Quality assurance and in vivo dosimetry for SBRT

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Outline (1)

Pre-treatment QA:

i) **Linac QC**: Laser, Isocenter, Multileafs verification

ii) **Imaging system QC**: Isocenter verification

iii) Patient specific **QA**

iv) **End to end** test

v) Inter(national) **Audit**

Linac QC

AAPM REPORTS & DOCUMENTS

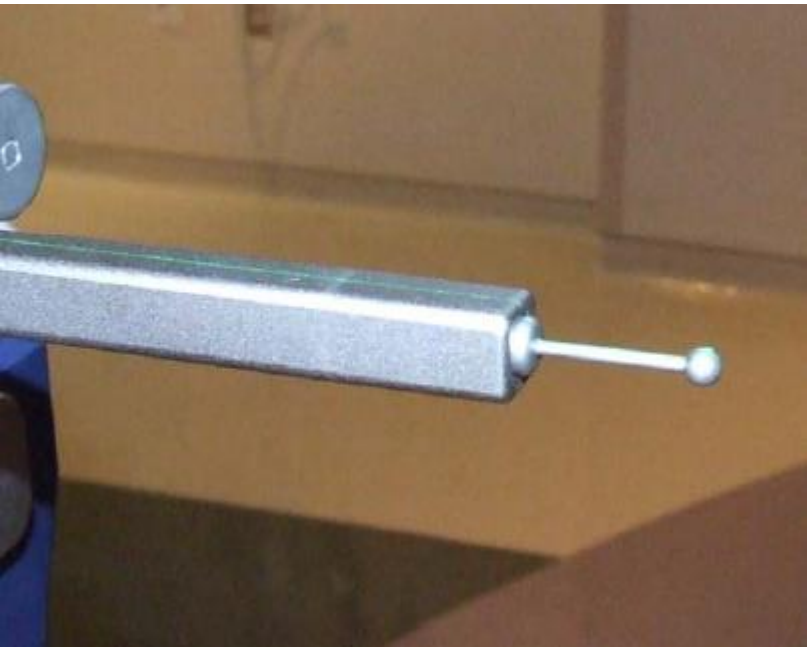
AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS-SBRT

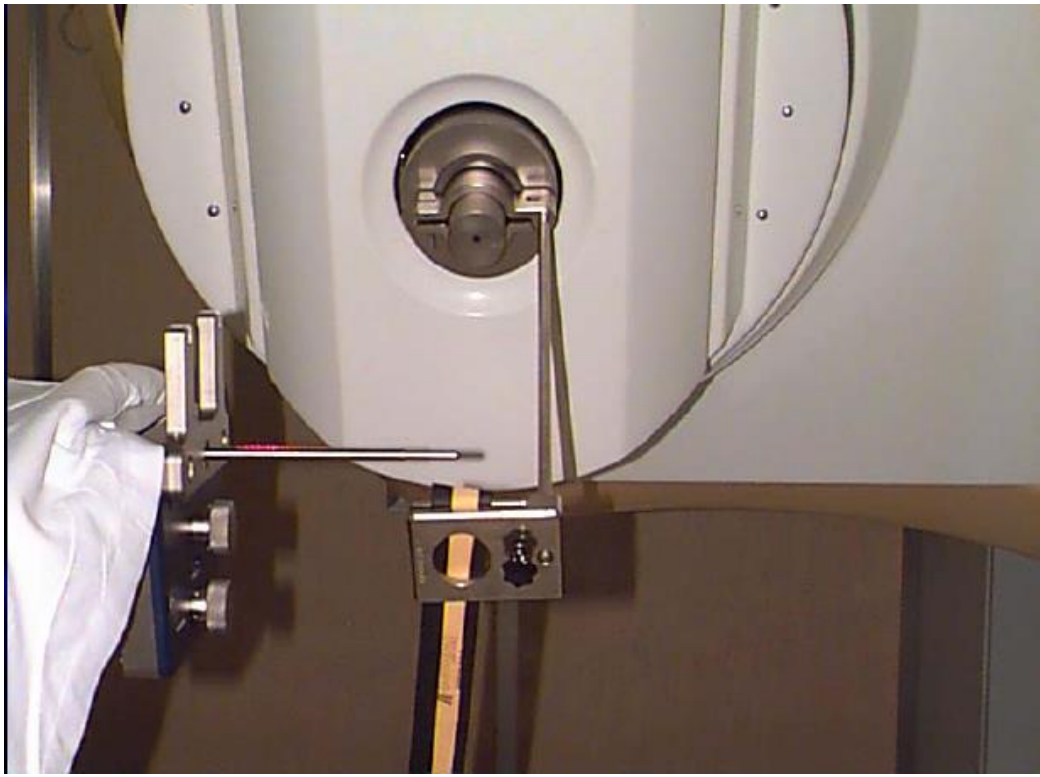
TABLE 1 Minimum SRS-SBRT relevant equipment QA and tolerances for C-arm linac systems.

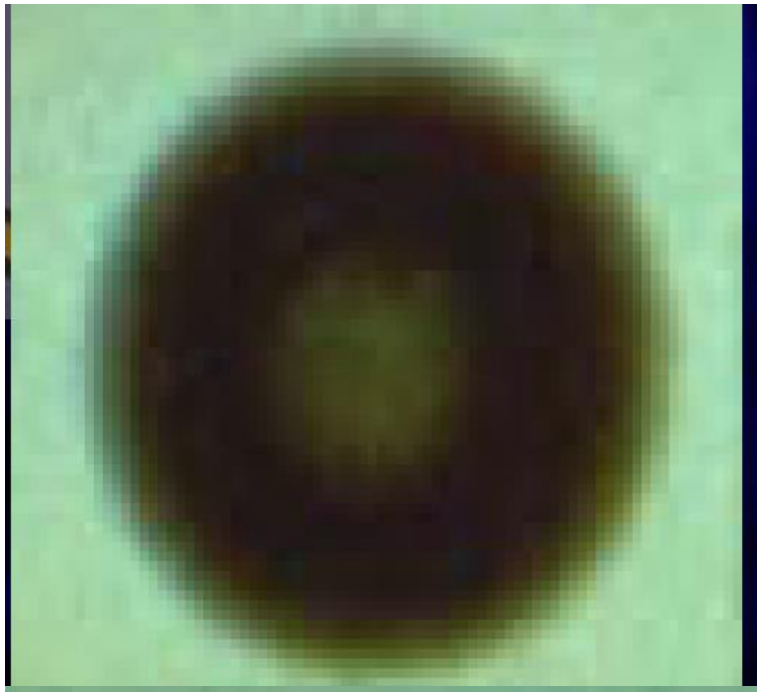
Frequency	Test	Tolerance
Daily	Laser localization — only if using SRS techniques relying on lasers for target localization (e.g., frame-based SRS without X-ray IGRT)	1 mm
	Collimator size indicator for clinically relevant aperture	2 mm total
	Radiation isocentricity test (limited gantry and couch positions) — maximum deviation in center of target object relative to each projection's beam central axis	1.0 mm SRS, 1.5 mm SBRT
	IGRT positioning/repositioning	1 mm SRS, 2 mm SBRT
	Imaging subsystem interlocks	Functional
	Stereotactic interlocks — cone size, backup jaws	Functional
	Accelerator output constancy	±3%
Monthly	Radiation isocentricity test — covering complete range of gantry, couch, collimator positions used clinically — *maximum deviation in center of target object relative to each projection's beam central axis* **Note: If both MLC and fixed conical collimators are used, both must be evaluated at least monthly*	1.0 mm SRS, 1.5 mm SBRT
	Treatment couch position indicators: relative over the maximum clinical range	1 mm/0.5°
	Output constancy at relevant dose rates	2%
Annually	SRS arc rotation mode (if used clinically)	1 MU, 1°
	MU linearity (≥5 MU to highest MU used clinically)	±2%
	Accelerator output	±1.5%
	Coincidence of radiation and mechanical isocenter	±1.0 mm maximum 3-D displacement from center of target object
	Verification of small-field beam data — relative output factors for cones and/or MLC	±2% from baseline for >1.0 cm apertures, ±5% from baseline for ≤1.0 cm apertures
	E2E localization assessment "hidden target test" using SRS frame and/or IGRT system	1.0 mm
	E2E dosimetric evaluation using SRS frame and/or IGRT system	±5% measured vs. calculated

Tolerances are absolute accuracy, not variation from baseline, unless otherwise stated.

