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Patient Pre-treatment QA and In-vivo Dosimetry

ICTP School of Medical Physics for Radiation Therapy: Dosimetry and Treatment Planning for Basic and Advanced Applications

11 – 22 September 2023

The Abdus Salam International Centre for Theoretical Physics

Outline

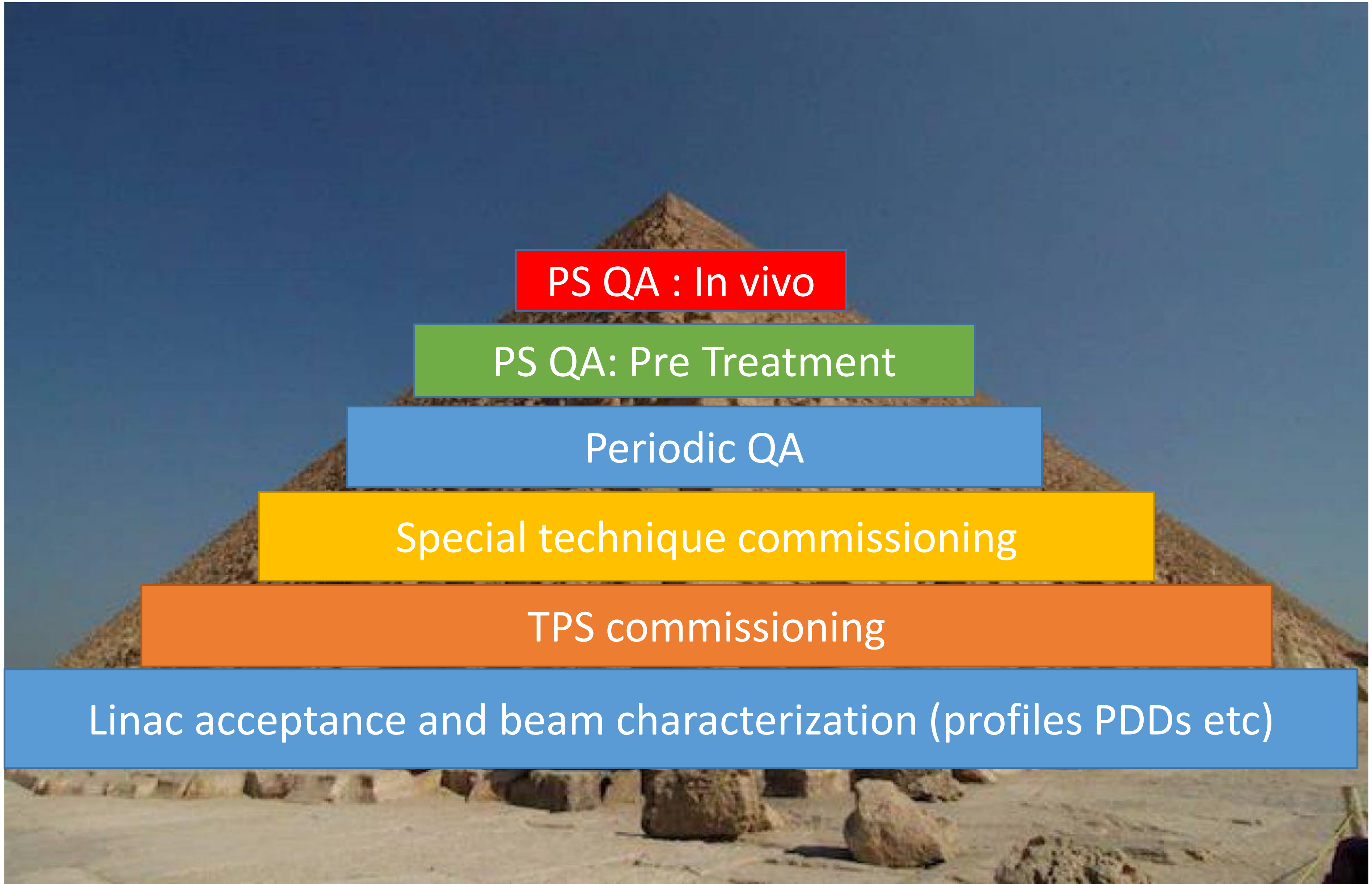
- Introduction
- Patient specific QA: Pre treatment QA
- During the treatment QA: in vivo dosimetry

1) Definitions

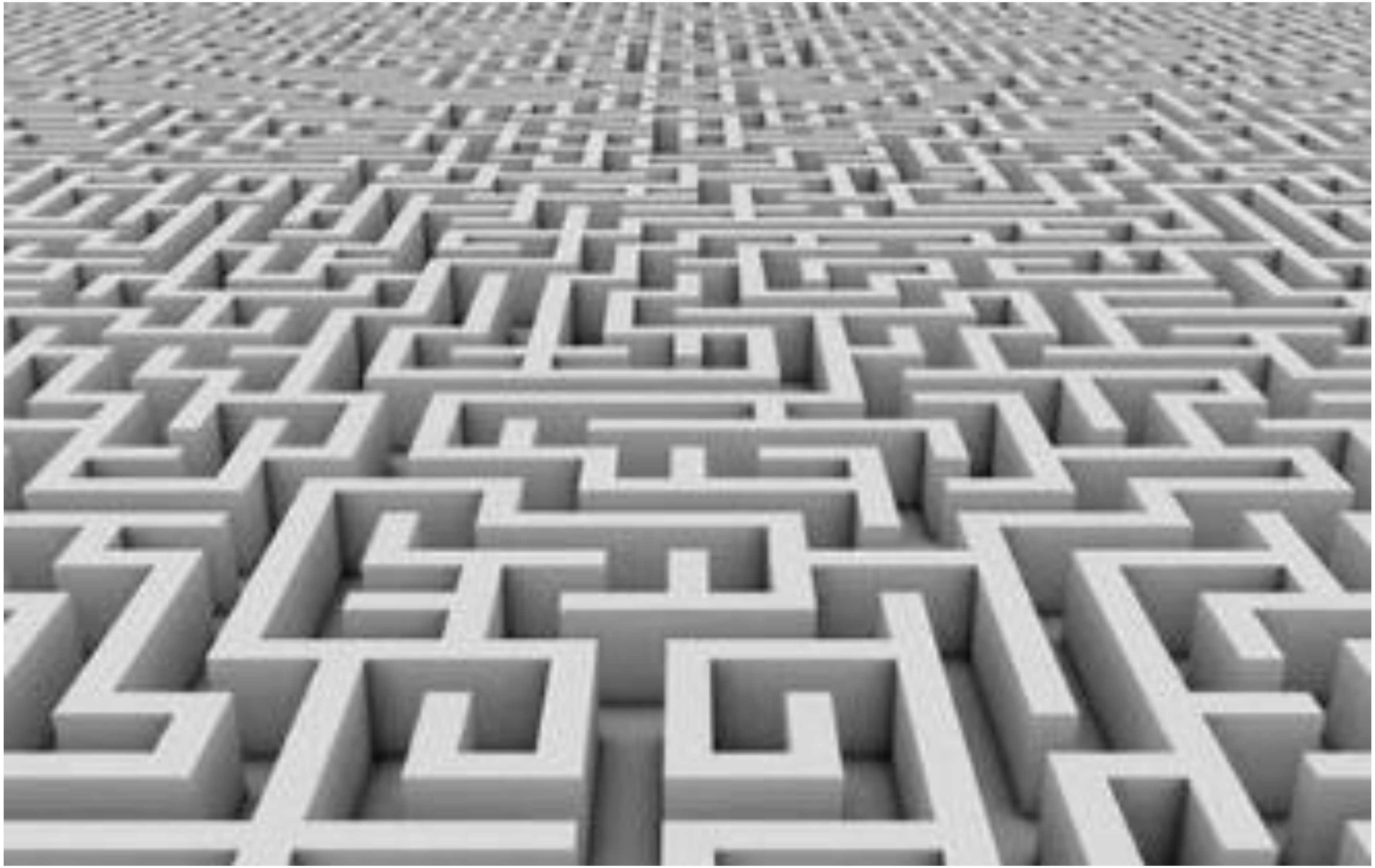
2) Devices

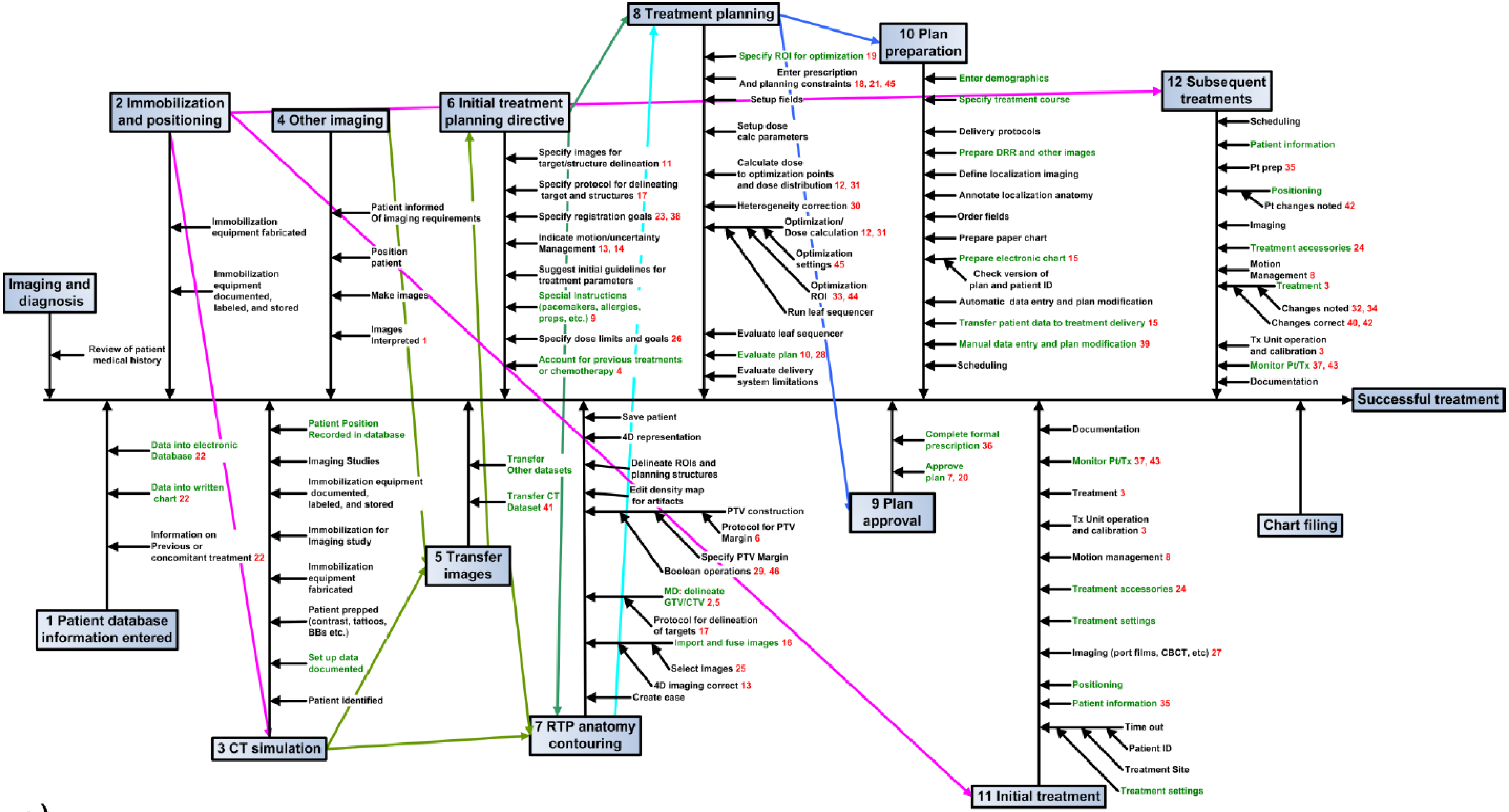
3) Results

What a quality assurance procedure look like?



