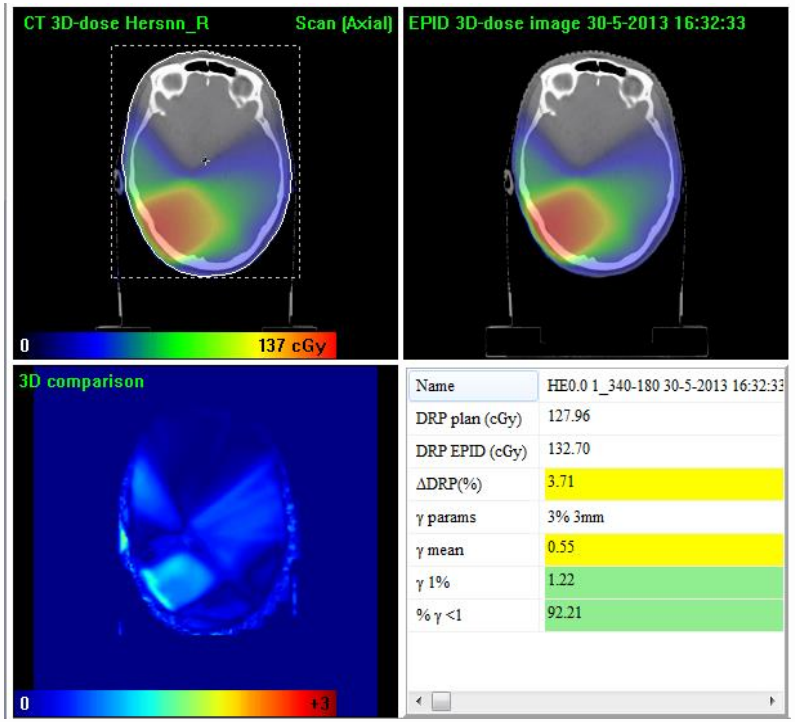
Pre-treatment and *in vivo* dose verification of IMRT and VMAT treatments using Elekta iViewDose



Igor Olaciregui-Ruiz

Elekta

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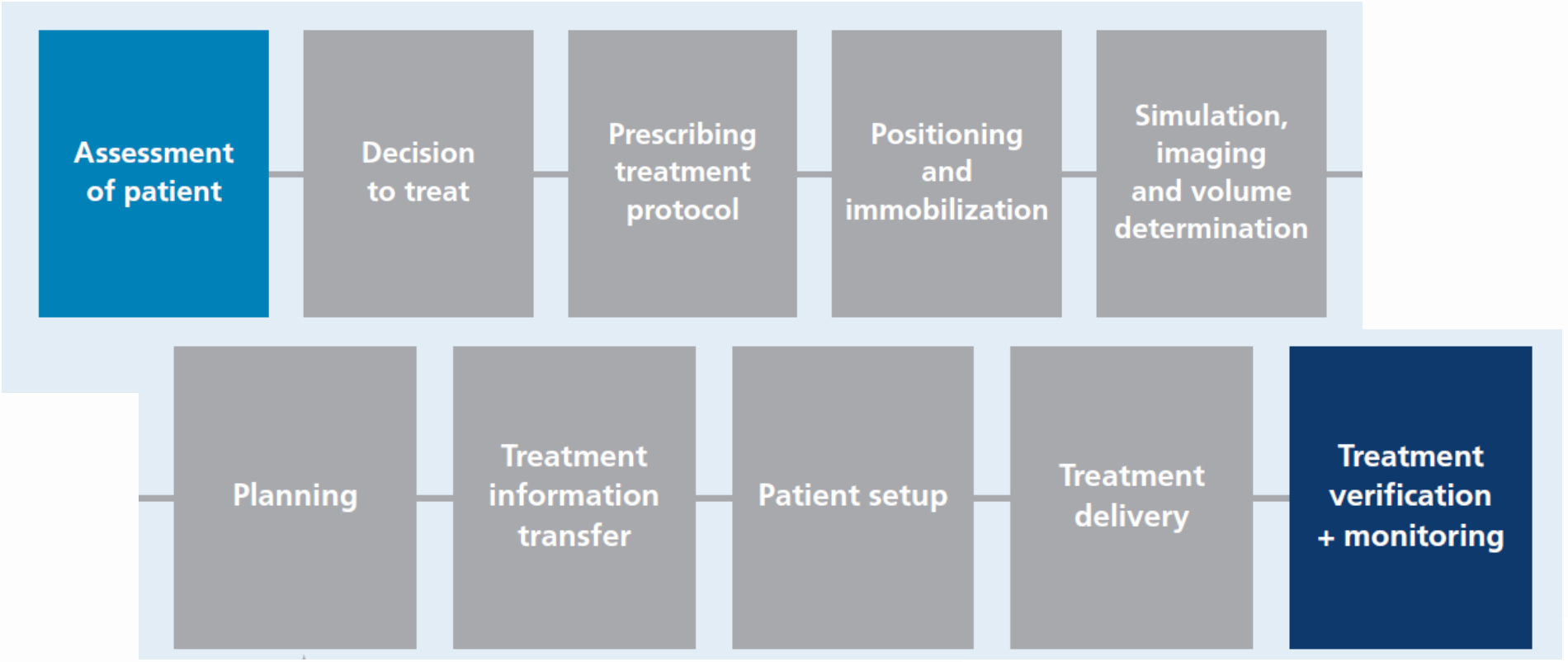
The Radiotherapy chain

Radiotherapy treatment is a multi-stage and complex process



Radiation safety protocols must take place at all stages

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Treatment verification

- End-to-end verification of the radiotherapy chain (as much as possible)
- Independent verification system (machine, TPS and patient/setup errors)
- Gross error detection (and most adverse events and near misses)
- Large scale clinical implementation: verify ALL treatments (~6.000 year)
- Minimal impact on the clinical radiotherapy workflow
- Optimal balance between sensitivity and specificity (no FPs, no FNs)
- Little extra workload