Winston-Lutz test







Test OK

Test NOT OK

On Board Imaging System QC

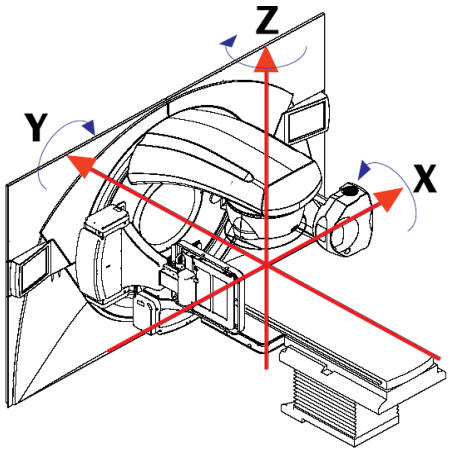
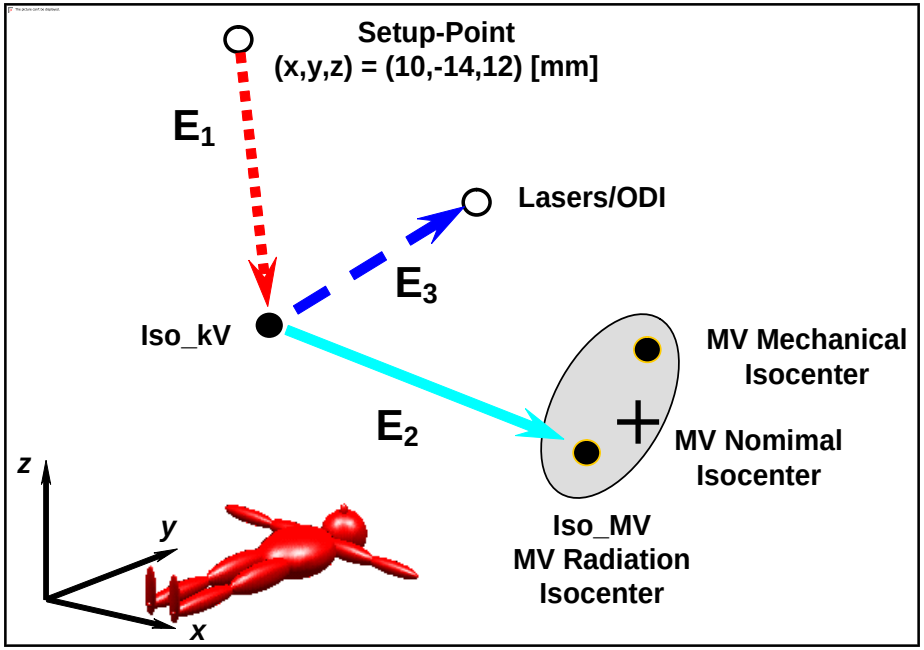
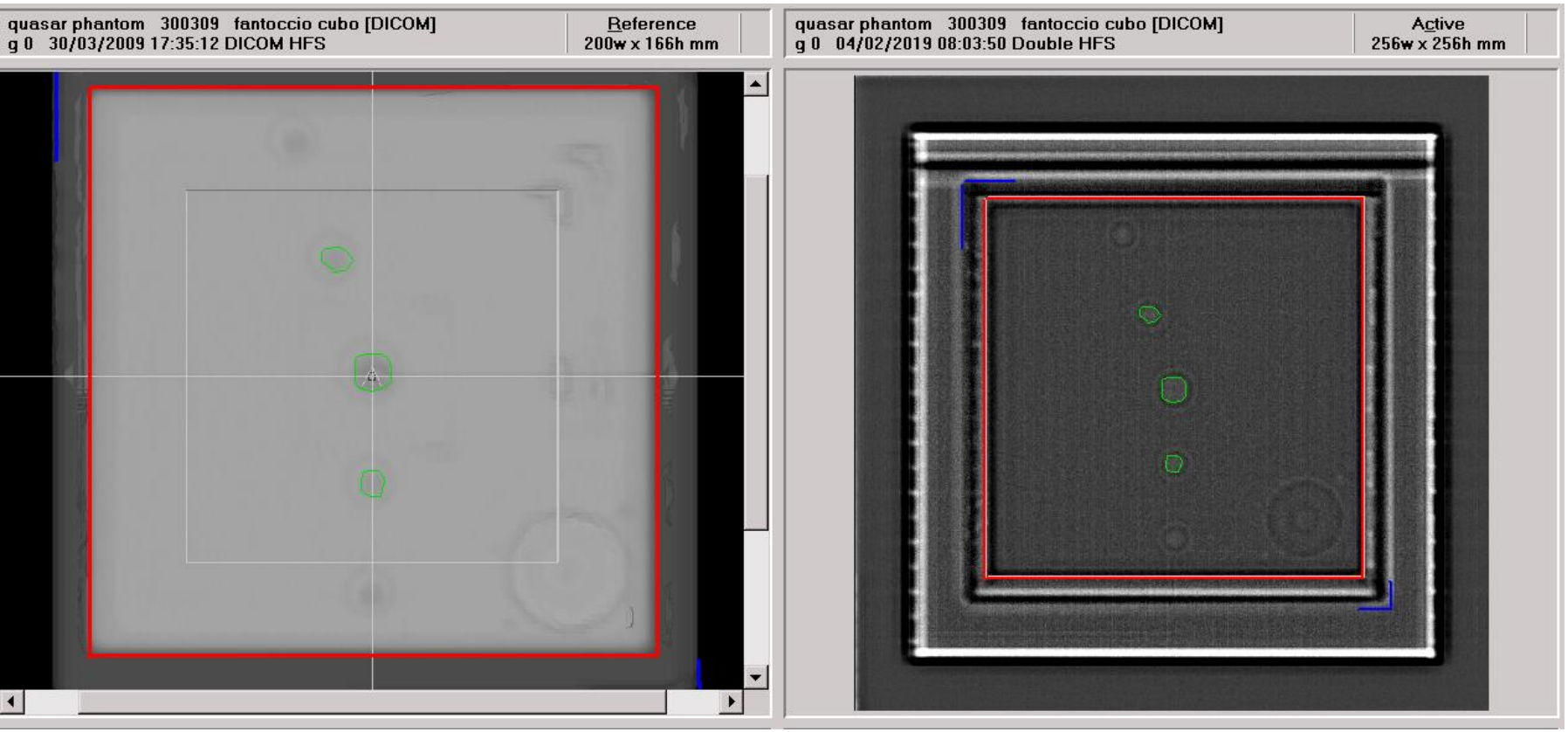
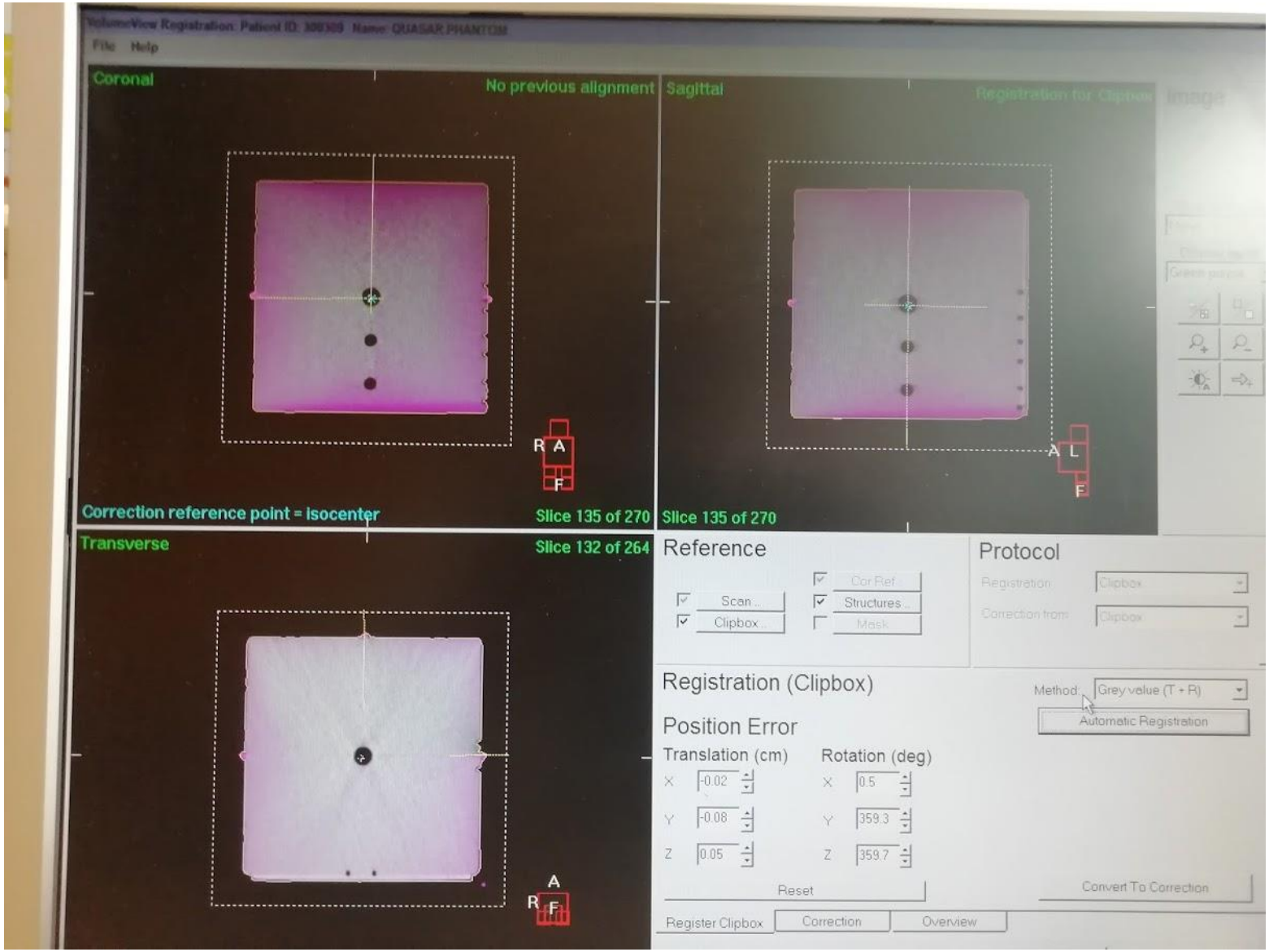
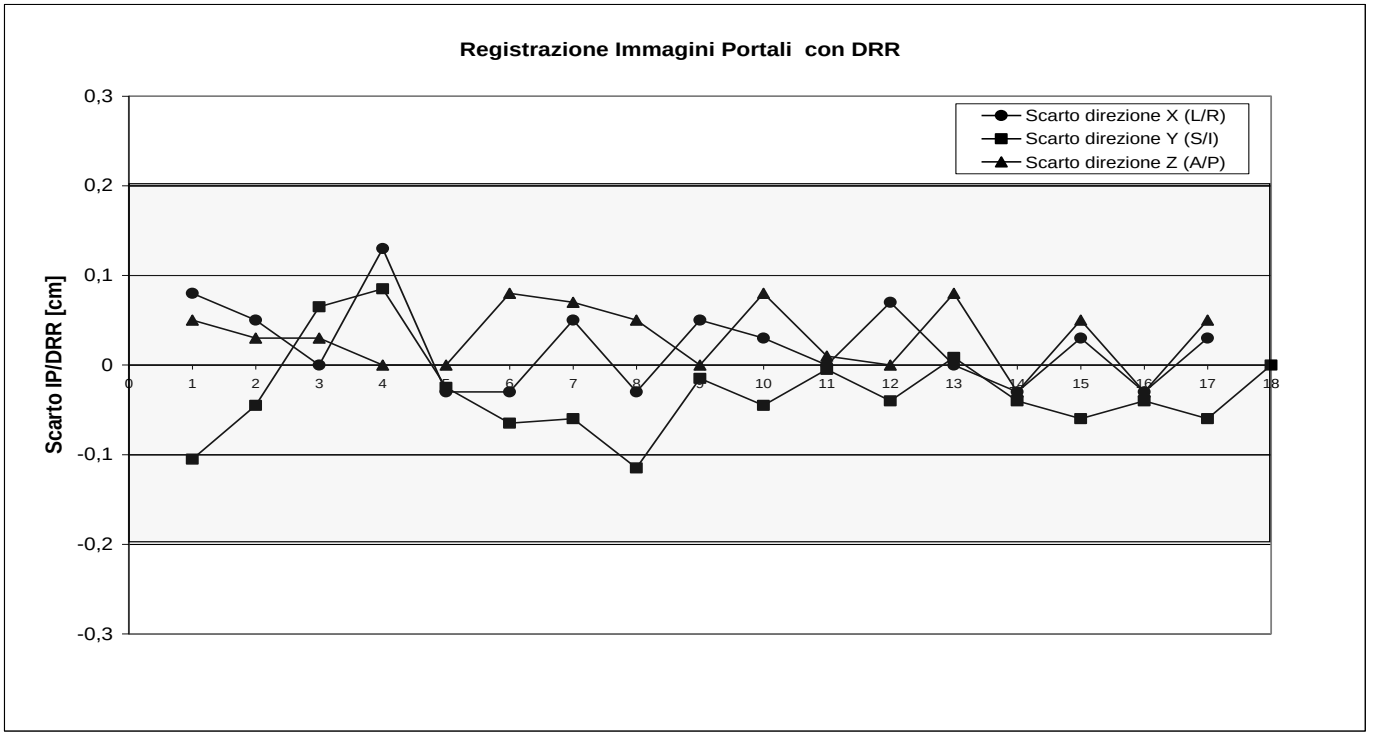