What a radiotherapy worflow look like?





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2 Immobilization and positioning
4 Other imaging
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(pacemakers, allergies,
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Immobilization
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Previous or
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information entered
Patient Position
Recorded in database
Imaging Studies
Immobilization equipment
documented,
labeled, and stored
Immobilization for
Imaging study
Immobilization
equipment
fabricated
Patient prepped
(contrast, tattoos,
BBs etc.)
Set up data
documented
Patient Identified
3 CT simulation
Transfer
Other datasets
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Positioning
Patient information 35
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Patient ID
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Treatment settings
11 Initial treatment
Chart filing

a)

Errors in modern radiotherapy

Failure mode	*n*	Example cause
Wrong isocenter information	56	Error in the localization of the coordinate system in the CT scan or treatment plan. Leading to an incorrect setup to the treatment isocenter.
Patient misalignment during treatment	48	Patient incorrectly positioned for treatment.
Error in CT data	30	Error in CT scan data used for planning. For example, wrong breathing scan used for planning.
Missing or incorrect documentation	16	Missing or incorrect information about prior patient treatments, or no approval of plan by physician or physicist.
Prescription error	15	Error in plans fractionation, location or total dose.
Error in planning	11	Error in field parameters made during planning stage.
Corrupted plan	10	An element of the plan incorrectly modified during data transfer.
Incorrect contouring	9	Portion of contour missing or incorrect volume used for planning.
Patient health status miscommunication	7	Adverse health condition not communicated that led to issues in treatment.
Unclear clinical directive	5	Unclear instructions/objectives associated with treatment.
Scheduling error	5	Error in scheduling patient that resulted in a significant delay of treatment.
Movement on table	4	Patient movement on the table during treatment.
Personnel could not be contacted	3	Personnel could not be reached to check patient or approve plan.
Treatment machine error	3	A change in the machine output or a failure of machine component during beam delivery.
Record and verify system error	2	Crash in the record and verify system stopping treatment.
Error in field delivery	2	Unintended fields delivered to patient during treatment.
Wrong or faulty equipment used	2	Incorrect or damaged equipment used.
Physics calculation error	1	Miscalculation of treatment parameters.

→ Set-up 30%

→ Planning 26%

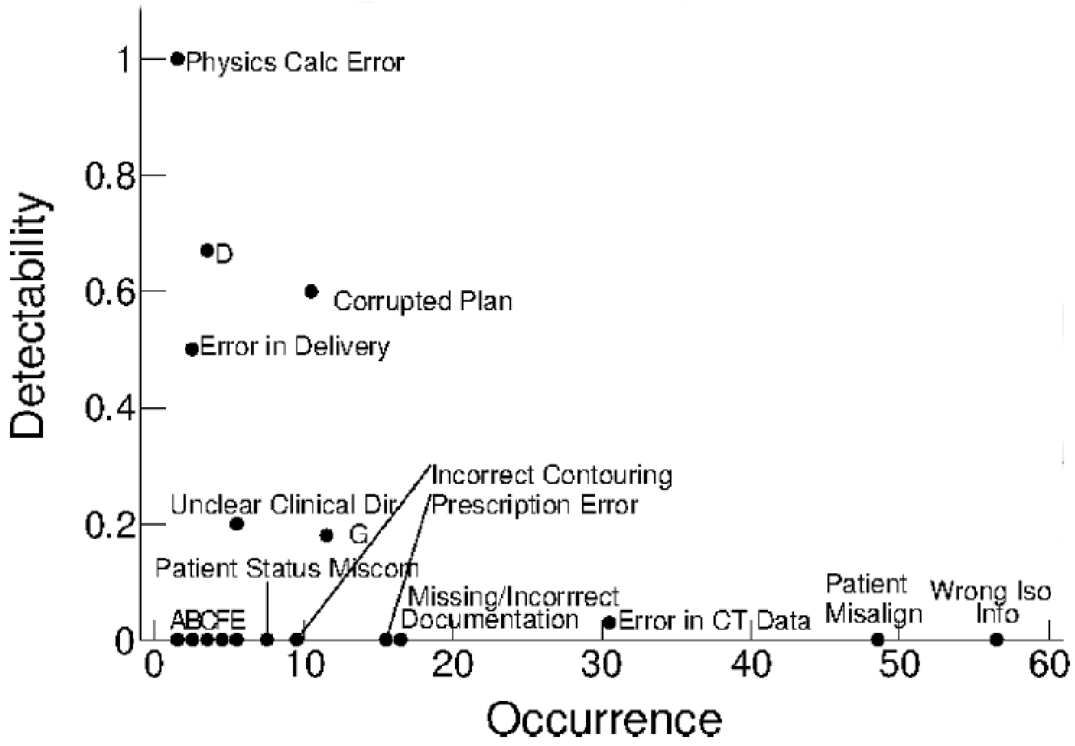
→ Clinical 5%

→ Delivery 2%

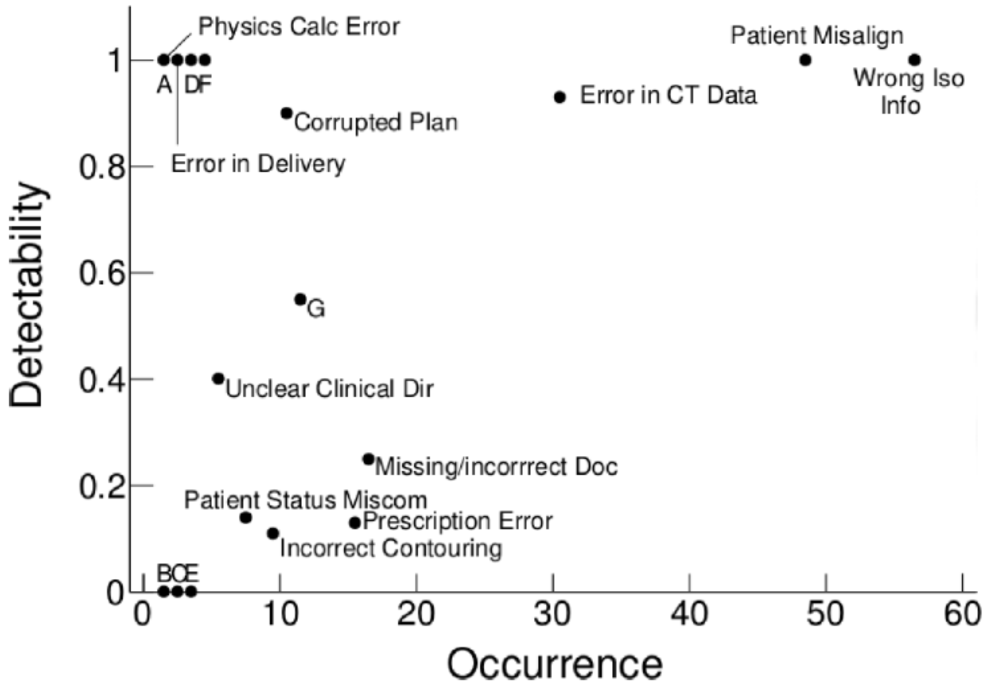
Physics calculation 0.3%

Bojechko et al **Med. Phys. 42 (9), September 2015**

IVD vs pre-treatment QA



Pre-treatment QA



In vivo Dosimetry

Pre-treatment Patient Specific QA

- It is really necessary to validate TPS and linac delivery for all patients?
- Accuracy of TPS computation and linac delivery depends on plan complexity and can decrease dramatically in special cases.
- Even if rare, the impact of these errors could be severe in SBRT

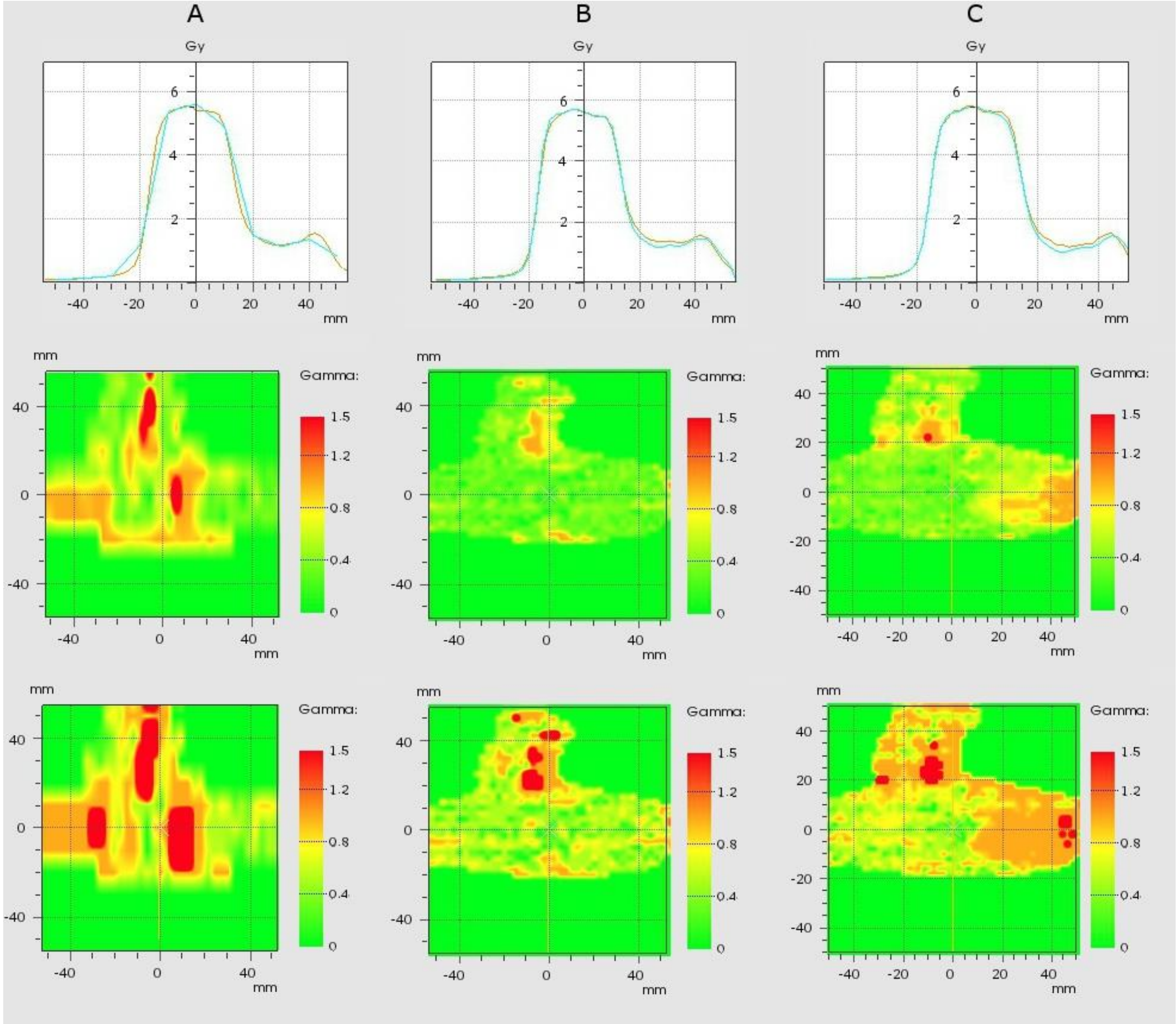
Pre-treatment Patient Specific QA

- AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS/SBRT:

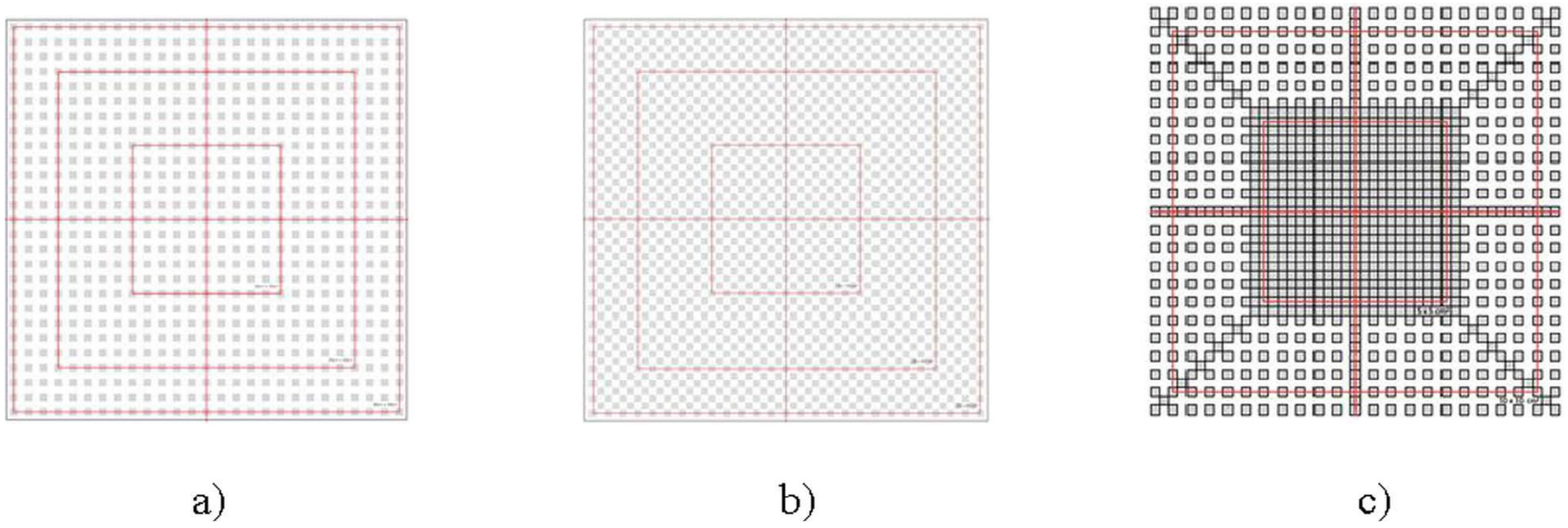
Measurement-based Patient QA is strongly recommended

- AAPM TG 218: Appropriate choice of PSQA device is necessary to ensure the accurate dose delivery to the patients
- The major requirement of a PSQA systems is to have a dosimetry system with highest resolution, lowest dose rate and angular dependence, rapid response, real time data analysis and fast setup

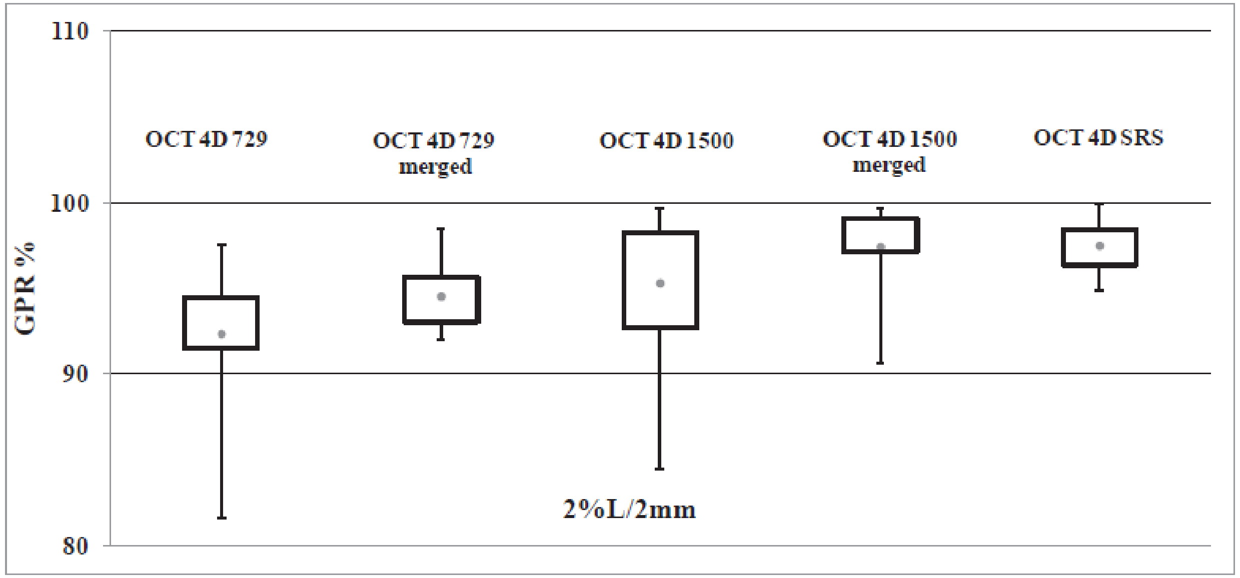
Pre-treatment Patient Specific QA



G-T profile at the isocenter (top), the 2D γ distribution on the coronal plane passing through the isocenter at 2% 2mm (middle) and 2% 1mm (bottom) are shown:
A PTW Octavius 4D 729, B PTW Octavius 4D 1000 SRS (SRS), and C Dosimetry Check.



Measuring area of PTW OCTAVIUS 4D 729 (a), 1500 (b) and 1000 SRS (c).



A. Bruschi et al. *Physica Medica 49 (2018) 129–134*

Pre-treatment Patient Specific QA

Devices resolution should be the highest for steepdose gradient end small field

1) Ion chambers matrix
2) Solid state matrix
3) Radiochromic film
4) EPID based software
5) Three dimensional Gel

Pre-treatment Patient Specific QA

Gamma passing rate criteria: looking for magic number

AAPM TG 135 - Robotic radiosurgery : >90% for 2%/2 mm 3D Global analysis with 20% threshold dose

- In some study a more strict criteria of 90% using 2%/1 mm for 2D Local or Global analysis is reccomanded

Physica Medica 32 (2016) 838–846

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

ELSEVIER

Original paper

High resolution ion chamber array delivery quality assurance for robotic radiosurgery: Commissioning and validation

CrossMark

Oliver Blanck[a,b,*], Laura Masi[c], Mark K.H. Chan[d], Sebastian Adamczyk[e,f], Christian Albrecht[g], Marie-Christin Damme[b,h], Britta Loutfi-Krauss[i], Manfred Alraun[g], Roman Fehr[j], Ulla Ramm[i], Frank-Andre Siebert[a], Tenzin Sonam Stelljes[k], Daniela Poppinga[k], Björn Poppe[k]

www.impactjournals.com/oncotarget/ Oncotarget, 2017, Vol. 8, (No. 44), pp: 76076-76084

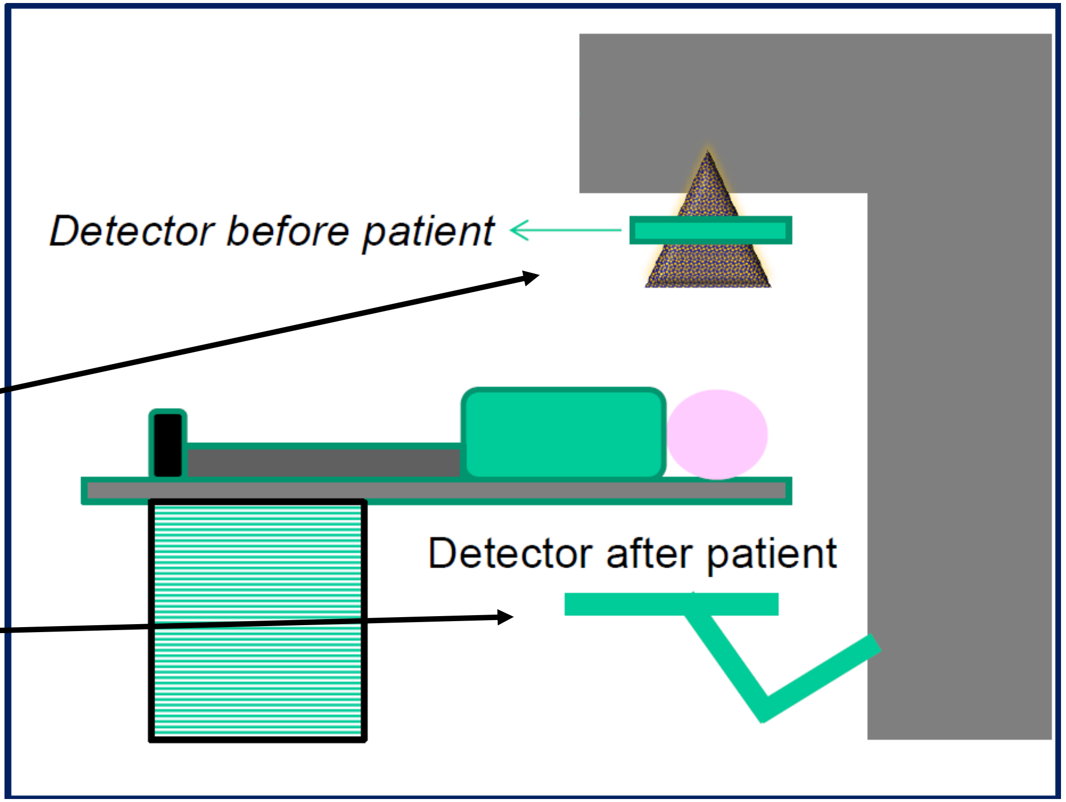
Research Paper

Gamma analysis with a gamma criterion of 2%/1 mm for stereotactic ablative radiotherapy delivered with volumetric modulated arc therapy technique: a single institution experience

Jung-in Kim[1,2,3], Minsoo Chun[1,2,3], Hong-Gyun Wu[1,2,3,4], Eui Kyu Chie[1,2,3,4], Hak Jae Kim[1,2,3,4], Jin Ho Kim[1,2,3] and Jong Min Park[1,2,3,5]

Measurements during the dose delivery

- Point dosimeters
- Log file analysis software
- Transmission 2D dosimeters
- EPID based dosimetry
- Dose accumulation methods



Measurements during the dose delivery

In-vivo dosimetry: An IVD system must be able to capture errors due to equipment failure, errors in dose calculation, patient positioning errors, and patient anatomy changes.