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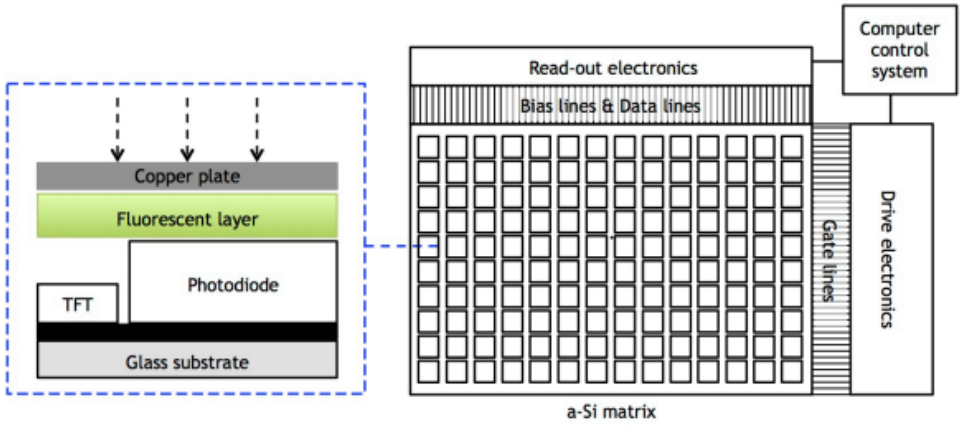
Treatment verification

Why EPID ☺



- The detector is already fixed to the linac
- High resolution 2D digital images
- Images contain dose information
- No additional clinical time (images acquired behind patient during treatment)
- 2D or 3D dose reconstruction
- Automation

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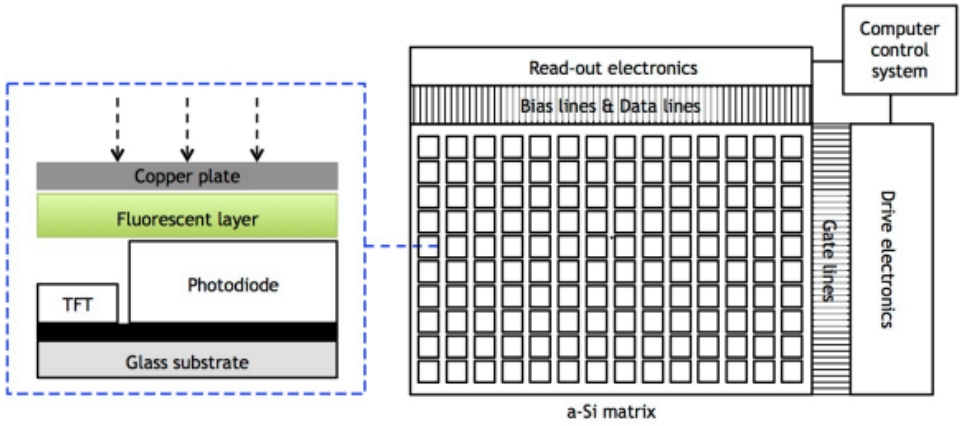
Treatment verification

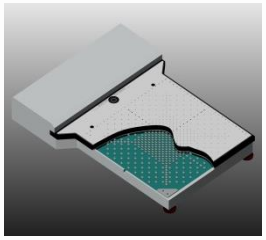
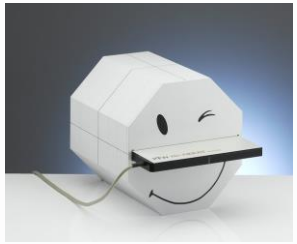
Why EPID ☹



- Pixel-to-pixel variations in response (±5%)
- Ghosting and lag
- Scatter within the EPID
- Energy-dependent response
- Acquisition software issues
- Patient scatter *f*(field size, patient thickness and distance to panel)
- Mechanical flex and EPID sag (shifts in image location as function of gantry angle)
- Inaccuracies in gantry angle readouts

Treatment verification

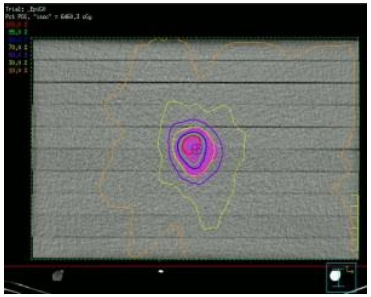
- With PT it is difficult to establish the relevance of the detected deviations


Even if 3D, dose is not reconstructed within the patient anatomy !

TPS patient

TPS phantom



double arc lung VMAT treatment

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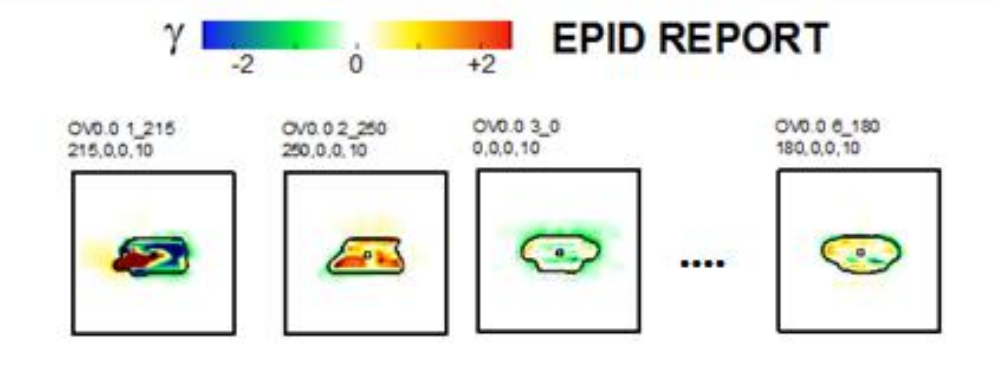
Treatment verification