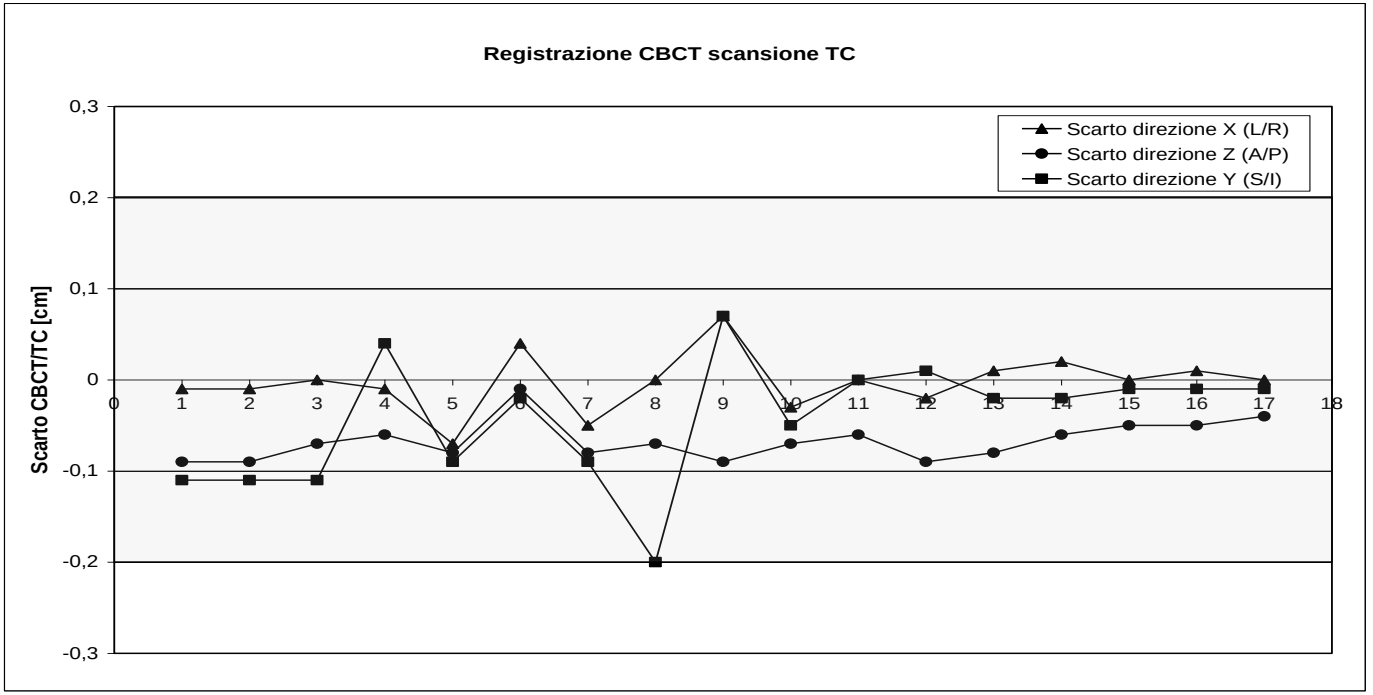
Figure 11.12 Fixed room axes (arrowheads indicate positive directions for rotations & translations)




quasar phantom 300309 fantoccio cubo [DICOM]
g 0 30/03/2009 17:35:12 DICOM HFS
Reference
200w x 166h mm
quasar phantom 300309 fantoccio cubo [DICOM]
g 0 04/02/2019 08:03:50 Double HFS
Active
256w x 256h mm


File Help
Coronal
No previous alignment
R A
F
Correction reference point = isocenter
Slice 135 of 270
Sagittal
A L
F
Slice 135 of 270
Transverse
Slice 132 of 264
A
R F
Reference
Scan...
Clipbox...
Cor Ref.
Structures...
Mask
Protocol
Registration
Clipbox
Correction from
Clipbox
Registration (Clipbox)
Method
Grey value (T + R)
Automatic Registration
Position Error
Translation (cm)
Rotation (deg)
X -0.02
Y -0.08
Z 0.05
X 0.5
Y 359.3
Z 359.7
Reset
Convert To Correction
Register Clipbox
Correction
Overview


Registrazione Immagini Portali con DRR
Scarto IP/DRR [cm]
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Scarto direzione X (L/R)
Scarto direzione Y (S/I)
Scarto direzione Z (A/P)


Registrazione CBCT scansione TC
Scarto CBCT/TC [cm]
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Scarto direzione X (L/R)
Scarto direzione Z (A/P)
Scarto direzione Y (S/I)

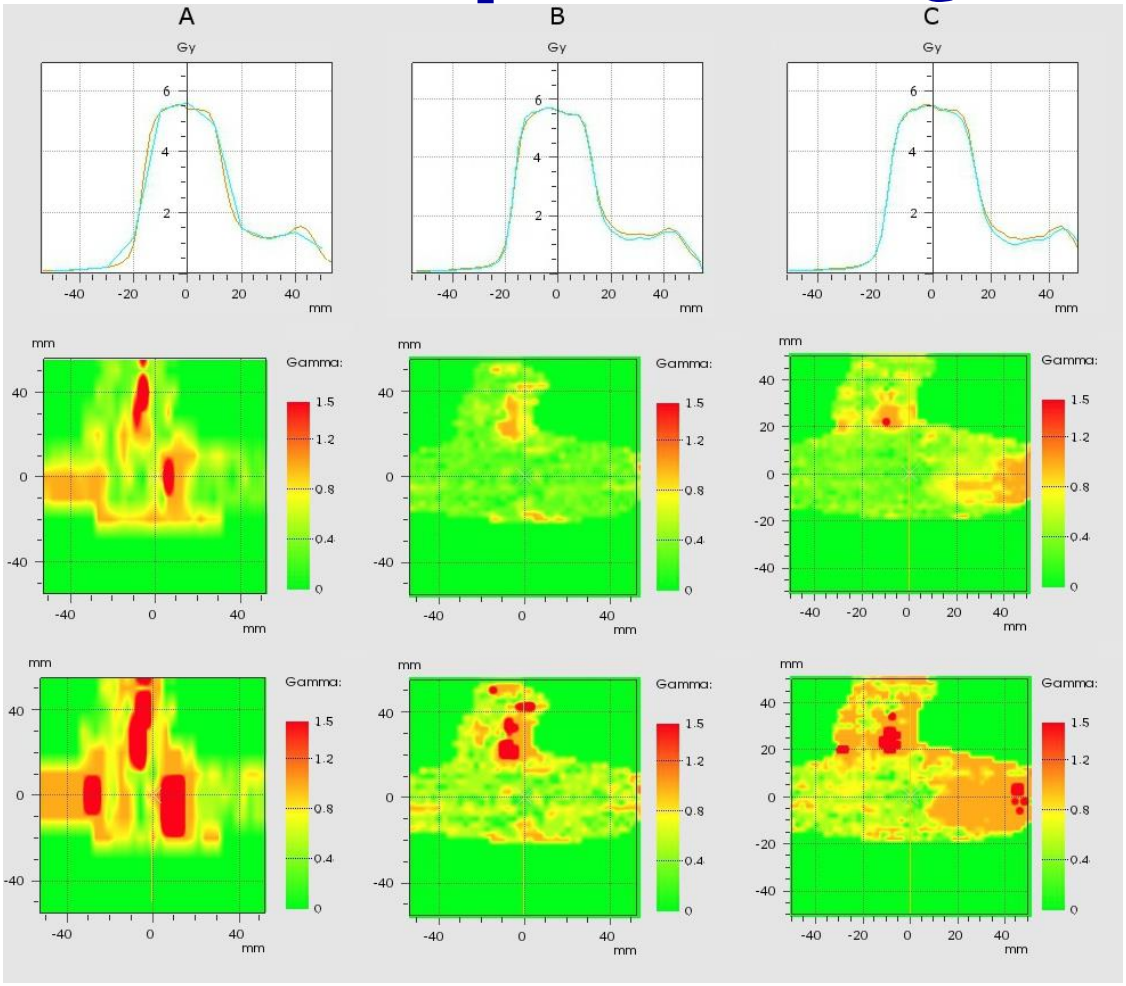
Patient specific QA

Pre-treatment patient specific **QA is mandatory**

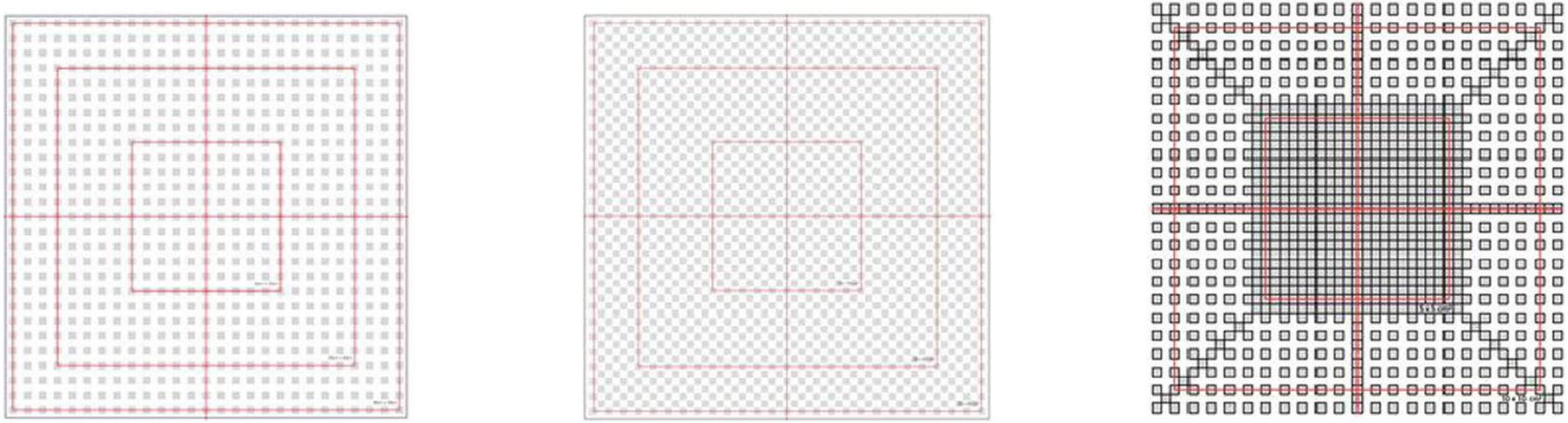
The **revelator resolution** is a critical parameter because of the **small target dimension**

Gamma **A**greement **I**ndex **2%2mm** should be used

Patient specific QA

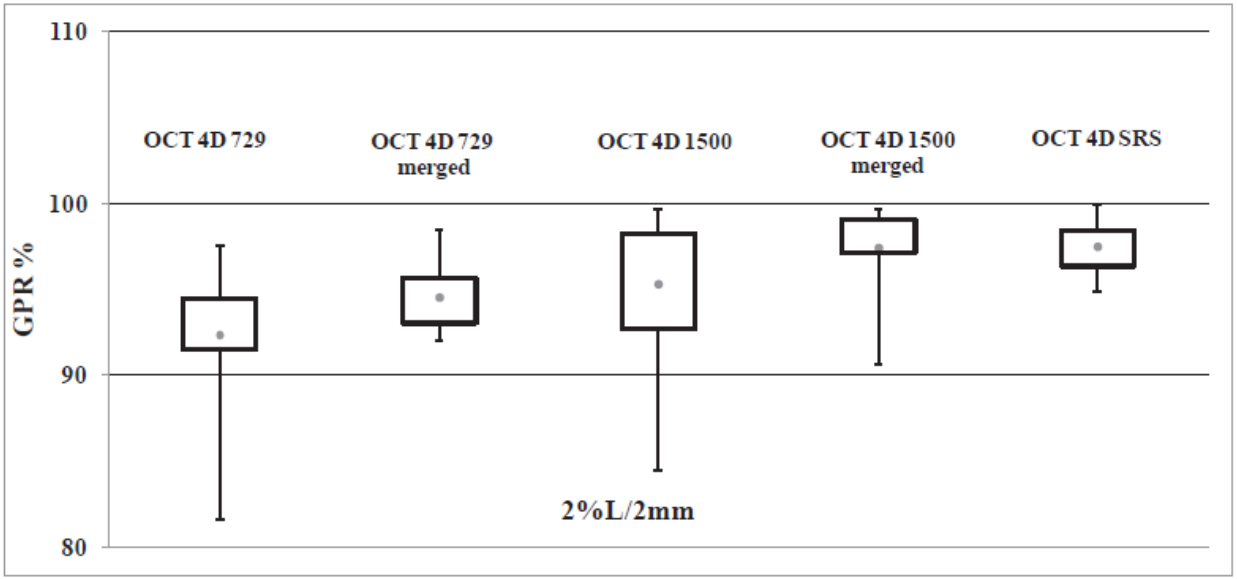


G-T profile at the isocenter (top), the 2D γ distribution on the coronal plane passing through the isocenter at 2% 2mm (middle) and 2% 1mm (bottom) are shown:
A PTW Octavius 4D 729, B PTW Octavius 4D 1000 SRS (SRS), and C Dosimetry Check.