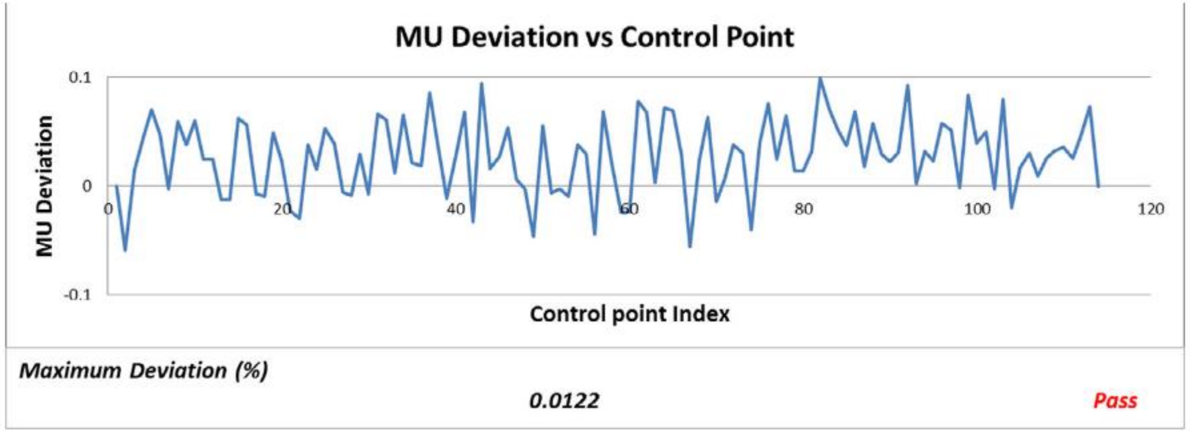
On-line measurements methods: any measurement performed during therapy able to capture at least one class of errors.

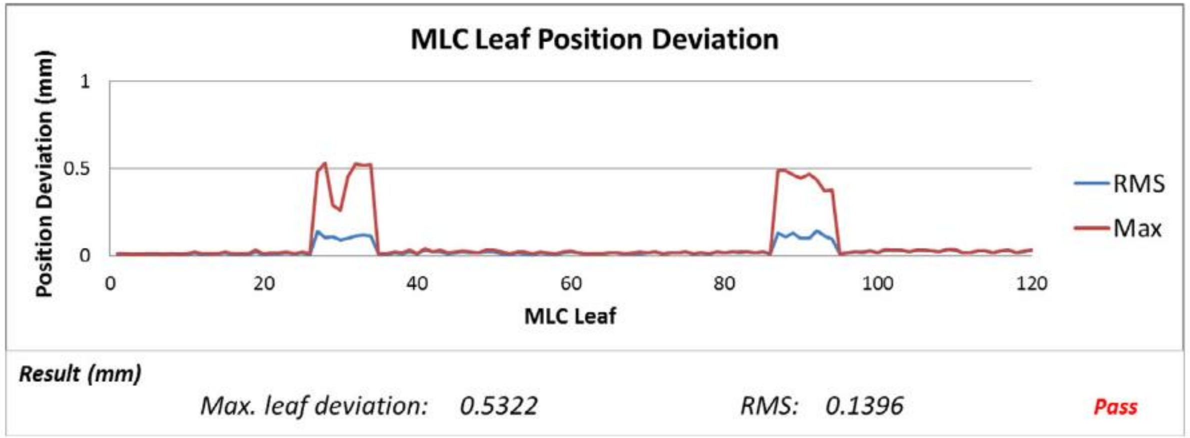
Olaciregui-Ruiz I,et al Phys Imaging Radiat Oncol. 2020 Aug 29;15:108-116.
Esposito M. et al Radiot and Oncol 149 (2020) 158–167

Log file analysis

Table 1 Parameters for verifying the accuracy of plan delivery

Parameters to be checked by LOGQA	Quantitative Indicators with passing criteria
(1) Dose index (fractional monitor unit delivered) versus gantry angle	Correlation coefficient (CC) ≥0.985
(2) Gantry angle deviation versus control point	Maximum deviation ≤0.3 degree
(3) Monitor unit (MU) deviation versus control point	Maximum deviation ≤0.04%
(4) Multileaf collimator (MLC) leaf position deviation	Maximum deviation ≤1 mm Root-mean-square (RMS) ≤0.5 mm
(5) Integrated transient fluence map (ITFM)	Correlation coefficient (CC) ≥0.985





Vivian U. Y. Chow et al J Appl Clin Med Phys2020;21:11:179–187

Log file analysis

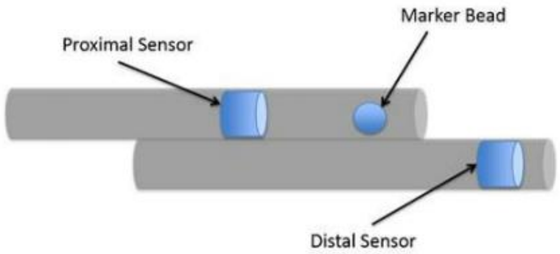
TABLE 2 Average error of MLC leaf positions, gantry angles, and monitor unit of 120 VMAT SBRT plans with various treatment sites

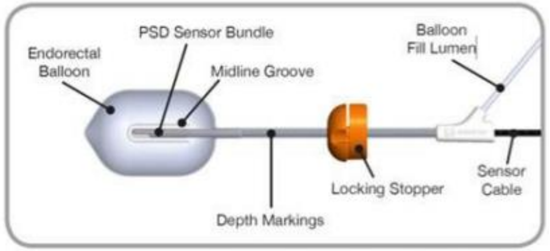
Treatment Site	MLC error (mm)	Gantry angle error (^{0})	Monitor unit error (%)
Abdomen	0.1318 ± 0.0184	0.1321 ± 0.0268	0.0152 ± 0.0075
Liver	0.1470 ± 0.0182	0.1263 ± 0.0127	0.0160 ± 0.0044
Lung	0.1445 ± 0.0200	0.1275 ± 0.0158	0.0142 ± 0.0022
Pelvis	0.1339 ± 0.0217	0.1287 ± 0.0222	0.0126 ± 0.0045
Prostate	0.1514 ± 0.0078	0.0999 ± 0.0165	0.0075 ± 0.0040
Spine	0.1276 ± 0.0112	0.0899 ± 0.0056	0.0063 ± 0.0012

Point dosimeters

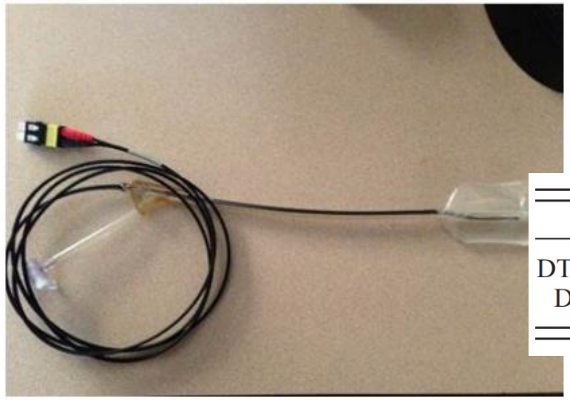
System	In vivo evaluation	Test	Verified plans	Type of treatment
Diode Therados DPD6	Noel et al. 1995	Entrance dose	7519	3D CRT
Diode Scanditronix EDP 11	Fiorino et al. 2000	Entrance dose	1433	3D CRT
Diode EquiDose™II	Higgins et al. 2003	Entrance dose	51	IMRT
TLD-100, Harshaw	Engstro et al. 2005	Entrance dose	177	IMRT H&N
TLD-700, Harshaw	Lonski P. et al. 2017	Out of field dose	110	SABR
TLD GR200A	Dipasquale G. et al. 2014	Intracavitary PTV dose	61	VMAT
LiF TLD	D.C. Weber et al. 2001	Intracavitary PTV dose	31	3D CRT
MOSkin	Legge K. et al. 2017	Intracavitary OAR dose	12	VMAT - SBRT
Plastic Scintillator	Cantley et al. 2016	Intracavitary OAR dose	1	VMAT - SBRT

System	Reference	Test	Accuracy in phantom	Verified plans	Type of treatment	Tolerance	Out of tolerance plans
TLD-700, Harshaw	Lonski P. et al. 2017	out of field dose for single beam	4%	110	SABR	N/A	Systematic underestimation of TPS photon dose was found
TLD GR200A	Dipasquale G. et al. 2014	intracavitary target point dose	8%	61	VMAT	8%	5%
MOSkin	Legge K. et al. 2017	intracavitary OAR point dose	6%	12	VMAT - SBRT	6%	83%
Plastic Scintillator	Cantley et al. 2016	intracavitary OAR point dose	2%	1	VMAT - SBRT	12%	N/A





	Fraction 1	*Fraction 2*	*Fraction 3*	*Fraction 4*	*Fraction 5*	*Total*
Measured Dose	417.11	603.90	425.91	291.71	420.66	2159.29
Pinnacle Dose	458	458	458	458	458	2290
% Difference	-8.93%	+31.86%	-7.01%	-36.31%	-8.15%	-5.71%
MIM Dose	531	399	497	395	474	2296
% Difference	-21.45%	+51.35%	-14.30%	-26.15%	-11.25%	-5.95%



	Fraction 1	*Fraction 2*	*Fraction 3*	*Fraction 4*	*Fraction*
DTA – Proximal Detector (mm)	4.5	5.0	2.5	3.5	2.0
DTA – Distal Detector (mm)	0.6	9.0	4.5	4.0	2.5

Transmission 2D dosimeters

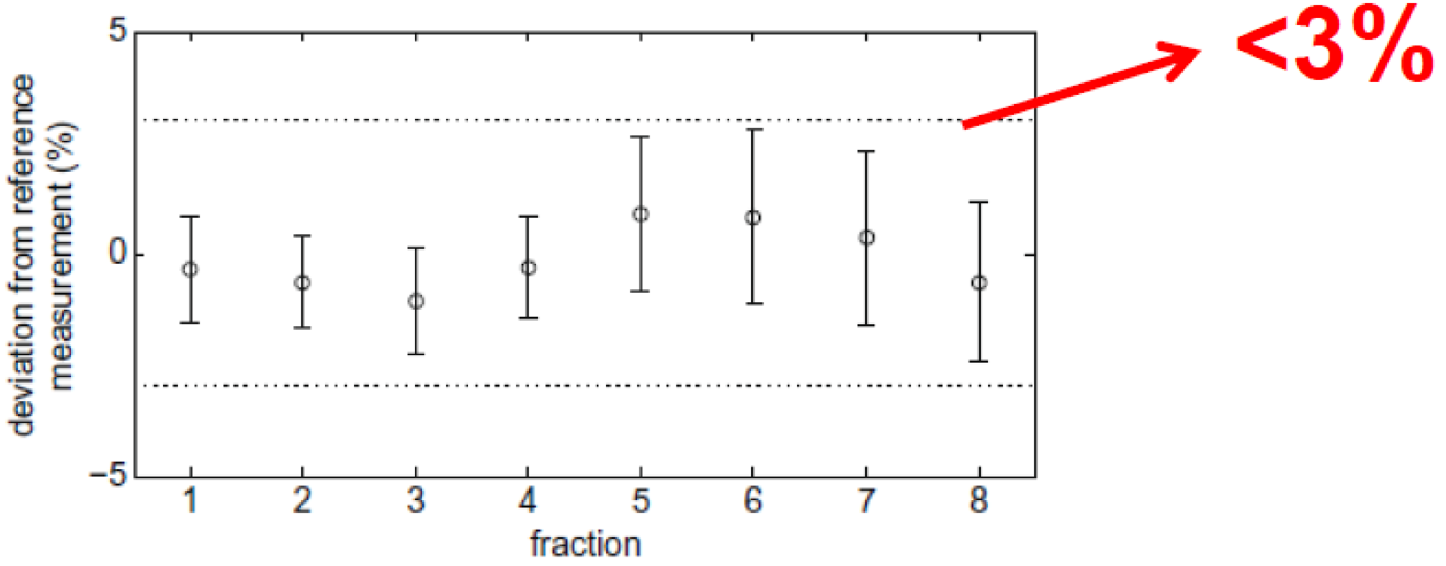
Ionization chamber and solid state devices have been considered

They allow measurement of machine parameters during treatment

2D devices can increase the skin dose
X rays spectrum can be modified
A tray factor should be considered in TPS

