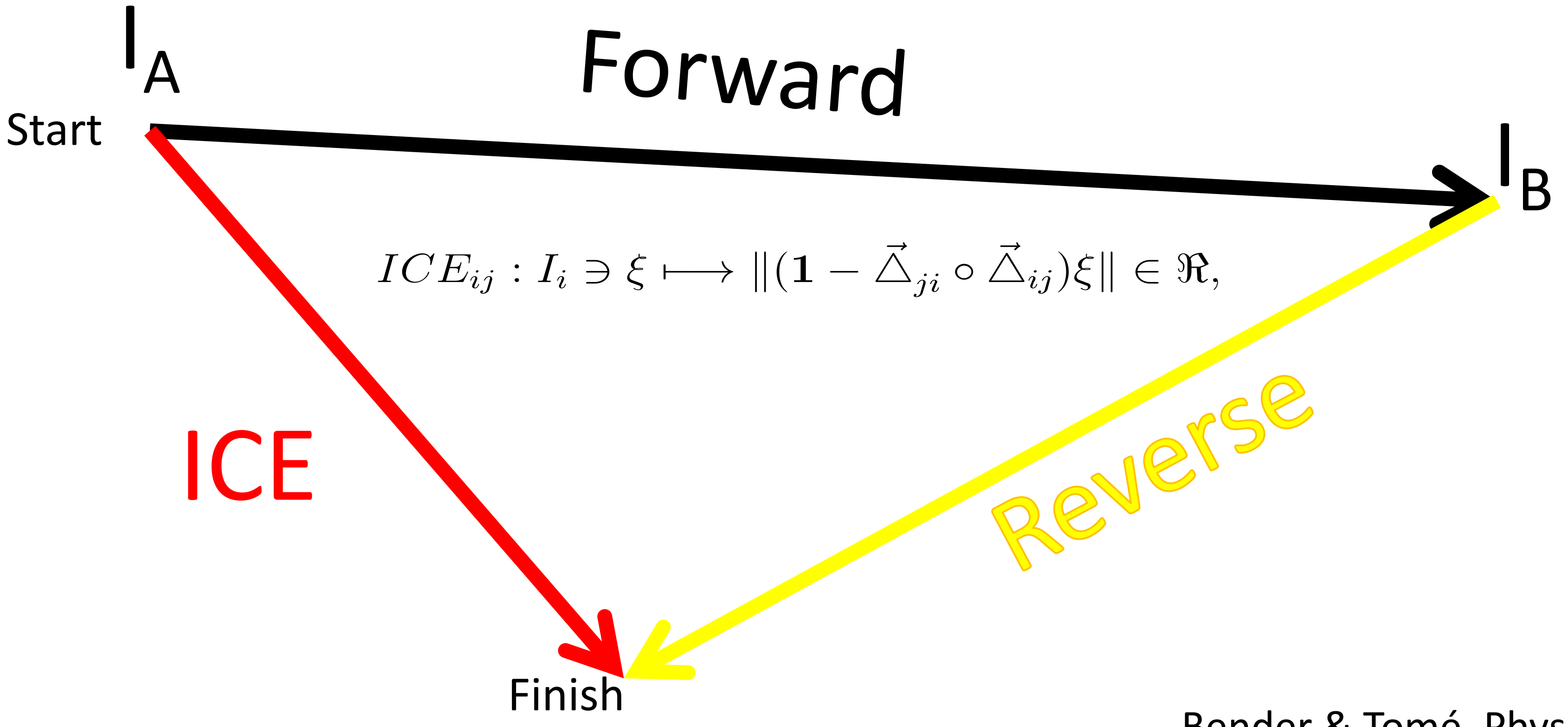
# Problems with DIR – contrast drives algorithm





# Problems with DIR – Inverse Consistency

## Inverse Consistency Error (ICE)




Bender & Tomé, Phys. Med. Biol. 54 2009

Slide courtesy of Nick Hardcastle

# Keep a healthy sense of scepticism…

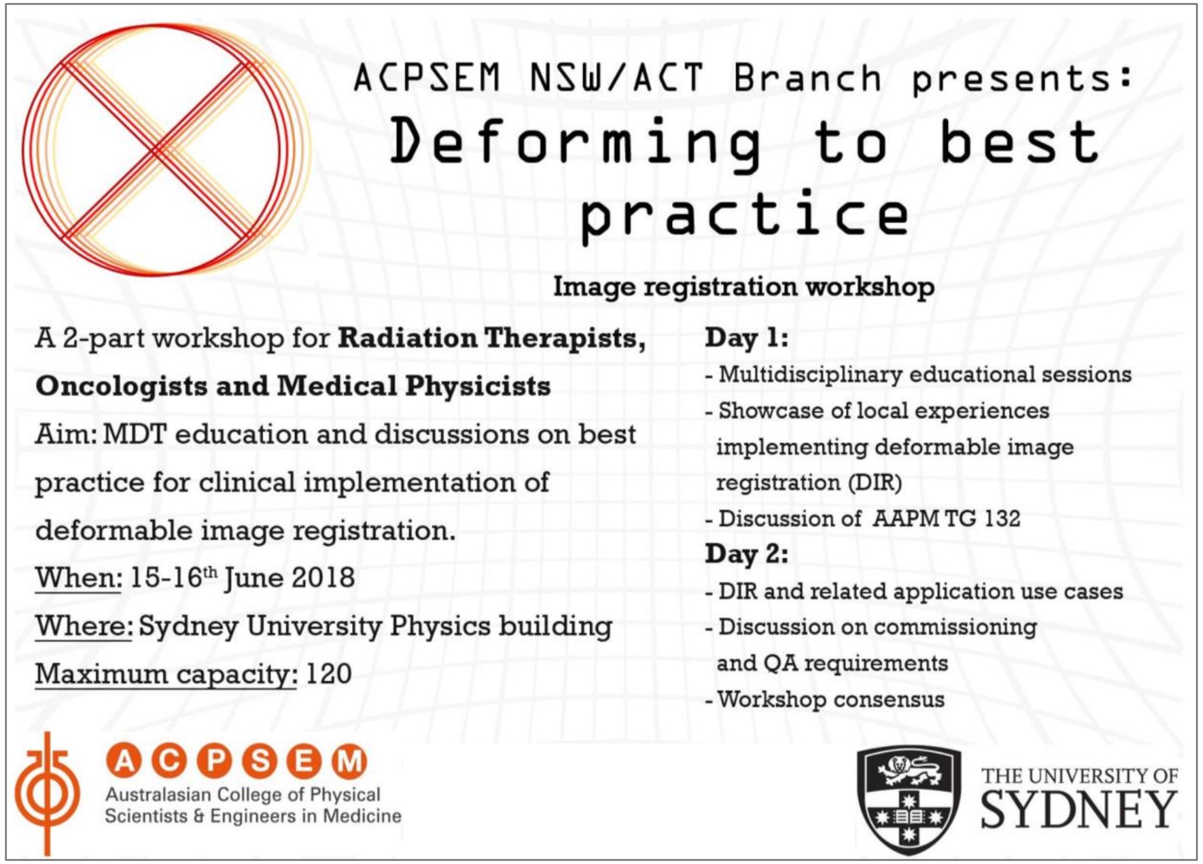

CLEARLY.

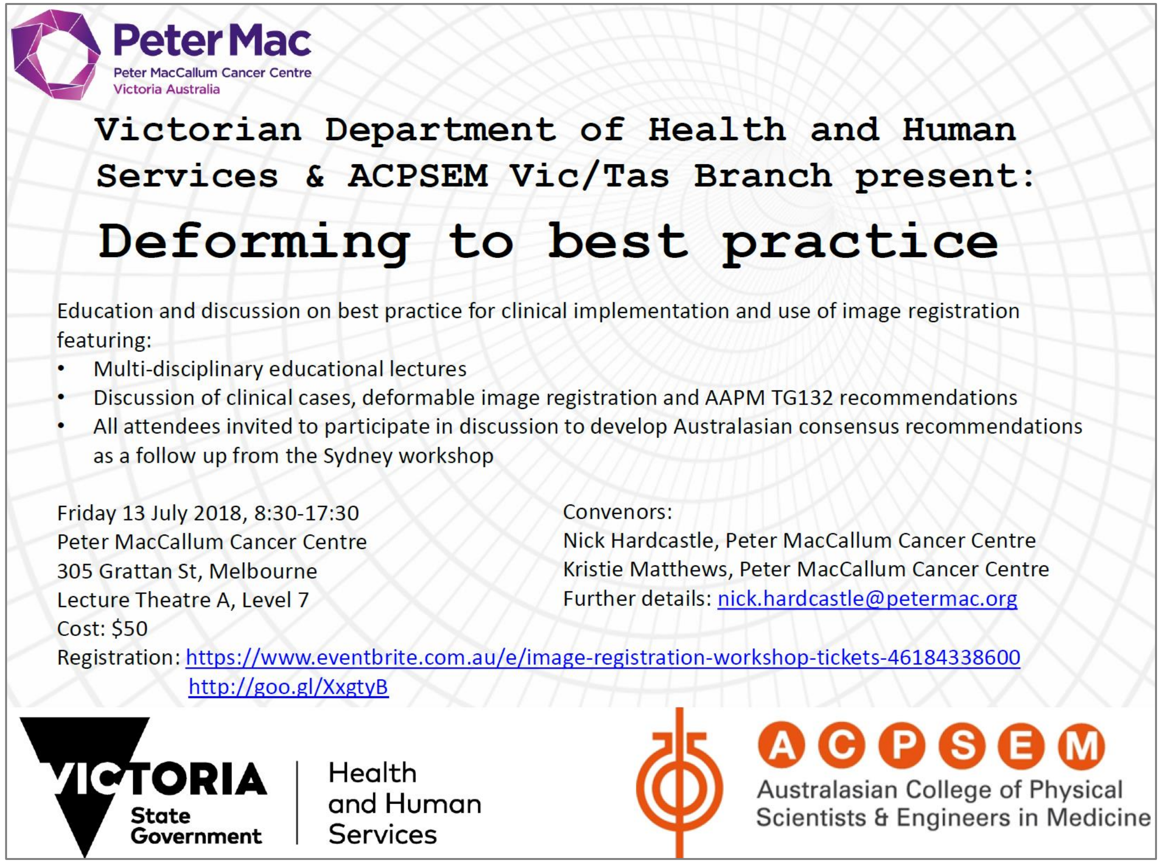
The water is way too blue.

SMIRF

Society of Medical Image Registration and Fusion

- → Many in the room already started working with DIR applications, probably coming across similar issues.
- → We want to leverage all the big brains in one room to smooth those problems.



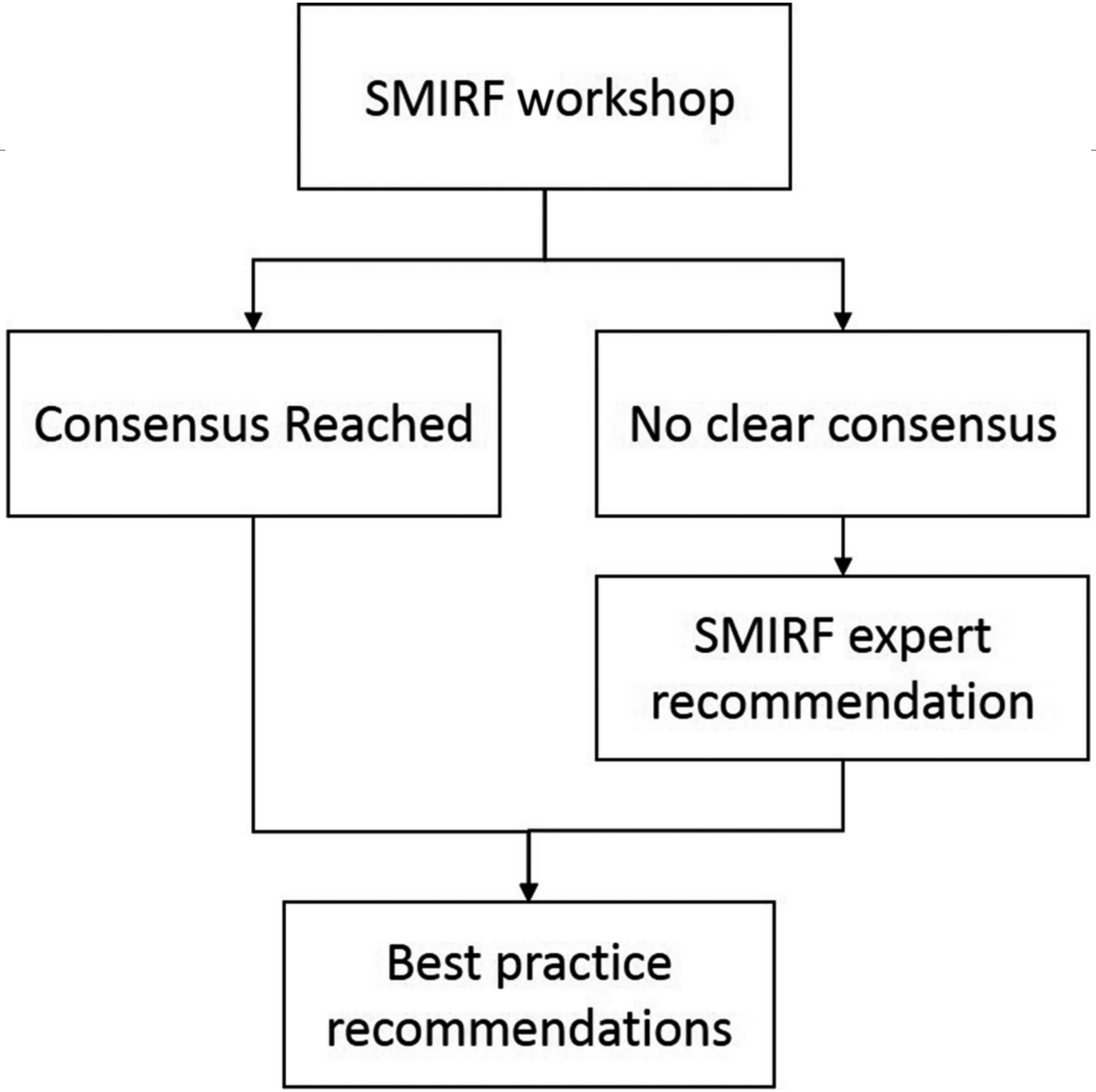
# In Press

PRACTICE GUIDELINE | OPEN ACCESS

## 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] | Amy Walker PhD [4,5,6] | Adam Yeo PhD [7,9] | Ben Archibald-Heeren MSc [10] | Kristie Harrison MSc [11] | Annette Haworth PhD [2] | David Thwaites PhD [1,2]