- *In vivo* catches delivery errors due to machine errors or data transfer problems

Example:

- Error while importing RTP file of a 6-field IMRT plan in Mosaiq
- The 1st field was delivered with the MLC shape of the 2nd field (*in vivo* detected at 1st fraction)
- Technician typed by mistake a key-combination that copies MLCs across beams

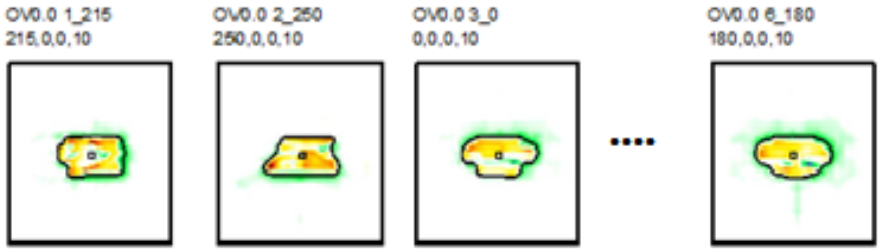
1st fraction



Action:

- Plan again imported in Mosaiq
- Extra phantom check before second fraction
- After analysis of dose impact in Pinnacle : no re-planning

2nd fraction



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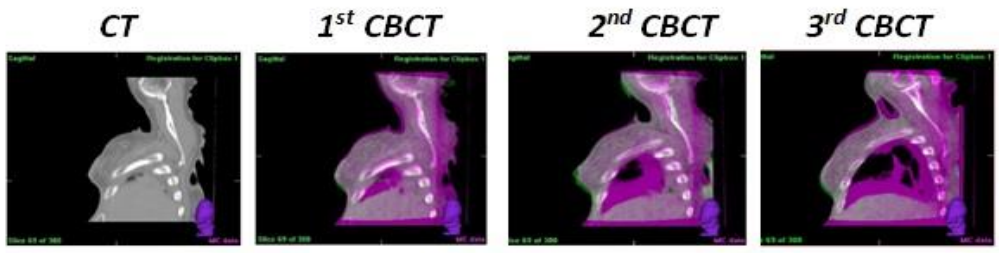
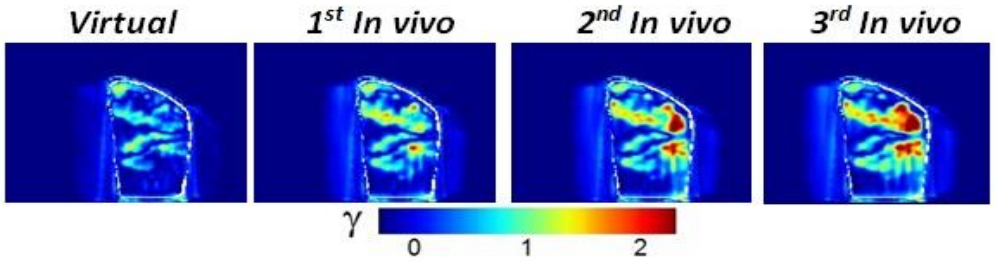
Treatment verification

- The actual delivered dose to the patient deviates from the planned dose due to anatomy changes or to setup errors





γ-mean	0.46	0.58	0.72	0.83
γ-max	1.44	1.76	2.41	2.71
γ-pass rate	92.7%	84.6%	75.4%	68.7%
%ΔISOC	0.2%	0.8%	1.4%	2.8%
$\%\Delta PTV_{D50}$	-0.4%	1.0%	2.0%	3.4%

7-field IMRT lung treatment which presented a strong case of decrease in atelectasis. The *in vivo* verification results worsen as the changes in lung density increase. After the result of the 3rd *in vivo* verification the radiation oncologist was consulted.

- Less workload and less machine time than PT !!

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Treatment verification

- Direct comparison between the reconstructed and the planned patient dose distributions (ala IGRT) providing clinical relevant feedback

- Alert criteria based on either γ-statistics or on deviations of DVH parameters
- Estimate the cumulative delivered dose over the entire treatment course
- Integration with adaptive radiotherapy approaches
- Medical/legal record of delivered patient dose.

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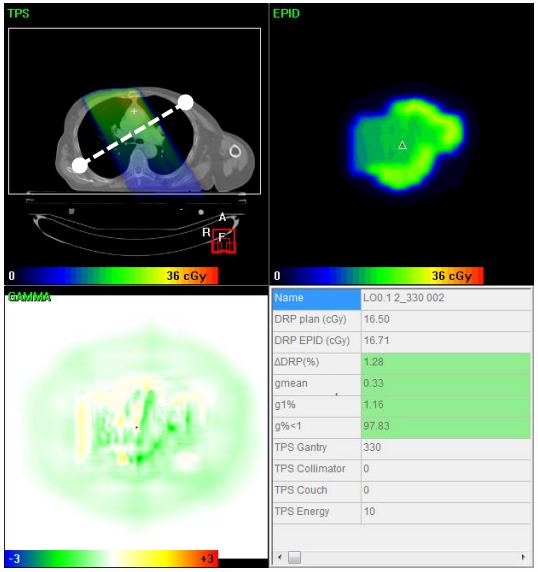
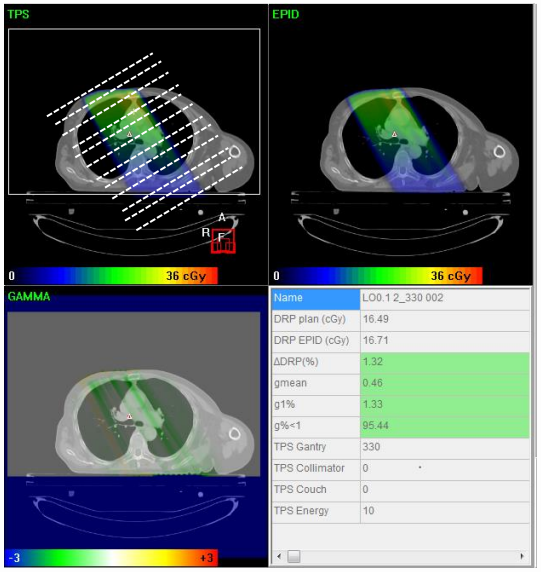
The iViewDose reconstruction algorithm IMRT/3DCRT