37 patients
80 channel system
Δ=3% for warning
Δ=5% for alarm

2 case exceeded 3%

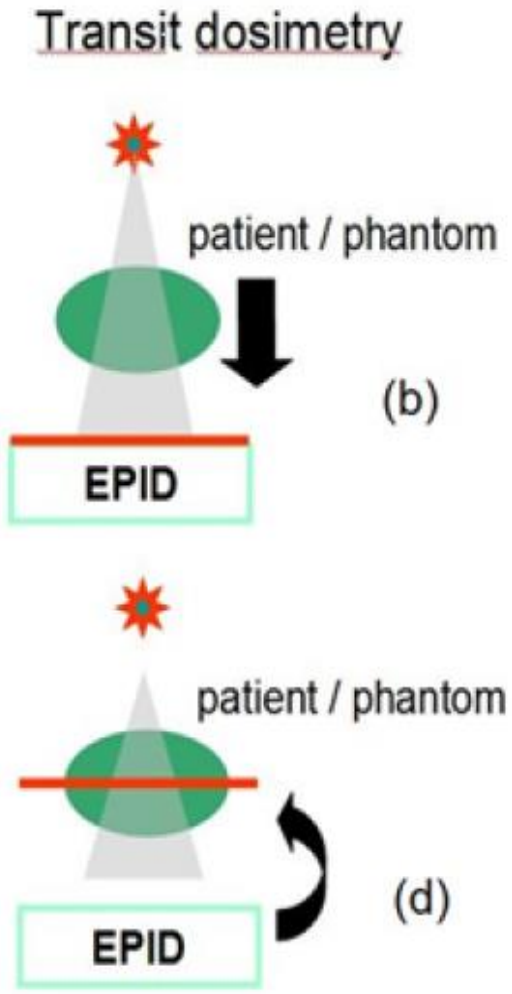


Case1: decalibrated upper collimator block.
Case2: plan was re-imported into the R&V system a few segments was lost

Poppe et al. Radiotherapy and Oncology 95 (2010) 158–165

EPID transit dosimetry

Projection algorithm



Backprojection algorithm

Exit fluence
projected on EPID

Comparison predicted signal vs actual signal

EPID signal
Backprojected on patient CT

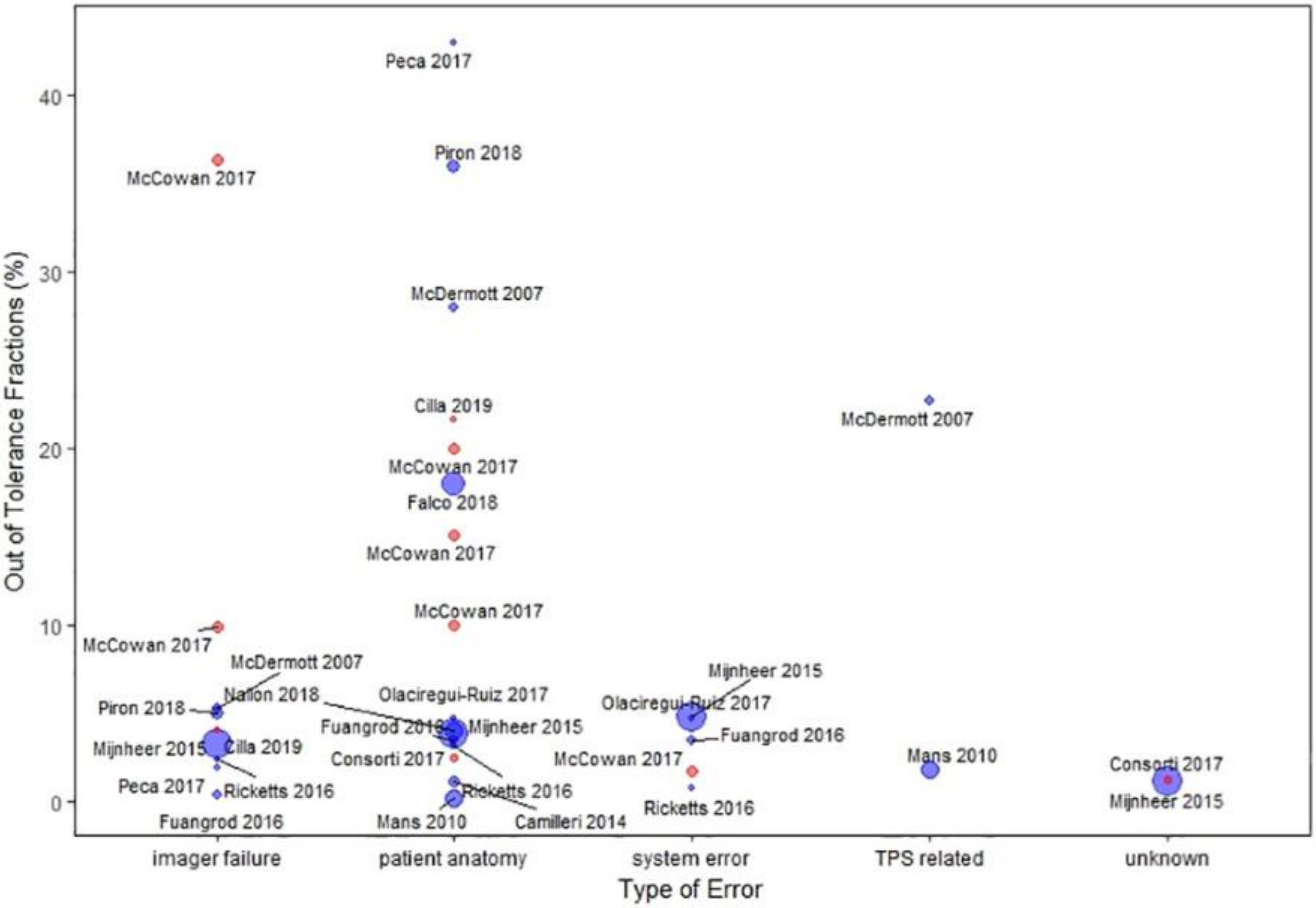
Comparison TPS e measured dose

EPID transit dosimetry

System	Algorithm	Dose	Test
Renner et al. 2003*	Backprojection	Dose 3d	DVH, Gamma
Piermattei et al. 2006*	Backprojection	Iso Dose	Iso Dose diff
van Elmpt el al. 2007*	Backprojection	Dose 2d/3d	Gamma 3%/3mm, DVH
Francois et al. 2011*	Backprojection	Iso Dose	Dose diff
Berry et al. 2012	Projection	Dose EPID	Gamma 3%/3mm
Fuandrog et al. 2013 §	Projection	Dose EPID	Gamma 3%, 3mm
Bedford et al. 2014	Projection	Dose EPID	Gamma 3%/3mm
Mc Cowan et al. 2015	Backprojection	Dose 3d	Gamma 3%/3mm
Yoon et al. 2016	Projection	4d Dose EPID	Gamma 3%3mm
Spreeuw et al. 2016 §	Backprojection	Dose 3d	DVH PTV

In phantom accuracy

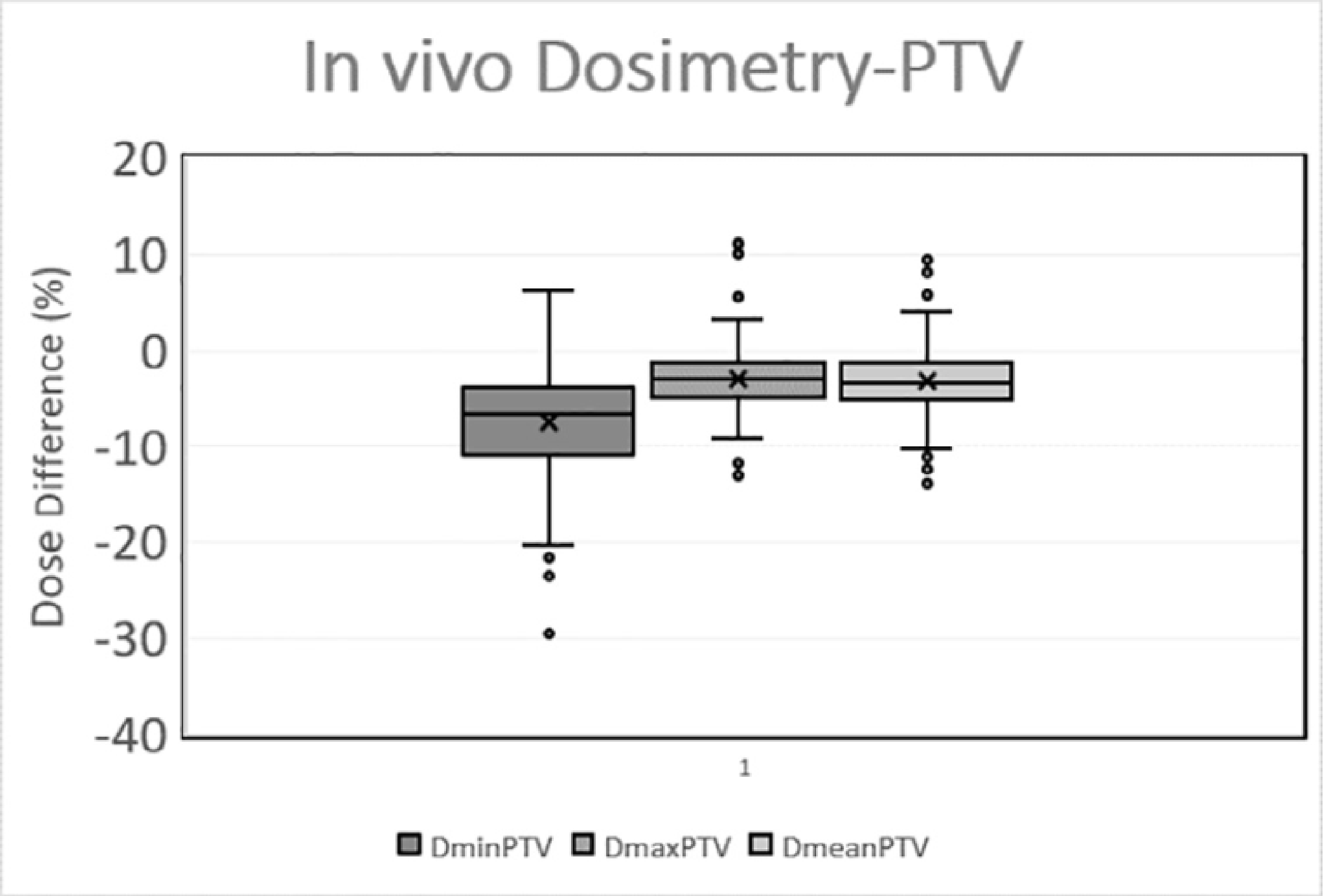
System	Algorithm	Test	Homogeneous phantom	Inhomogenehous phantom
Renner et al. 2003	Backprojection	Dose Iso	< 3.5% *	<10% * (<3.5%)
Piermattei et al 2006	Backprojection	Dose Iso	< 5%	NV
van Elmpt el al 2007	Backprojection	Dose Iso	<1%	<5% (<1%)
Francois et al 2011	Backprojection	Dose Iso	<5% *	<10% * (<5%)
Berry et al 2012	Projection	Gamma 3%/3mm	>95%	>95%
Fuandrog 2013 §	Projection	Gamma 3-4%, 3-4mm	>86%-89%	NV
Bedford 2014	Projection	Gamma 3%/3mm	>90%	>90%
Mc Cowan et al. 2015	Backprojection	Gamma 3%/3mm	>94%	>94%
Yoon et al. 2016	Projection	Gamma 3%3mm	>92%	>92%
Spreeuw et al.2016 §	Backprojection	Dose Iso	<1%	<5% (<1%)