Journal of Medical Radiation Sciences OPEN


SMIRF workshop
Consensus Reached
No clear consensus
SMIRF expert recommendation
Best practice recommendations

# SMIRF Recommendations

**What is covered**

- General tips for (D)IR
- Recommendations for use cases
- Commissioning & QA
- Training & Education
- Implementation & Automation
- Research packages & Risk frameworks

**What isn't covered**

- How to for *your* system
- How to do *your* case
- How to commission *your* system
- How to train *your* staff
- How to implement in *your* clinic

**Table 2.** General technical considerations when performing DIR.

| |
|---|
| Determining the bounding box or Region of Interest (ROI) for registration |
| For the initial RIR, be careful not to include/clip high-contrast structures that move relative to the target soft tissue structures within a rectangular ROI as these will bias the registration, for example pubis when registering prostate.<br><br>Individual ROIs should be defined appropriately for each registration application, based on the clinical goal of the registration.<br><br>If bounding boxes are used for DIR, the box should include enough contrast and, if possible, should encompass entire organs that may deform, to avoid discontinuity at borders.<br><br>If a good result cannot be obtained for the full registration ROI, try using sequentially smaller regions to progressively tune the result. Watch out for discontinuity between regions. |
| Initial RIR is critical for effective DIR |
| Ensure the RIR is accounting for systematic variation between images (provides a global/coarse fit in the region of interest), so that the DIR can focus on deformation alone.<br><br>In images with large variations, the RIR should be optimised to provide the strongest registration at areas of greatest clinical importance. Potentially, multiple registrations are needed to focus on separate areas across the image. |
| Contrast within the ROI |
| Regions of low contrast provide little intensity variation 'features' for algorithms to compute the deformation and thus may give incorrect or non-physical results when using DIR. This is of importance when deforming PET or dose images according to the registration between two CT images.<br><br>Use thresholds and window/level settings to improve contrast where possible. |
| Understand the limitations of RIR and DIR |
| Image registration is a mathematical tool, with limited or no biological information involved in the process. There are limitations in compensating for large changes in pose, expansions and contractions, and differential movement of tissues with varying biomechanical properties and attachment.<br><br>Recognise when RIR/DIR is appropriate, and consider viewing images side by side if neither RIR/DIR provide accuracy required.<br><br>Communicate and document the accuracy or uncertainty level which represents a recommendation for end use; include residual errors or uncertainties for downstream processes.<br><br>Limitations may be due to software, the images used, operator experience or the task itself. |
| Iterative deformation can improve accuracy |
| Where available, tools that allow refinement of deformations can be used to iteratively improve DIR and correct poorly performing areas, for example focus structures and anchor points. |

**Table 3.** General process and workflow considerations when performing DIR.

| |
|---|
| Review registrations |
| The amount of QA should reflect the risk of the task. This may indicate that multiple QA tools are used to assess the registrations, preferably by multiple staff.<br><br>Reviews of registration should contain both quantitative and qualitative assessments of the performance of the similarity term and the transform term (feasibility of deformation vectors).<br><br>Consider using the RIR if the DIR does not improve the accuracy level significantly.<br><br>Ultimate approval lies with the radiation oncologist, taking into account the clinical scenario. |
| Registration naming and storage conventions |
| RIR and DIR should be saved and accessible with naming that conveys date and purpose of IR.<br><br>Use comment fields to record information that may change downstream (dates, users, etc.).<br><br>Keep records indicating how a structure has been derived, resampled and finalised from DIR.<br><br>Clarity and consistency in naming increase the safety of using DIR. |
| Consider reproducibility of registrations |
| Where user-dependent interactions are required, protocols should be employed to ensure consistency. For example: when utilising tools that are user-dependent (such as local registration lock points or contours), the process may not be repeatable, or the method may not be evident at a future date.[~~65~~67] It is also possible to make deformations that may look 'correct' but are unrealistic. Caution is urged with user-dependent tools. |
| Acquire all images in similar position where possible |
| Discussions with radiology and nuclear medicine staff can lead to standard procedures for better diagnostic scans that more closely match RT planning scans – optimised acquisition parameters, creating flat couch areas, etc.; 'low-tech' solutions like using MR-safe and small-bore compatible radiotherapy immobilisation equipment during MR or PET imaging to replicate treatment positions, and RT attendance for imaging, can result in more accurate imaging tasks downstream. |

**Table 4.** Summary of key considerations for DIR between various image modalities used in radiotherapy.

| Image modalities | Key Considerations | Ref |
|---|---|---|
| CT-pCT registration | No specific considerations extending Table 2. | |
| CBCT-pCT registration | Limitations of CBCT (FOV, HU accuracy, length limits) should be evaluated when estimating dose calculated on CBCT. Consider using tissue, air and bone overrides. | 8 |
| MR-pCT registration | MR-pCT DIR should not be used routinely with the current tools available, unless multiple users have evaluated results on both technical and clinical grounds. | 11 |
| PET-pCT registration | Validate the consistent frame of reference between the PET and its attenuation correction CT before coupling other registrations. PET-pCT DIR should only be performed using the intermediate registration between the attenuation correction CT and pCT. | 15 |

**Table 5.** Summary of key considerations for clinical application use cases of DIR

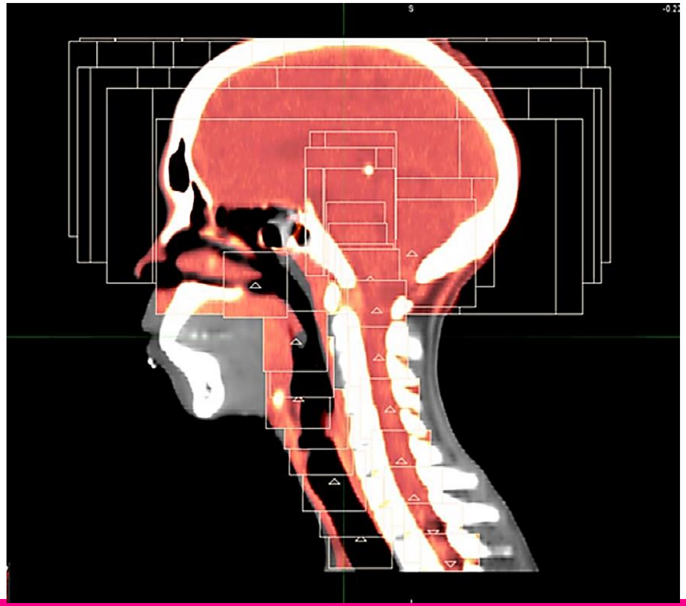
| Clinical Application | Key considerations | Ref |
|---|---|---|
| Contour propagation between<br><br>pCT and rCT | Any structure derived from another should not be propagated, but instead re-created from the corrected propagated anatomical structures (e.g. margin expansions and Boolean products). | 1 |
| | Propagation of rigid/deformed isodose contours (e.g. for retreatments) are to be assessed for accuracy level achieved, as they cannot be corrected with subsequent editing.<br><br>All deformably propagated structures should be reviewed and any errors corrected/assessed prior to further use | 31 |
| Atlas<br><br>Segmentation | Dice similarity coefficient should be used in combination with other metrics such as volume, location and surface measures. | 1,33 |
| | The clinical impact of automatically generated contours should be evaluated through determination of the dosimetric differences when using automatic versus manual segmentation for each department. | 36 |
| | Use pre- and post-processing steps to save time (e.g. build atlases with smoothed and cleaned contours; atlas contours contain every third slice then interpolate as a final step). | 37 |
| Adaptive Radiotherapy | Offline adaptation is feasible with current tools but resource-intensive. Each department needs to assess their capacity to implement. | 31 |
| | Online adaptation tools may be available, but workflows and expertise are not necessarily developed yet. More development is needed. | AQ10 ( |
| Replanning | DIR can increase efficiency of replanning workflows for contouring. Automated workflows reduce manual steps and may reduce errors. The same careful review as manual replanning is required. | 31, ~~67~~ |
| Retreatment | The best estimate of previous dose depends on the scenario and available tools. Uncertainties of warping previous dose should be weighed against gains from providing a spatially correlated indication of past treatment. | |
| Dose Accumulation | Current tools and workflows for dose accumulation are not ready for routine clinical application, and the value gained from dose accumulation is not yet proven. Use should be evaluated as suitable by multiple users on both technical and clinical grounds. | 3,31,~~68~~ |
| Brachytherapy | Many challenges exist in brachytherapy DIR, and it should not be used in routine clinical application yet. Use should be evaluated as suitable by multiple users on both technical and clinical grounds. | 52 |
| Response Assessment | Large potential for quantitative response assessment and combination with functional or radiomic information. Scope for significant research. | 57,58 |

# General DIR Recommendations

- **Initial RIR is critical for effective DIR**
  - RIR should account for systematic variation (global/coarse fit), DIR focus on deformation alone.
- Region of Interest for registration need to be set appropriately
  - Bounding boxes
  - Include appropriate contrast/structures
  - May need sequential smaller ROI
- Contrast within the ROI
  - Use thresholds and window/level settings to improve contrast where possible.

# General DIR Recommendations

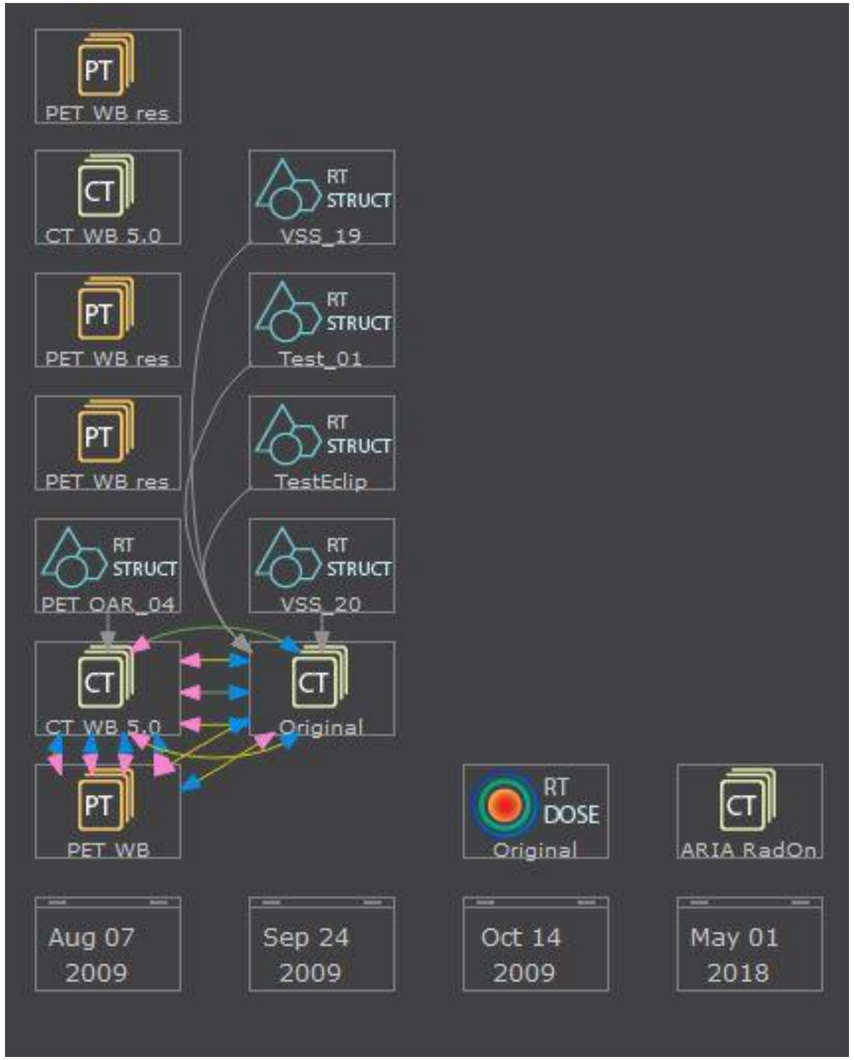
- Understand the limitations of DIR
  - Communicate and document for downstream processes
  - Limitations may be due to software, the images used, operator experience or the task itself.
- Consider reproducibility of registrations
  - Caution is urged with user-dependent tools. Reproducibility, consistency, appropriate for associated data?
- Acquire all images in similar position where possible
  - Discuss with Radiology and Nuclear Medicine staff, use low-tech solutions where possible



# General DIR Recommendations

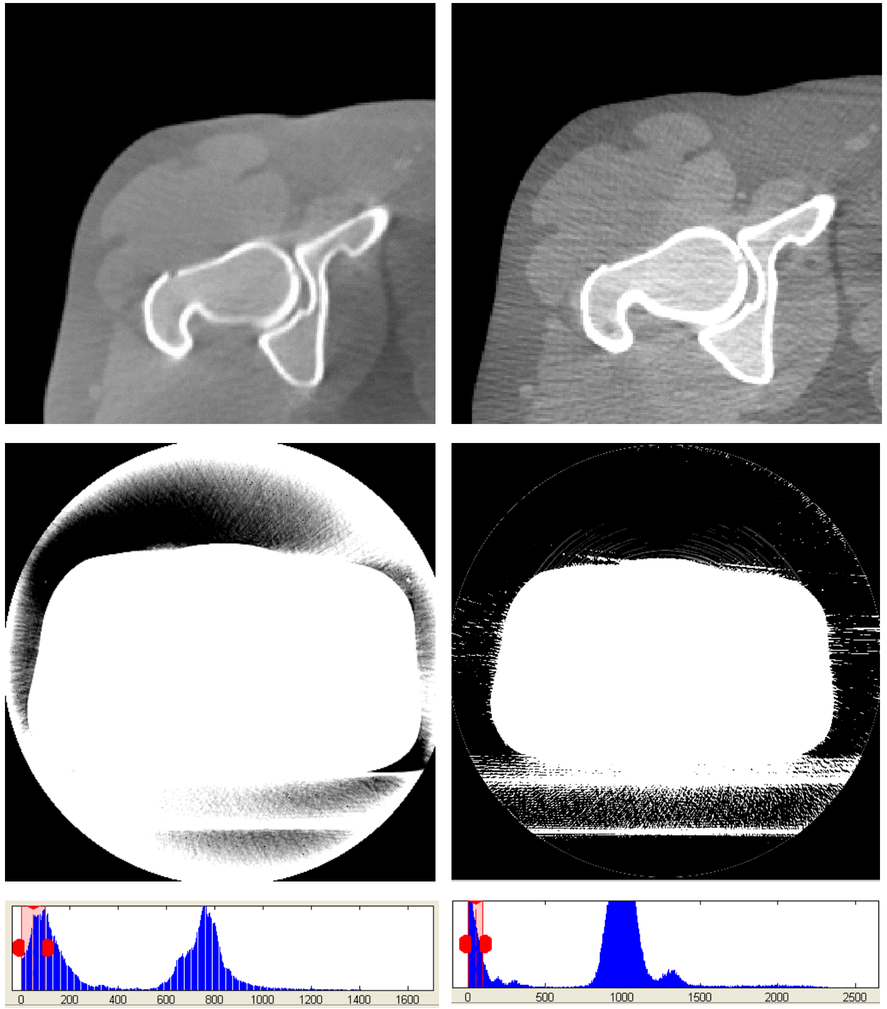
- Review registrations
  - **The amount of QA should reflect the risk of the task**.
  - Reviews of registration should contain both quantitative and qualitative
  - Consider using the RIR if the DIR does not improve the accuracy level significantly.