- iViewGT stores the total signal of all EPID frames between beam-on and beam-off into one accumulated single portal image
- iViewDose reconstructs
  - 2D beam dose distributions
  - 3D beam dose distributions (iteration multiple planes)
  - 3D fraction dose distributions (sum of beams)

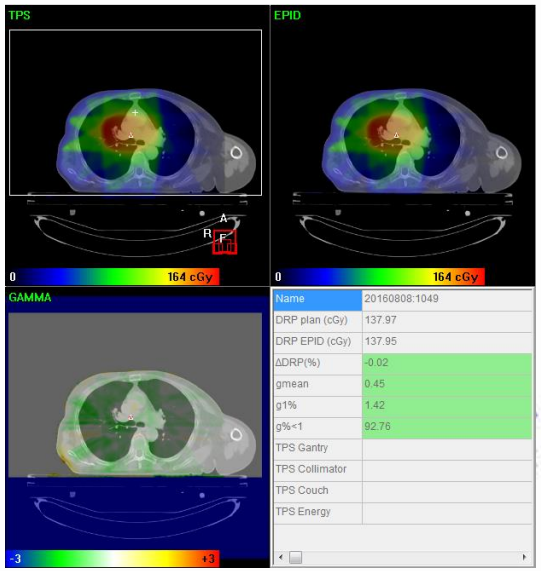
2D beam



3D beam



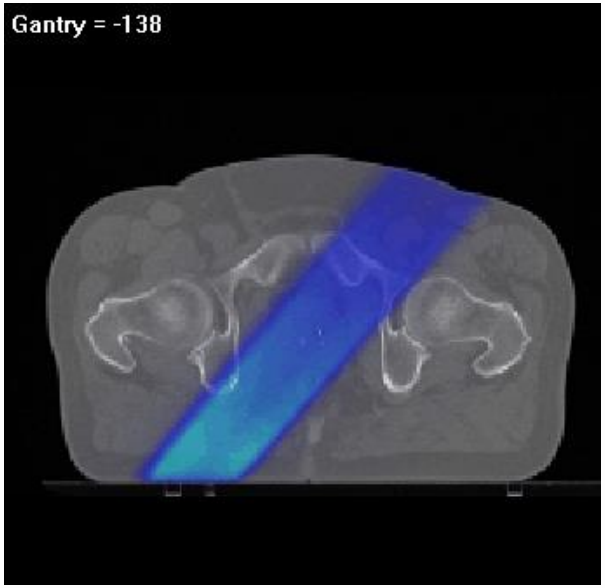
3D fraction



The iViewDose reconstruction algorithm

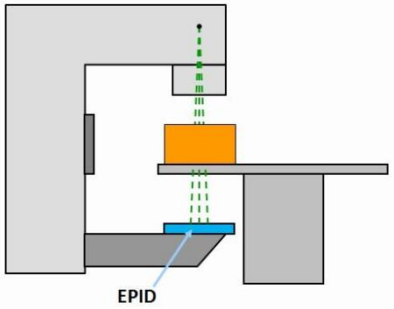
- iViewGT stores EPID frames separately
- iViewDose groups frames in bins (within a certain gantry range
- iViewDose reconstructs
  - 3D bin dose distributions
  - 3D arc dose distributions (sum of bins)
  - 3D fraction dose distributions (sum of arcs)

EPID acquisition movie



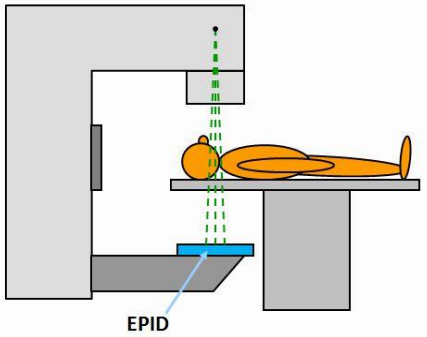
Dose per bin (2º)

Dose per arc



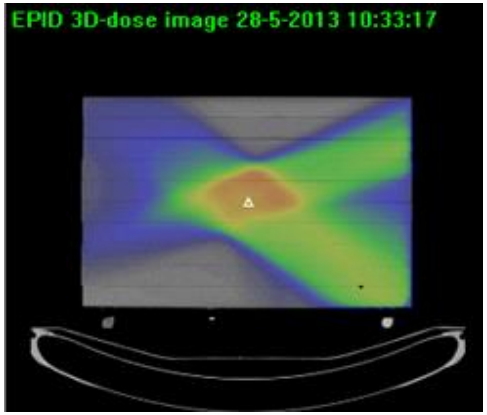
$Pr_{ij}^{EPID,phantom}$

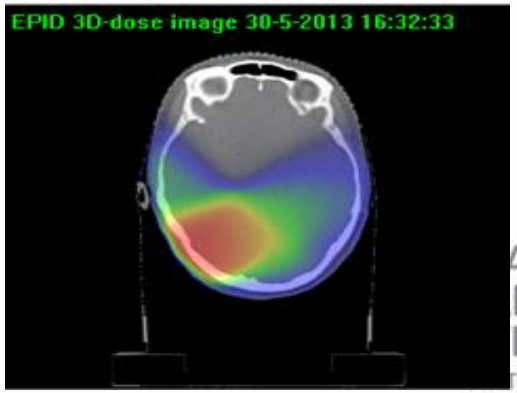
"real" dose delivered to the phantom



$Pr_{ij}^{EPID,in\ vivo}$

"real" dose delivered to the patient including patient-related errors.





