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: **An international survey on the clinical use of rigid and deformable image registration in radiotherapy**

Presented by Johnson Yuen

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

Presented by Jeffrey Barber

Webinar interactivity
Use the “Q&A” to ask questions (and participate in polls)!

CPD
**Poll information will be used to confirm ASMIRT CPD (for RTs), so it is important to participate!*
**Physicists will have CPD automatically logged through ACPSEM*

Post webinar survey!
Email will be sent.

Seminar material available online!
https://www.acpsem.org.au/About-the-College/Special-Interest-Groups/MIRSIG

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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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RADIATIONONCOLOGY PHYSICS

An international survey on the clinical use of rigid and deformable image registration in radiotherapy

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Learning objectives

Understand international and ANZ patterns of deformable registration by clinical application

Understand how deformable registration uptake varies
- By anatomical site
- By image modality
- In uptake of different DIR systems
- In quality management strategies for DIR

Understand how
- Staff roles for DIR have evolved for physicist, RTs, and ROs
- Centres have considered the benefits, risks, and trade-offs in the use of DIR

Outline

1. Introduction

2. Materials and Methods

2.A Question generation and review

2.B Survey data collection and analysis

3. Results

3.A Inclusion and exclusion of data and analysis

1. Introduction

- DIR can provide superior accuracy over RIR with appropriate patient specific QA (Brock 2017)
- DIR can be considered *ill-defined and over-constrained* (Brock 2017) with validation considered an resolved subject (Paganelli 2018)
- Need to understand when, what, who, and how IR is used
- **Aim to measure reference data for clinical DIR and RIR implementation**

2. Material and methods

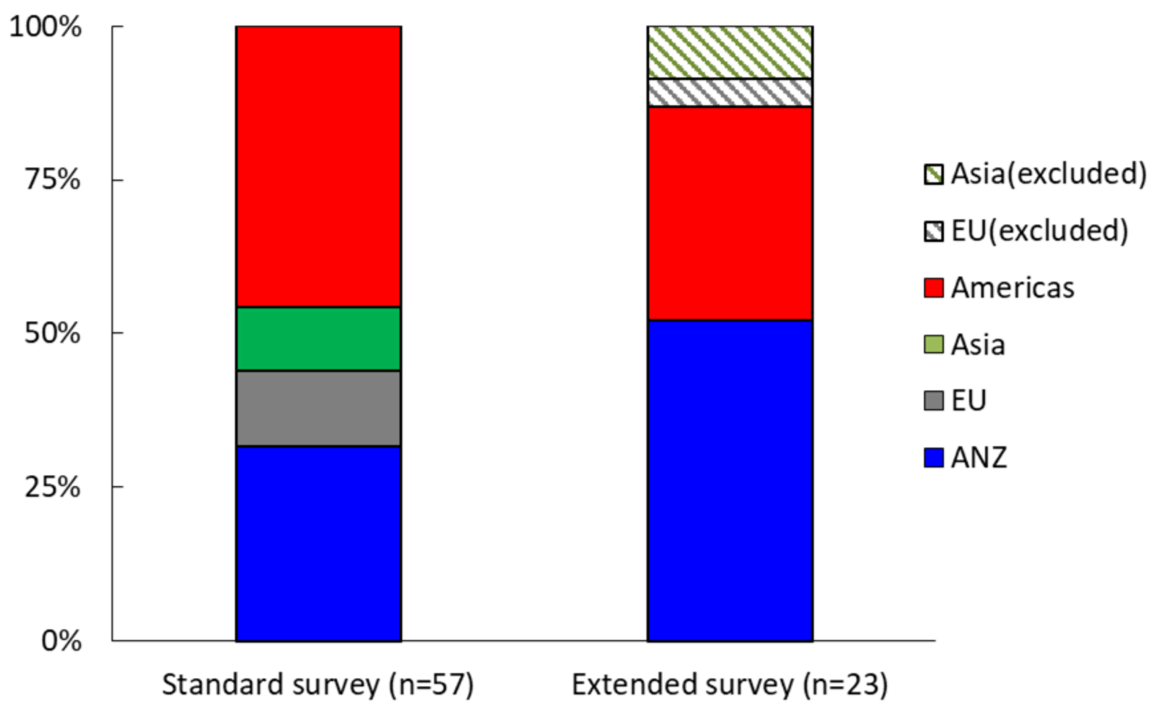
- Two versions of survey (English) for (a) ANZ and (b) international centres
- Basic (27q, 10m) and extended questions (54q,+30m)
- Non-official survey in **2018(April to Sept).**

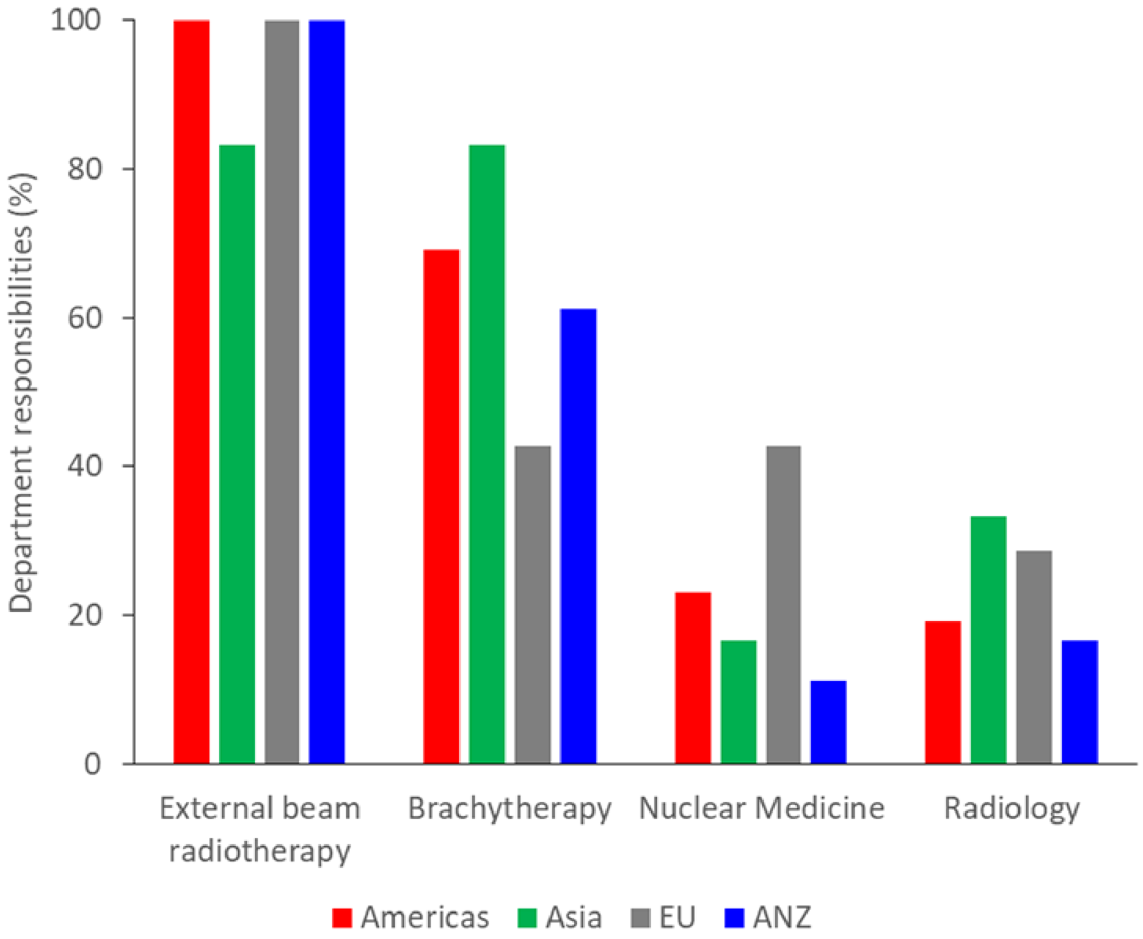
3.A Inclusion and exclusion of data and analysis

- Excluded analysis of areas with insufficient data
- Excluded questions on number of datasets for commissioning (no ability for respondents to skip question)

Outline

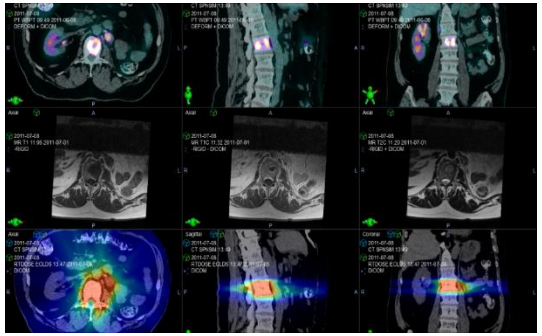
3.B.1 Respondent data and department responsibilities

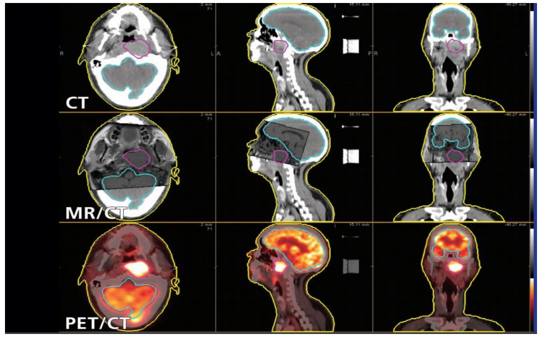




3.B.2 Standalone DIR and RTPS DIR software (SW)

Type of DIR SW	Software product	2013 INTL	2018 INTL	2023 INTL
Dedicated DIR SW	Velocity	14	41	45
	MIM	22	43	45
	Mirada	6	8	8
	Prosoma (o)		2	
	MRIdian (o)		2	
RTPS with DIR	Pinnacle	8	12	16
	Raystation	6	12	16
	Eclipse (o)		8	
	Brainlab (o)		4	
Open source DIR SW	Plastimatch (o)		6	
	Slicer (o)		4	
	ITK (o)		4	
	DIRART (o)		2	
DIR validation SW	ImSimQA	4	12	12





Screenshots of Velocity (top left), MIM(bot left), and Mirada(right) as dedicated DIR SW.