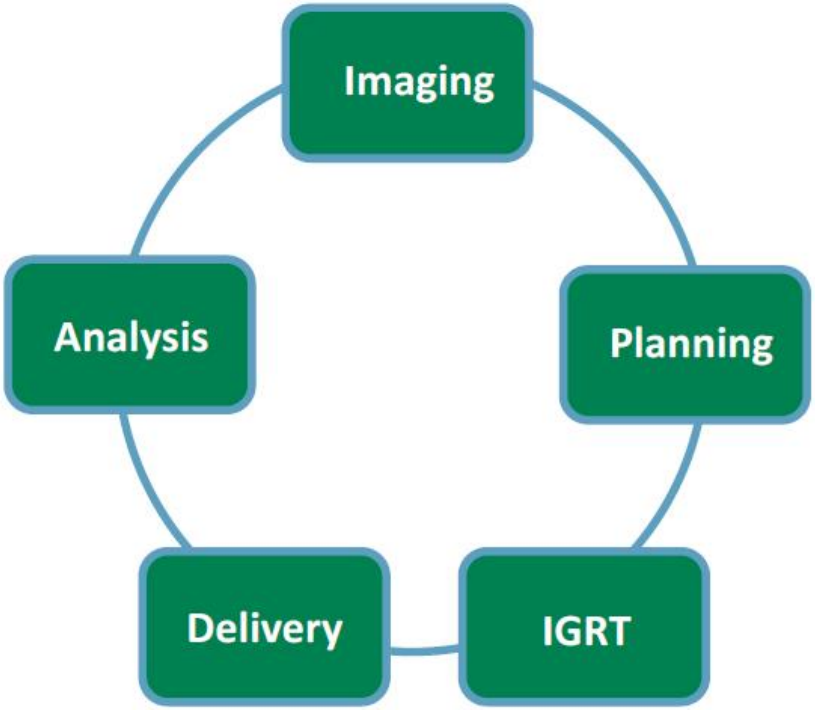
a) b) c)

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



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

End to end test



End to end test

Med Phys. 2015 Nov;42(11):6488-97. doi: 10.1118/1.4932363.

Technical Report: TG-142 compliant and comprehensive quality assurance tests for respiratory gating.

Woods K[1], Rong Y[2].

Received: 8 June 2017 | Revised: 7 September 2017 | Accepted: 17 October 2017

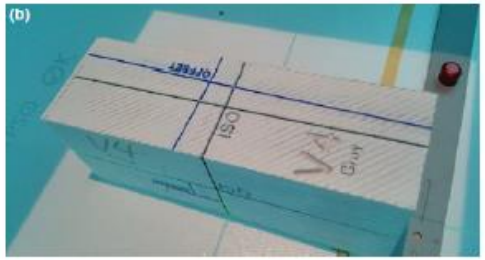
DOI: 10.1002/acm2.12227

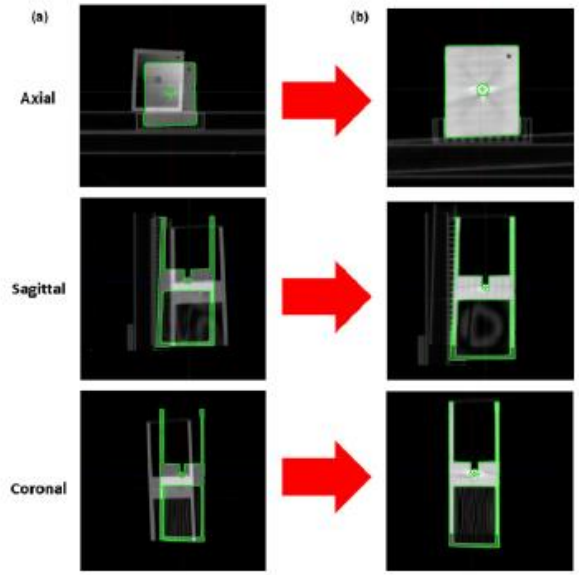
RADIATION ONCOLOGY PHYSICS

WILEY

Quality assurance for a six degrees-of-freedom table using a 3D printed phantom

Kyle Woods | Ahmet S. Ayan | Jeffrey Woollard | Nilendu Gupta





An end-to-end postal audit test to examine the coincidence between the imaging isocenter and treatment beam isocenter of the IGRT linac system for Japan Clinical Oncology Group (JCOG) clinical trials

Yu Kumazaki[a,*], Shuichi Ozawa[b], Mitsuhiro Nakamura[c], Satoshi Kito[d], Toshiyuki Minemura[e], Hidenobu Tachibana[f], Teiji Nishio[g], Satoshi Ishikura[h], Yasumasa Nishimura[i]

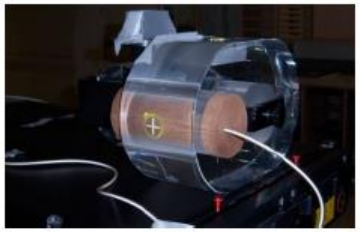
Physica Medica 53 (2018) 145–152

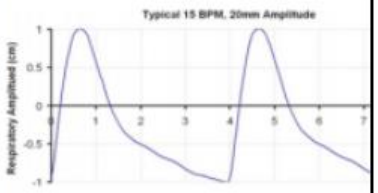
End to end test

7th International Conference on 3D Radiation Dosimetry (IC3DDose) IOP Publishing
Journal of Physics: Conference Series **444** (2013) 012073 doi:10.1088/1742-6596/444/1/012073

Stereotactic body radiation therapy delivery validation

T Olding[1], L Garcia[1], K Alexander[2], LJ Schreiner[1,2] and C Joshi[1,2]
[1]Cancer Centre of South Eastern Ontario at Kingston General Hospital, 25 King Street West, Kingston, ON, Canada, K7L5P9
[2]Department of Physics, Queen's University, Kingston, Ontario, Canada, K7L3N6





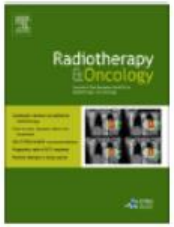
JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 16, NUMBER 1, 2015

Single-fraction spine SBRT end-to-end testing on TomoTherapy, Vero, TrueBeam, and CyberKnife treatment platforms using a novel anthropomorphic phantom

John J. Gallo,[1a] Isaac Kaufman,[2] Rachel Powell,[3] Shalini Pandya,[4] Archana Somnay,[5] Todd Bossenberger,[6,7] Ezequiel Ramirez,[8] Robert Reynolds,[8] Timothy Solberg,[9] Jay Burmeister,[6,7]

TABLE 1. Thoracic ion chamber measurements in vertebral body.

Treatment Plan	*Ion Chamber Measurement (Gy)*	*Treatment Platform*				
		TomoTherapy	*Vero*	*TrueBeam (Flattened)*	*TrueBeam (FFF)*	*CyberKnife*
Plan A	Calculated Dose	16.5	20.6	16.5	16.3	17.9
	Measured Dose	16.4	21.1	17.0	16.5	18.5
	% Difference	-0.3	2.6	3.1	1.4	3.0
Plan B	Calculated Dose	16.6	20.8	16.4	16.5	21.8
	Measured Dose	16.6	21.5	16.3	16.6	22.4
	% Difference	0.0	3.2	-0.3	0.6	2.4
Plan D	Calculated Dose	16.2	21.2	16.0	16.2	20.4
	Measured Dose	16.5	21.5	16.1	16.3	20.6
	% Difference	2.2	1.4	0.6	0.8	0.7



A national dosimetry audit for stereotactic ablative radiotherapy in lung

Gail Distefano [a,*], Jonny Lee [b], Shakardokht Jafari [c,d], Clare Gouldstone [e], Colin Baker [b,f], Helen Mayles [b], Catharine H. Clark [a,c,e]

Radiotherapy and Oncology 122 (2017) 406–410

External Audit

Examining credentialing criteria and poor performance indicators for IROC Houston's anthropomorphic head and neck phantom

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Andrea Molineu, Paige A. Taylor, and David S. Followill
IROC Houston Quality Assurance Center, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030

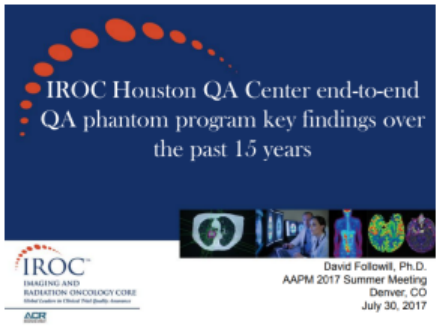
Francesco C. Stingo
Department of Biostatistics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030

Stephen F. Kry[a)]
IROC Houston Quality Assurance Center, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030

Published in final edited form as:
Int J Radiat Oncol Biol Phys. 2017 August 01; 98(5): 1197–1203. doi:10.1016/j.ijrobp.2017.03.049.

Treatment Planning System Calculation Errors Are Present in the Majority of IROC-Houston Phantom Failures

James R. Kerns[1,2,3], **Francesco Stingo**[4], **David Followill**[1,2,3], **Rebecca Howell**[1,2,3], **Adam Melancon**[1], and **Stephen F. Kry**[1,2,3]



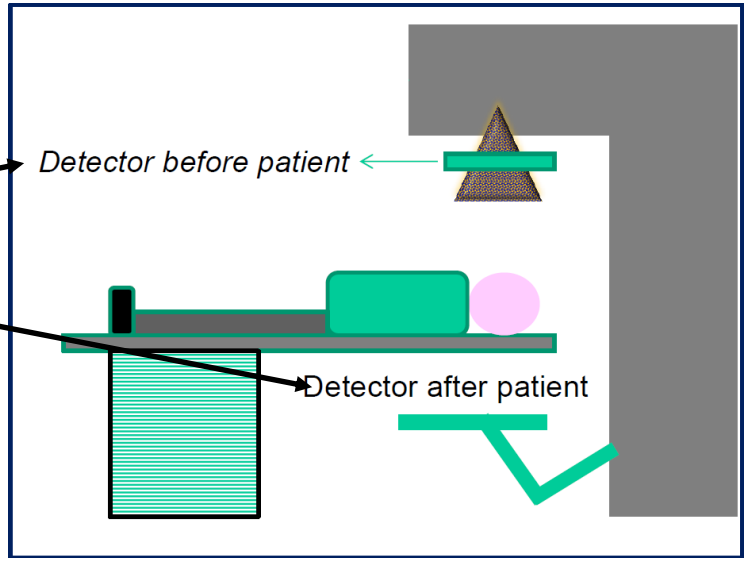
Phantom	H&N	Liver insert	Lung	Prostate	Spine
Irradiations	2052	165	1109	566	336
Pass	1755 (86%)	120 (73%)	921 (83%)	484 (86%)	261 (78%)
Fail	297	45	188	82	75
Criteria	7%/4mm	7%/4mm	5%/5mm	7%/4mm	5%/3mm

Take home messages

- SBRT requires **high** level of **accuracy** in **all phases** of the treatment process
- **QC** for each phase of the SBRT process **are foundamental**
- The **high** level of **accuracy** is achieved by applyng **tight tolerances**
- **E2E tests** detect errors, improve dose delivery accuracy and provide confidence
- Partecipation in **external Audits** is very effective to **guarantee patient safety**

Outline (2)

- In-vivo dosimetry: introduction and definitions
- Devices for in vivo dosimetry:
  - i) Point dosimeters
  - ii) Transmission 2d dosimeters
  - iii) EPID based dosimetry
  - iv) Dose reconstruction methods
- Clinical results
- Real time in vivo dosimetry



Definitions

- In-vivo Dosimetry (IVD): any measure performed during therapy that enable an estimation of actual dose absorbed by patient.
- Aim of IVD: to establish if the difference between planned and measured dose is within a tolerance level Δ.
- IVD quasi real time: results are available just after the fraction, errors detected can be corrected in the next fractions.
- IVD real time: results are available during the treatment, the treatment can be stopped before fraction is compromised

Why IVD ?