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Pre-treatment vs *in vivo* dose verification (NKI-AVL)

- 3D EPID-based *in vivo* dosimetry
  - All IMRT, VMAT and 3D CRT (palliative) treatments
  - Conventional fraction dose: 3 fractions per patient
  - High fraction dose (SRS, SBRT, SABR): all fractions
  - Head-and-neck IMRT/VMAT: all fractions

- Pre-treatment verification (EPID and occasionally Octavius) 5%
  - New techniques (extensively)
  - Single fractions (SRS, SBRT, SABR)
  - Fields too large (avoiding damage electronics)
  - EPID would hit the couch during VMAT

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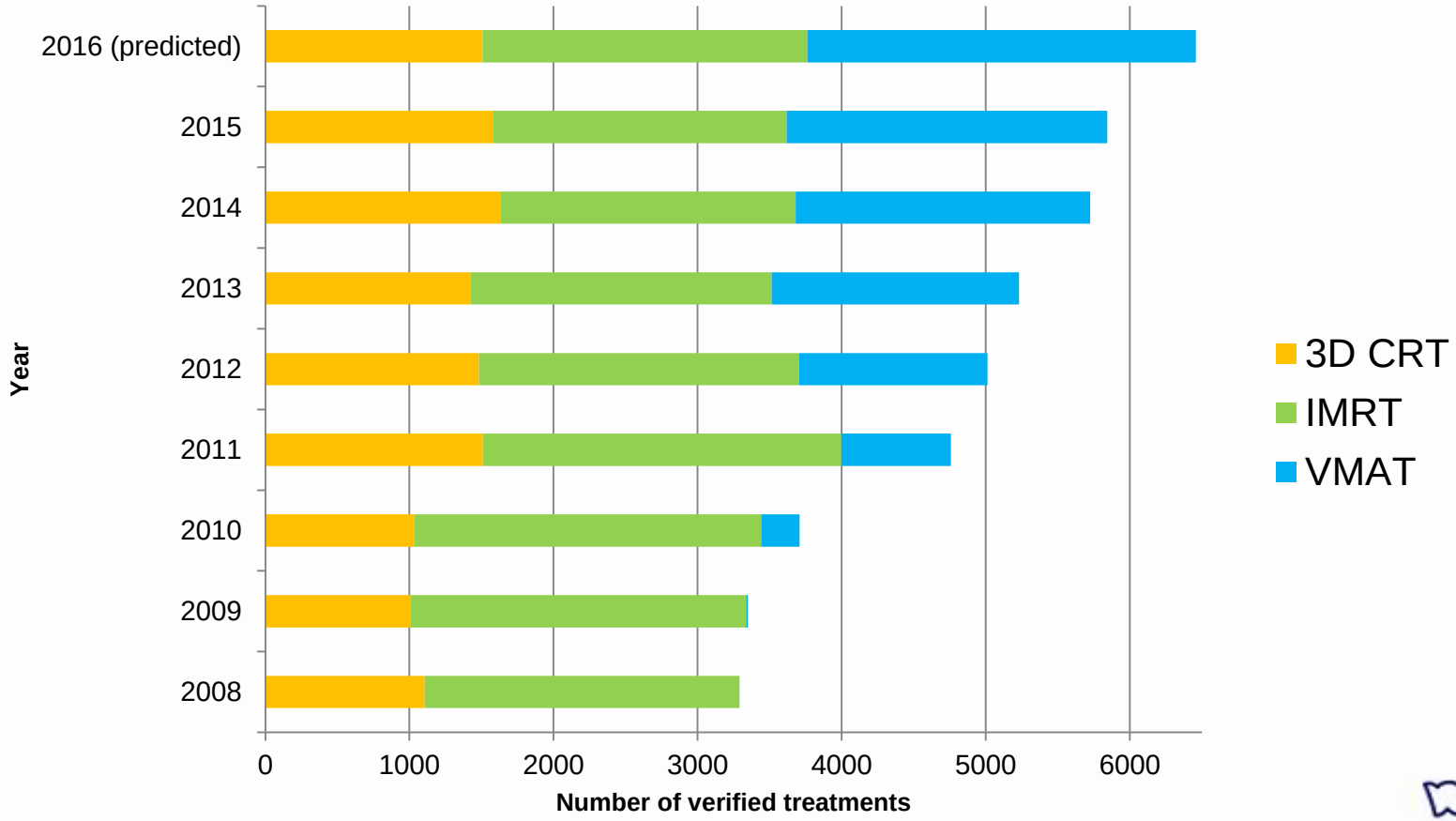
3D in vivo EPID dosimetry at NKI-AVL



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3D in vivo EPID dosimetry at NKI-AVL

Error and **warning** action level criteria

Site	γ-evaluation	γ-mean		γ1%		%γ<1		%ΔDRP *	
Default	3% / 3mm	**1.0**	**0.5**	**4.0**	**2.0**	**70**	**85**	**5**	**3**
H&N Boost	3% / 3mm	**1.5**	**0.7**	**6.0**	**2.5**	**60**	**80**	**7**	**4**
Rectum, H&N Gyneacology Stomach	3% / 3mm	**1.0**	**0.7**	**4.0**	**2.5**	**70**	**80**	**5**	**4**
Breast	3% / 3mm	**2.0**	**1.4**	**8.0**	**5.0**	**30**	**50**	**5**	**3**

* DRP = Dose Reference Point

* DVH deviation metrics (soon) using median dose D50, near-maximum dose D2 and near-minimum dose D98

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3D in vivo EPID dosimetry at NKI-AVL

B. J. Mijnheer, P. Gonzalez, I. Olaciregui-Ruiz, R. A. Rozendaal, M. van Herk, and A. Mans, "Overview of 3-year experience with large-scale electronic portal imaging device-based 3-dimensional transit dosimetry," *Pract. Radiat. Oncol.*, vol. 5, no. 6, pp. e679–e687, 2015.