Type of DIR SW	Software product	2013 INTL	2018 INTL	2023 INTL
Any open source DIR SW	All SW		8	
Both dedicated DIR and RTPS with DIR	All SW	8	16	20
Multiple dedicated DIR SW	All SW	6	20	20
Any RTPS with DIR	All SW	12	24	29
Any dedicated DIR SW	All SW	33	73	75
Either dedicated DIR or RTPS with DIR	All SW	49	80	84

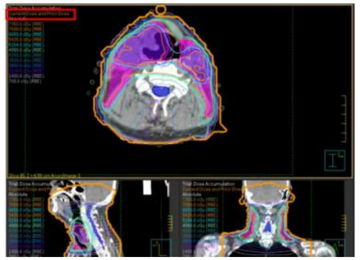
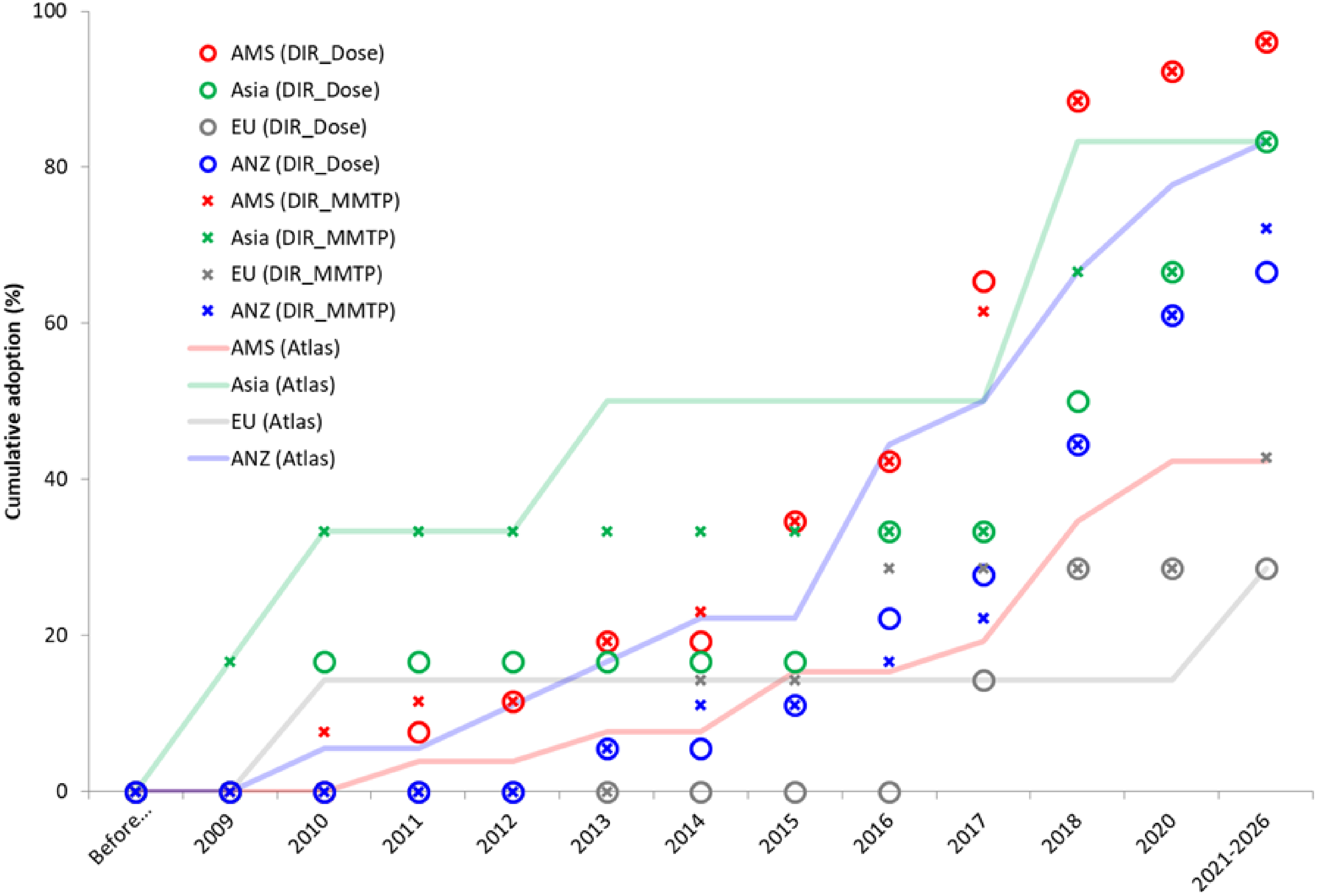


Figure showing RTPS DIR SW with Raystation (left) and Pinnacle dynamic planning (right)

Outline

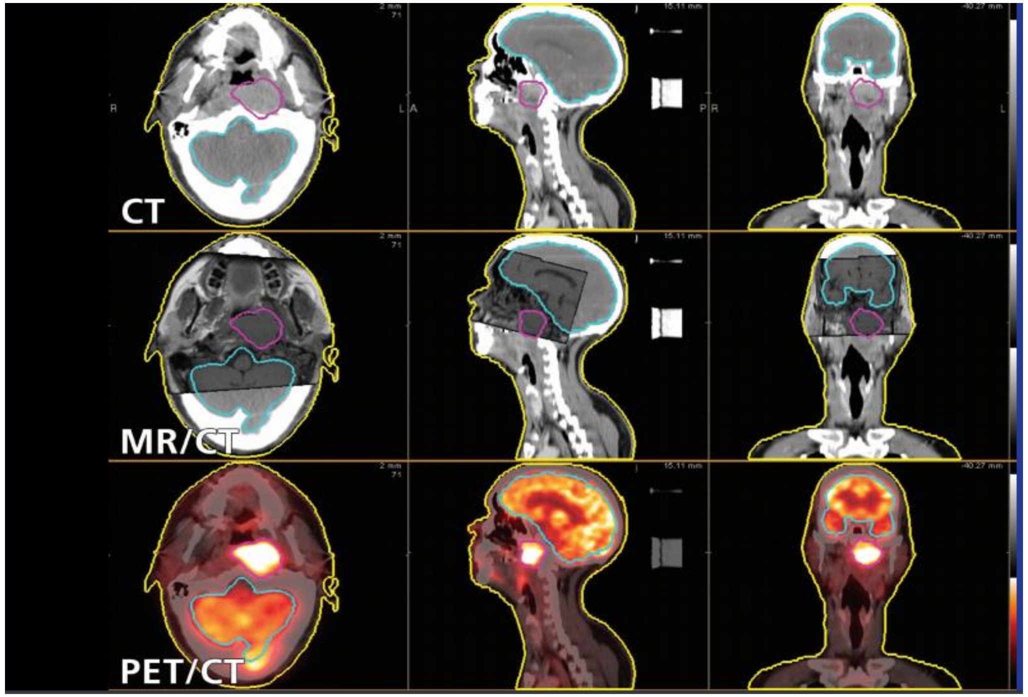
3.C.1 Cumulative adoption of image registration techniques



Cumulative adoption of atlas based segmentation (Atlas), deformable image registration with dose (DIR_Dose) and multi-modality treatment planning (DIR_MMTP); note that data for 2018 and onwards are indicative of respondent intentions and not actual adoption.

3.C.2 Uptake of RIR and DIR by image modality pair (%)

	Americas	Asia	EU	ANZ	INTL
CT-CT					
RIR	92	100	100	100	96
DIR	77	33	43	22	51
CT-MR					
RIR	92	83	86	100	93
DIR	27	33	29	0	19
CT-PET					
RIR	73	83	71	94	81
DIR	77	50	0	22	47
CT-CBCT					
RIR	85	83	100	78	84
DIR	15	33	43	11	19
CT-US					
RIR	8	17	0	11	9
DIR	0	0	0	0	0
MR-MR					
RIR	46	33	57	56	49
DIR	4	17	14	0	5



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DIR	77	50	0	22	47
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RIR	85	83	100	78	84
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CT-US					
RIR	8	17	0	11	9
DIR	0	0	0	0	0
MR-MR					
RIR	46	33	57	56	49
DIR	4	17	14	0	5