- **Naming conventions**
  - DIR naming - date and purpose of IR
  - Use comment fields
  - Indicate derived or resampled from DIR.
  - Clarity and consistency in naming increases safety



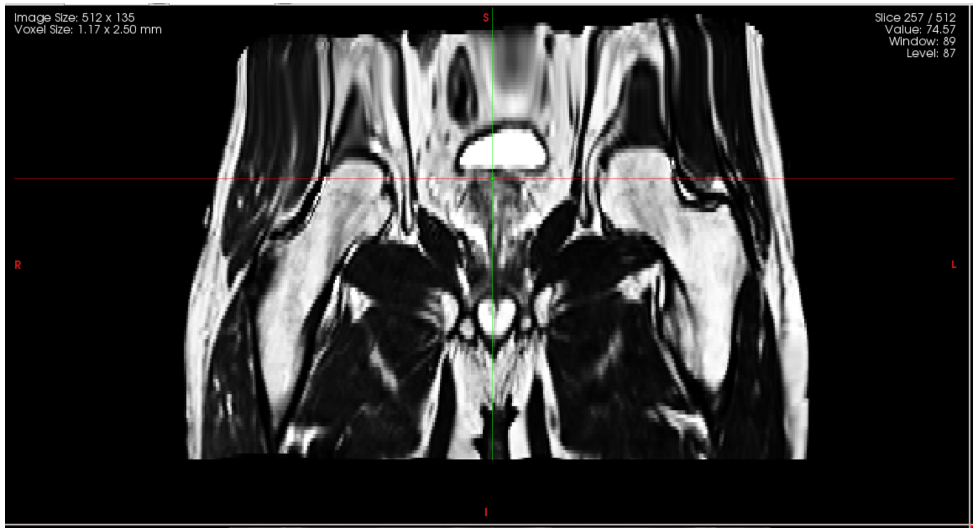
# Use case: CT-CT & CT-CBCT consensus

- ~ Half RT workforce regularly do soft tissue matching
- **Soft tissue matching** & 6DOF matching
  - basic skill (prerequisite?) for more advanced tasks (DIR, ART)
- Plan evaluation directly on CBCT is feasible
  - However accuracy is impacted by limited field of view, limited image length, decreased image quality of CBCT, and artefacts inherent to CBCT.
- The **accuracy of CBCT** HU is complex
  - Changes with image dose, size and geometry of the subject and beam spectrum.



# Use case: MR-CT consensus

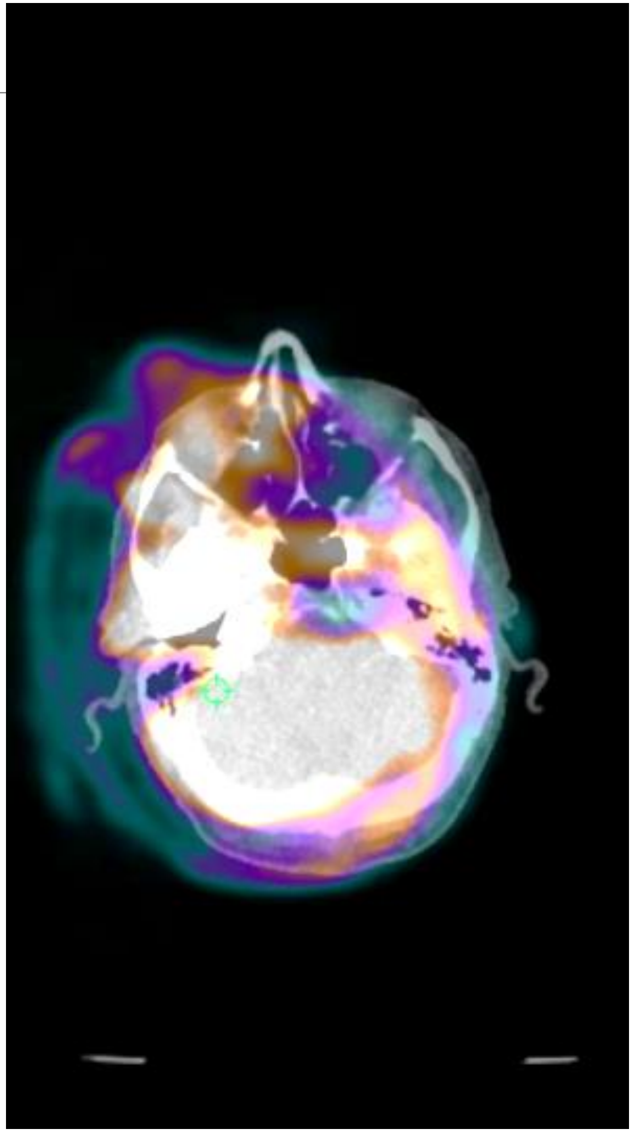
- **RIR is the best approach** to register MR imaging for radiotherapy planning in most scenarios.
- Current DIR algorithms struggle with dissimilar image information.
  - More important to do good RIR focused to a local region, and use multiple RIR if needed across a larger volume.
- Be aware of MR artefacts and distortions
  - know of work-arounds
- If MRI is to be used for planning, it is imperative that routine QA of MRI spatial distortion is performed.


Images courtesy of Jason Dowling

# Use case: PET-CT consensus

- **DIR can be used with PET/CT**, and this is performed in several departments at present.
  - The uncertainties in DIR were deemed equivalent or not significantly more than using linked RIR, given the innate uncertainties of using PET images.
  - It is recommended to validate the consistent frame of reference between the PET and acCT images before coupling other registrations, in case there is patient movement between scans or if the two bores of the PET/CT scanner are not well aligned.
  - Check calibrated units before quantitative analysis
- PET-pCT DIR should only be performed making use of the intermediate acCT-pCT



# Use case: Contour propagation

- Only contours that are anatomical in basis such as organs at risk should be automatically propagated
- **Any structure derived from another should not be automatically propagated** (Boolean combinations or margin expansions), instead re-create them
- **Use caution when deforming tumour structures,** deformation algorithm may not change the shape of the structure the same way that the actual cells are behaving.
- Propagation of deformed isodose contours can't be edited, requires assessment as to the accuracy level achieved.
- All structures deformably propagated should be reviewed and any errors corrected prior to further use.

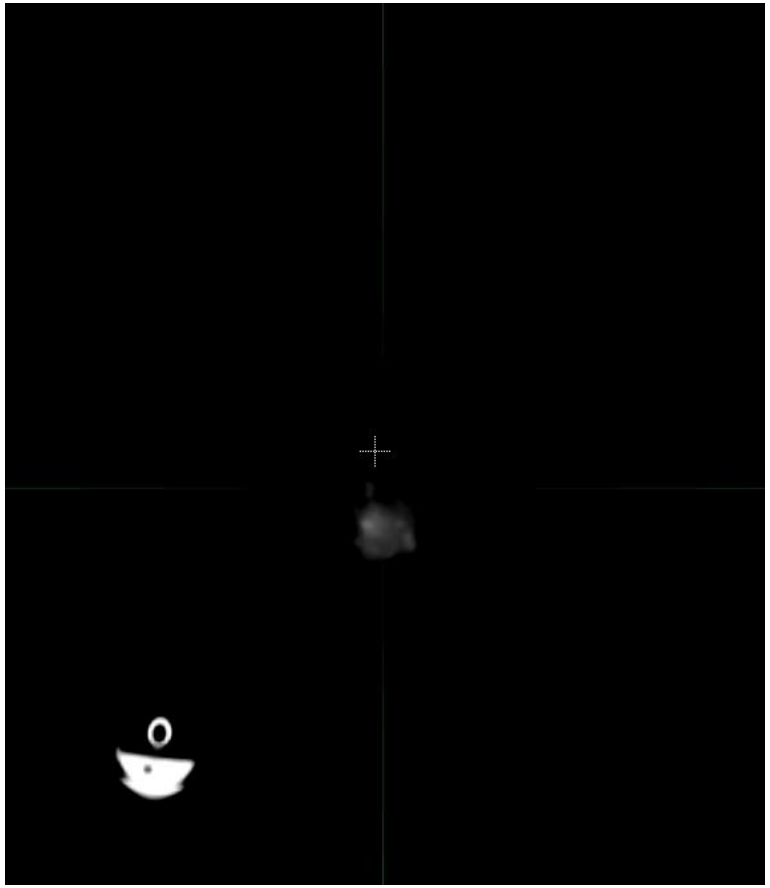


Image courtesy of Michael Jameson

# Use case: Atlas-based automatic segmentation

- Robust agreement on structures between all users of an atlas is a key starting point.
- While DSC is commonly used to assess atlas performance, it should be used in combination with other metrics such as volume, location and surface measures such as Mean Distance Agreement (MDA) or Hausdorff Distance.
- To reduce editing time and computational performance, use pre- and post-processing steps (e.g. build atlases with smoothed and cleaned contours, and reduce contours to every third slice – this can be filled with interpolation once the atlas is applied).
- While sharing of atlases is viewed favourably by attendees, there are obstacles to overcome in terms of infrastructure and governance (privacy requirements, data transfer and storage and effort required).

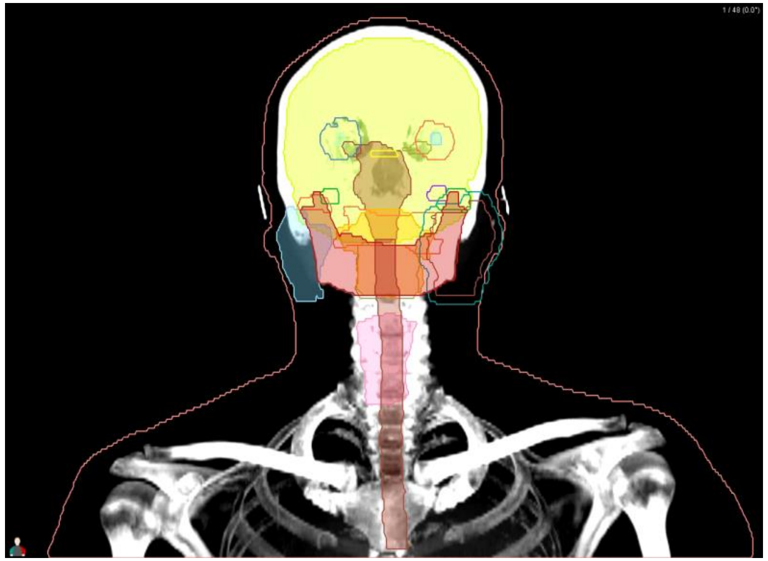


Image courtesy of Michael Jameson

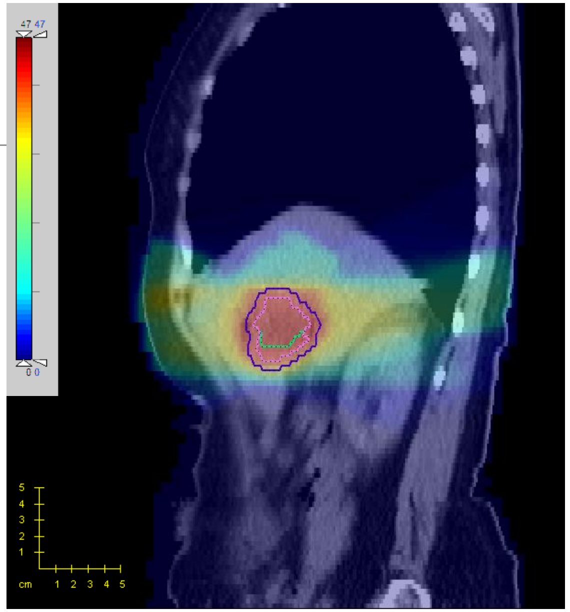
# Use case: Retreatment

- **This may be the use with the most immediate impact for clinicians**
- RIR may be sufficient to transfer previous dose to a new pCT
- DIR for retreatment has a positive benefit/risk ratio, particularly when there is
  - (1) significant time lapse between courses and already high uncertainties in tissue changes, forgotten dose, etc. or
  - (2) simulation images acquired in different positions
    - high uncertainty in correspondence of dose due to anatomy deformation
    - difficult to indicate range of dose overlap
- Increased uncertainty in a retreatment may result in practical impacts such as larger target volumes, increased toxicity or changing from radical to palliative intent. It is recommended to use the best estimate of previous dose possible, with the tools available.


Image courtesy of Joel Poder

# Use case: Dose Warping

- Dose warping (or dose deformation) is a purely mathematical tool
- **Does not directly relate to physical processes, but it can be valuable in some scenarios**
  - especially as DVHs cannot be summed between plans calculated on different underlying anatomy.
- Some scenarios where it may make sense to use dose warping include between images in a 4DCT set, treatment dose accumulation, retreatment (local and distant), and for assessing dose response relationships to functional imaging.
- Any dose deformation should be rigorously reviewed.