- Prevent accidents → $\Delta >> 10\%$
- Correct clinical relevant errors → $(\Delta > 5\%)$
- Measure the overall accuracy and reproducibility of treatment → $\Delta = ?$

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%

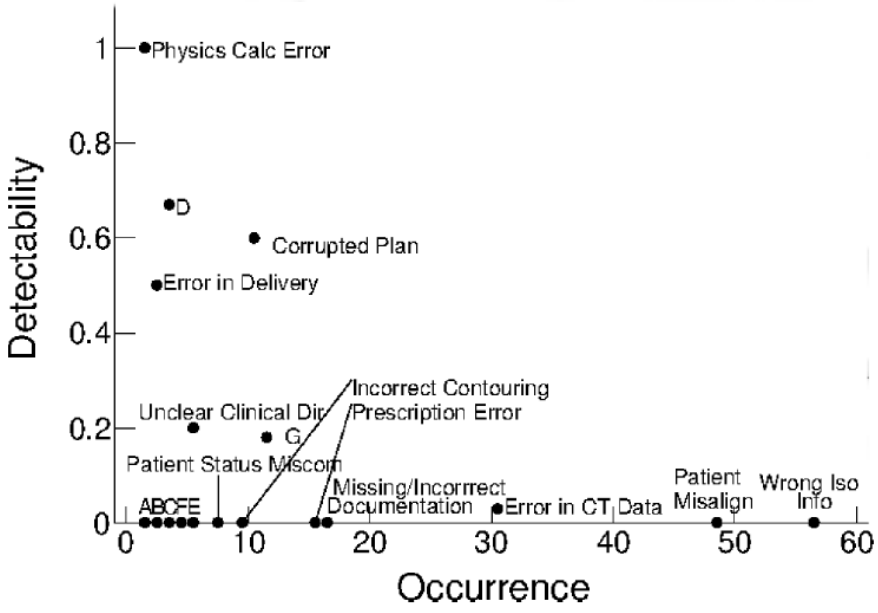
→ Clinical 5%

→ Delivery 2%

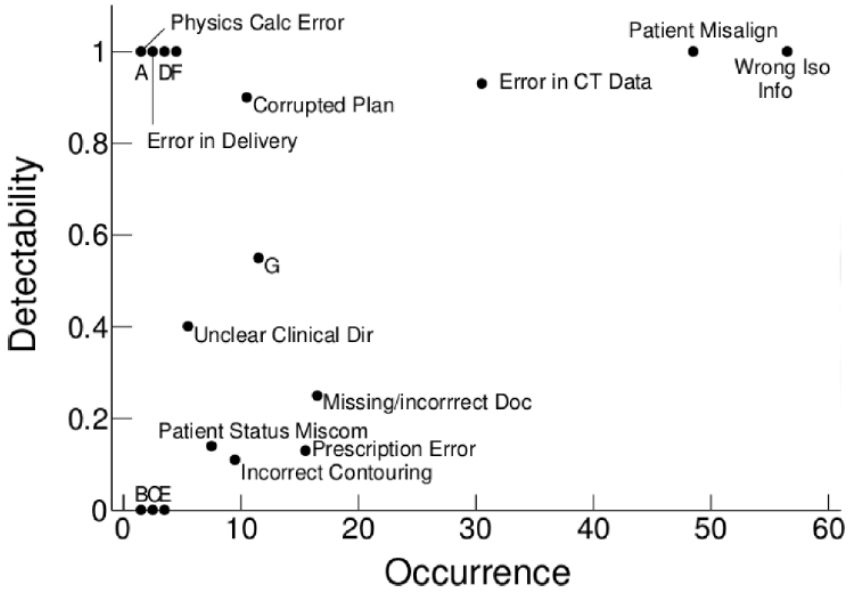
Physics calculation 0.3%

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

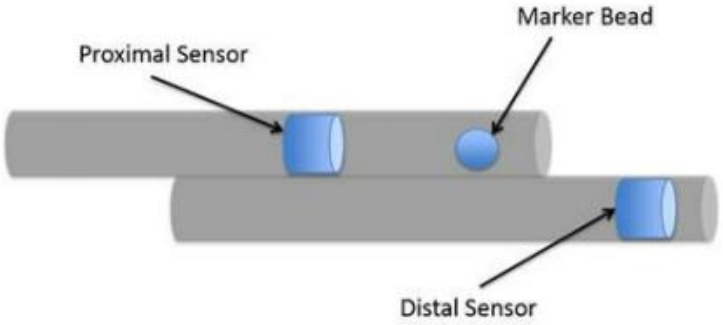
IVD vs pre-treatment QA

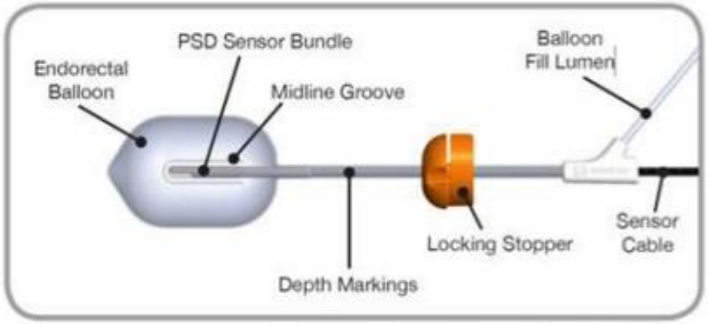


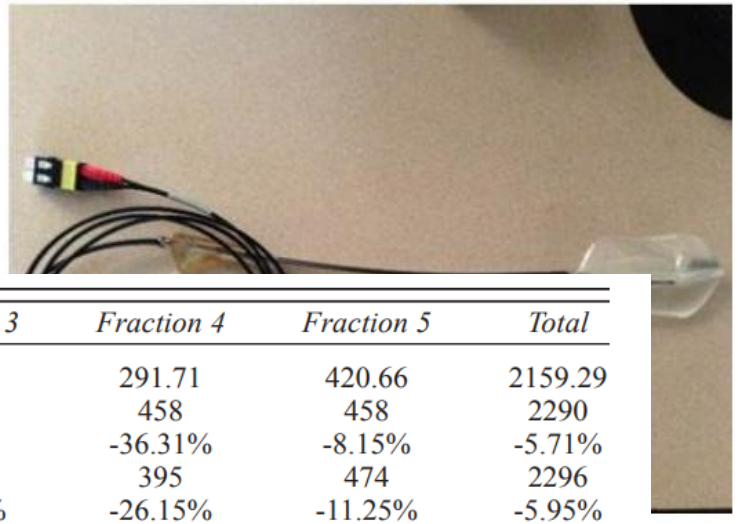
Pre-treatment QA



In vivo Dosimetry







	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%

MOSk SBRT

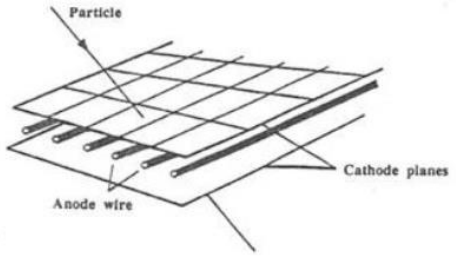
Plastic Scintillator Cantley et al. 2016 Intracavitary OAR dose 1 VMAT - SBRT

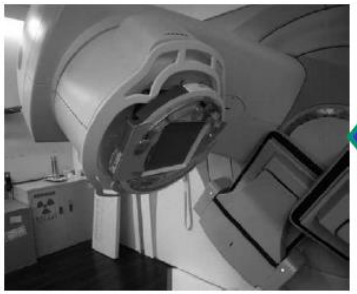
	Fraction 1	*Fraction 2*	*Fraction 3*	*Fraction 4*	*Fraction 5*
DTA – Proximal Detector (mm)	4.5	5.0	2.5	3.5	2.0
DTA – Distal Detector (mm)	0.6	9.0	4.5	4.0	2.5

Journal of Applied Clinical Medical Physics, Vol. 17, No. 6, 2016

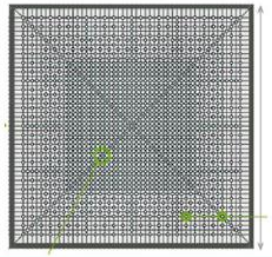
Transmission 2d dosimeters

Multi wire proportional chamber





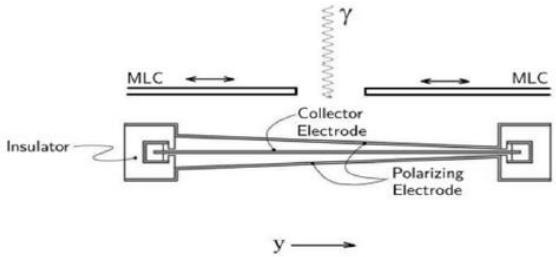
plane-parallel IC array



1513 IC
3d dose
in planning CT

Comparison of
80 channel signal
respect to QA

One large area ionization chamber
with a gradient in the electrode plate separation

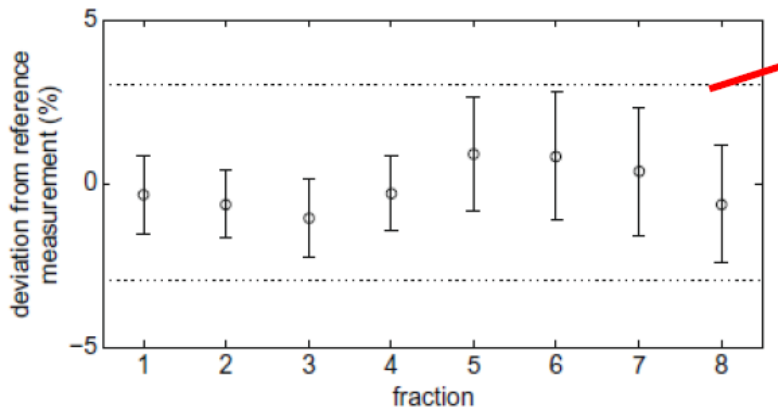


Single IC
Segment-by-Segment
Signal comparisons in
real time.