Table 2 Number of alerted plans during 2012-2014

Treatment site	No. of verified plans	No. of alerted plans	% alerted plans
Bone metastasis	3224	378	12
Brain	787	289	37
Breast (including thoracic wall)	3649	1611	44
GE (excluding rectum and esophagus)	228	63	28
Gynecology	374	83	22
Head and neck	1282	555	43
Lung	1785	610	34
Lymphoma	268	78	29
Esophagus	247	92	37
Other	1034	298	29
Prostate	1178	344	29
Rectum	575	106	18
Sarcoma	192	101	53
Urology (excluding prostate)	253	81	32
Total	15,076	4689	31

% alerted plans ~ **30%** using **warning** action level
% alerted plans ~ **12%** using **error** action level
% alerted plans ~ **1%** using **~10%** action level

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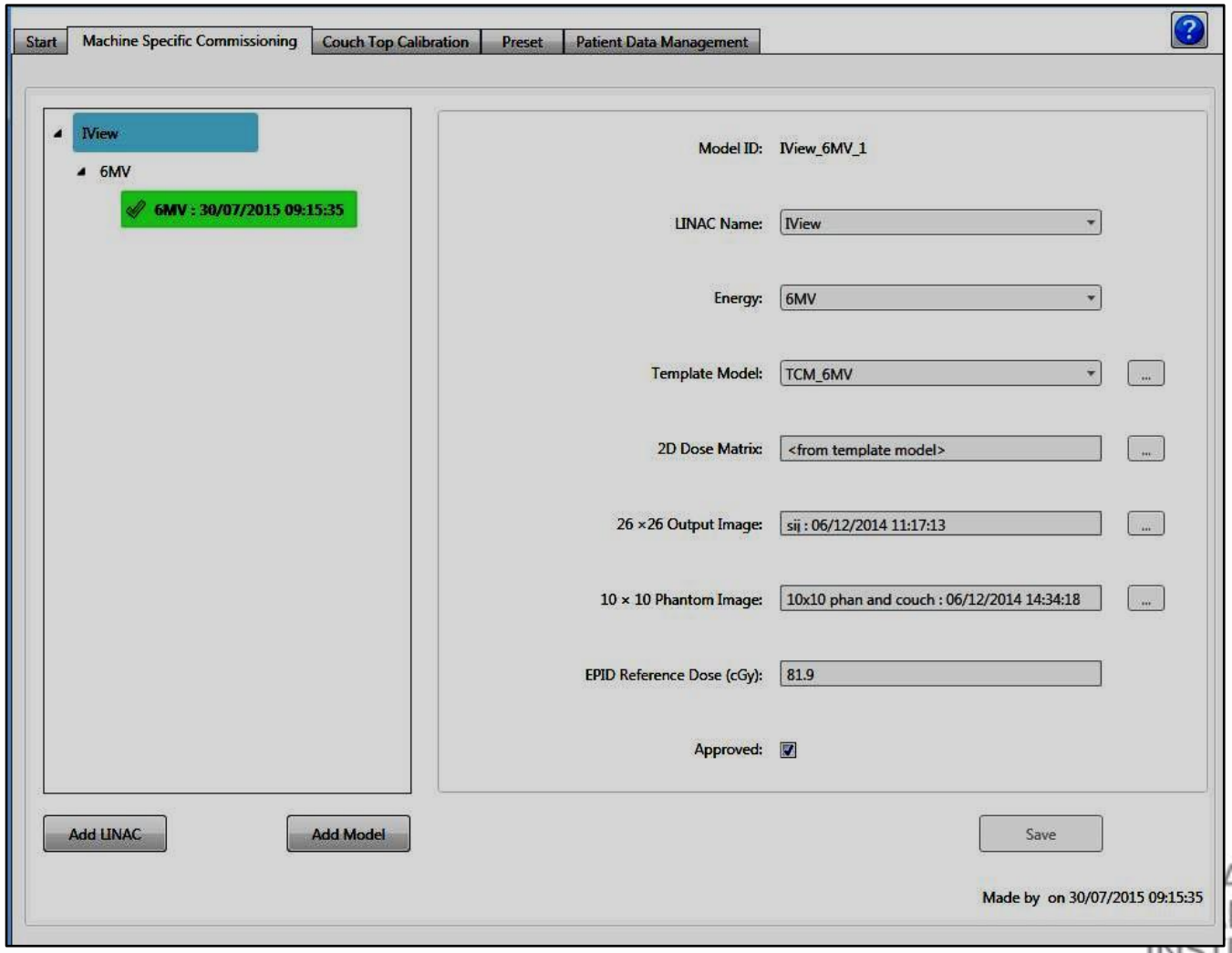
- Since 2011 a collaboration between NKI-AVL and Elekta
  - Shared development for the integration of AVL software in iViewDose
  - Physics: creation of Template Commissioning Models (TCM)
  - Product definition and requirements
  - Clinical workflows and support

- A portal dosimetry consortium:
  - Royal Marsden Hospital, London
  - St James's University, Leeds
  - University of Washington, Seattle
  - OUH, Odense
  - Champalimaud Foundation, Lissabon

  - Invaluable feedback
  - Test and measurements facilities



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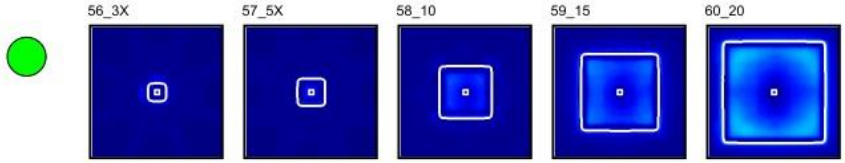
γ 0 1 2 3 **iViewDose Report**