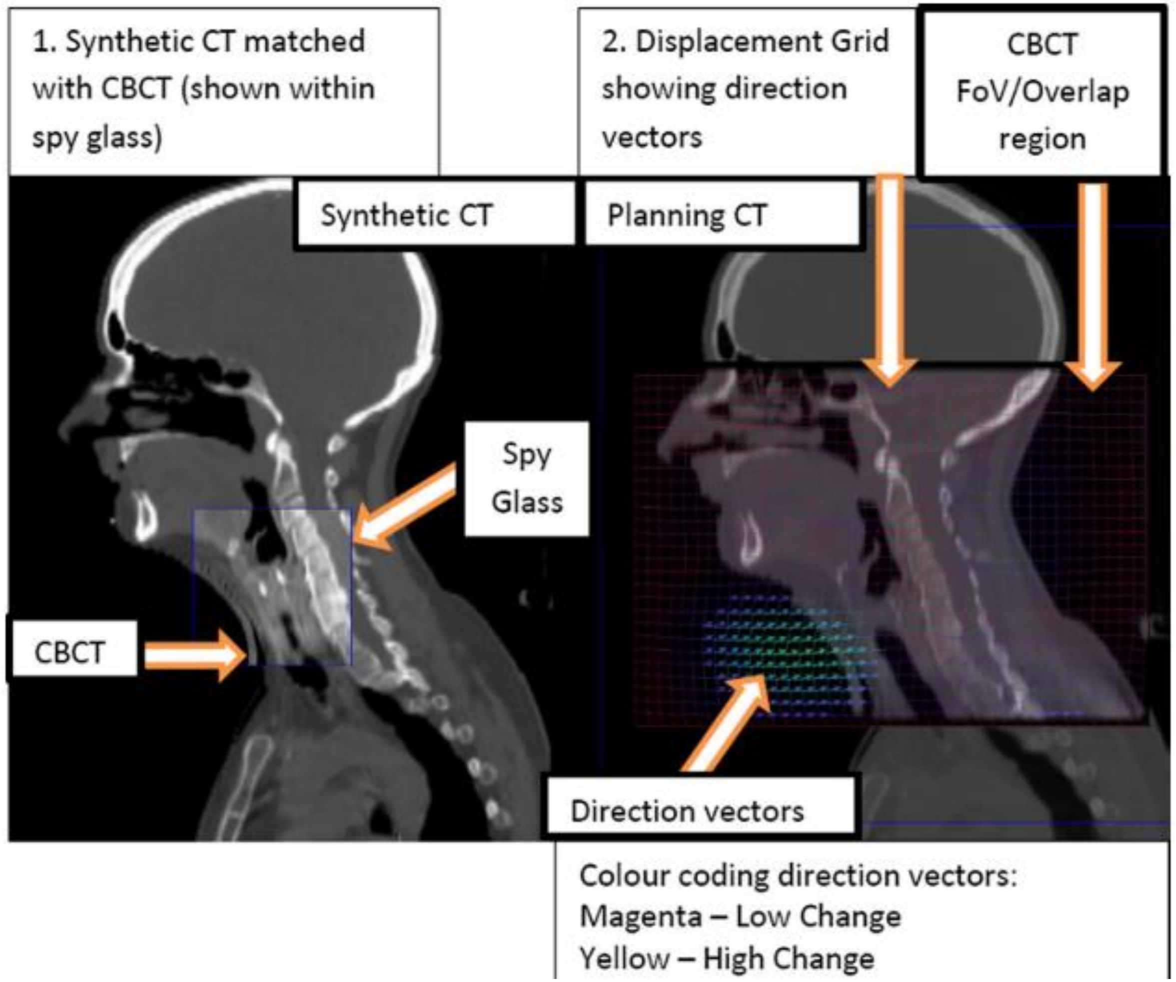
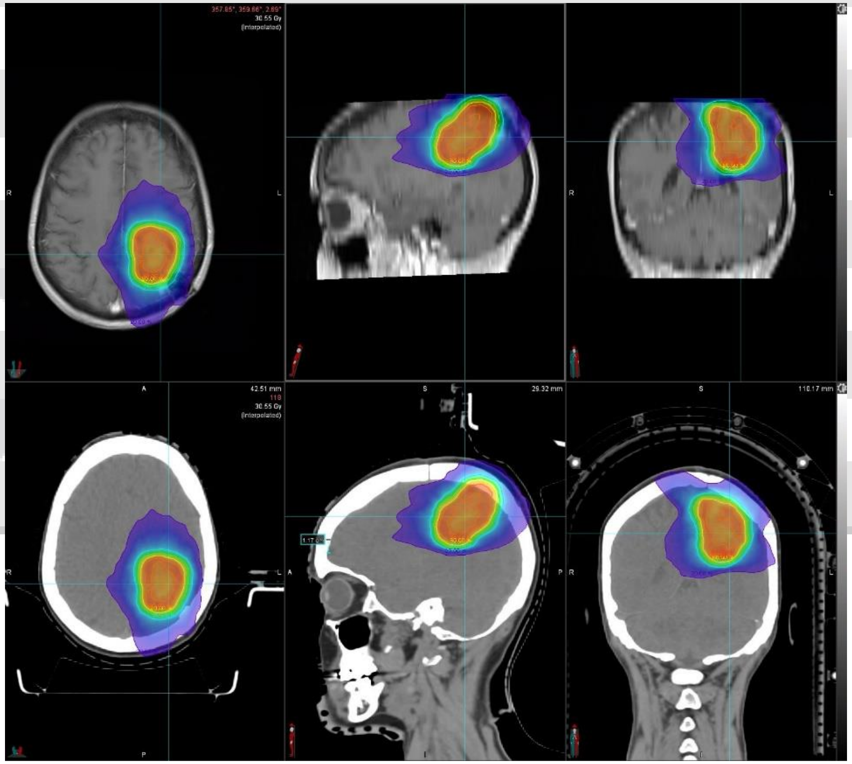


Diagram adapted from Hay 2020, illustrating use of CBCTs obtained during the treatment course to deform and register the planning CT (pCT) to the CBCT anatomy. This generates a synthetic CT (sCT) set with the Hounsfield units (HU) of the planning CT. Note data truncation on the CBCT.

3.C.3 Uptake of DIR by anatomical site

TABLE 3 International data by anatomical site on the use of rigid (RIR) and deformable image registration (DIR) for multi-modality treatment planning (MMTP), accounting for previous treatment (Prev Tx eval), adaptive radiotherapy (ART), and atlas-based segmentation (%). Ratings of uncertainty of DIR with images and dose are in the last column (higher value represents more uncertainty, scaled from 0 to 100%).

	MMTP		Prev Tx eval		ART		Atlas-based segmentation	Uncertainty DIR
	RIR	DIR	RIR	DIR	RIR	DIR		
Brain	96	30	83	26	48	17	43	24
Head and neck	100	57	87	57	65	43	43	51
Breast	52	22	70	30	35	[illegible]	[illegible]	[illegible]
Lung	100	43	87	39	52	[illegible]	[illegible]	[illegible]
Esophagus	87	43	87	35	43	[illegible]	[illegible]	[illegible]
Pelvis	96	30	83	30	52	[illegible]	[illegible]	[illegible]
Prostate	96	30	87	35	48	[illegible]	[illegible]	[illegible]
Upper GI	83	30	83	30	39	[illegible]	[illegible]	[illegible]
Sarcoma	65	26	61	13	39	[illegible]	[illegible]	[illegible]
Hematological	39	13	48	13	26	[illegible]	[illegible]	[illegible]



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	MMTP		Prev Tx eval		ART		Atlas-based segmentation	Uncertainty DIR
	RIR	DIR	RIR	DIR	RIR	DIR		
Brain	96	30	83	26				
Head and neck	100	57	87	57				
Breast	52	22	70	30				
Lung	100	43	87	39				
Esophagus	87	43	87	35				
Pelvis	96	30	83	30				
Prostate	96	30	87	35				
Upper GI	83	30	83	30				
Sarcoma	65	26	61	13				
Hematological	39	13	48	13				

Adapted figure showing main difficulties for DIR methods from Paganelli 2018

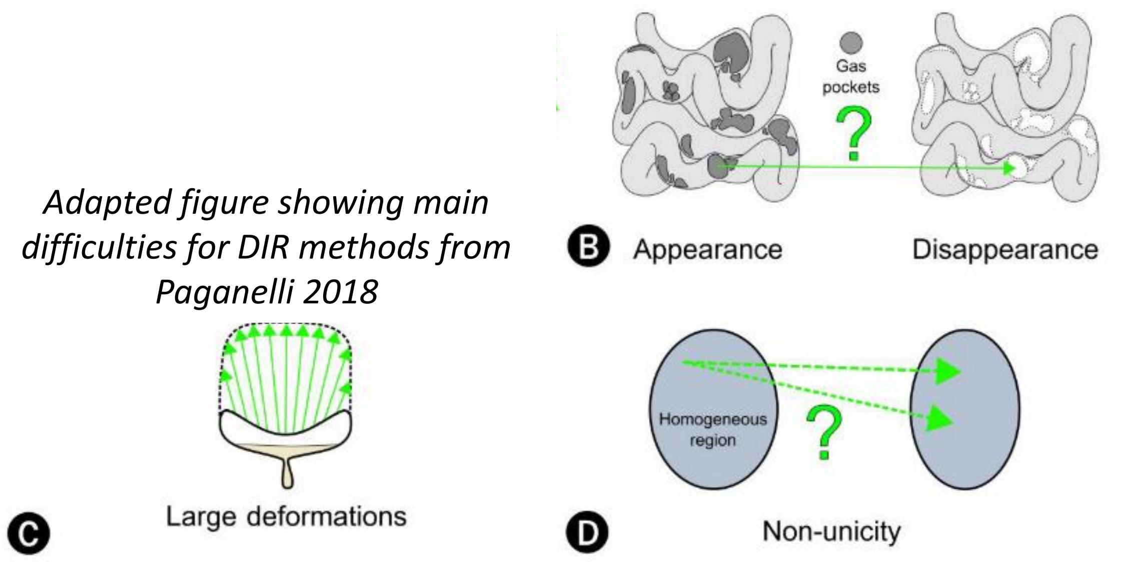
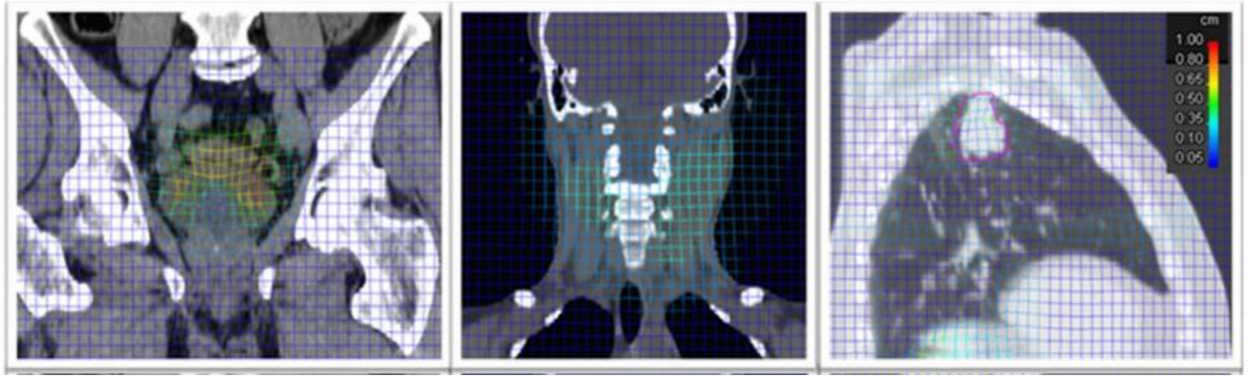


Figure S-3: Illustration of the main difficulties for DIR methods

3.C.3 Uptake of DIR by anatomical site

Table 3 International data by anatomical site on the use of rigid (RIR) and deformable image registration (DIR) for multi-modality treatment planning (MMTP), accounting for previous treatment (Prev Tx eval), adaptive radiotherapy (ART), and atlas-based segmentation (%). Ratings of uncertainty of DIR with images and dose are in the last column (higher value represents more uncertainty, scaled from 0 to 100%).