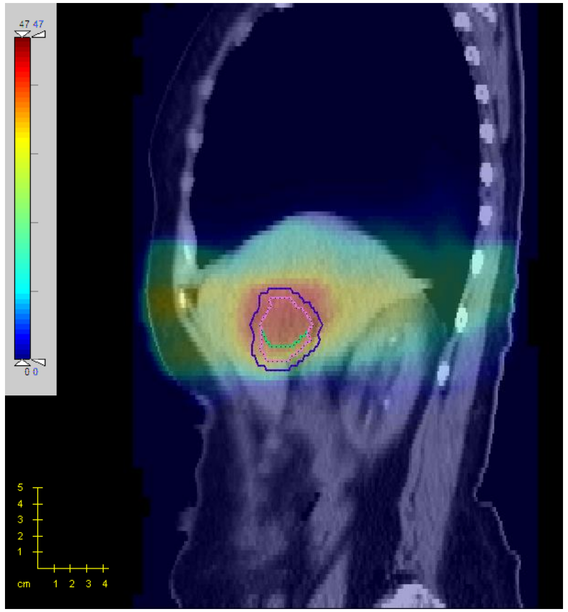
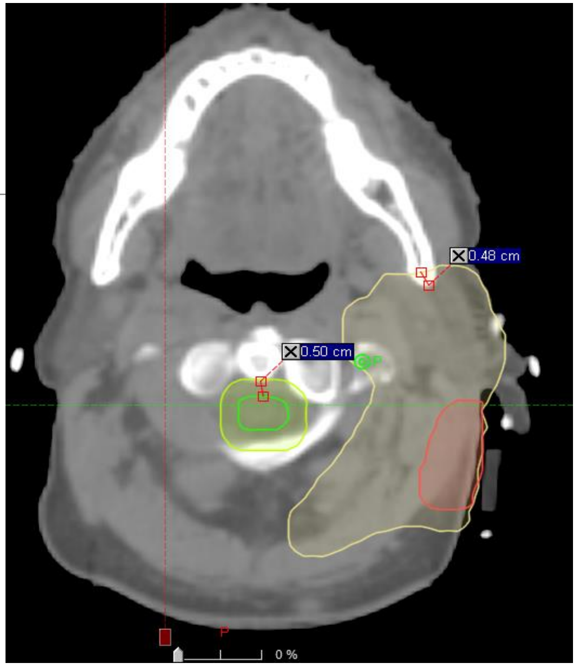


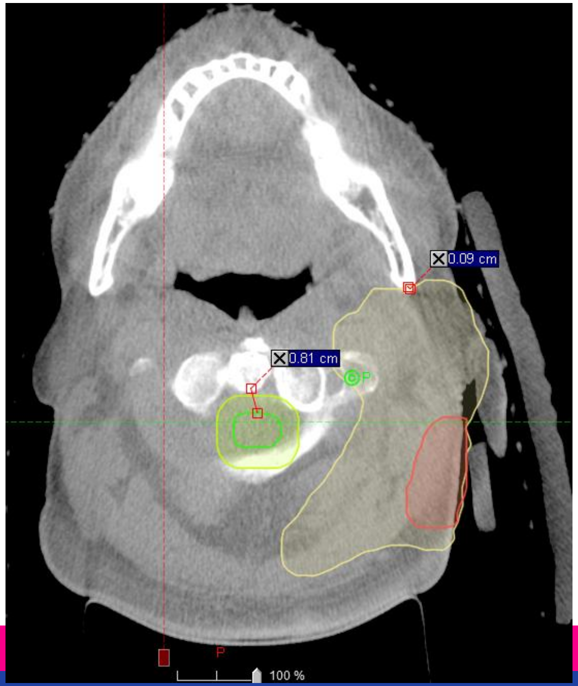
Image courtesy of Adam Yeo

# Use case: Replanning

- **DIR in replanning workflows can increase efficiency** and improve plan turn-around time, as well as reduce the number of manual tasks required.
  - Replan assessment with image warping, Contour propagation, Atlas
- Automated DIR processes still need careful review as would normally be performed for manual replans.
- Take care when reviewing DVH between different plans.

  **Summing DVH from different anatomy is not correct**.
  Radiobiology may also be considered



# Use case: Adaptive Radiation Therapy

- Offline adaptation (scheduled replans, adaptive dose monitoring and regular replans between treatments) is feasible with current tools.
  - It is resource intensive and should be undertaken with care to ensure it is feasible within a working department.

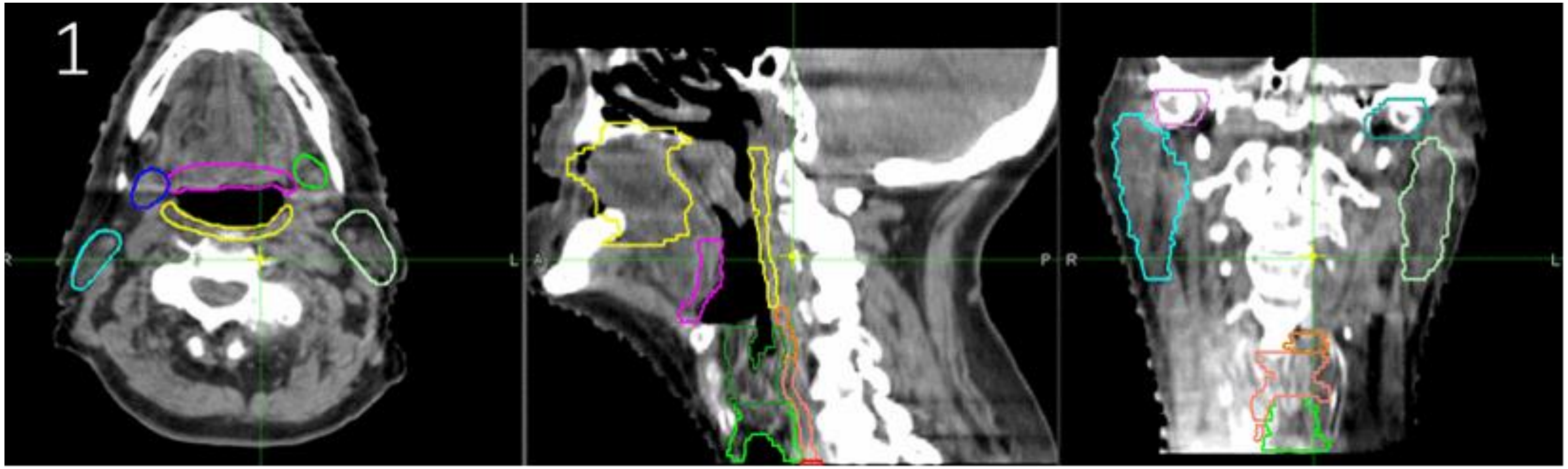



Image courtesy of Jonathan Sykes

# Use case: Adaptive Radiation Therapy

- Online adaptation tools are typically available, but workflows and expertise are not sufficient in most cases.
  - Likely to improve in the near future as vendors provide more integrated solutions.
  - This will bring challenges for the radiotherapy community to cope with the additional information and decisions in an optimal manner.

**WATCH THIS SPACE**

**"Off the shelf" adaptive systems**

# Use case: Treated Dose Accumulation

- Considerable experience and understanding of the local treatment systems is required to be able to make meaningful decisions based on dose accumulation results
- **The value of dose accumulation is not yet proven, and it is unclear if treated dose correlates with response in the same manner as the current planned dose evidence base.**
- At present, any dose deformation should be rigorously reviewed due to inherent uncertainties and assumptions, before being used for clinical decision making.

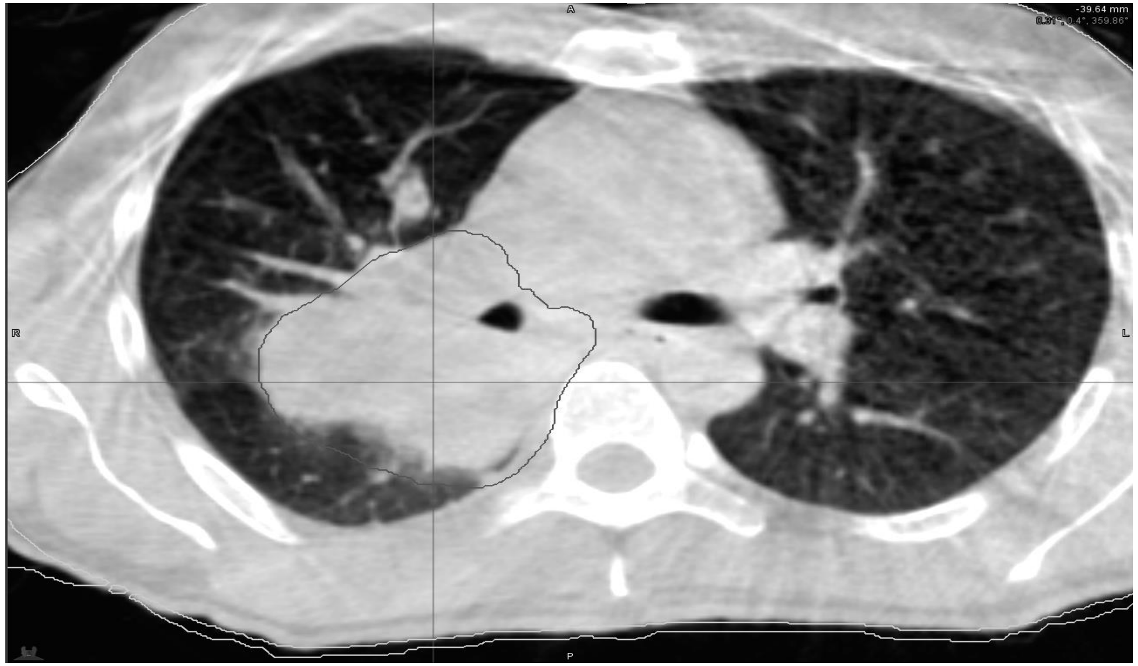
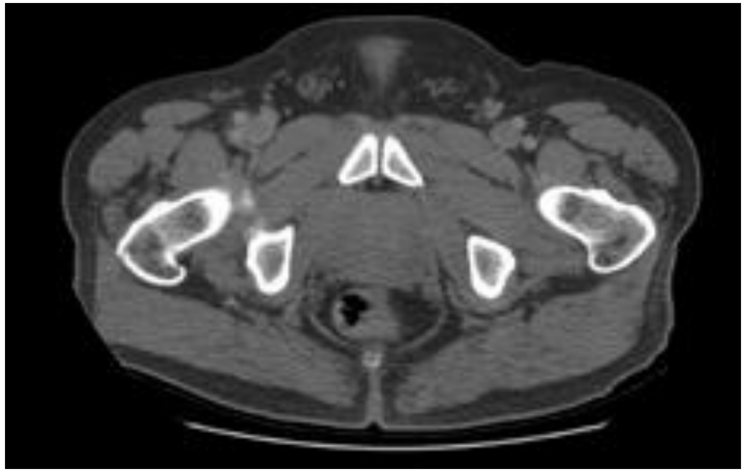


Image courtesy of Nick Hardcastle

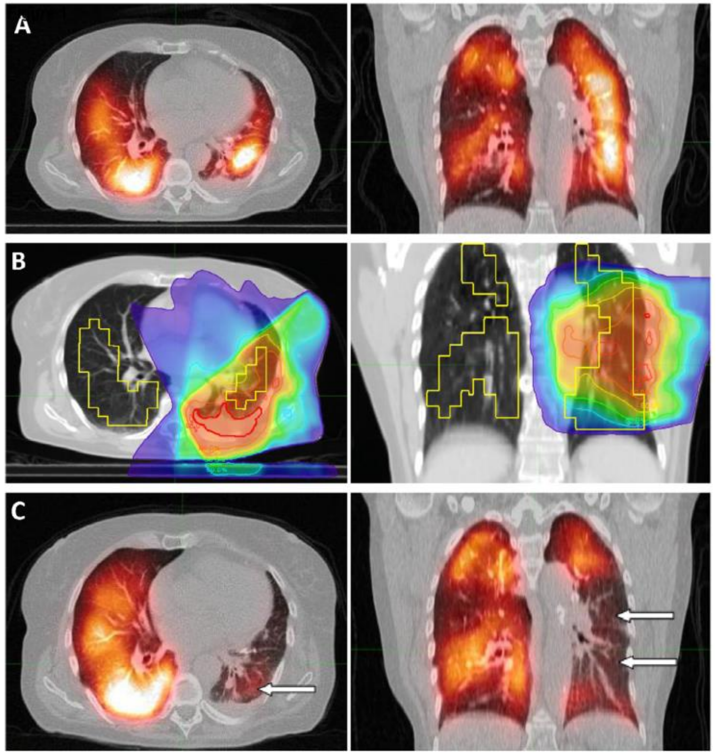
# Use case: Brachytherapy

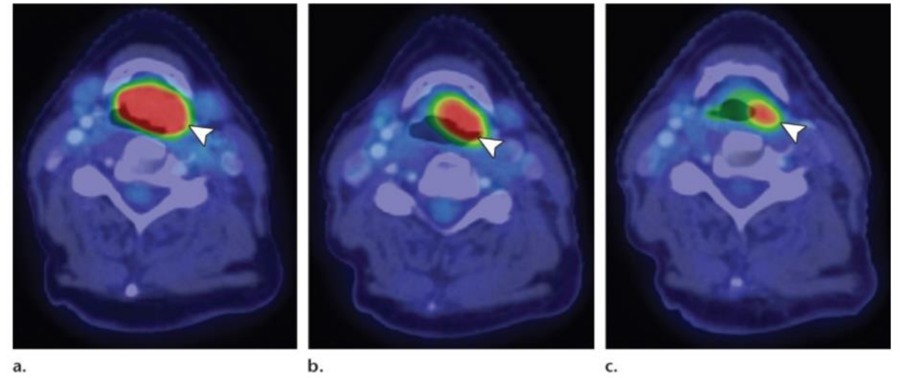
- Brachytherapy can potentially benefit from DIR significantly, due to the deformations between image series
  - presence of applicators or TRUS probes in Bx images but not EBRT images
  - new applicator insertions for each HDR session
- Very steep dose gradients associated with BT place strict demands on accuracy of DIR on every voxel – impact on dose accumulation
- **DIR in Brachytherapy is still research focused**, or used as additional information only. There are many unknown factors at present



# Use case: Response Assessment

- DIR can create a common reference for assessing images prior to, during and after treatment.
- There is potential for significant advances in quantitative response assessment, beyond the RECIST criteria
- Combining functional imaging with DIR methods is creating new opportunities such as mapping changes in lung function with perfusion and ventilation imaging
- Future advances in radiomics will also need to work with or alongside DIR.