- Transmission QA systems place an array of detectors between the collimated beam and patient
- They allow intra-fraction measurement of machine parameters during treatment
- A tray factor should be considered in TPS

Transmission 2d dosimeters- Clinical results

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



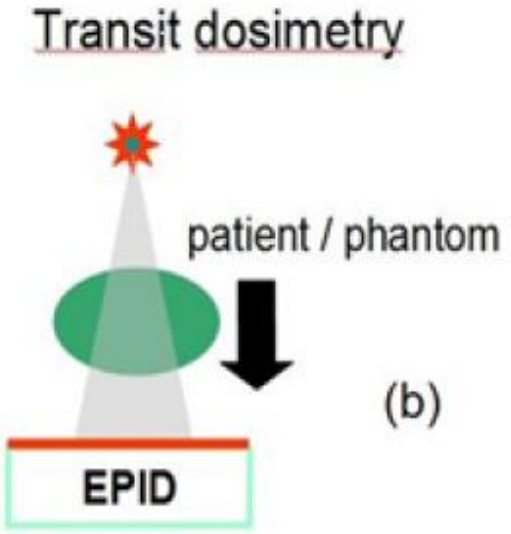
2 case exceeded 3%

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

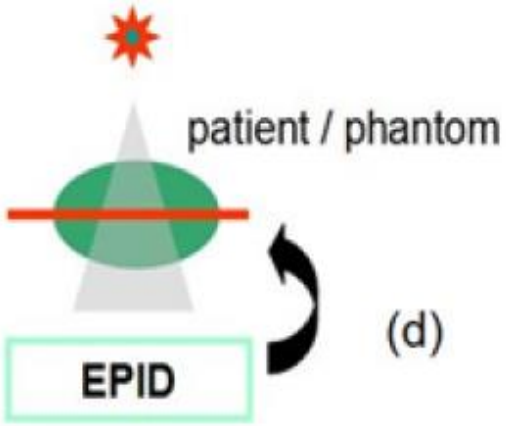
Projection algorithm



Exit fluence projected on EPID

Comparison predicted signal vs actual signal

Backprojection algorithm



EPID signal Backprojected on patient CT

Comparison TPS e measured dose

B Mijnheer IOP Conf. Series: Journal of Physics: Conf. Series **847** (2017) 012024

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

* Commercial system

§ Real time systems

In phantom accuracy

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

* Independent measure

§ Real time system

Clinical results EPID (1)

Antoni van Leeuwenhoek Hospital, Amsterdam: van Elmpt el al 2007
15076 plans between 2012 e il 2014: 30% out of tolerance
1/407 plans contained clinically significant errors

Table 1 Current clinical alert criteria for the dose difference at the DRP and for the 3D γ evaluation (3%/3 mm) within the 50% isodose surface

Treatment site	DRP dose difference (%)	Mean γ	γ pass rate (%)	1% γ
Most	3.0	0.5	85	2.0
Head and neck/rectum/gynecology	4.0	0.7	80	2.5
Breast	3.0	1.4	50	5.0

3D, 3-dimensional; DRP, dose reference point.

Error type	Count
TPS dose calculation VMAT	12
TPS dose calculation IMRT	2
Anatomy change	**14**
Patient positioning	**2**
Suboptimal setup verification protocol	**1**
Imperfect bolus material placement	**1**
TPS: density override on contrast forgotten	**1**
Problem with 4D CT	**1**
Plan transfer error	**1**
Total	35

B. Mijnheer et al. Pract Rad Onc (2015)

Table 3 Number of plans verified in 2013 by means of 3D transit dosimetry and the classification of the alerted plans

Treatment site	No. of verified plans	No. of alerted plans	% alerted plans	Unknown	External	Patient	Model
Bone metastasis	991	100	10	20	44	24	30
Brain:							
Total	268	87	32	21	12	1	62
Hypofractionated	131	32	27	12	0	0	24
Conventional fractionation	137	55	47	9	12	1	38
Breast (including thoracic wall)	1188	442	37	15	226	217	386
Gastroenterology (excluding rectum and esophagus)	73	17	23	2	4	11	2
Gynecology	121	32	26		11	13	12
Head and neck	437	183	42	29	98	57	53
Lung:							
Total	570	203	36	35	2	112	71
Hypofractionated	160	58	36	10	0	31	17
Conventional fractionation	410	145	35	25	2	81	54
Lymphoma	103	29	28	5	6	12	17
Esophagus	69	25	36	5	0	17	6
Other	355	88	25	13	17	41	32
Prostate	379	99	26	16	51	39	9
Rectum:							
Total	180	31	17	4	3	11	16
Hypofractionated	96	17	19	2	2	6	9
Conventional fractionation	84	14	15	2	1	5	7
Sarcoma	51	29	57	5	10	11	12
Urology (excluding prostate)	94	23	24	1	5	13	7
Total	4879	1388	28	171	489	579	715

Clinical results EPID (2)

Cancer Care Manitoba: Mc Cowan el al 2017 117 SBRT patients.

Tolerance level =85% PTV (D>20% Prescription Dose)
Gamma (3%G/3mm)<1

After EPID acquisition optimization out of tolerance cases decreased from 22% to 8%

Table 2 Flagged alert level results for group 2 of the lung SBRT patients

Patient number	Identified error description for flagged Fx	Flagged Fx count	Total Fx	Flagged Fx	Lost Fx (EPID)	% Flagged Fx's
49	Fx1 (immob, roll, & trans)	1	284	20	34	8.0%
51	Fx3 (immob)	1				
52	Fx1 (roll), Fx2 (pitch & trans)	2				
54	Fx1 (roll), Fx2 (roll), Fx3 (roll)	3				
56	All − algorithmic	8				
65	Fx4 (trans), Fx5 (immob), Fx6 (immob), Fx7 (roll)	1				
88	Fx3 (roll), Fx4 (roll)	2				
89	Fx3, Fx4 (near diaphragm)	2				

Abbreviations as in Table 1.

Clinical results EPID (3)

Working group of AIFM about EPID in vivo dosimetry

Multicentric evaluation:
1) Systems used
2) Test evaluated
3) Tolerance levels set
4) Number of patients evaluated
5) Number of test out of tolerance
6) Identification of errors

Up to now 7 centers (3 commercial systems) 12000 evaluations about 2000 patients

Dosimetry Check USL Firenze VMAT SBRT & VMAT

Test ΔCTV mean dose, Tolerance 5%. All the Tests were carried out using optimized patient setup (CBCT)

Technique	Anatomical site	P	T	T/P	T out of tolerance	T% out of tolerance	T (and T%) Incorrect set up	T (and T%) Device Immobilization	T (and T%) incorrect computation	T (and T%) Anatomical variations	T (and T%) unknown causes
VMAT SBRT	Abdomen / pelvis	50	83	1.7	20	24%	5 (6%)	4 (5%)			11 (13%)
VMAT SBRT	lung	31	139	4.5	17	12%	7 (5%)		2 (1%)		8 (6%)
VMAT	Head and Neck	23	100	4.3	14	14%		5 (5%)		9 (9%)	
TOTAL		**104**	**322**	**3.1**	**51**	**17%**	**4%**	**3%**	**1%**	**3%**	**6%**

DOSIMETRY CHECK was also used in the center of PIACENZA for 77 PATIENTS WITH 94 TESTS. THE RESULTS WERE CONSISTENT WITH THOSE OF FIRENZE.

Per Fraction Candiolo Torino VMAT

Test ΔPTV mean dose, Tolerance 3%. All the Tests were carried out using optimized patient setup (CBCT)

Technique	Anatomical site	P	T	T/P	T out of tolerance	T% out of tolerance	T (and T%) Incorrect set up	T (and T%) Device Immobilization	T (and T%) Machine depending	T (and T%) Anatomical variations	T (and T%) unknown causes
VMAT	Prostate	16	159	9.9	22	14%	6 (4%)			16 (10%)	
VMAT	Abdomen /pelvis	8	74	9.3	9	12%	3 (4%)				6 (8%)
VMAT	Lung+ mediast.	10	54	5.4	25	46%	6 (11%)			19 (35%)	
VMAT	Breast	9	46	5.1	5	11%	5 (11%)				
VMAT	Head and Neck	5	49	9.8	8	16%	8 (16%)				
VMAT	Brain	3	35	11.7	0	0%					
VMAT	Palliative	25	135	5.4	8	6%				1 (1%)	7 (5%)
TOTAL		**76**	**552**	**7.3**	**77**	**14%**	**5%**			**7%**	**2%**

IN CONCLUSION DOSIMETRY CHECK IN ITALY WAS APPLIED ON: **181 PATIENTS WITH 416 TESTS**

AND PER FRACTION WAS APPLIED ON: **76 PATIENTS WITH 552 TESTS**

SOFTDISO USED AT ROME FOR 823 PATIENTS WITH 11357 TESTS, OBTAINED BY 3 LINACS. 9 PATIENTS/DAY/LINAC THE WORKLOAD WAS 35MIN/DAY/LINAC

SOFTDISO was also used in the center of CHIETI, CHENGDU (CINA), CAMPOBASSO, FOR 523 PATIENTS WITH 11.146 TESTS, OBTAINING RESULTS SIMILAR TO ROME

IN TOTAL IN THE LAST YEARS SOFTDISO WAS USED FOR : **1612 PATIENT WITH 23471 TESTS**

SOFTDISO Gemelli Roma VMAT

Warning message if at least one off tolerance of: R (Diso), γ%, γmean indexes. All the Tests were carried out using optimized patient setup (CBCT or VPI / DRR)

Anatomical site and tolerance	P	T (per beam)	~T/P	T out of tolerance	T% out of tolerance	T (and T%) Incorrect set up	T (and T%) Device Immobilization	T (and T%) incorrect computation	T (and T%) Anatomical variations	T (and T%) unknown causes
Breast (5%, 5mm)	7	118	17	14	12%	10 (8%)	4 (3%)			
Torax (5%, 5mm)	37	474	13	43	9%	23 (5%)	20 (4%)			
Abdomen (5%, 5mm)	65	875	13	70	8%	41 (5%)	20 (2%)		9 (1%)	
Pelvis (5%, 5mm)	263	3855	15	231	6%	190 (5%)	41 (1%)			
H&N (3%, 3mm)	80	1462	18	44	3%	32 (2%)	12 (1%)			
Brain (3%, 3mm)	31	451	15	9	2%	7 (2%)	2 (0%)			
TOTAL	**483**	**7235**	**15**	**411**	**5.7%**	**4.2%**	**1.4%**		**0.1%**	

After the corrections, triggered by at list one index out tolerance (R > 5%, γ% <90% and γmean >0.4),
the mean indexes for single patient were within the tolerance level: R within 5%, γ% ≥ 90%, γmean< 0.4

SOFTDISO Gemelli Roma 3DCRT

Warning message if at least one off tolerance of: R (Diso), γ%, γmean indexes. All the Tests were carried out using optimized patient setup (VPI / DRR)

Anatomical site and tolerance	P	T (per beam)	~T/P	T out of tolerance	T% out of tolerance	T (and T%) Incorrect set up	T (and T%) Device Immobilization	T (and T%) incorrect computation	T (and T%) Anatomical variations	T (and T%) unknown causes
Breast (5%, 5mm)	198	1718	9	378	22%	210 (12%)	168 (10%)			
Torax (5%, 5mm)	27	505	19	96	19%	56 (11%)	20 (4%)		20 (4%)	
Abdomen (5%, 5mm)	33	579	18	139	24%	84 (15%)	40 (7%)		15 (3%)	
Pelvis (5%, 5mm)	21	511	24	128	25%	101 (20%)	13 (3%)		14 (3%)	
H&N (3%, 3mm)	16	212	13	40	19%	15 (7%)	25 (12%)			
Brain (3%, 3mm)	45	597	13	101	17%	80 (13%)	21 (4%)			
TOTAL	**340**	**4122**	**12.1**	**882**	**21%**	**13%**	**7%**		**1%**	