	MMTP		Prev Tx eval		ART		Atlas-based	Uncertainty
	RIR	DIR	RIR	DIR	RIR	DIR	segmentation	DIR
Brain	96	30	83	26	48	17	43	24
Head and neck	100	57	87	57	65	43	43	51
Breast	52	22	70	30	35	17	22	46
Lung	100	43	87	39	52	35	26	55
Esophagus	87	43	87	35	43	17	17	52
Pelvis	96	30	83	30	52	17	26	52
Prostate	96	30	87	35	48	22	30	48
Upper GI	83	30	83	30	39	17	17	56
Sarcoma	65	26	61	13	39			
Hematological	39	13	48	13	26			



*Figures showing deformable vector fields from Loi 2018, illustrating publication of multiple institution study with **DIR performance for HN, thorax, and pelvis.***

Outline

1. Introduction

2. Materials and Methods

2.A Question generation and review
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3. Results

3.A Inclusion and exclusion of data and analysis

3.B Respondent data

3.B.1 Department responsibilities
3.B.2 Standalone DIR and RTPS DIR software

3.C Clinical adoption of rigid and deformable image registration

3.C.1 Cumulative adoption of image registration techniques
3.C.2 Uptake of RIR and DIR by image modality
3.C.3 Uptake of DIR by anatomical site
3.C.4 Staff involvement in rigid and deformable image registration

3.D Implementation and operational characteristics

3.D.1 Image registration training
3.D.2 Image registration process evaluation
3.D.3 Image registration challenges
3.D.4 Evaluation of image registration methods
3.D.5 Evaluation of image registration quality assurance metrics
3.D.6 Image registration validation datasets
3.D.7 Image registration request and report form

3.E Quality, safety, and value in the implementation of image registration

3.E.1 Criteria for commissioning and implementing image registration
3.E.2 Measures of quality and safety for image registration
3.E.3 Evaluation of value in implementation of DIR with risk-benefit rating by use case

4. Discussion

5. Conclusion

3.D.1 Image registration training

TABLE 5 Data from image registration training question.

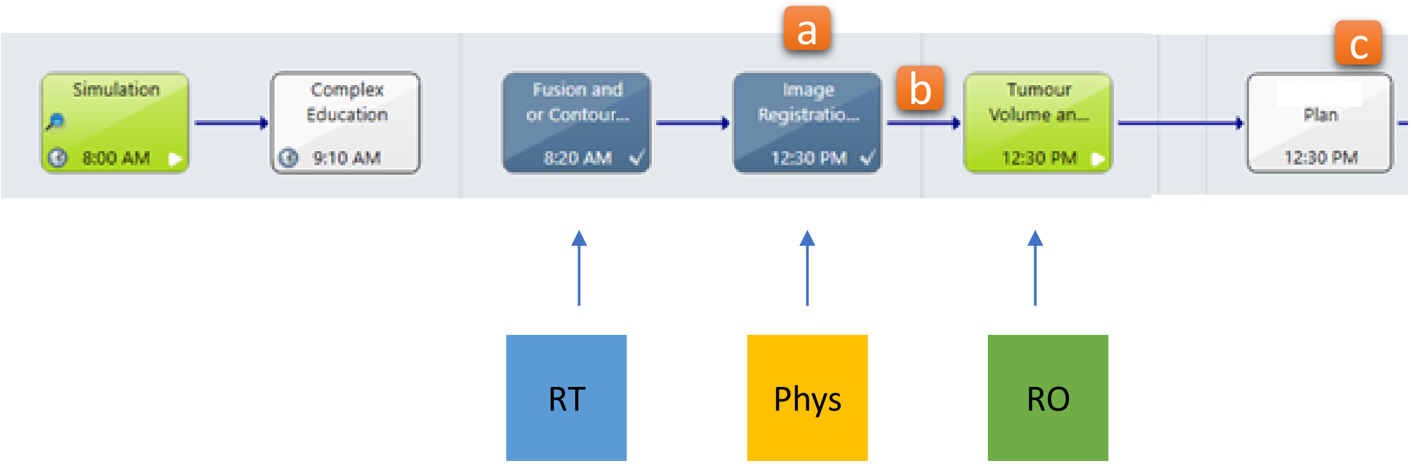
Respondent responses (%) per continent	Americas	Asia	EU	ANZ
Self-training with vendor material	65	33	29	33
Self-training with online material	46	33	0	28
Self-training with standard operating procedures	27	33	29	44
Informal peer training	58	33	71	100
Vendor training	85	33	29	67
Competency based assessment — self assessed	73	50	57	61
Competency based assessment — trainer assessed	0	0	14	33
Competency based assessment — written exam	0	0	0	0
Competency based assessment — practical exam	0	0	0	0
Clinical training guide for trainees	0	0	0	6
Training program for RO	0	33	0	11
Training program for RT	0	0	14	33
Training program for Physicist	8	17	14	11
Anatomical site specific training	0	17	14	28
No formal training program	15	33	0	0

Live Poll

Please answer with multiple choices when the pop up window appears

3.D.1 (Staff training) Staff involvement with RIR and DIR

	RIR current	DIR current	DIR ideal
Radiation Oncologist			
ANZ	66	19	77
AMS	33	28	55
ASIA	60	33	NA
EU	16	10	NA
Medical Physicist			
ANZ	38	23	77
AMS	56	57	73
ASIA	50	27	NA
EU	47	39	NA
Radiation Therapist			
ANZ	76	21	83
AMS	30	12	23
ASIA	17	13	NA
EU	44	13	NA
Dosimetrist			
AMS	66	51	80
ASIA	30	17	NA
EU	44	33	NA

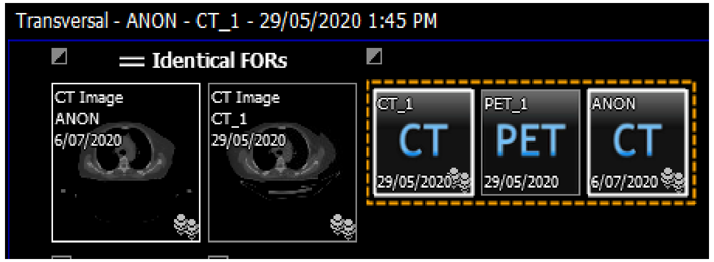


Example of a clinical workflow# in an oncology information system (ARIA) with Fusion(RT task), Image registration review(Physicist task), and Tumor volume(RO task).*

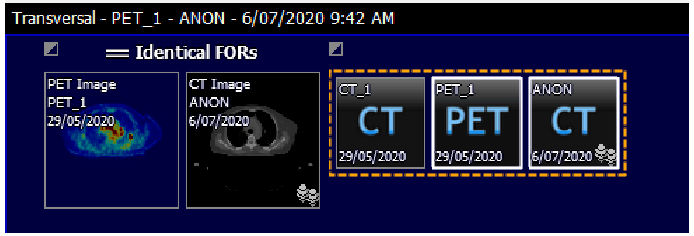
(a) *Image registration review task for DIR only (Patient specific physics QA before contouring)*
(b) *It may be possible to "interlock" a task(tumor volume) unless a preceding task is completed (image registration review)*
(c) *There may also be DIR QA related tasks after a plan is ready.*

3.D.2 Image registration process evaluation

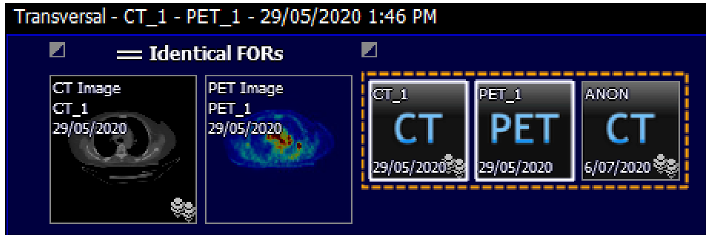
	Average staff group involvement	
	Americas	**ANZ**
Upstream	1.8	1.7
Registration	1.4	1.4
Downstream	1.2	0.8
Management	1.0	1.7