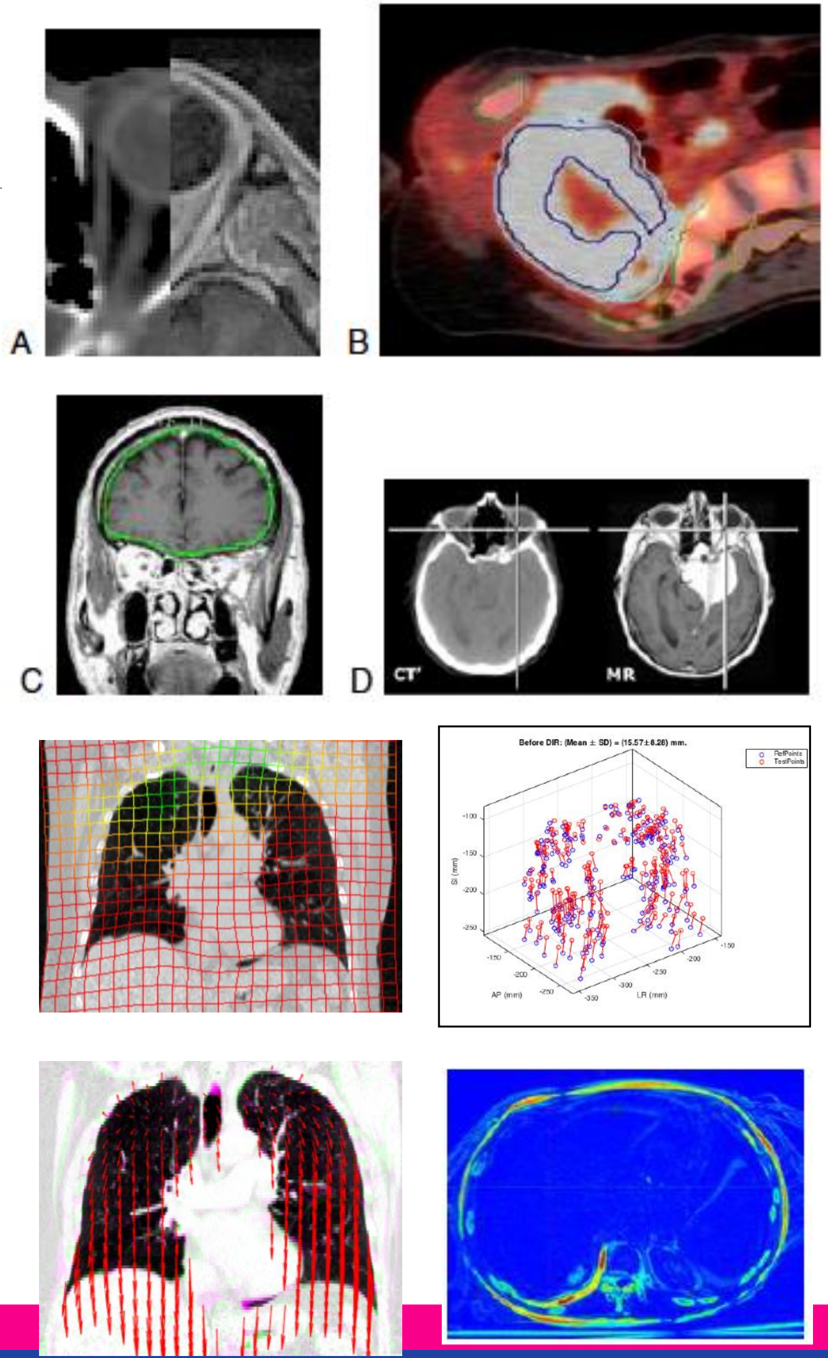



# Commissioning

- Ideally, the performance of DIR should be evaluated for all possible clinical scenarios using local clinical datasets prior to clinical implementation.
- However, this is not feasible in practice, and it is **recommended to take a pragmatic approach that covers a range of example datasets representing desired use cases, and a risk-based approach assessing DIR as part of the overall radiotherapy treatment chain.**
- TG-132 report provides a framework for commissioning DIR
  - tests for data integrity, baselines for periodic testing after upgrades, end-to-end tests for each new development in the clinic.
- Routine QA should follow from baselines acquired during commissioning and also reflect clinical usage.

# Patient-specific QA

- Despite many attempts in the literature no robust quantitative measure for individual DIR accuracy has been developed.
- A range of QA metrics and visual inspection should be used in all clinical applications.
- Aim is to be happy with the result, within the desired uncertainty for clinical goal (typically 2mm in areas of interest)



# How do we validate?

- Anatomy (qualitative)
- Dice
- TRE (target registration error)
- DVF & Jacobian maps

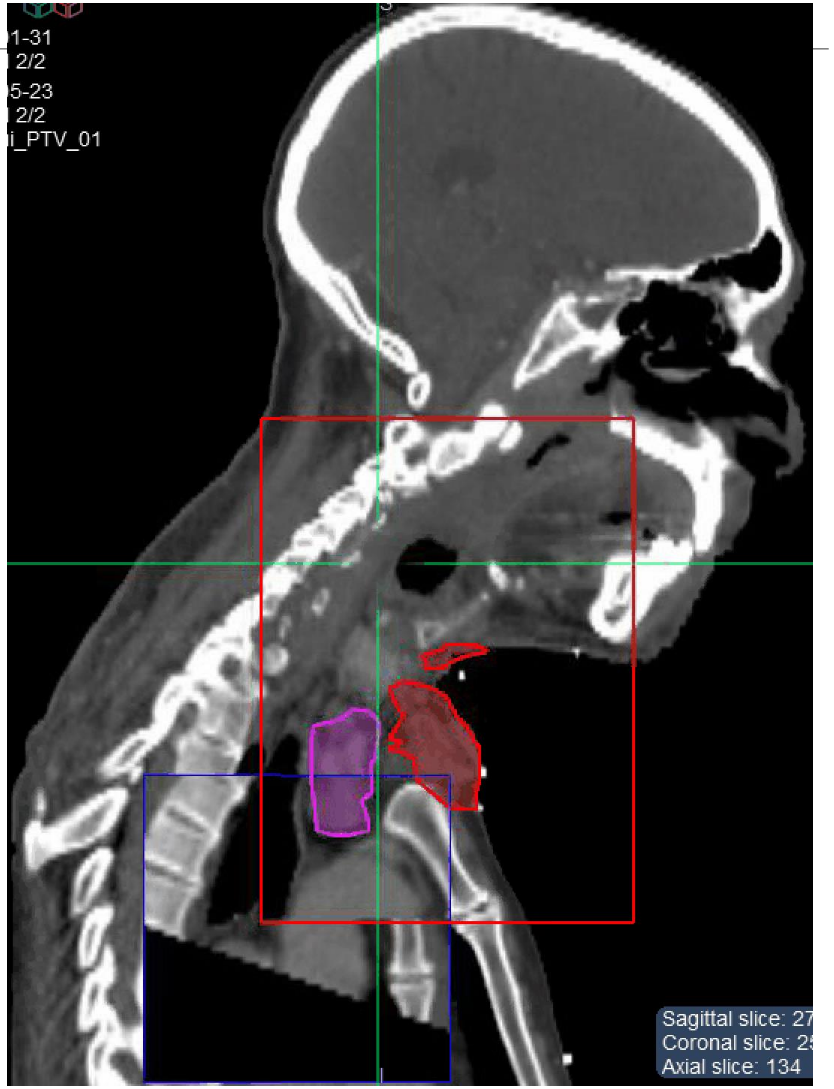



Image courtesy of Nick & Adam

# How do we validate?

- Anatomy (qualitative)
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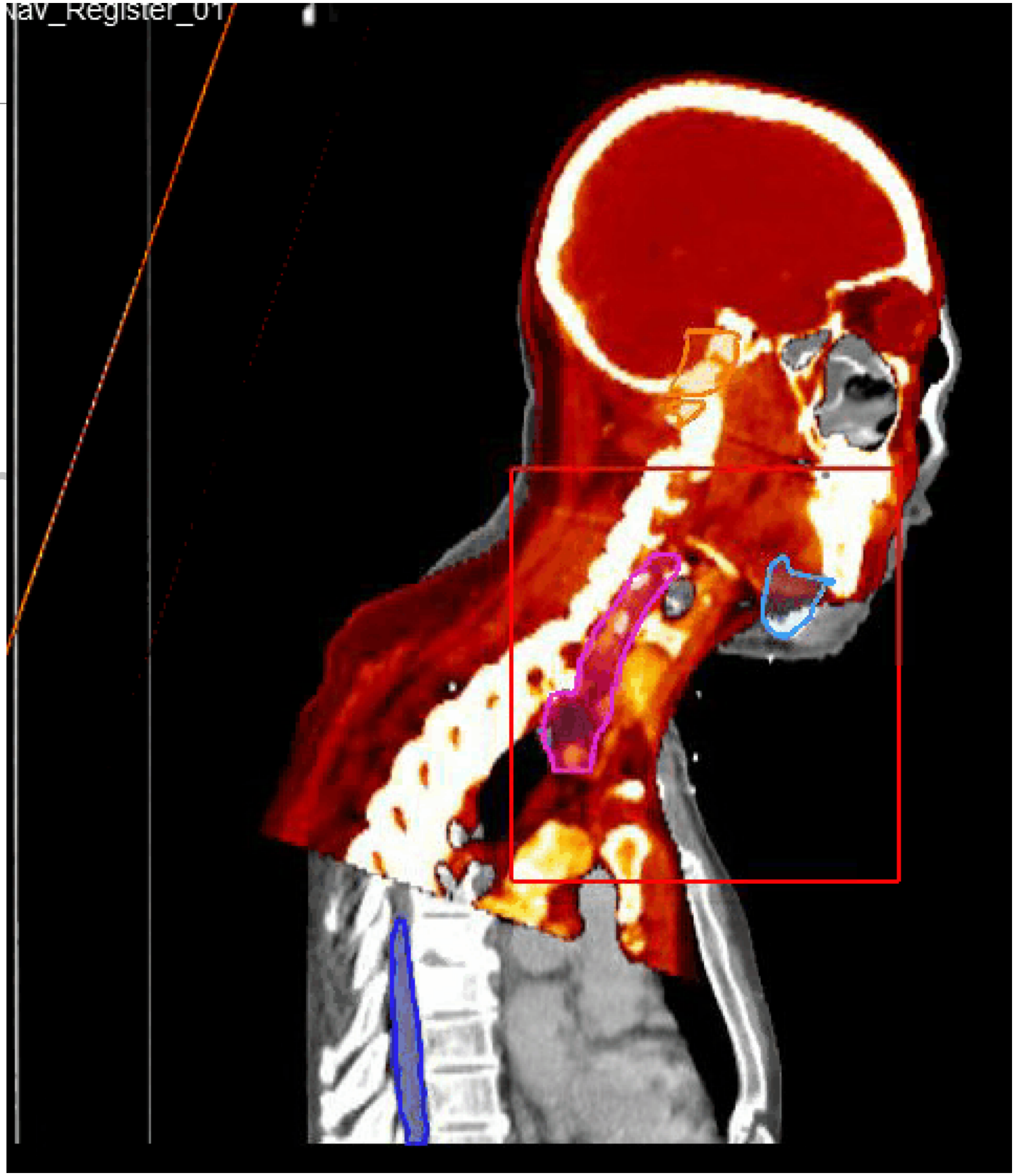


Image courtesy of Nick & Adam

# How do we validate?

- Anatomy (qualitative)
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Image courtesy of Nick & Adam