Patient Name	PDQPhantoms, Octaviu,
Patient ID	F20141104x
Treatment Site	CAT20cm <570436>
Plan Name	
Preset	5cm
	Gamma 5.0%, 3.0mm, > 20% isodose [2D per Beam]
DRP	5cm_above
External	ext
In Aqua	No
Fields Ignored	None

No. Fields **Plan** 5 **EPID** 5

Fraction 10/03/2015 09:42 **Linac** 2609_iView **Couch** A3



Analysis Date 15/07/2015 18:20
No. Fields EPID 5

Model	A3 _10MVFFF_2	A3 _10MVFFF_2	A3 _10MVFFF_2	A3 _10MVFFF_2	A3 _10MVFFF_2
Field	56_3X	57_5X	58_10	59_15	60_20
Gantry (degrees)	0	0	0	0	0
Collimator (degrees)	0	0	0	0	0
Table (degrees)	1	1	1	1	1
Energy (MV)	10	10	10	10	10
Couch Factor (%)	2.6	2.6	2.6	2.6	2.6
Mean Gamma	0.17	0.18	0.27	0.37	0.48
Gamma 1%	0.37	0.40	0.52	0.64	0.85
Gamma Pass Rate	100.0	100.0	100.0	100.0	100.0
Planned Dose (cGy)	132.2	130.9	128.3	126.9	125.3
Epid Dose (cGy)	130.5	130.1	128.4	127.5	127.2
Gamma	0.26	0.13	0.02	0.09	0.30

γ 0 1 2 3 **iViewDose Report**

Patient Name	ZZAPelvis, Octavius,
Patient ID	F141105M
Treatment Site	Pros <855608>
Plan Name	1
Preset	DEFAULT
	Gamma 3.0%, 3.0mm, > 50% isodose [3D per Fraction]
DRP	isocentre
External	ext
In Aqua	No
Fields Ignored	None

No. Fields **Plan** 4 **EPID** 4

Fraction 10/03/2015 10:52 **Linac** 2609_iView **Couch** A3

Pros <855608>

Analysis Date 15/07/2015 18:33
No. Fields EPID 4

Planned Dose (cGy)	EPID Dose (cGy)	Gamma	Dose Difference
223.8	227.6	0.56	1.7%

Model	A3_10MVFFF_2
Gamma Mean	0.23
Gamma 1%	0.53
Gamma Pass Rate	100.0

γ 0 1 2 3 **iViewDose Report**

Patient Name	ZZAHandN, Octavius,
Patient ID	F141105L
Treatment Site	Mondb_10 <171234>
Plan Name	
Preset	DEFAULT
	Gamma 3.0%, 3.0mm, > 50% isodose [3D per Fraction]
DRP	isocentre
External	ext_1
In Aqua	No
Fields Ignored	None

No. Fields **Plan** 1 **EPID** 1

Fraction 10/03/2015 10:22 **Linac** 2609_iView **Couch** A3

Mondb_10 <171234>

Analysis Date 15/07/2015 17:44
No. Fields EPID 1

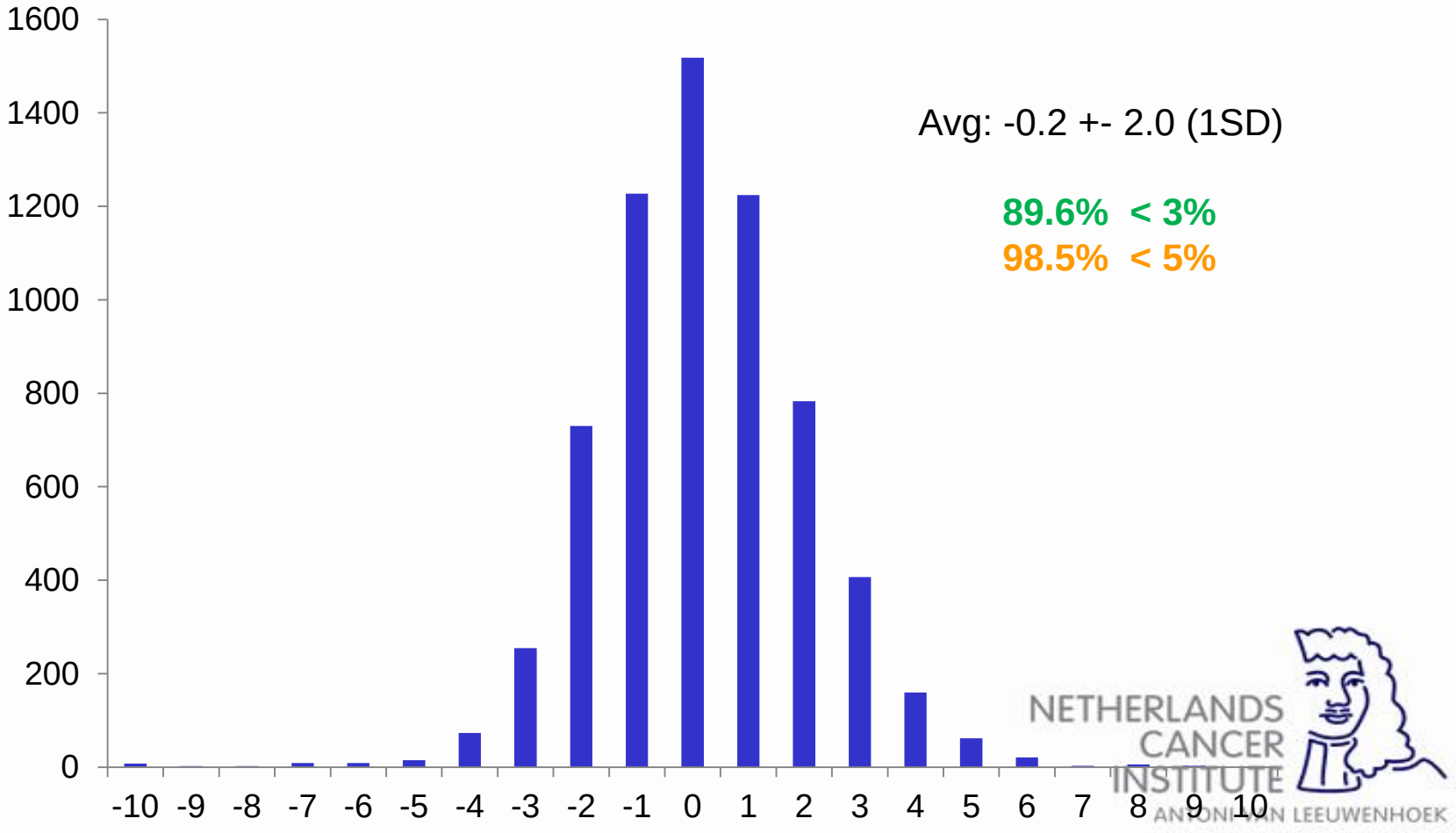
Planned Dose (cGy)	EPID Dose (cGy)	Gamma	Dose Difference
328.6	324.8	0.35	-1.1%