Registration QA



Reg. Accuracy OK



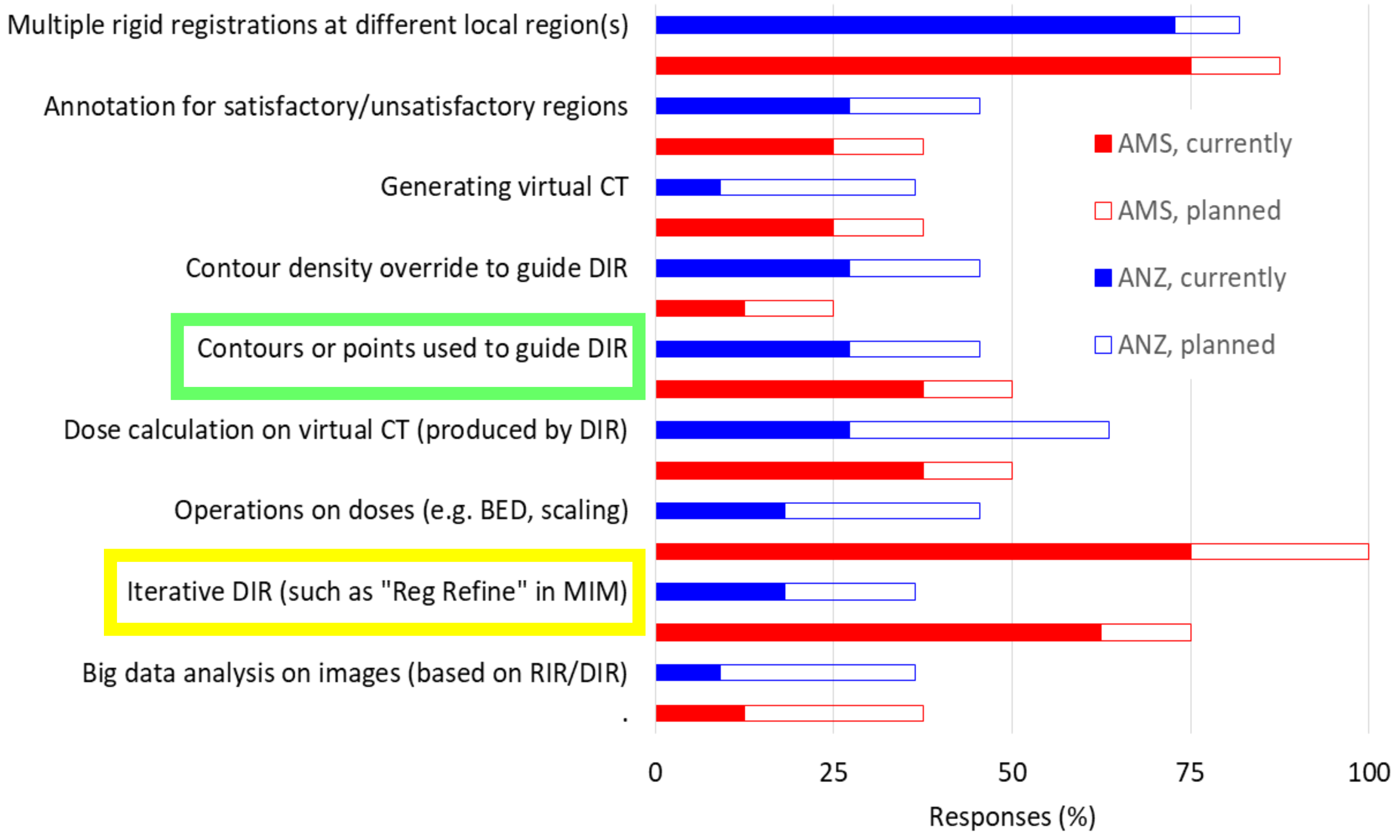
Reg. Accuracy Not OK
side by side

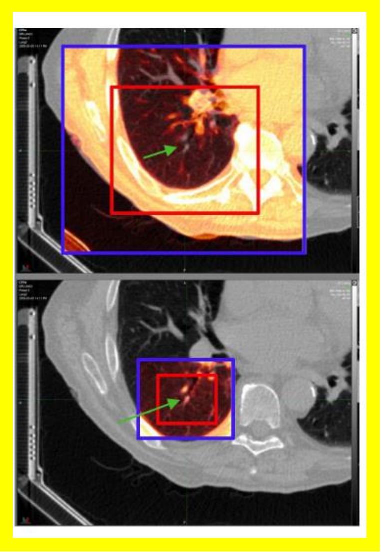
Screenshot illustrating how the RTPS(Eclipse) can be used to qualitatively visualise the registration quality with the pCT with diagCT(top) from dedicated DIR software (Velocity). When the registration accuracy is satisfactory, the RO can visualise the pCT with PET(bot left); When the registration accuracy is not within limits, side by side view is possible by visualising diagCT with PET (bot right, not overlaid with pCT).

3.D.3 Image registration challenges

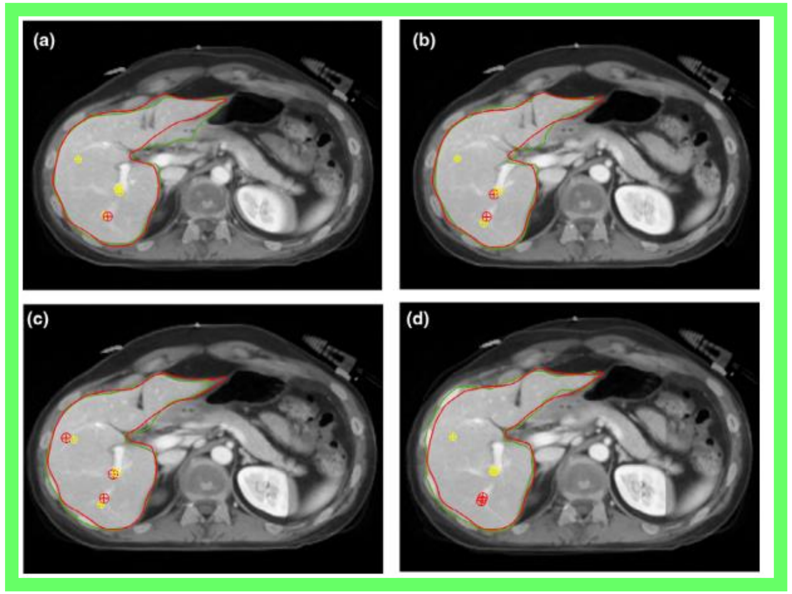
	Respondent responses (%) per continent	Americas	Asia	EU	ANZ
Upstream	Image quality issues (resolution, contrast, etc.)	42	50	71	44
	Image cropped (scan length, field of view, etc.)	35	33	57	39
	Communication on intended use and technique	35	33	43	39
	Selecting the appropriate image	31	17	14	39
	Determining which registration landmark required	35	33	14	22
Registration	Determining when registration satisfactory	50	50	43	44
	DIR Quantitative QA of ensuring deformation is OK	58	17	43	39
	DIR Qualitative QA of ensuring deformation is OK	46	17	43	33
Downstream	Determining action when registration unsatisfactory	50	50	14	44
	Documentation of registration accuracy and follow-up	35	33	14	39
Management	Image transfer (import/export) of multiple systems	15	33	29	39
	Image infrastructure (storage, backup, etc.)	12	0	14	33
	Image or software accessibility	12	0	29	28
	Insufficient definition of roles	12	33	14	11
	In-house software engineering	4	0	0	17

3.D.4 Image registration methods





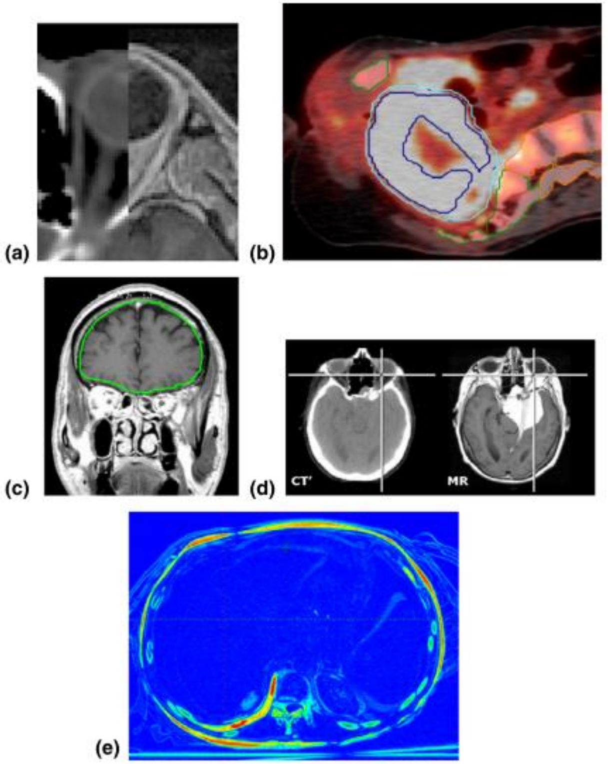
Investigation into iterative DIR with the "Reg refine" tool in MIM (Johnson 2016), use of lock points to guide DIR.



Investigation into structure guided DIR for liver (Kuznetsova 2019) showed superior performance of SG-DIR, especially with the combination of contours and landmarks; (a) RIR, (b) DIR, (c) SG-DIR, (d) SG-DIR with landmarks

3.D.5 Image registration quality assurance metrics

	% divide per region	Americas				ANZ		
		RO	Phys	RT	Dos	RO	Phys	RT
Qualitative	Anatomical landmarks visualised	50	63	38	75	67	67	83
	Anatomical landmarks with screenshots	13	25	0	13	17	42	33
	Anatomical landmarks with grid/ruler	25	38	13	25	25	50	50
	Comparison with contours	50	50	25	50	33	67	67
	Subjective considerations	63	75	25	50	75	33	58
Quantitative	Target registration error (TRE)	13	13	0	13	17	17	17
	Mean distance to agreement (MDA)	0	13	0	13	8	33	17
	Dice similarity coefficient (DSC)	0	13	0	13	0	33	8
	Jacobian	0	13	0	13	8	8	8
	Consistency (transitivity)	0	25	0	13	0	17	0

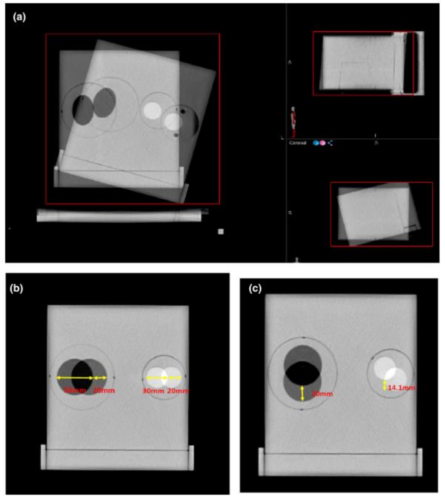


Excerpt of qualitative registration QA from the AAPM TG132 report (Brock 2017)

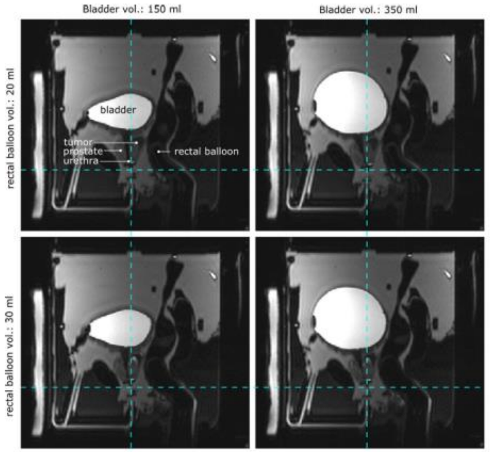
3.D.6 Image registration validation datasets

	Digital datasets		Physical datasets		Clinical datasets* (Rigid and/or Deformable)	
	Rigid	Deformable	Rigid	Deformable	Retrospective	Prospective
CT	30	40	60	15	60	25
MR	20	15	35	5	40	20
PET	20	15	20	0	35	20
CBCT	20	15	45	5	55	30
US	5	5	15	0	20	10
4DCT	5	10	30	10	35	20
4DCBCT	0	5	30	10	30	20