# How do we validate?

- Anatomy (qualitative)
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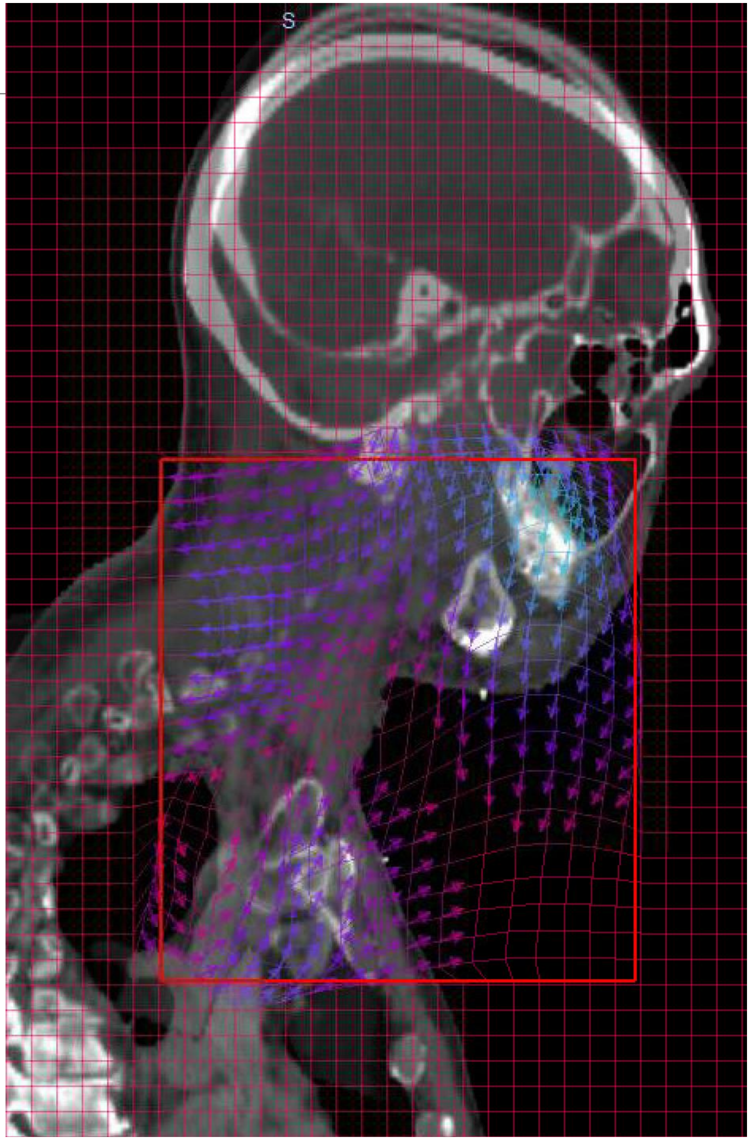
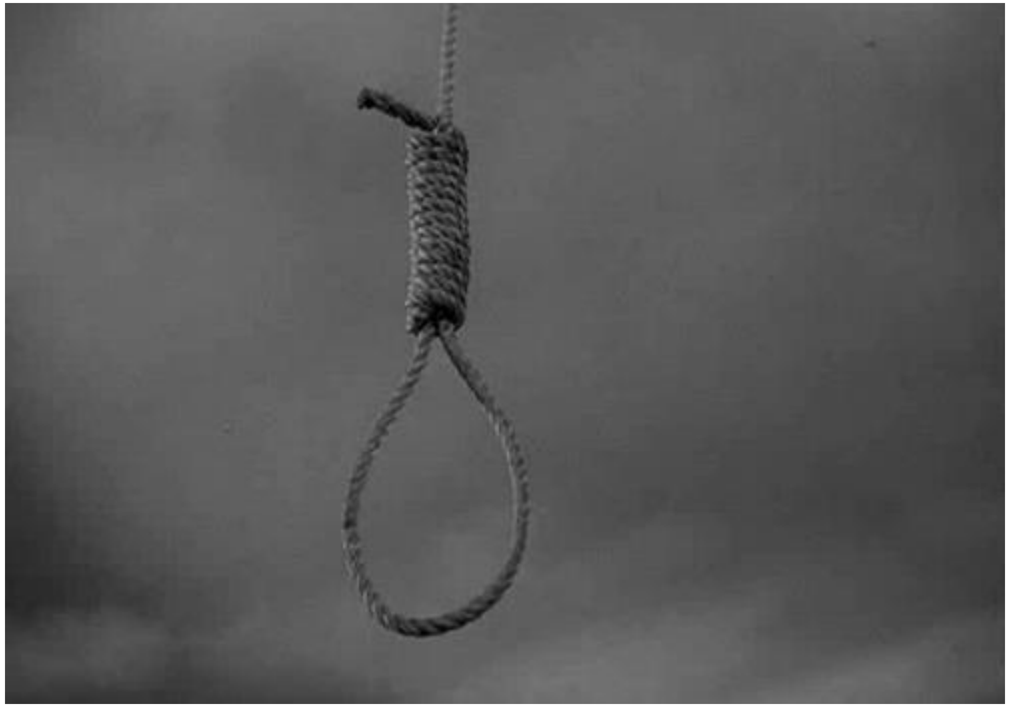
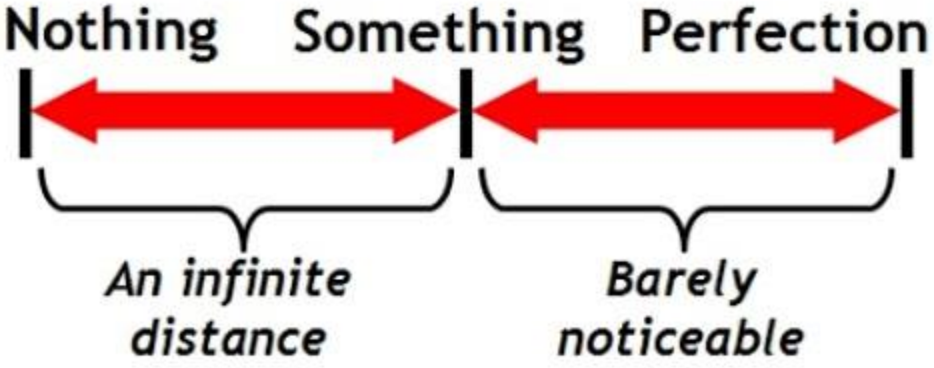



Image courtesy of Nick & Adam

## Enough rope?



## Perfect the enemy of good?



# Documentation

- SOP, DIR reports, OIS reports, QC….
- Approvals, naming conventions, document control
- **Strong consensus agreement for adoption of the TG132 Request and Report forms**

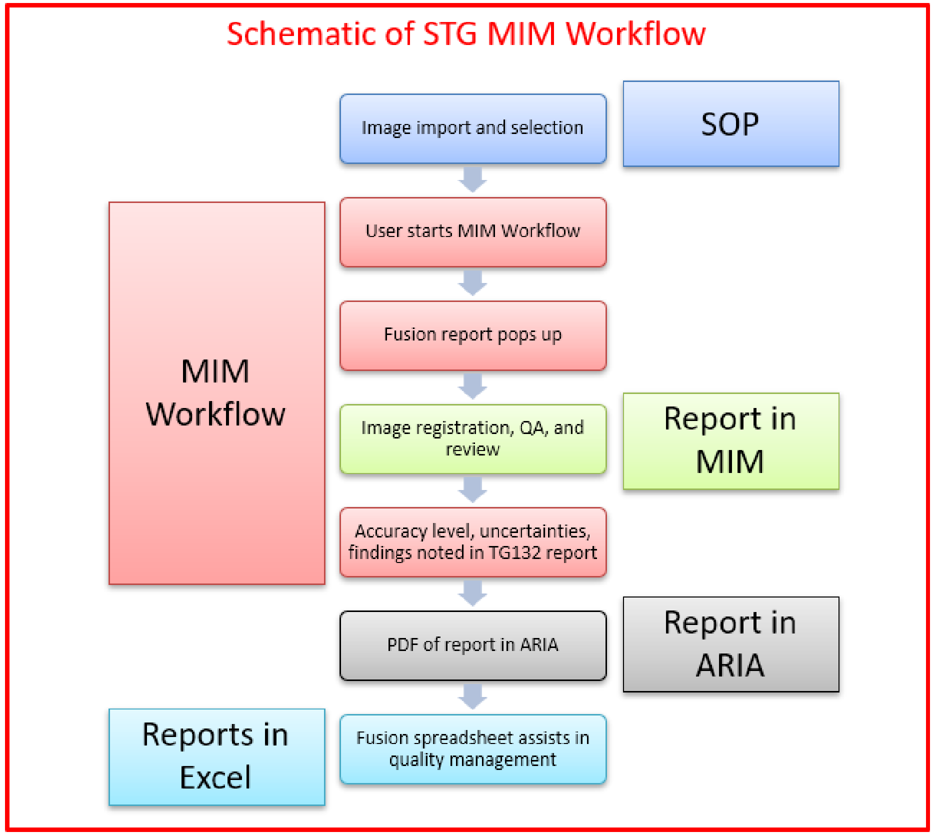



Image courtesy of Johnson Yuen

## Image Registration Request

**Primary Reference Image**

o Simulation CT o MRI o PET Date__________ Details____________________

**Images to be registered to the primary reference image**

o CT o PET o MRI (o sag o cor o axial) Date__________ Details____________________

o CT o PET o MRI (o sag o cor o axial) Date__________ Details____________________

**Intended Use**

o Target or structure delineation o Dose compositing

o Motion management o Disease progression or response

Comment: ________________________________________

**Local Regions of Importance**

| | Region | Comment | Landmarks |
|---|---|---|---|
| 1. | ________ | ________________ | ______________ |
| 2. | ________ | ________________ | ______________ |
| 3. | ________ | ________________ | ______________ |
| 4. | ________ | ________________ | ______________ |

**Registration Technique**

o Rigid Only o Rigid and Deformable o Deformable only

**Accuracy Requirements**

◯ 0: Whole Scan Aligned

◯ 1: Locally Aligned

◯ 2: Useable if deformation exists (registered image for complimentary information only)

◯ 3: Registration for diagnosis only (registration needed to identify general area)

Comment: ____________________________

**Requesting Physician:** ________________

**Date:** ________________

**Signature:** ________________

## Image Registration Report

**Primary Reference Image:**

Modality________ Date__________ Details____________________

**Images to be registered to the primary reference image**

Modality________ Date__________ Details____________________ Technique__________

Modality________ Date__________ Details____________________ Technique__________

**Intended Use**

o Target or structure delineation o Dose compositing

o Motion management o Disease progression or response

Comment: ________________________________________

**Local Region Alignment Accuracy**

| | Region/Metric | Accuracy Level | Comment | Screen Shot |
|---|---|---|---|---|
| 1. | ________ | ______________ | ______________ | o |
| 2. | ________ | ______________ | ______________ | o |
| 3. | ________ | ______________ | ______________ | o |
| 4. | ________ | ______________ | ______________ | o |

**Accuracy Level**

◯ 0: Whole Scan Aligned

◯ 1: Locally Aligned

◯ 2: Useable with risk of deformation (additional PTV/PRV margin may be required)

◯ 3: Useable for diagnosis only (registration only suitable to identify general area)

◯ 4: Alignment not acceptable (Do Not Use!)

Comment: ____________________________________

**Notes:**____________________________________________

________________________________________________

________________________________________________

**Clinician Performing Registration:** ________________

**Signature:** ______________ **Date:** ______________

# TG-132 Uncertainty Assessment

TABLE VII. Registration uncertainty assessment level and description.

| Uncertainty assessment | Phrase | Description |
|---|---|---|
| 0 | Whole scan aligned | • Anatomy within 1 mm everywhere<br>• Useful for structure definition everywhere<br>• Appropriate for stereotactic localization |
| 1 | Locally aligned | • Anatomy local to the area of interest is undistorted and aligned within 1 mm<br>• Useful for structure definition within the local region<br>• Appropriate for localization provided target is in locally aligned region |
| 2 | Useable with risk of deformation | • Aligned locally, with mild anatomical variation<br>• Acceptable registration required deformation which risks altering anatomy<br>• Registered image shouldn't be used solely for target definition as target may be deformed<br>• Increased reliance on additional information is highly recommended<br>• Registered image information should be used in complimentary manner and no image should be used by itself |
| 3 | Useable for diagnosis only | • Registration not good enough to rely on geometric integrity<br>• Possible use to identify general location of lesion (e.g., PET hot spot) |
| 4 | Alignment not acceptable | • Unable to align anatomy to acceptable levels<br>• Patient position variation too great between scans (e.g., surgical resection of the anatomy of interest or dramatic weight change between scans) |

# TG-132 Uncertainty Assessment

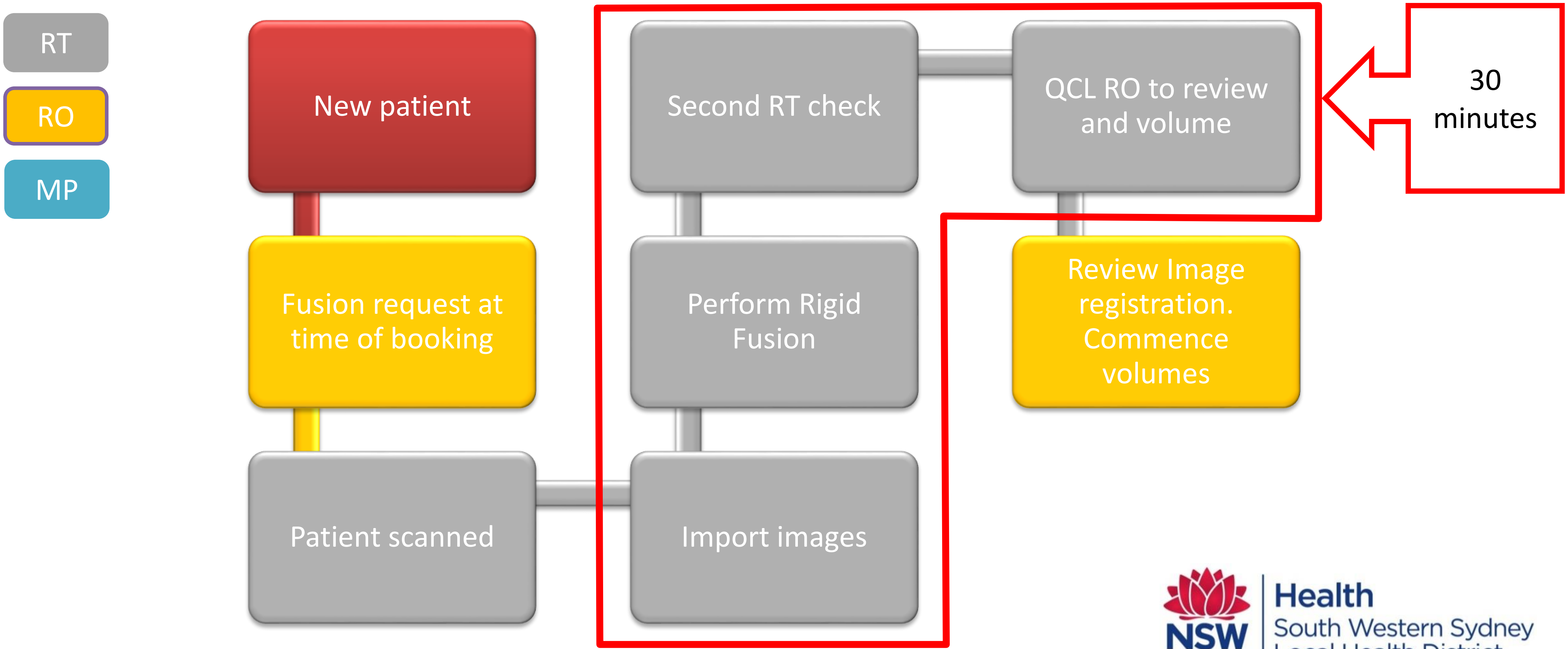
TABLE VII. Registration uncertainty assessment level and description.

| | | |
|---|---|---|
| 0 | **Aligned < 1mm** | accurate for SRS planning |
| 1 | **Locally aligned** | undistorted, target OK, use for delineation |
| 2 | **Usable with risk** | mild variations; DIR used; review in context |
| 3 | **Diagnosis only** | geometric integrity not good enough |
| 4 | **Not acceptable** | unable to align, or variation too great |