After the corrections triggered by at list one index out tolerance (R > 5%, γ% <90% and γmean >0.4)
the mean indexes for single patient were within the tolerance level: R within 5%, γ% ≥ 90%, γmean< 0.4

Dose reconstruction methods

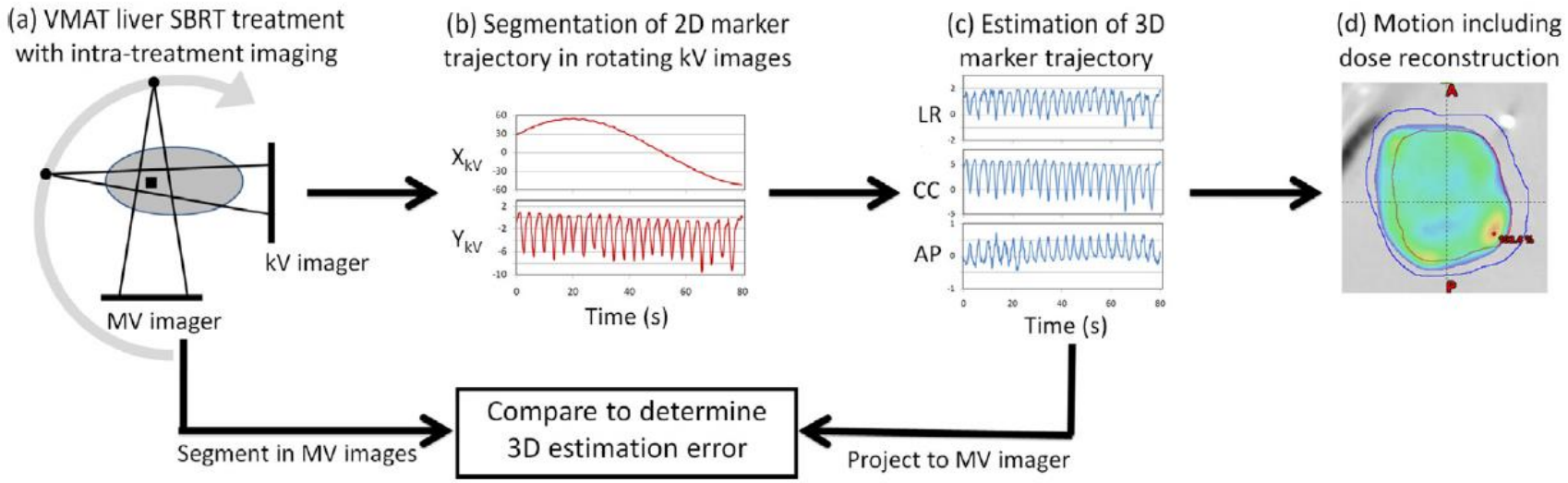
A family of computation methods that allows reconstruction of dose inside planning CT

Using information from:

Linac logfiles, CBCT, online imaging, external tracking systems, EPID.

- Evaluate effect of intra-fraction movements
- Suitable for measuring the tracking accuracy in real time

Dose reconstruction methods



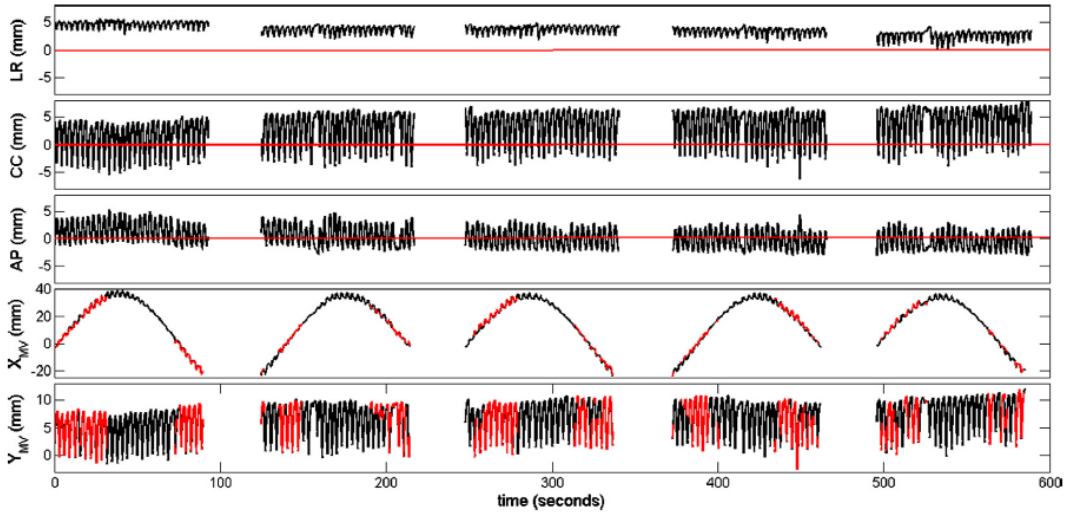
Dose was reconstructed by modeling the motion of a rigid target as multiple isocenter shifts with TPS

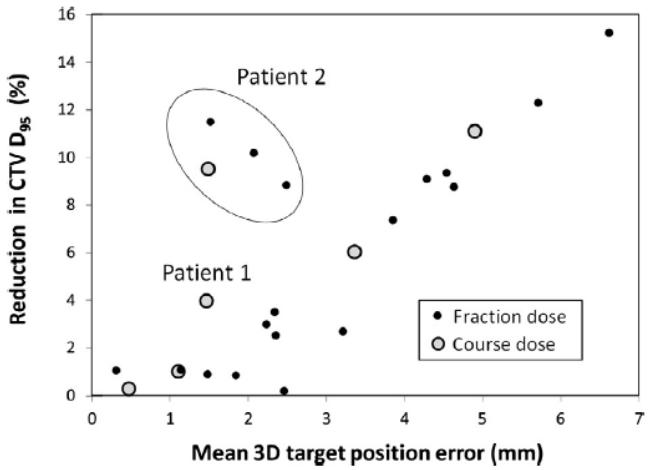
Poulsen et al Radiotherapy and Oncology 111 (2014) 424–430

Dose reconstruction methods

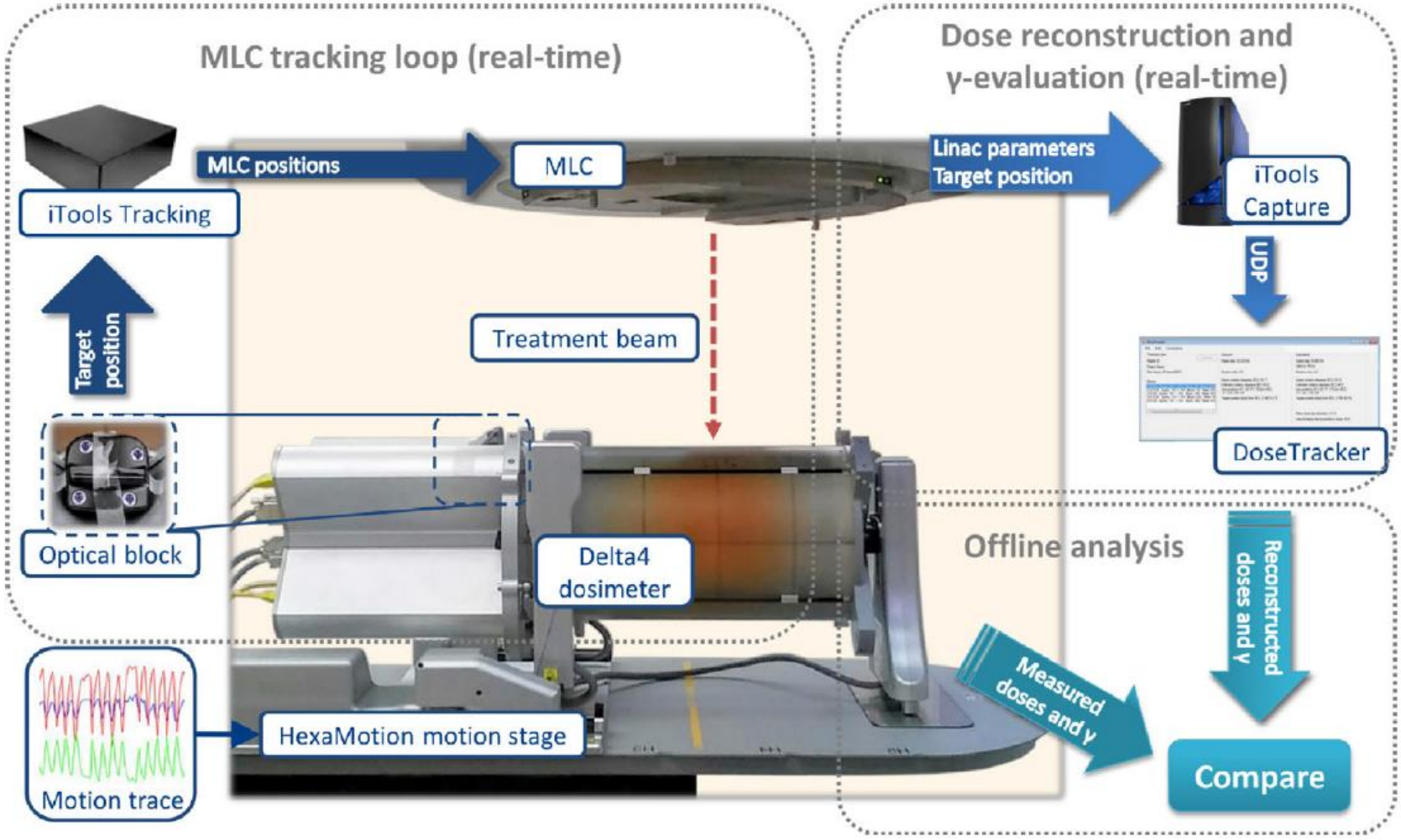
Liver VMAT SBRT, 6 patients, 18 fractions

Pt	Motion range (mm)		Magnitude of error (mm)	MV images		KIM rmse in MV images (mm)		KIM rmse (mm)	CTV ΔD_{95} (%)	CTV ΔD_{mean} (%)
	Total LR/CC/AP	Baseline LR/CC/AP	LR/CC/AP	Total	% with marker	Parallel to kV mean [max]	Perpendicular to kV mean [max]			
1	3.7/12.7/2.4	0.8/1.1/0.4	1.0/3.0/1.3	2958	23	0.43 [0.50]	0.41 [0.49]	0.28	4.0	1.6
2	2.9/27.1/8.2	0.6/2.1/0.8	1.3/1.0/0.7	4586	3	0.41 [0.61]	0.41 [0.60]	0.28	9.5	5.4
3	5.4/8.8/5.2	1.9/1.1/1.0	1.3/0.6/0.4	3143	32	0.30 [0.35]	0.38 [0.40]	0.38	0.3	0.8
4	5.6/21.1/8.7	0.5/1.5/0.7	0.5/3.0/1.5	–	–	–	–	0.33	6.0	2.2
5	4.7/12.1/7.7	1.2/1.5/1.0	3.1/3.4/1.8	3355	40	0.30 [0.48]	0.67 [0.81]	0.42	11.1	3.0
6	6.2/15.6/6.5	0.5/1.4/0.7	1.1/0.8/1.1	–	–	–	–	0.36	1.0	0.2
All	4.8/16.2/6.4	0.9/1.4/0.8	1.4/2.0/1.1	14042	22	0.36 [0.61]	0.47 [0.81]	0.34	5.3	2.2