*International data (AMS and ANZ extended survey) with percentage (%) of respondents having datasets of a particular category (by image modality, and subcategories from digital, physical, or clinical dataset types); *note that validation clinical datasets did not specify whether it was directed towards RIR or DIR validation.*

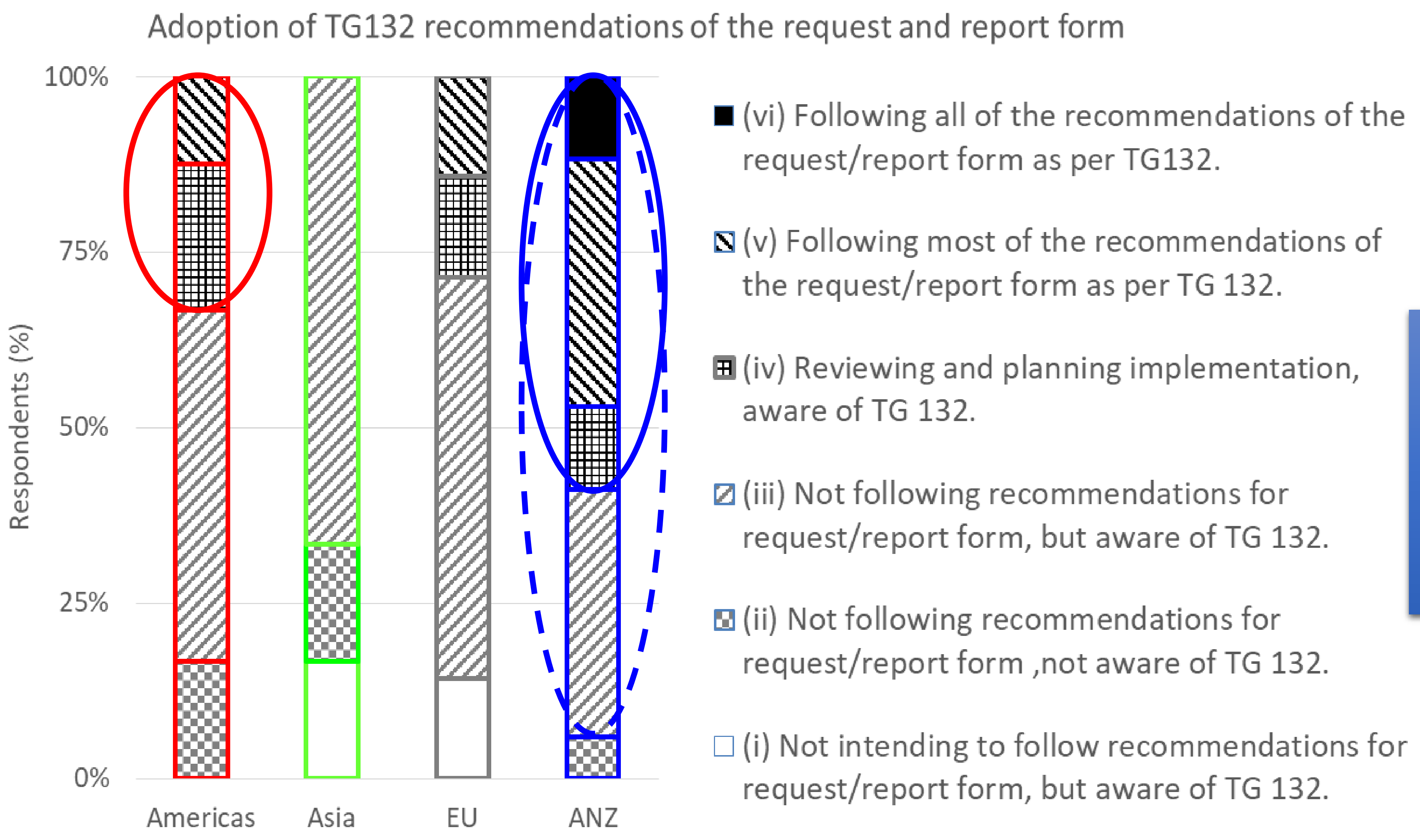


Example of a geometric deformable physical phantom (Wu 2019)



Example of a anthropomorphic deformable and multimodal phantom for MRgRT with various bladder filling (Niebuhr 2019)

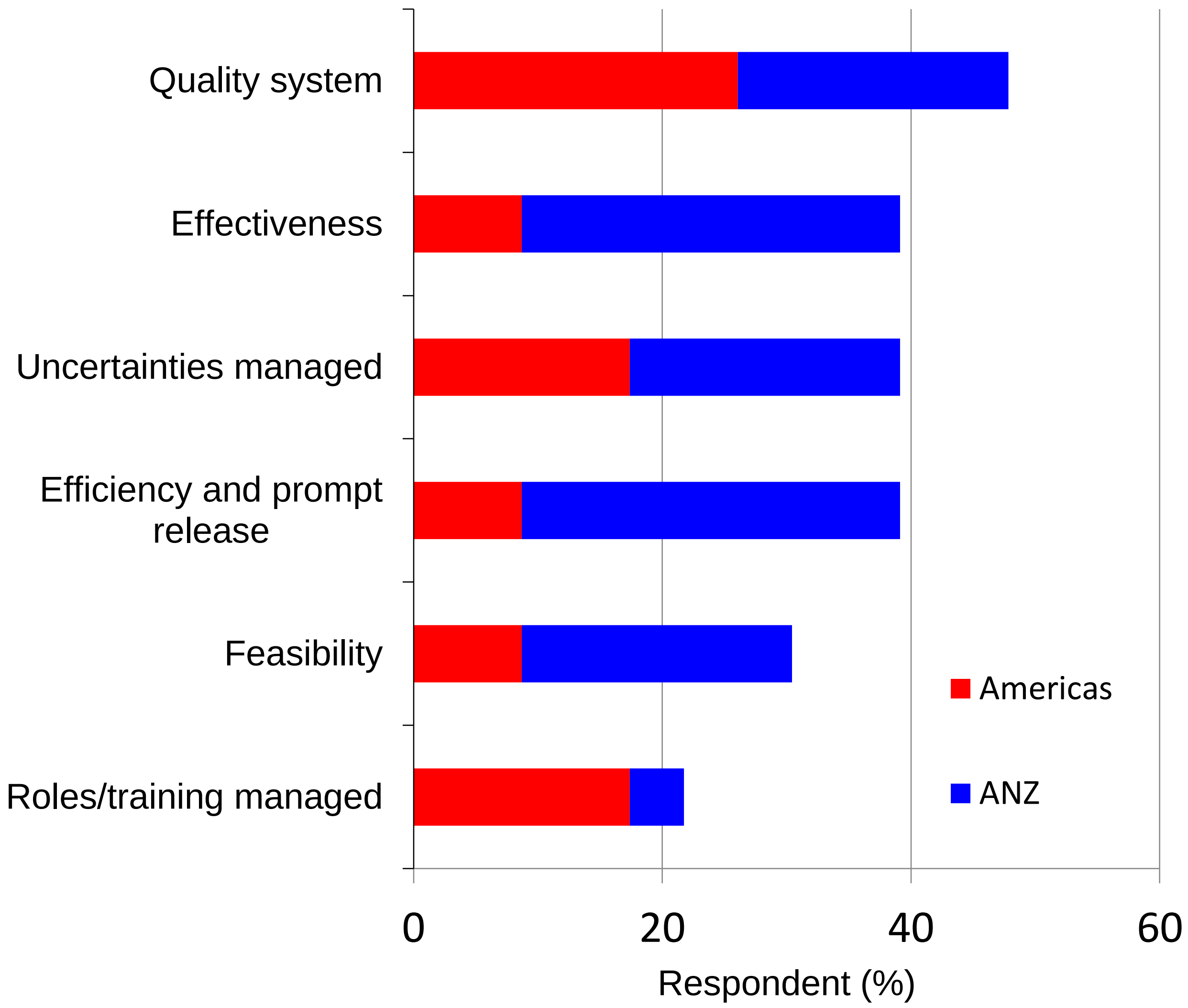
3.D.7 Image registration request and report form



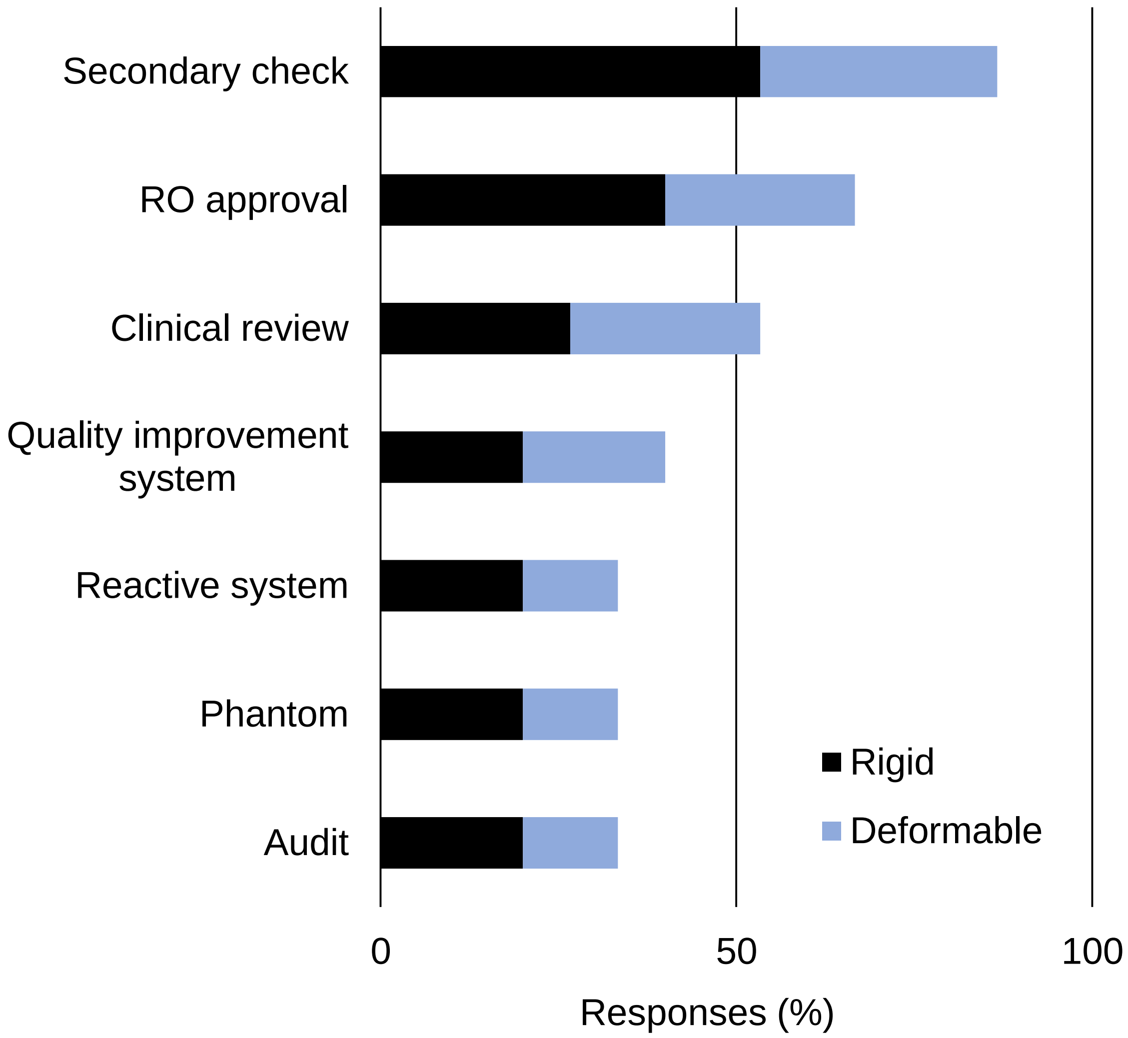
Indications of ANZ adoption of the AAPM TG132 request and report form