Out of Tolerance Fractions (%)
Type of Error
imager failure
patient anatomy
system error
TPS related
unknown
0
10
20
30
40
Peca 2017
Piron 2018
McCowan 2017
McDermott 2007
Cilla 2019
Falco 2018
Nailon 2018
Olaciregui-Ruiz 2017
Mijnheer 2015
Fuangrod 2016
Consorti 2017
Ricketts 2016
Mans 2010
Camilleri 2014

SBRT applications: Abdomen Pelvis

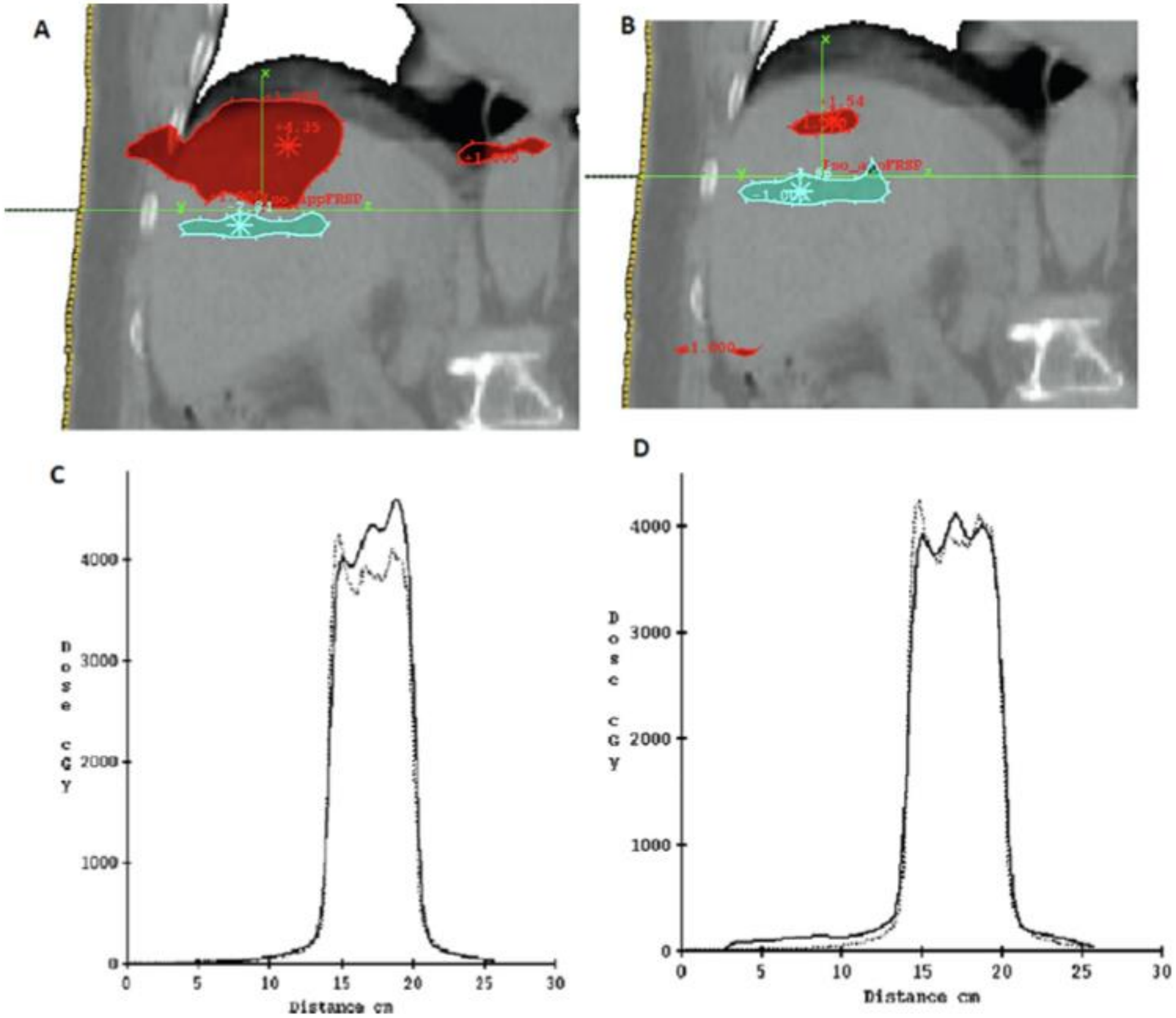
152 fraction from 80 patients in three years
16 Liver
11 Adrenal gland
12 spine
41 Pelvic nodes



M. Esposito et al
Radiotherapy and Oncology 154 (2021) 14–20

Reports the out of tolerance fractions obtained with four indices: Gamma Agreement Index in PTV < 85% (85% GAI PTV), PTV dose difference < 3.5%, and the limits based on SPC theory applied to CTV and PTV mean dose difference (SCL_{CTV}, SCL_{PTV}).

Tolerance levels	85% GAI PTV	3.5% ΔPTVmean	SCLCTV	SCLPTV
Out of tolerance	57 (37.8%)	73 (48%)	15 (10.1%)	10 (6.7%)
Residual set-up	5 (3.3%)	5 (3.3%)	5 (3.3%)	4 (2.5%)
4D-intrafraction	3 (2.1%)	3 (2.1%)	3 (2.1%)	3 (2.1%)
Immobilization devices	3 (2.1%)	3 (2.1%)	3 (2.1%)	3 (2.1%)
Algorithm failure	26 (17.1%)	40 (27%)	1 (0.5%)	–
Unknown/unidentified	20 (13.2%)	21 (13.5%)	3 (2.1%)	–

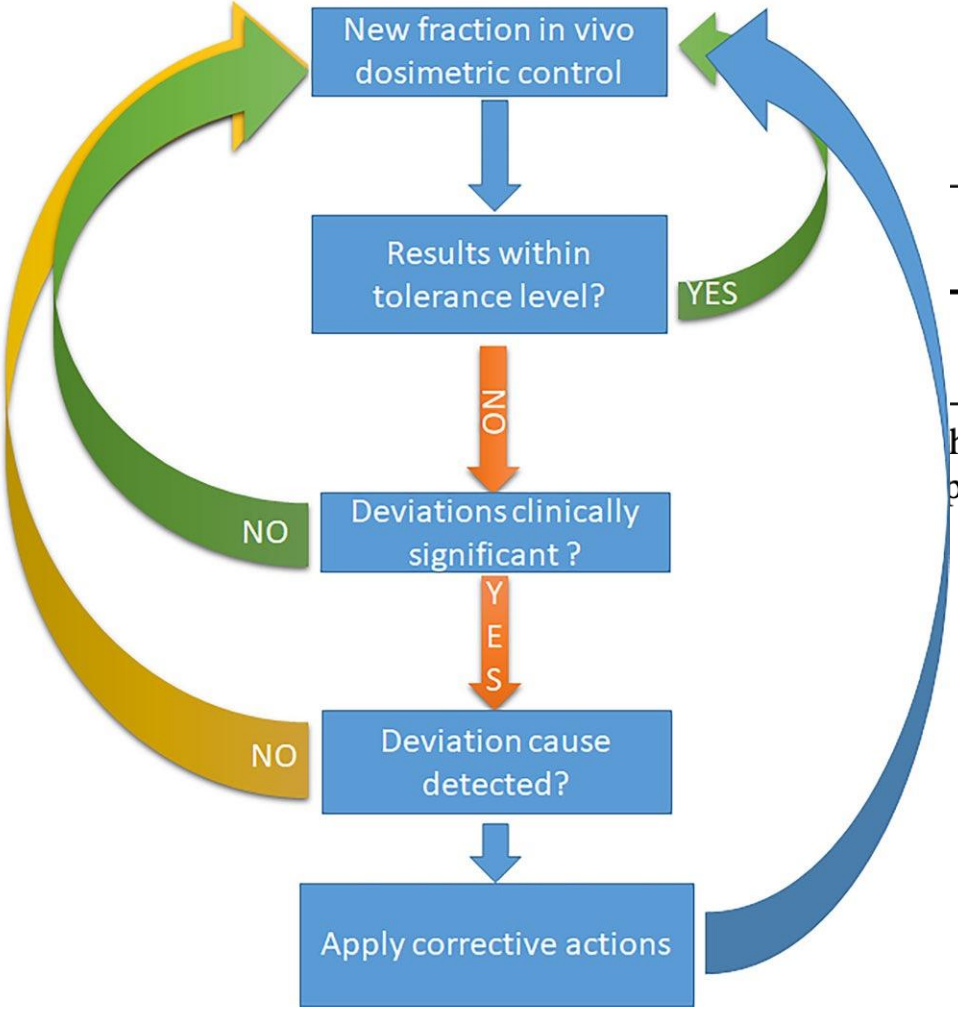

A
B
C
D
4000
3000
2000
1000
0
Dose cGy
0
5
10
15
20
25
30
Distance cm

SBRT applications: lungs

Table 1 Planning and target characteristics

	Patients (n)	PTV, [min-	Upper lobe (n)	Lower lobe (n)
Observational phase	41	(39±	28	13
Active phase	52	(36±	34	18

The second column shows the number of patie… …h and fifth columns report the number of patients treated with different prescri… …per and lower lung lobe
PTV planning target volume, *SD* standard devia…

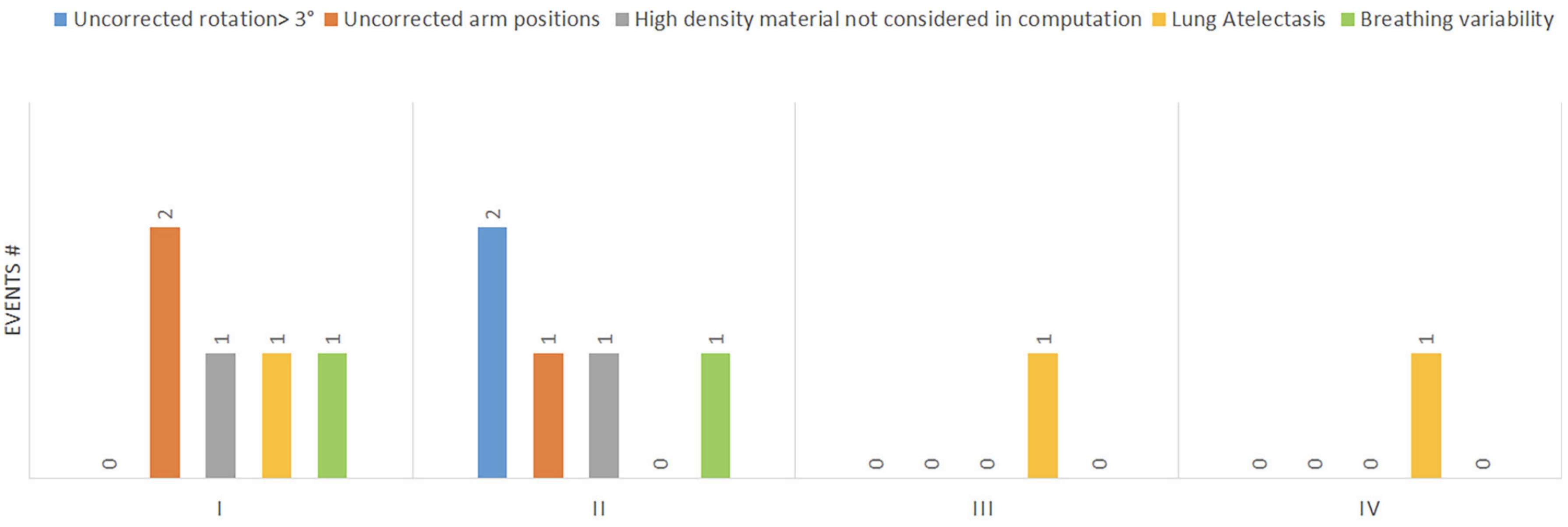


Esposito et al Strahlentherapie und Onkologie 2023 https://doi.org/10.1007/s00066-023-02081-x