# Implementation

- Clinical roll-out model depends on local department.
  - Prioritise one use case and anatomical site to start, driven by need.
  - Start small, multidisciplinary review, develop common language and roles/responsibilities up front.
- Data management policies
  - Where is data? In which system? What order are tasks performed?
  - Naming conventions, approval processes and version control all need to be considered.
- **Automated workflows are encouraged to reduce simple errors, but manual checkpoints and methods for validation/correcting automated results are needed**
- DIR takes resources. But has potential to reduce time for contouring, and for future new ART

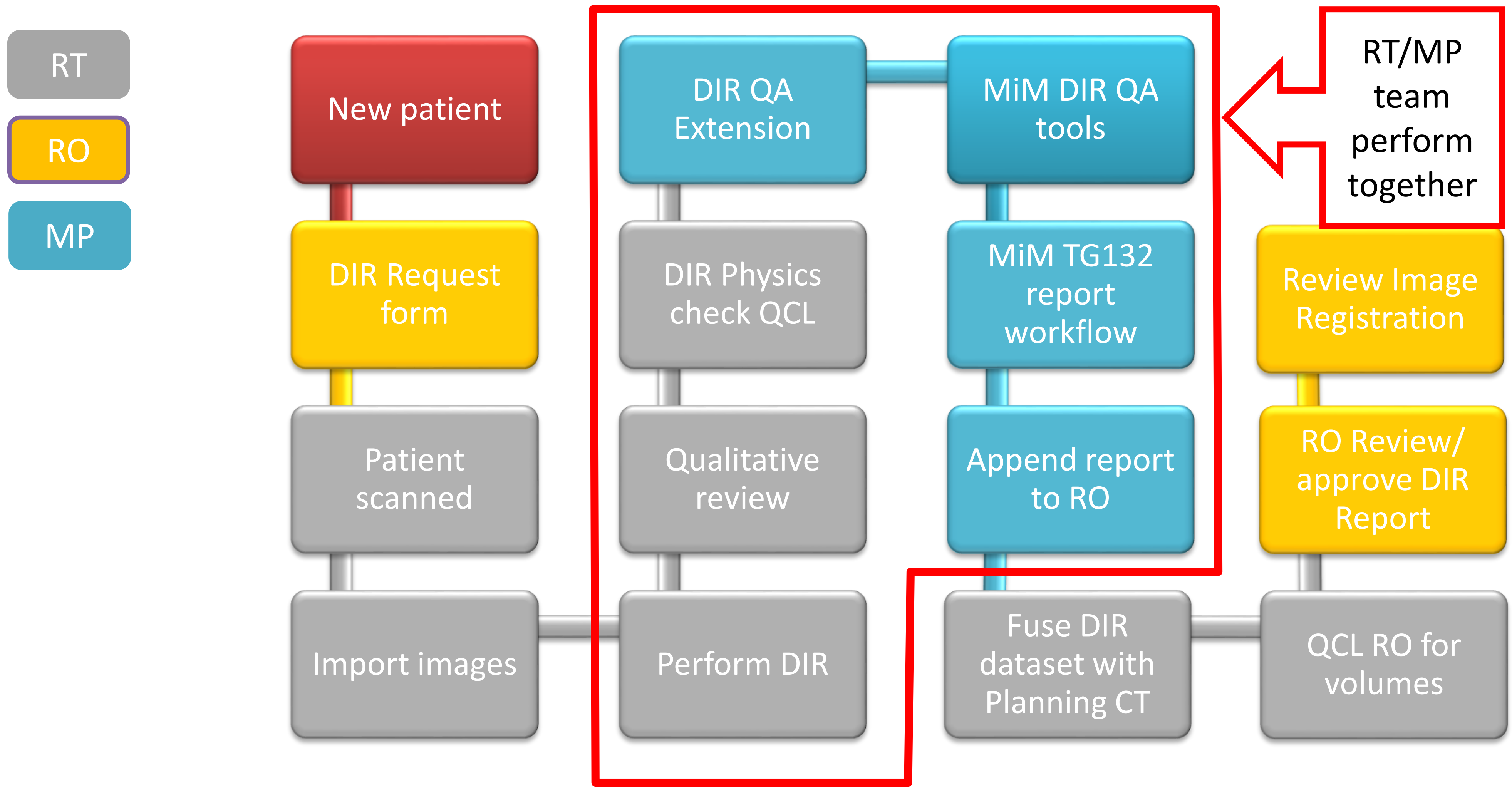
# *Rigid Image Registration Workflow*




Health
South Western Sydney
Local Health District

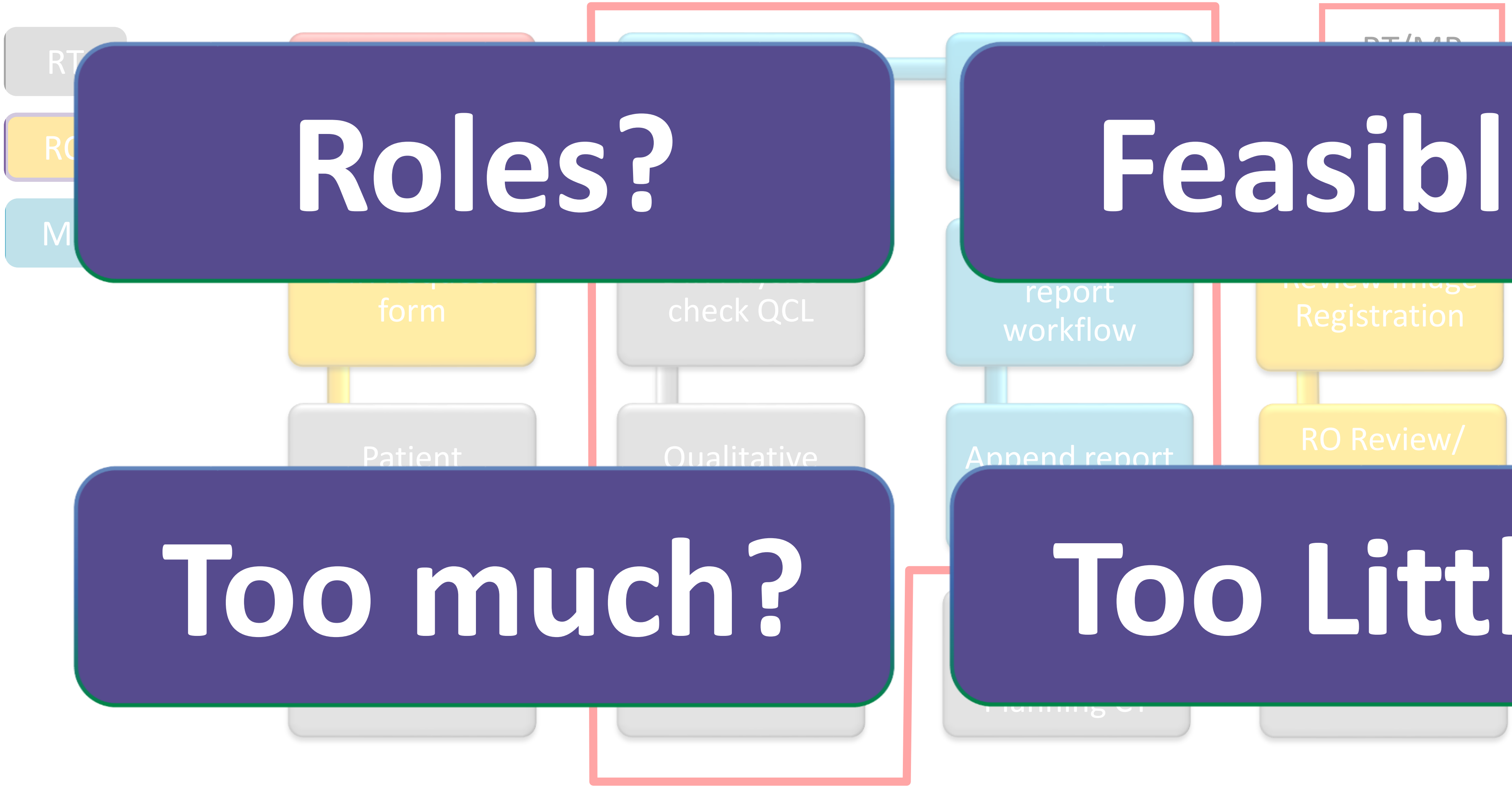
Slide courtesy of Callie Choong

# Proposed DIR workflow




Slide courtesy of Callie Choong

# *Process Evaluation Needed*




**Roles?**

**Feasible?**

**Too much?**

**Too Little?**

Slide courtesy of Callie Choong

# Education & Training

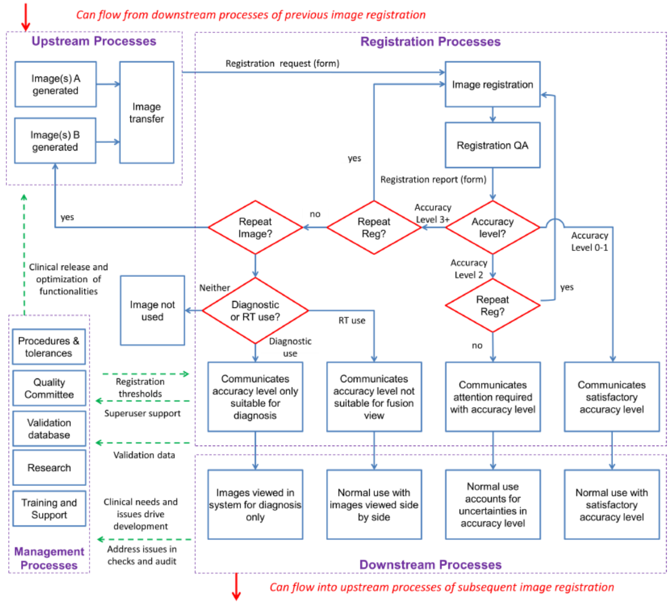
- Training for RIR and DIR is important, and consideration needs to be made for the appropriate model of training for a department.
- **Training amongst all staff groups is required.**
  - DIR requires a collaborative approach as uncertainties, technical limitations and clinical decisions associated with using DIR need to be understood by all groups.
  - Site visits and discussions with experienced departments are encouraged. Training should cover "how-to" training for new software, as well as background theory to develop critical analysis to identify and rectify sub-optimal results.
- There is limited formal training available in this area, and it will tend toward software-specific.

# Research Packages

- **Open source and research tools are not recommended for routine clinical use**.
  - require specialised expertise and if used clinically should be within a well-documented protocol e.g. clinical trials.
  - They can however supplement existing practices as tools for training, benchmarking or extending clinical systems
    - generate virtual phantoms, perform cross validation with different DIR algorithms, test advanced concepts like masking, multi-algorithm registrations and prototype pipelines for workflows
  - all data going in and out of an OIS/TPS should be parsed through a Therapeutic Goods Administration approved software first to ensure integrity.

# Risk-based framework

- Risk based approaches (e.g., TG-100 model) can help develop effective, feasible, and practical quality control
- Overall image registration process can be evaluated for residual risk and uncertainty with departmental consensus on acceptable risk, uncertainty, and trade-offs based on available solutions
- Risks in use of DIR depend on the application of the DIR results.
  - Propagating deformed contours is usually lower risk than propagating deformed dose.
  - Validation of deformed contours can be done with existing expertise and correction.
  - Validation of deformed dose depends on the intended use and accuracy level and is specific to DIR used.




| Category | Failure mode | Effects of failure | O | S | D | RPN |
|---|---|---|---|---|---|---|
| Upstream | Quality management of scanner | Errors relating to distortion, artefact, noise, orientation, etc. | 3.7 | 4.7 | 4.8 | 73 |
| | Image(s) acquisition | Errors relating to scan extent, orientation, image quality, setup and immobilisation, etc. | 4.8 | 4.7 | 4.3 | 95 |
| | Image Transfer | Errors relating to incorrect orientation, reduced image quality, wrong patient or site | 2.7 | 6.2 | 4.0 | 61 |
| | Image Registration Request form | Misinterpretation of image registration requirements, inefficiencies, suboptimal quality | 6.5 | 4.7 | 4.5 | 134 |
| Registration | Standard Image Registration | Suboptimal image registration and spatial errors | 5.7 | 4.7 | 5.3 | 164 |
| | Image Registration QA | Clinical use of images with unacceptable errors, clinical use of image without sufficient error handling | 4.7 | 5.7 | 6.2 | 177 |
| | Iterative Image Registration | Suboptimal technique leading to unreliable registration | 5.2 | 4.5 | 6.8 | 174 |
| Downstream | Error handling with margins | Errors in image registration not known, errors not handled with margin policy | 6.0 | 4.7 | 5.5 | 176 |
| | Image Registration Report form | Inappropriate use of image registration output, mismatch between requirements and registration | 6.2 | 4.5 | 5.8 | 200 |
| Management | Clinical release of image registration functions | Insufficient knowledge to formulate processes, risks not managed | 5.0 | 5.2 | 5.0 | 126 |

Images courtesy of Johnson Yuen

# Some recent developments…

# 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

Advances in Radiation Oncology (2019) 4, 559-565
https://doi.org/10.1016/j.adro.2019.05.007

ELSEVIER

Seminars in Radiation Oncology
Volume 30, Issue 3, July 2020, Pages 204-211

## The Medical Physics Management of Reirradiation Patients

Kelly C. Paradis PhD, Martha M. Matuszak PhD

Show more

https://doi.org/10.1016/j.semradonc.2020.02.008

Get rights and content

### Special Medical Physics Consultation – Previous Treatment Evaluation

**Guidelines:** The special medical radiation physics consultation for evaluation of previous treatment is appropriate when a patient has received radiation to a site relevant to the current treatment. Some examples of why this consultation may be performed are the following: evaluation of treatment overlap, design of field borders, determination of dose fractionation / total dose, and / or determination of tailored dose constraints.

Blue: Required Physician input
Green: Required Physicist input

| Physicist(s) performing SMPC: | |
|---|---|
| ☐ Yes ☐ No | All SMPC composite dose limits met (describe in comments if No) |
| ☐ Yes ☐ No | MD peer review requested to evaluate SMPC results (describe in comments if Yes)<br>If requested this peer review is in addition to Chart Rounds |

Comments: (Concisely summarize the results of the SMPC here as needed, adding screenshots if useful. This information will be reviewed in Chart Rounds.)