Outline

3.E.1
Criteria for commissioning and implementation

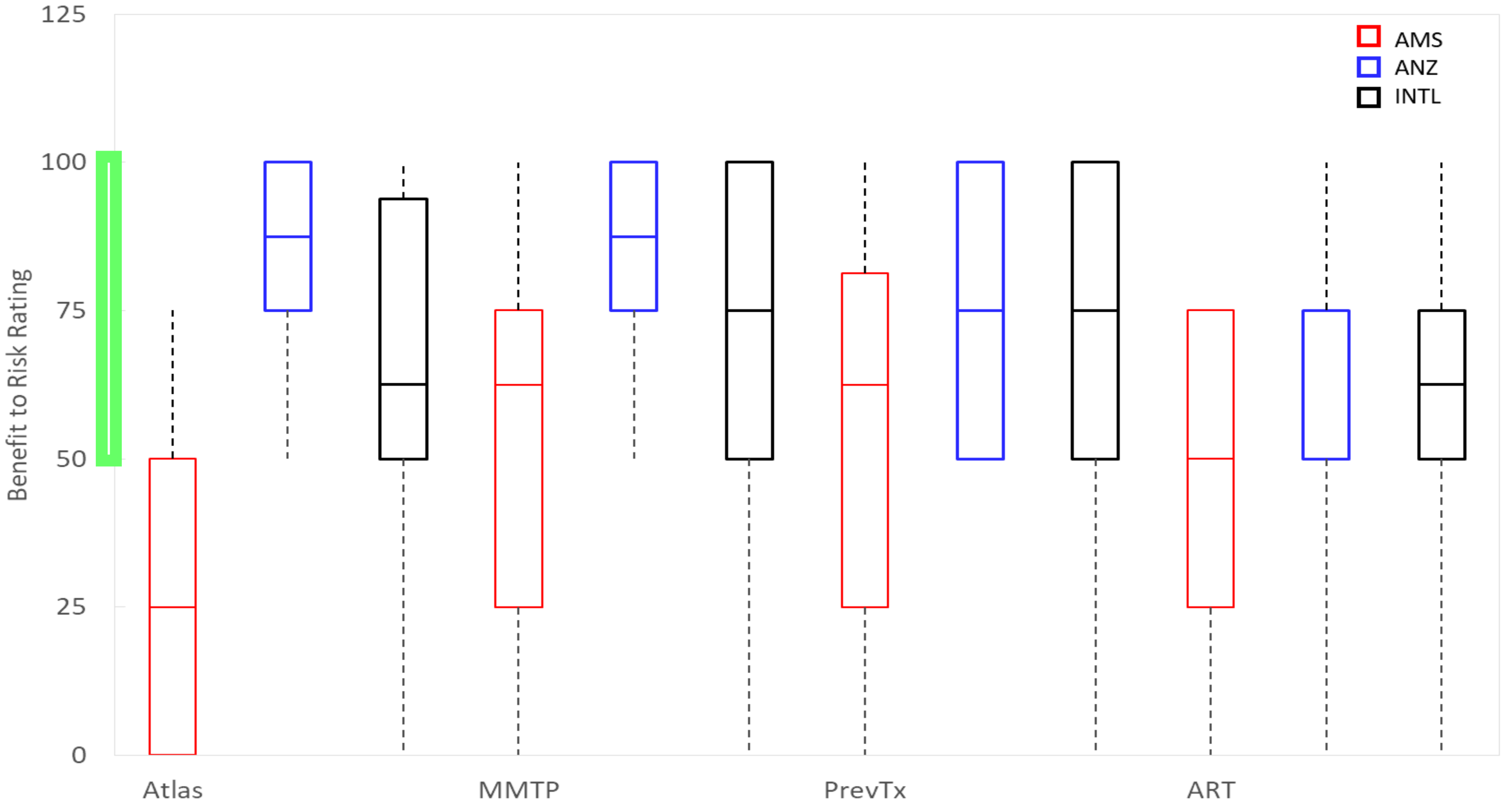


3.E.2
Measures of quality and Safety of Image registration

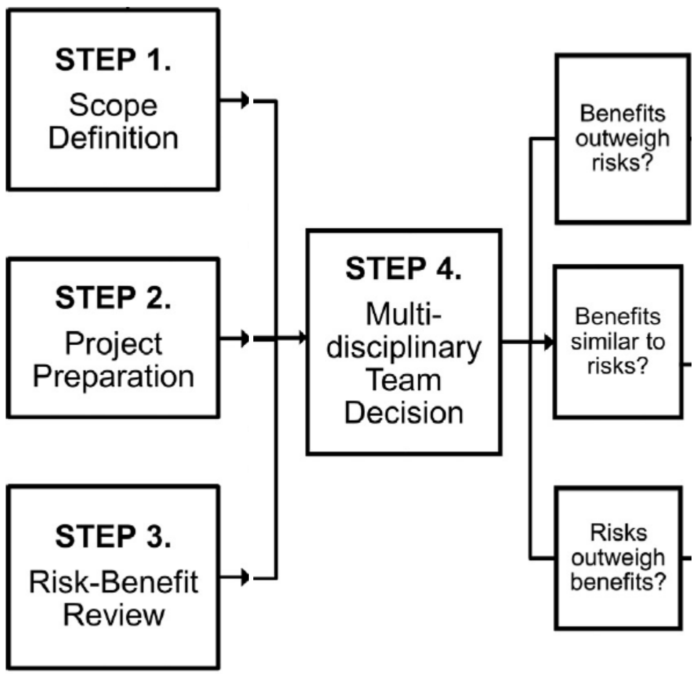


3.E.3

Evaluation of value in implementation of DIR with risk-benefit rating by use case



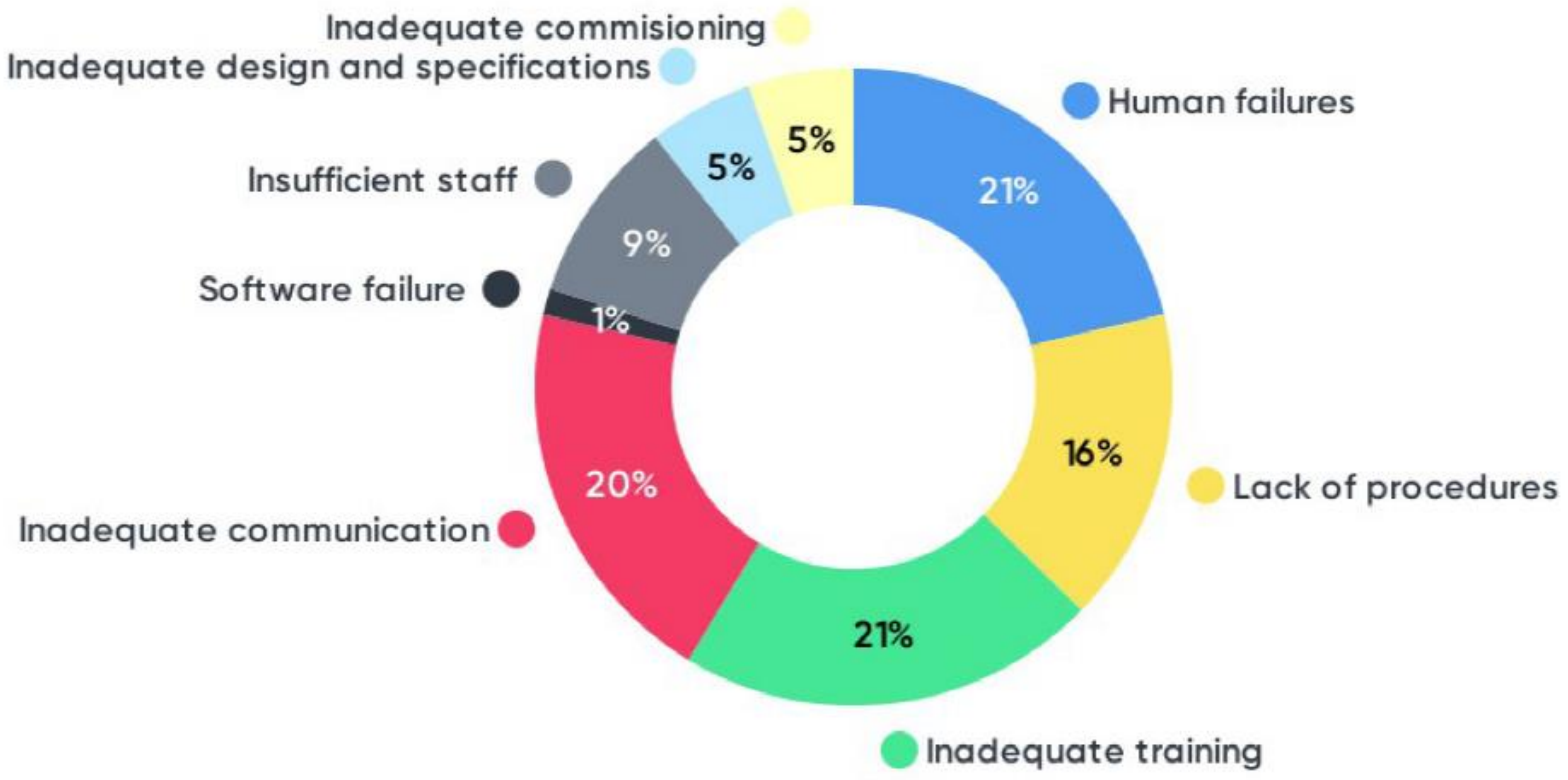
Box plot of benefit to risk rating of Americas (AMS, red). Australasian (ANZ, blue), and International (INTL, black) perceptions of the value of atlas based segmentation, use of DIR for multi-modality treatment planning (MMTP), use of DIR for accounting for previous treatment (PrevTx), and adaptive radiotherapy (ART); Benefit to risk rating of 100% indicates that the benefits outweigh the risks significantly.