Table 2 Errors found and corrective actions taken in the first observational phase and in the second active phase. In the first phase, corrective actions were not applied (NA)

	Incorrect setup				Computational errors in TPS		Anatomical variations			
Error category	Observational phase		Active phase		Observational phase	Active phase	Observational phase		Active phase	
	Uncorrected rotation > 3°	Uncorrected arm positions	Uncorrected rotation > 3°	Uncorrected arm positions	High density material not considered in computation	High-density material not considered in computation	Lung atelectasis	Breathing variability	Lung atelectasis	Breathing variability
Non correction needed errors	1	0	2	1	1	1	2	2	2	1
Correction needed errors	1	2	0	2	2	1	1	1	1	1
Successful corrective actions	NA	NA	0	1	NA	1	NA	NA	1	1

NA not applied



Dose accumulation methods

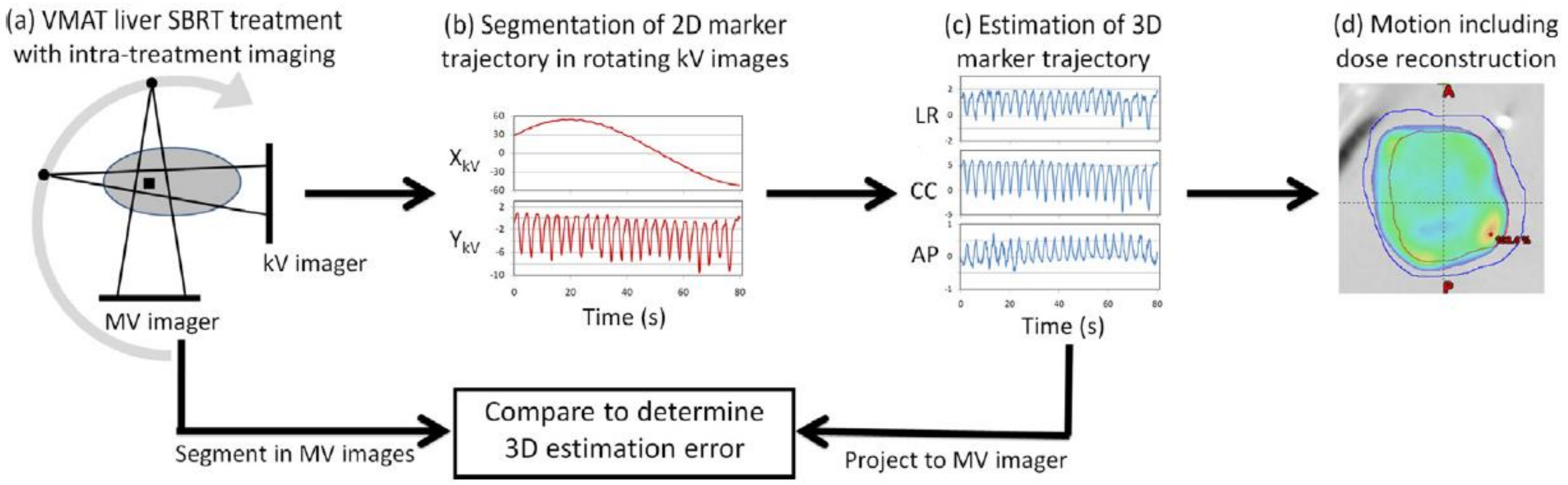
A family of computation methods that allows dose reconstruction taking tumor intrafraction movements into account

DAM elements:

(i) a tracking system to monitor patient and target positions,

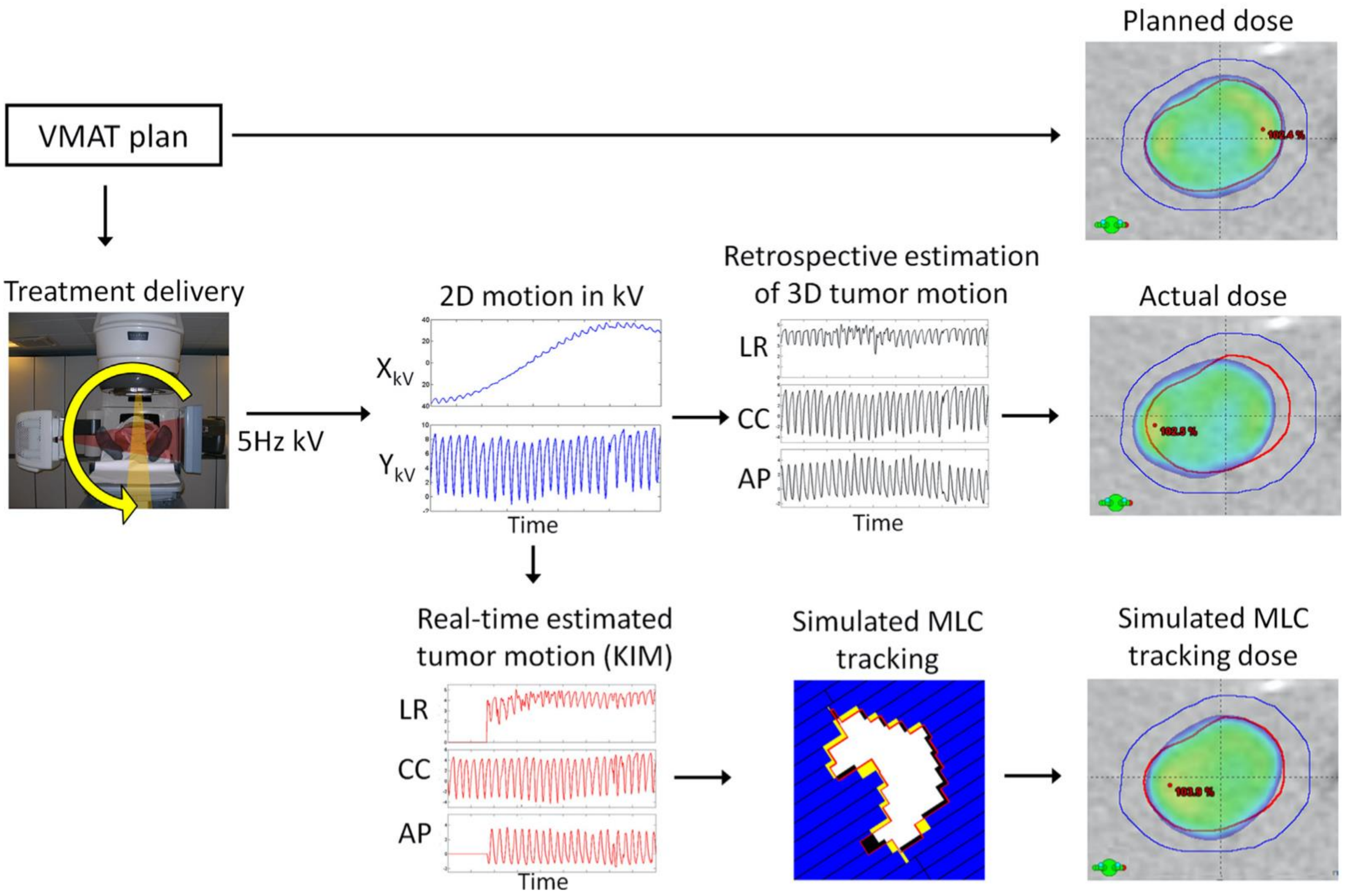
(ii) a linac machine status monitoring system,

(iii) a dose computation tool that reconstructs and accumulates the dose during the fraction.

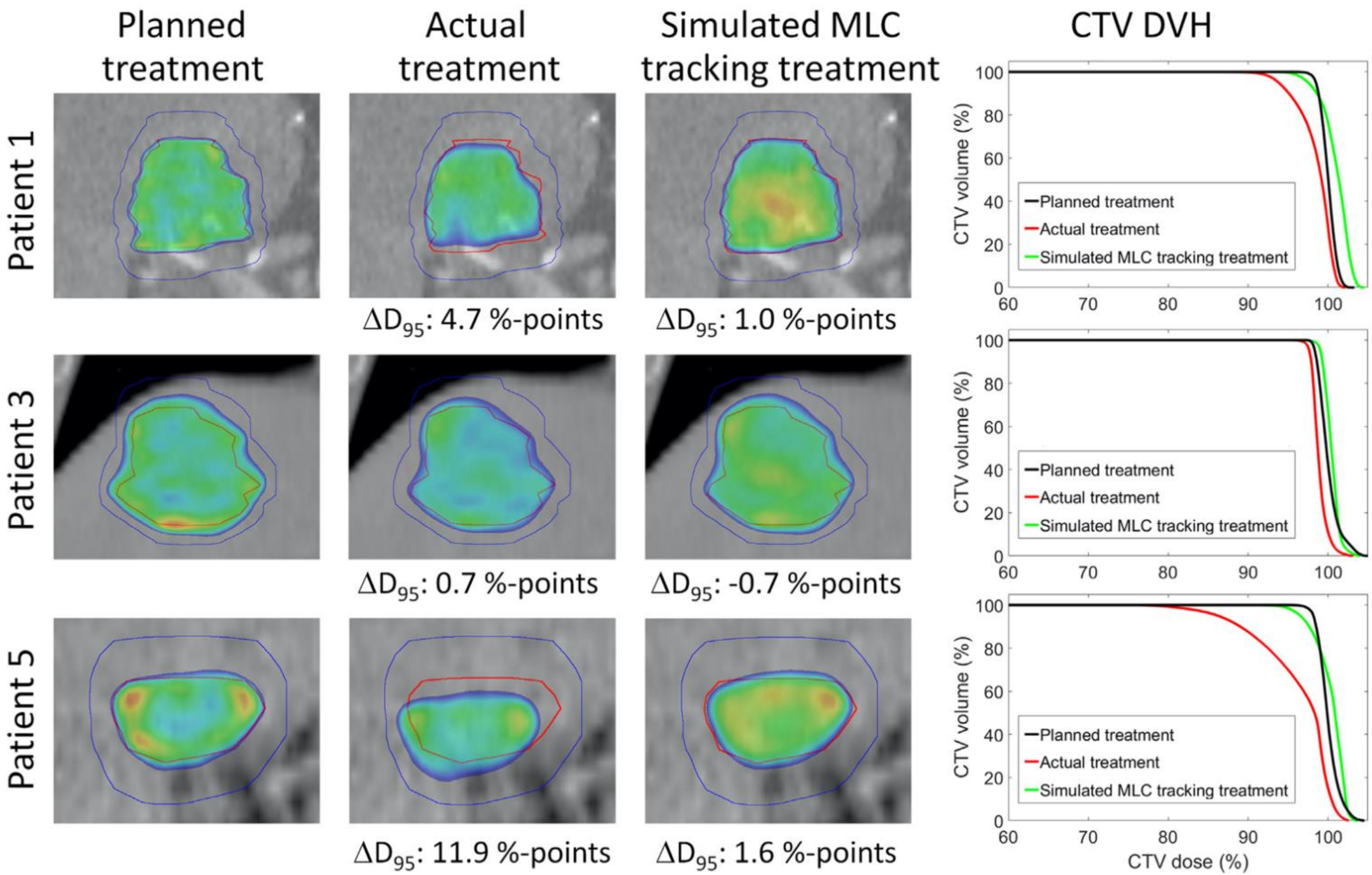


Dose was reconstructed by modeling the motion of a rigid target as multiple isocenter shifts into the TPS