**Prior radiation therapy courses:**

| Course End Date | Target Area | Target Dose [Gy] | # of Fx | Outside Institution |
|---|---|---|---|---|
| | | | | ☐ |
| | | | | ☐ |
| | | | | ☐ |
| | | | | ☐ |
| | | | | ☐ |

**Narrative description of previous treatment(s):**

Please enter relevant previous treatment information. Outside records, including those in MiChart, should be scanned into ARIA prior to dropping the special medical physics consult task.

**Physician request/medical necessity:**

Please describe purpose of evaluation and areas of particular concern:

☐ Assess treatment overlap

...s from composite plan that includes ... Note:

...mposite plans. Biocorrected DVH's may be

...ntially from physical dose

| | | | | Previous dose discount (%) [0% means no discount] For >3 years, 50% discount suggested | | | |
|---|---|---|---|---|---|---|---|
| | | | | < 3 mo | 3-6 mo | 6 mo – 1 yr | 1 – 3 yrs |
| | | | | 0 | 10 | 25 | 50 |
| | | | | 0 | 10 | 25 | 50 |
| | | | | 0 | 10 | 25 | 50 |
| | | | | 0 | 10 | 25 | 50 |
| | | | | 0 | 10 | 25 | 50 |
| | | | | 0 | 10 | 25 | 50 |
| | | | | 0 | 0 | 10 | 25 |
| | | | | 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 |

Cite this article as:
Hussein M, Heijmen BJM, Verellen D, Nisbet A. Automation in intensity modulated radiotherapy treatment planning—a review of recent innovations. *Br J Radiol* 2018; **91**: 20180270.

REVIEW ARTICLE

## Automation in intensity modulated radiotherapy treatment planning—a review of recent innovations

[1]MOHAMMAD HUSSEIN, PhD, [2]BEN J M HEIJMEN, PhD, [3,4]DIRK VERELLEN, PhD and [5,6]ANDREW NISBET, PhD

BJR 2019

REVIEW ARTICLE

## Artificial intelligence in oncology, its scope and future prospects with specific reference to radiation oncology

[1]RAJIT RATTAN, MD, [1]TEJINDER KATARIA, MD, DNB, [1]SUSOVAN BANERJEE, MD, [1]SHIKHA GOYAL, MD,DNB, [1]DEEPAK GUPTA, MD, [2]AKSHI PANDITA, MD, SHYAM BISHT, MD, [1]KUSHAL NARANG, MD and [1]SAUMYA RANJAN MISHRA, MD

[1]Division of Radiation Oncology, Medanta- The Medicity, Gurgaon, Haryana, India
[2]Department of Dermatology, P. N. Behl Skin Institute, New Delhi, India

*Journal of Medical Imaging and Radiation Oncology* **64** (2020) 163–177

RADIATION ONCOLOGY—REVIEW ARTICLE

## Magnetic resonance-guided radiation therapy: A review

Stephen Chin,[1,2] Cynthia L Eccles,[3,4] Alan McWilliam,[4,5] Robert Chuter,[4,5] Emma Walker,[5] Philip Whitehurst,[5] Joseph Berresford,[5] Marcel Van Herk,[4,5] Peter J Hoskin[1,4] and Ananya Choudhury[1,4]

1 Department of Clinical Oncology, The Christie NHS Foundation Trust, Manchester, UK
2 Westmead Clinical School, University of Sydney, Sydney, New South Wales, Australia
3 Department of Radiotherapy, The Christie NHS Foundation Trust, Manchester, UK
4 Division of Cancer Sciences, The University of Manchester, Manchester, UK
5 Christie Medical Physics and Engineering, The Christie NHS Foundation Trust, Manchester, UK

Radiotherapy and Oncology 146 (2020) 66–75

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

ELSEVIER

Review Article

## Quantitative imaging for radiotherapy purposes

Oliver J. Gurney-Champion[a,*], Faisal Mahmood[b,c], Marcel van Schie[d], Robert Julian[e], Ben George[f], Marielle E.P. Philippens[g], Uulke A. van der Heide[d], Daniela Thorwarth[h], Kathrine R. Redalen[i]

FULL TEXT ARTICLE

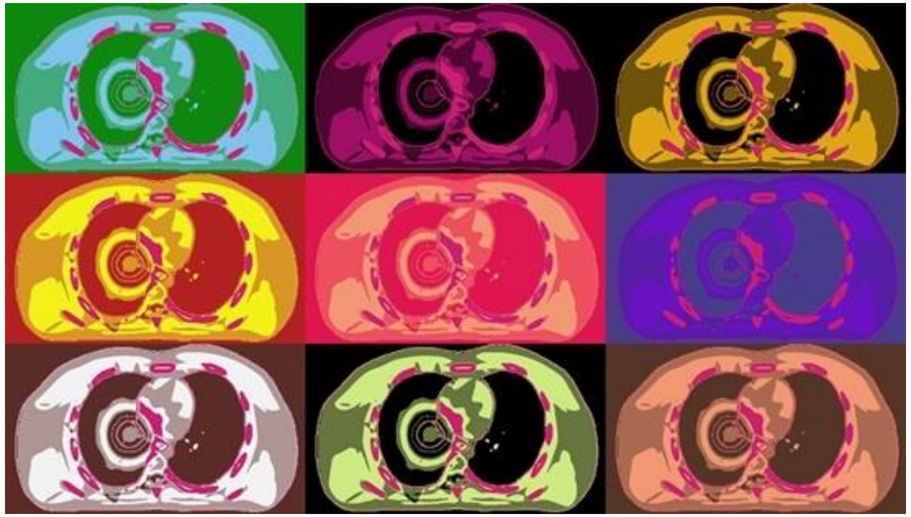
# Patterns of practice for adaptive and real-time radiation therapy (POP-ART RT) part II: offline and online plan adaption for interfractional changes

Article in Press: Accepted Manuscript

Jenny Bertholet, Gail Anastasi, David Noble, Arjan Bel, Ruud van Leeuwen, Toon Roggen, Michael Duchateau, Sara Pilskog, Cristina Garibaldi, Nina Tilly, Rafael García-Mollá, Jorge Bonaque, Uwe Oelfke, Marianne C. Aznar and Ben Heijmen

Radiotherapy and Oncology, Copyright © 2020

https://doi.org/10.1016/j.radonc.2020.06.017



*“Note also that image registration is not a science. It is a pure engineering practice, and therefore, there are no correct answers, nor “truths” to be found. It is all about how much quality you want, and how must computation time, and development time you are willing to pay for that quality. The “satisfying” answer for your specific application must be found by exploring the trade-offs between the different parameters that regulate the image registration process.”*

*Johnson (2016) ITK Software Guide.*

# The SMIRFS (past, presenters, future)

Jeff Barber

**Laurel Schmidt**

**Johnson Yuen**

**Joel Poder**

Jonathan Sykes

Emily Flower

Michael Jameson

Alison Gray

Amy Walker

**Callie Choong**

Alisha Moore

Elizabeth Brown

**Nick Hardcastle**

**Adam Yeo**

Alex Quinn

John Kipritidis

Annette Haworth

Kristie Harrison

Mark Lee

Charlotte Atkinson

Kristie Matthews

Sarat Chander

Fiona Hegi-Johnson

Lois Holloway

Anna Ralston

**Ben Archibald-Heeren**

Mikel Byrne

# In Press

PRACTICE GUIDELINE | OPEN ACCESS

## 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] | Amy Walker PhD [4,5,6] | Adam Yeo PhD [7,9] | Ben Archibald-Heeren MSc [10] | Kristie Harrison MSc [11] | Annette Haworth PhD [2] | David Thwaites PhD [1,2]

Journal of Medical Radiation Sciences OPEN

Australasian College of Physical Scientists & Engineers in Medicine

CPD Endorsed Activity

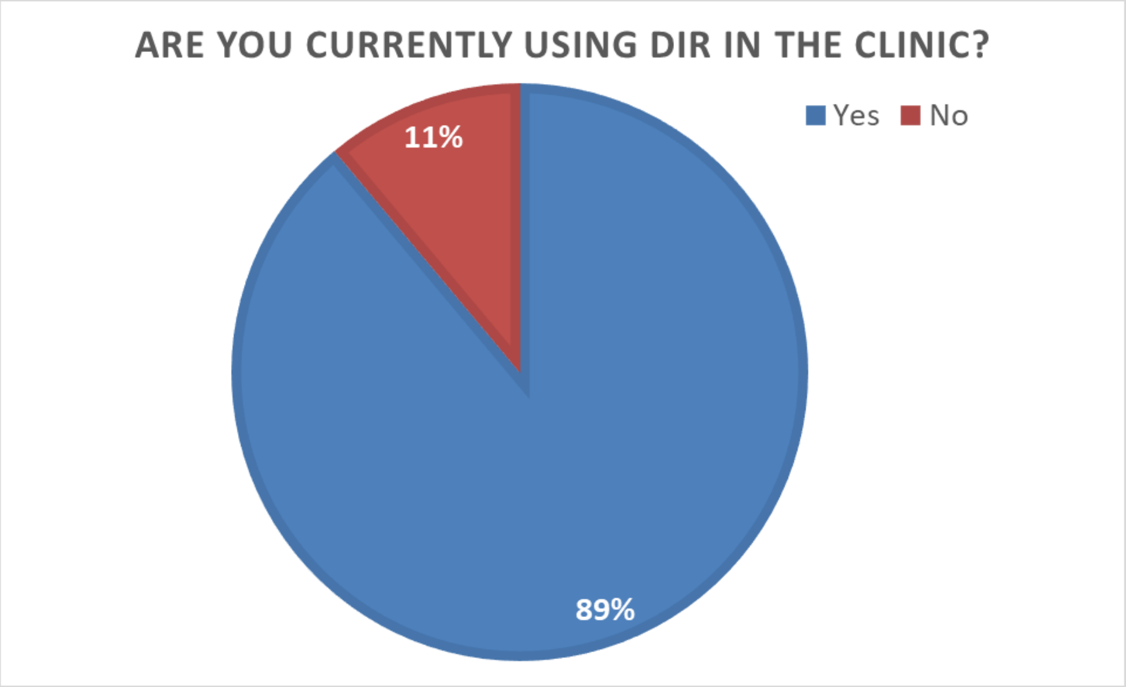
MIRSIG

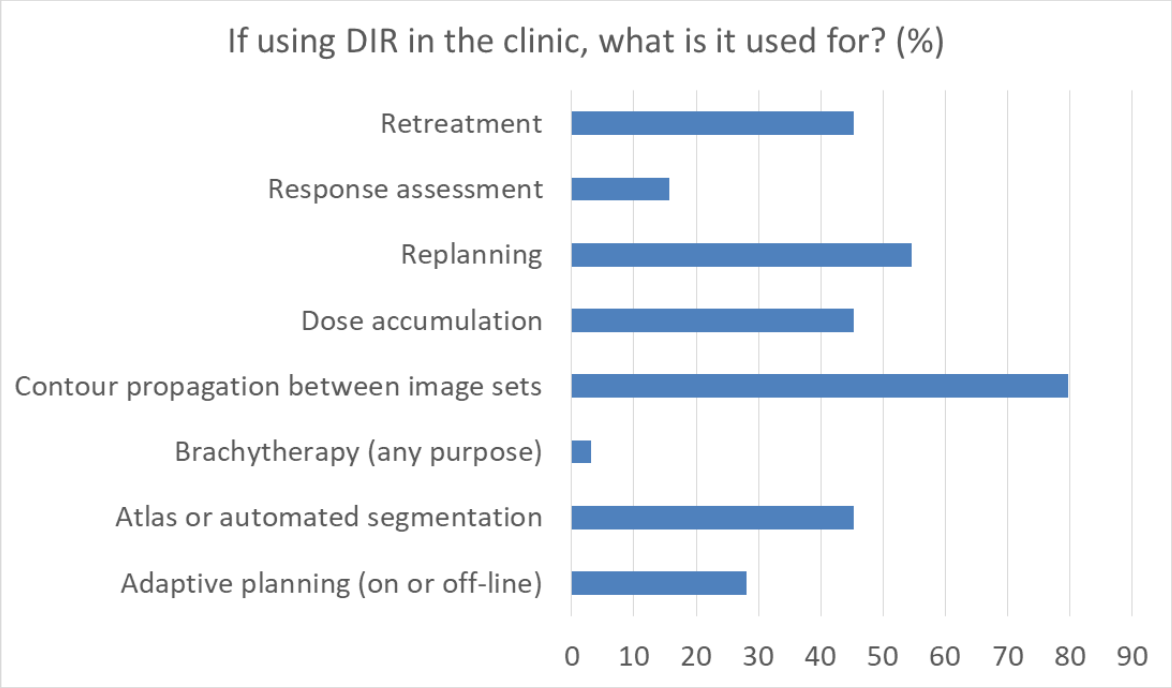
ASMIRT APPROVED CPD PROGRAM

Appellation Code: SGHCCC-001544-2020

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

## Online Poll data from the June 2020 Webinar Chaired by Laurel Schmidt (Talk 2 by Jeffrey Barber)



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

## Questions and Answers from the June 2020 Webinar Chaired by Laurel Schmidt (Talk 2 by Jeffrey Barber)

**Question 1:** What do you think about running something similar to dosimetry audits for registration with a phantom?

**Answers:** This is a great idea as adaptive MR Linacs come online. There is a pilot study by the ACDS for adaptive systems, and such tests will be able to validate registration processes. However, at this stage these may not be aimed for regular departments. Quality assurance with a physical phantom is a great idea as there are lots of uncertainties that can be checked.

**Question 2:** Is there any general guidance or QA tools on assessing quality of datasets coming in from external data sources for example MRI or PET distortion before using it for image registration?

**Answers:** Currently no. If external images are acquired, there may be a need to build a relationship with the external image provider to work out what the quality assurance is for various aspects (such as MR distortion). Generally, distrust could be a starting point until there is quantitative validation data from the external image provider.

**There are guidance documents e.g. AAPM TG 174 Utilisation of FDG PET in RT((https://doi.org/10.1002/mp.13676), and other AAPM reports which provide guidance on QA required for diagnostic imaging systems*