Adapted figure illustrating how addressing risks or increasing benefits can help with clinical translation (Ralston 2019)

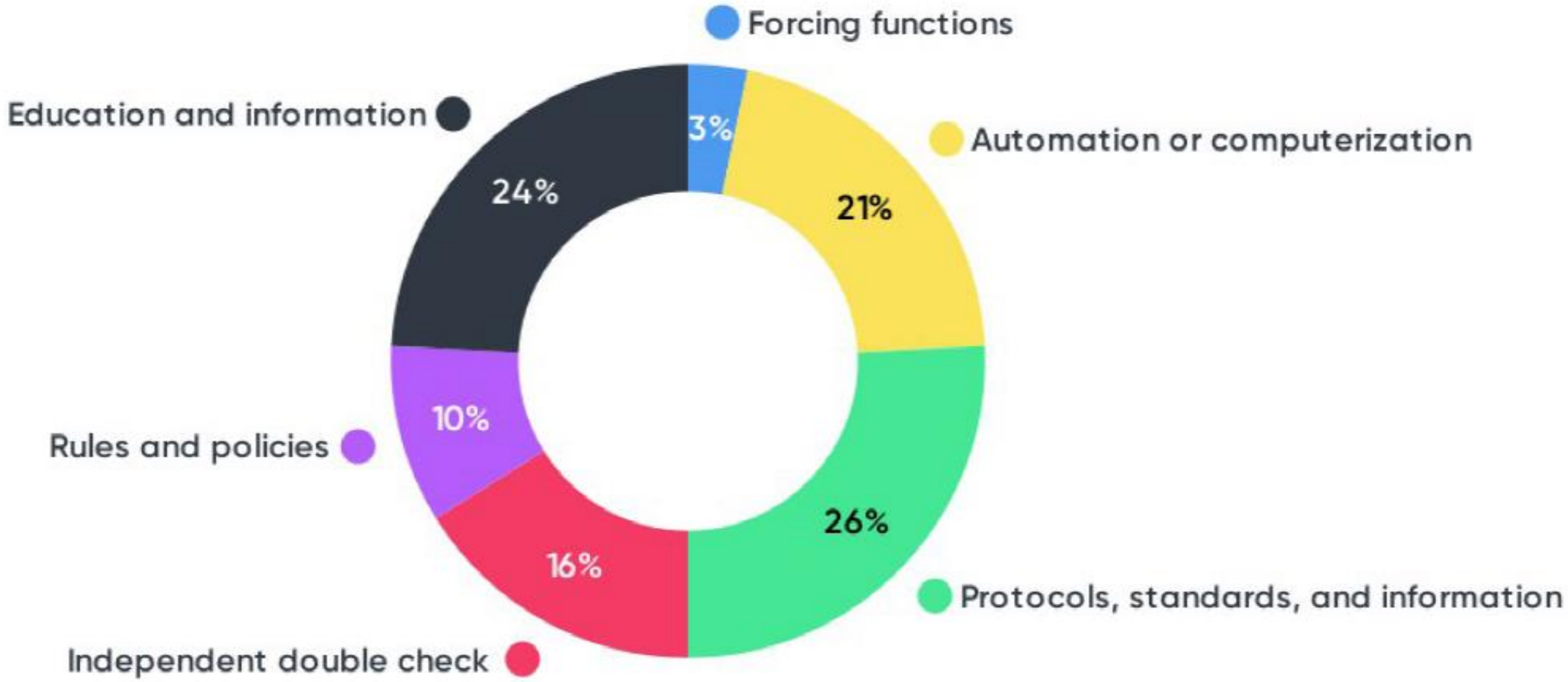
Outline

4.A Discussion(workshop data): Causes of issues in image registration



Based on AAPM TG100 categories of causes of failure modes, and based on data from "Deforming to best practice" 2018 Australian Workshop

4.B Discussion(workshop data): Quality control solutions for image registration



Based on AAPM TG100 categories of quality controls for failure modes, and based on data from "Deforming to best practice" 2018 Australian Workshop

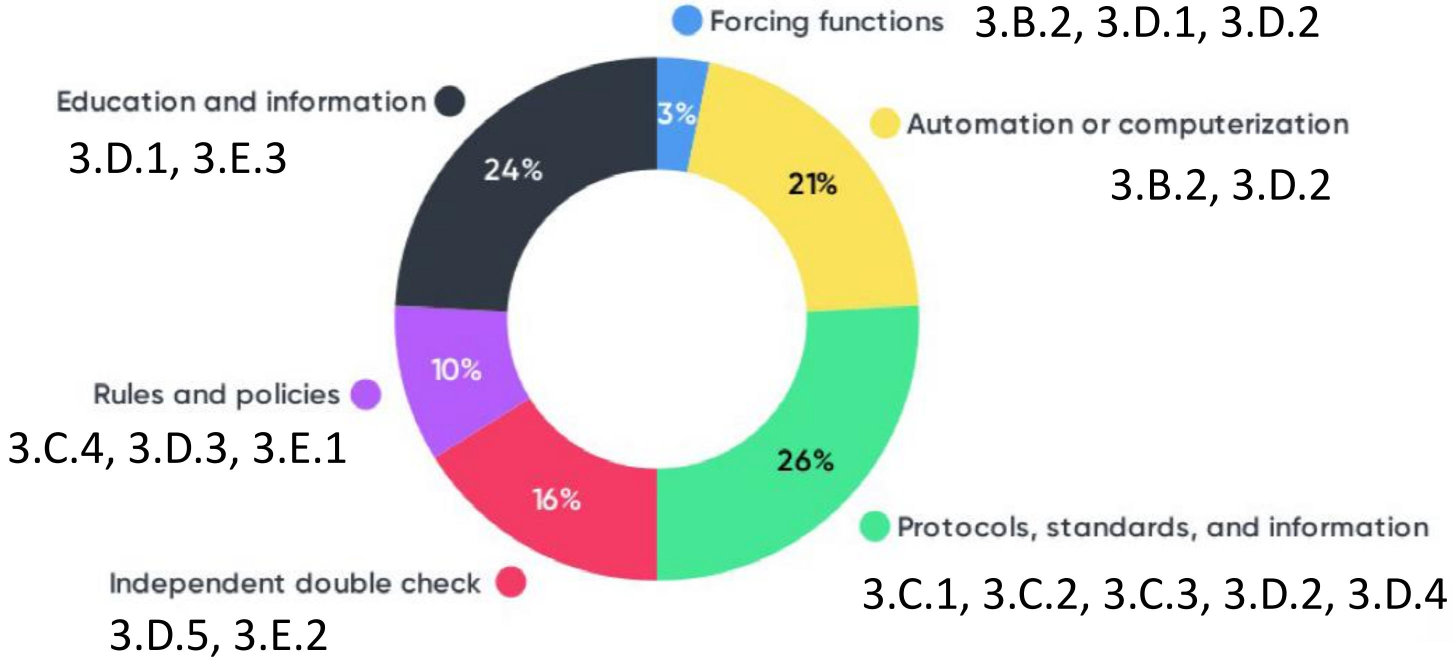
5. Conclusions

Measured practice pattern describing…

…international and ANZ patterns of deformable registration by clinical application

…how deformable registration uptake varies
- By anatomical site
- By image modality
- In uptake of different DIR systems
- In quality management strategies for DIR

…how
- Staff roles for DIR have evolved for physicist, RTs, and ROs
- Centres have considered the benefits, risks, and trade-offs in the use of DIR



Example of referencing practice pattern data (Yuen 2020) with AAPM TG100 QC solutions

In understanding what practice patterns are…

…it is possible to develop a coherent strategy for clinical adoption.

Practice pattern data can facilitate departmental or national development of best practice for the rapid implementation and safe use of image registration techniques.

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

Questions and Answers from the June 2020 Webinar Chaired by Laurel Schmidt (Talk 1 by Johnson Yuen)

Question 1: Do you think that the image registration request and report form is something a lot of centers will adopt?

Answers: Our data shows that most ANZ centres are looking into adopting the request and report forms (or equivalent).

The AAPM TG132 report notes that *“even the most comprehensive commissioning of the image registration algorithm cannot capture the entire scope of registration challenges that will be encountered in the clinic. A well-documented patient-specific verification protocol for routine practice is therefore essential as the image registration is used for many activities during radiotherapy planning and treatment.”*

Efficient adoption of the AAPM TG132 forms (or equivalent) for clinical use can facilitate multi-disciplinary teamwork, as a means to ensure patient-specific accuracy is maintained during handover tasks. On a practical note, there may be areas where patient specific registration QA can be simplified such as (i) by being grouped as part of a larger task (e.g. plan check), (ii) be a QA task that can be completed with variable amounts of complexity (from visual checks to a full report document with quantitative metrics).