Poulsen et al Radiotherapy and Oncology 111 (2014) 424–430



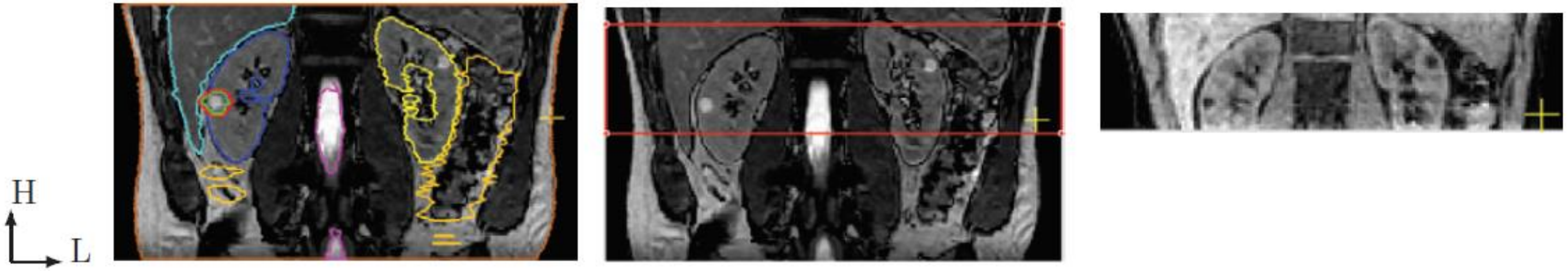
Poulsen et al Radiotherapy and Oncology 140 (2020) 93-100

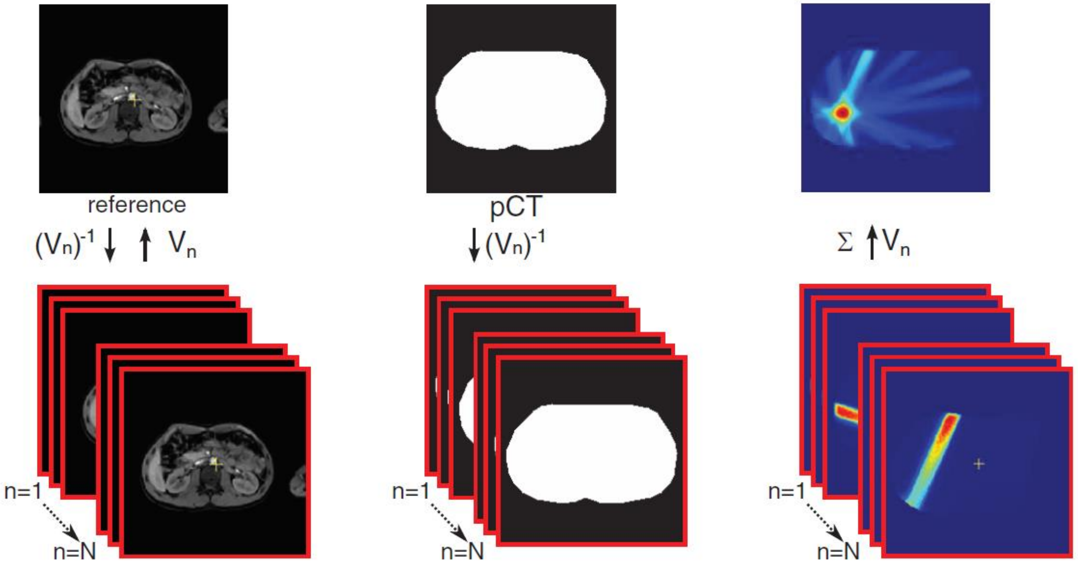


Planned treatment
Actual treatment
Simulated MLC tracking treatment
CTV DVH
Patient 1
Patient 3
Patient 5
ΔD95: 4.7 %-points
ΔD95: 1.0 %-points
ΔD95: 0.7 %-points
ΔD95: -0.7 %-points
ΔD95: 11.9 %-points
ΔD95: 1.6 %-points
CTV volume (%)
CTV dose (%)
Planned treatment
Actual treatment
Simulated MLC tracking treatment

Dose accumulation methods

4d-MRI imaging. The treatment was simulated

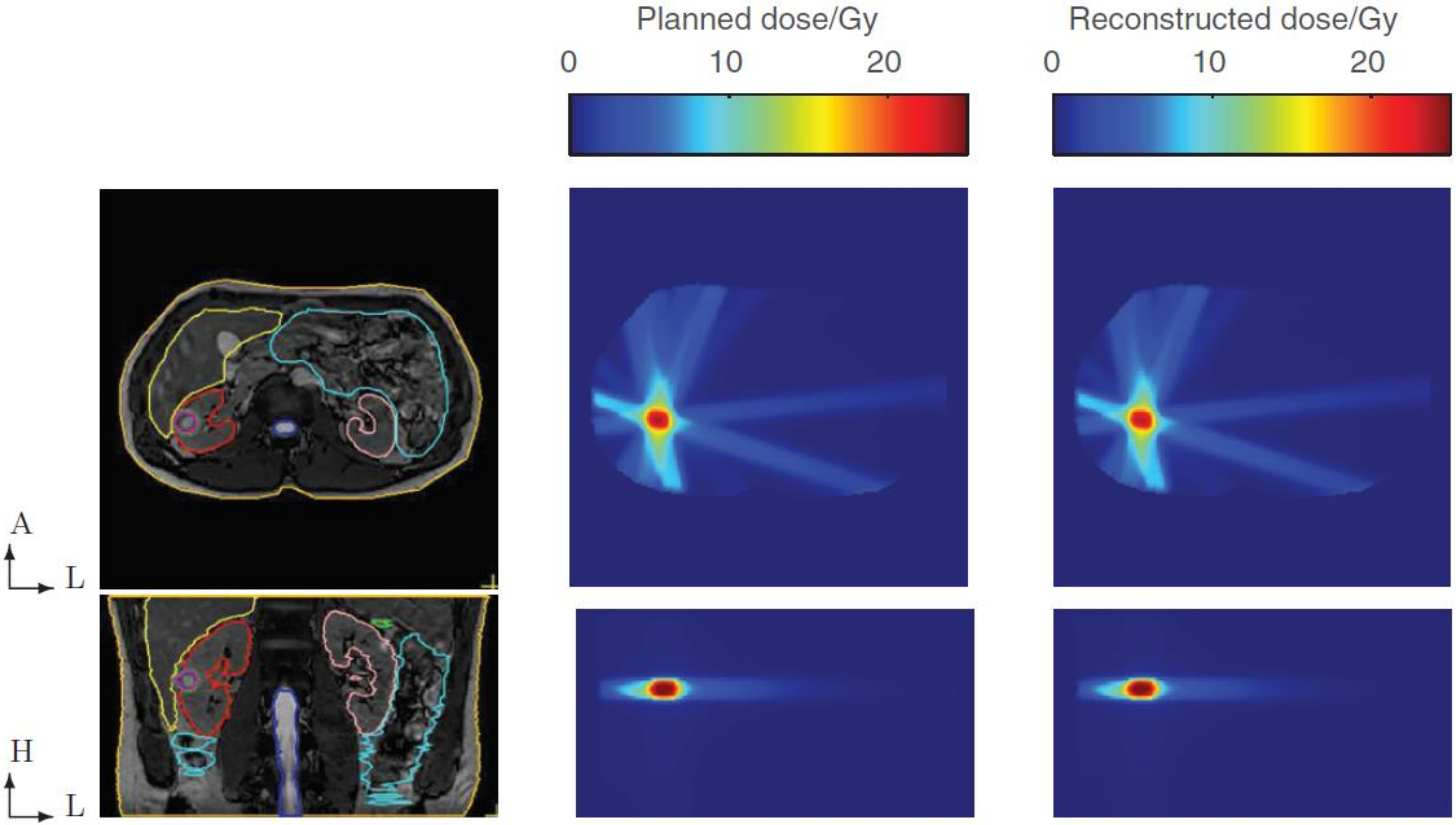




Each segment computed with Monte Carlo algorithm taking in to account linac parameters and volume position sampling 40 ms.

Dose was accumulated in a specific temporal phase using DVF

Glitzner et al. Phys. Med. Biol. **60** (2015) 8869–8883



(a)

Each segment needs 15 second for computation at 5% variance

Table 4
Comparison of the sensitivity of the various systems in detecting the errors listed in Table 2.

	Residual set-up errors	Anatomical variation	Plan Computation	Corrupted plan	Intra-fraction motion	Linac miscalibration	Linac delivery variability	Out of field dose assessment
Point Dosimeters	Reported by Noel et al. [30]; Fiorino et al. [31]; Higginns et al. [32] using entrance dose.	Potentially sensitive using exit dose, but never reported in literature	Potentially sensitive using exit dose, but never reported in literature	Potentially sensitive but never reported in literature	Limited sensitivity due to lack of spatial information reported by Legge et al. [37]	Potentially sensitive but never reported in literature	Not sensitive	Reported by Lonski et al. [42] using TDL and by Covington et al. [43] and Kragl et al. [44] using ion-ization chamber
Transmission Dosimeters	Not sensitive	Not sensitive	Not sensitive	Reported by Poppe et al. [45] using DAVID	Not sensitive	Collimators position miscalibration reported by Poppe et al. [44] using DAVID	Reported By Goulet et al. [52]; Marrazzo et al. [53] ; Razinskas et al. [54]; Li et al; Giglioli et al. [56]	Not sensitive
Log File analysis	Not sensitive	Not sensitive	Not sensitive	Potentially sensitive but never reported in literature	Not sensitive	Not sensitive	Reported by Hirashima et al. [65]; Neal et al. [64] reported erroneous informations stored in log files	Not sensitive
EPID	Reported by Zhuang et al. [88], Esposito et al. [89]; Olaciregui-Ruiz et al. [90]; Li et al. [91]; Mijnheer et al. [92]	Reported by Cowan et al. [80]; Foundrog et al. [84]; Olaciregui-Ruiz et al. [90]; Mc Mans et al. [76]; Bojechko et al. [92] Mijn-heer et al. [93]	Reported by Mans et al. [76]	Reported by Mans et al. [76]	Reported by Moustakis et al. [94]	Reported by Zhuang et al. [88]; Esposito et al. [89]; Li et al. [91]; Bojechko et al. [92]	Reported by Hsieh et al. [87]; Zhuang et al. [88]; Esposito et al. [89] ; Bojechko et al. [92]	Not sensitive
Dose Accumulation Methods	Reported by Poulsen et al. [103]; Ravkilde et al. [106]; Keall et al. [107] ; Fast et al. [109]; Kamerling et al. [110]	Reported by Poulsen et al. [103]; Ravkilde et al. [106]; Keall et al. [107]; Fast et al. [109]; Kamer-ling et al. [110]	Potentially sensitive but never reported in literature	Potentially sensitive but never reported in literature	Reported by Poulsen et al. [105]; Ravkilde et al. [106]; Keall et al. [105]; Fast et al. [109]; Kamer-ling et al. [110]	Not sensitive	Potentially sensitive, depending on the linac monitoring system used	Not sensitive

Conclusions

- Patient specific QA (pre treatment and in vivo) are needed in SBRT
- PS QA are useful only if all others QA are performed
- In vivo dosimetry systems and on line measurement methods were proven able to intercept and correct clinically relevant errors
- The clinical utility of on line methods has not yet been proved

Three dosimetric physical quantities:

Dp: planned dose → Computed by TPS

Dm: measured dose → Measured by a device

Dd: delivered dose → Actual dose

Dp≠Dm≠Dd

Dm is the best estimation for Dd