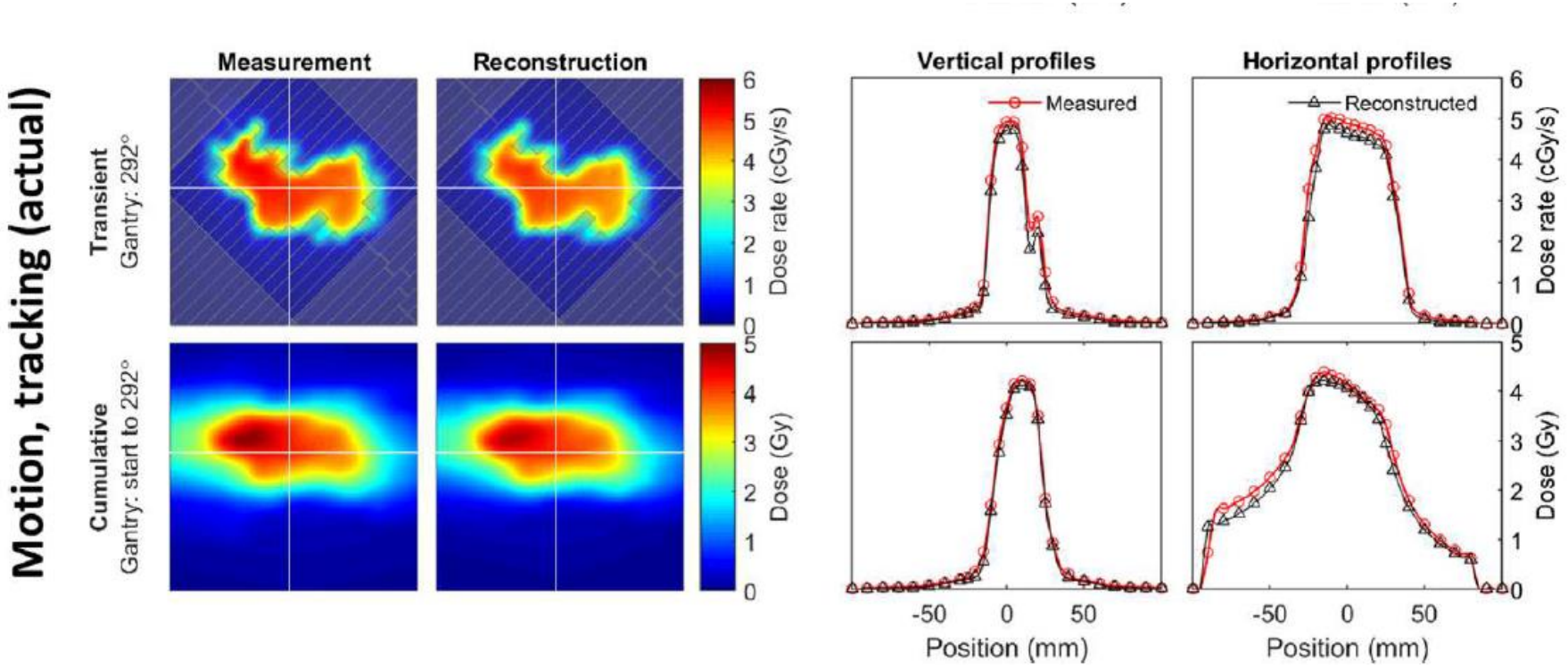


Dose reconstruction methods (online)



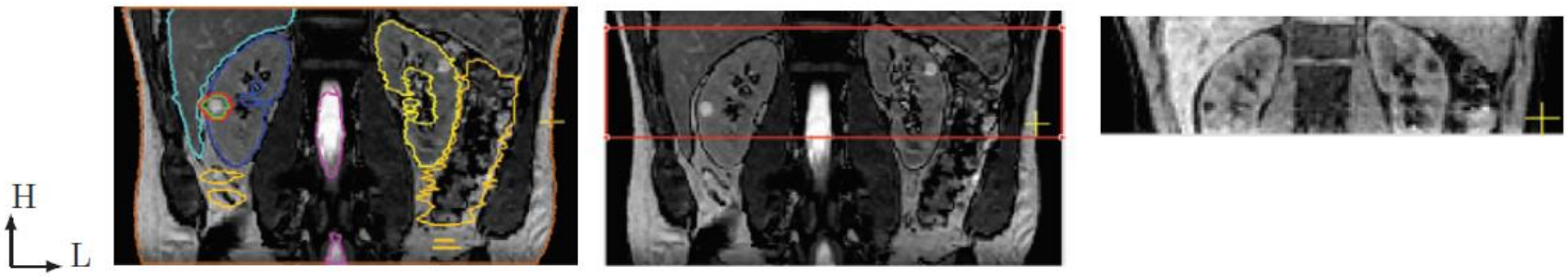
Ravkilde et al. Med. Phys. 45 (8), August 2018

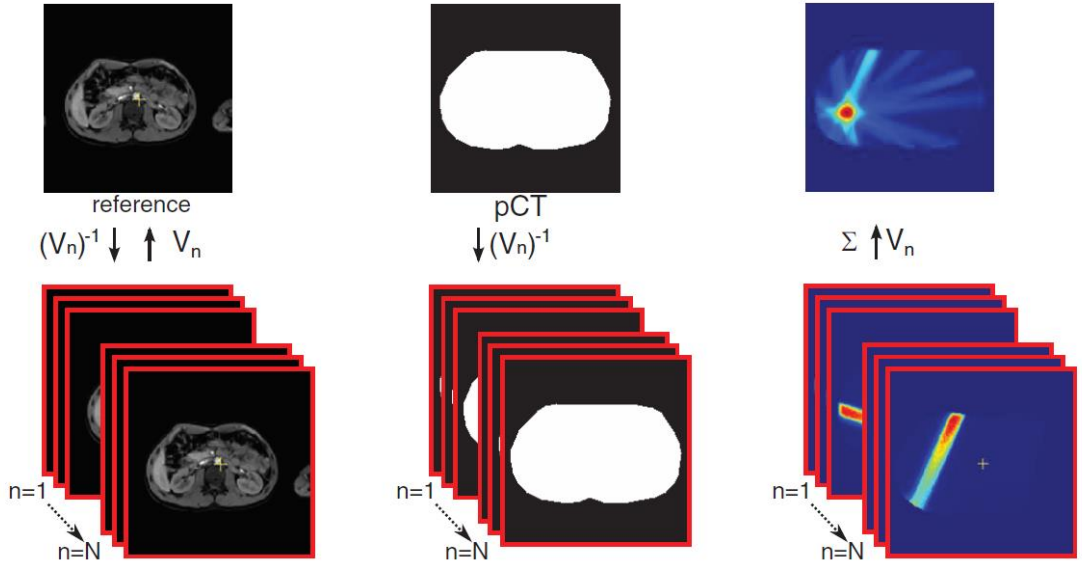
- Fast dose computation algorithm (accurate in homogeneous media)
- Takes in to account in real time the linac and target movements



Dose reconstruction methods

4d-MRI imaging. The treatment was simulated

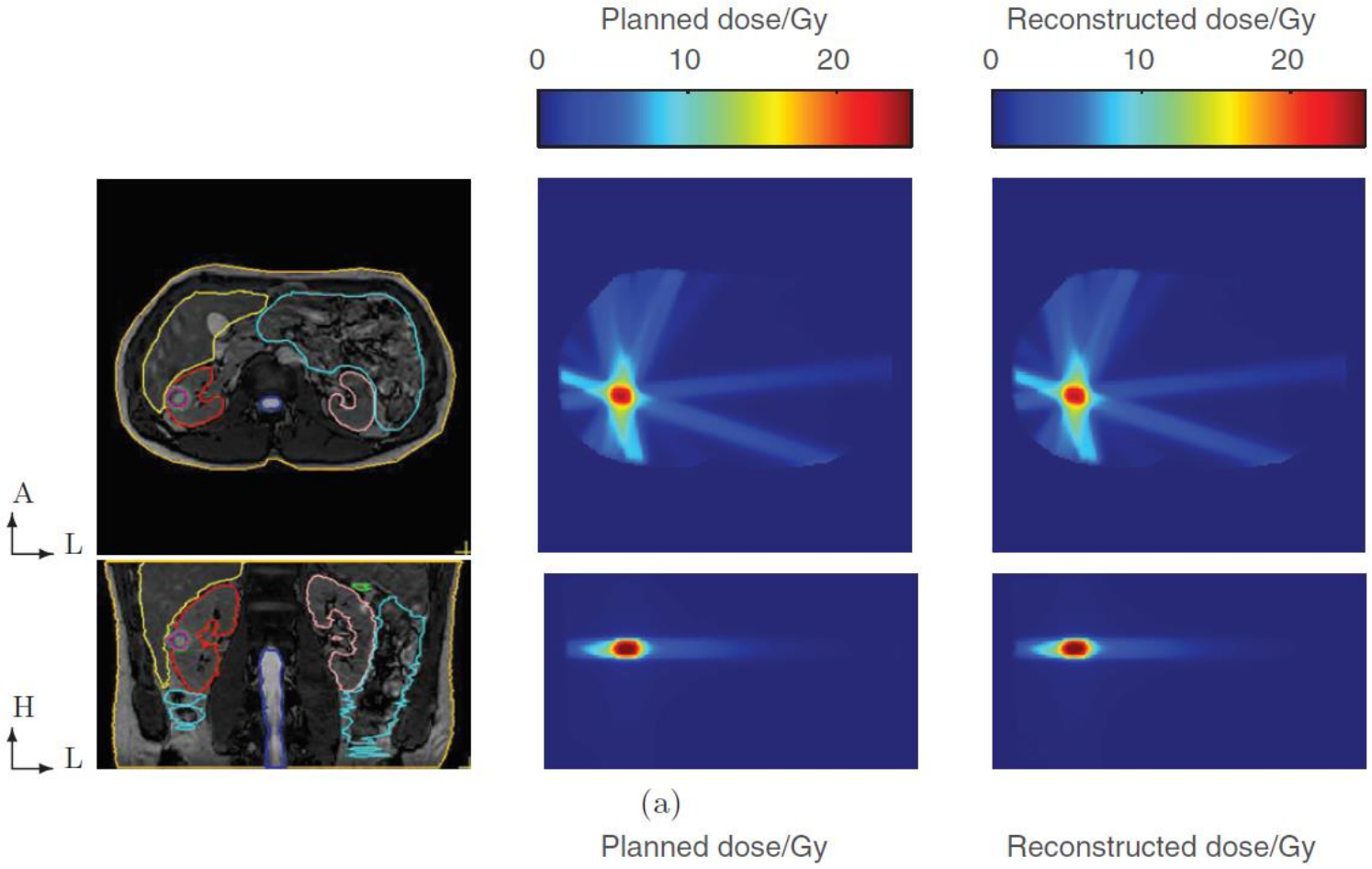




Each segment computed with Monte Carlo algorithm taking in to account linac parameters and volume position sampling 40 ms.

Dose was accumulated in a specific temporal phase using DVF

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



Each segment needs 15 second for computation at 5% variance

Take home messages (2)

- EPID in vivo dosimetry was proven able to intercept and correct clinically relevant errors
- Real time systems are under development and are ready for clinical use
- Dose reconstruction methods can guide online tracking systems