Model	A3_10MV_2
Gamma Mean	0.40
Gamma 1%	0.94
Gamma Pass Rate	99.4

The ROYAL MARSDEN NHS Foundation Trust

6530 treatments (+10 sites)

IMRT *in vivo* results



Avg: -0.2 +- 2.0 (1SD)

89.6% < 3%
98.5% < 5%

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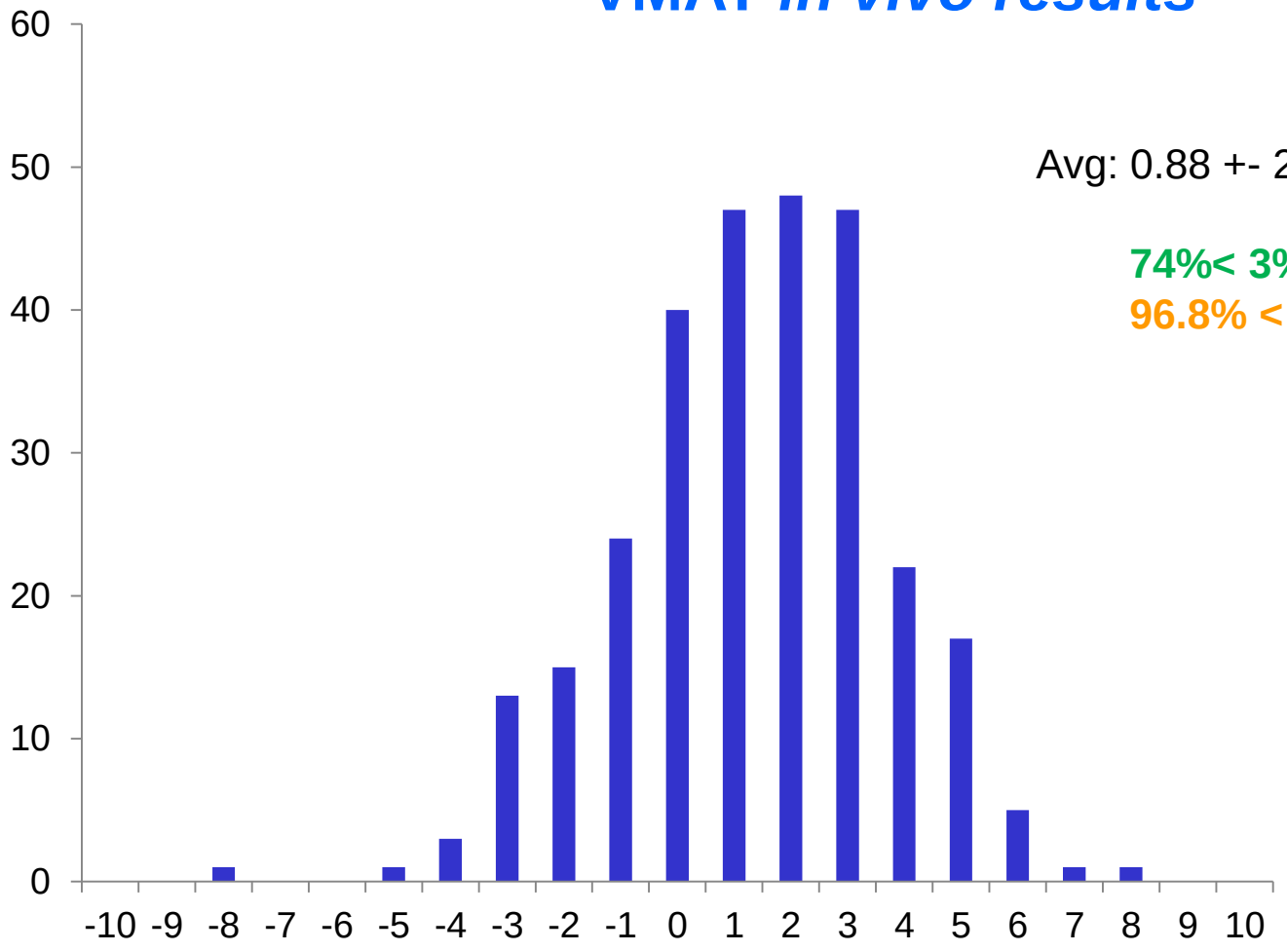
The ROYAL MARSDEN NHS Foundation Trust

285 treatments (+10 sites)

VMAT *in vivo results*



Avg: 0.88 +- 2.35 (1SD)

74%< 3%

96.8% < 5%

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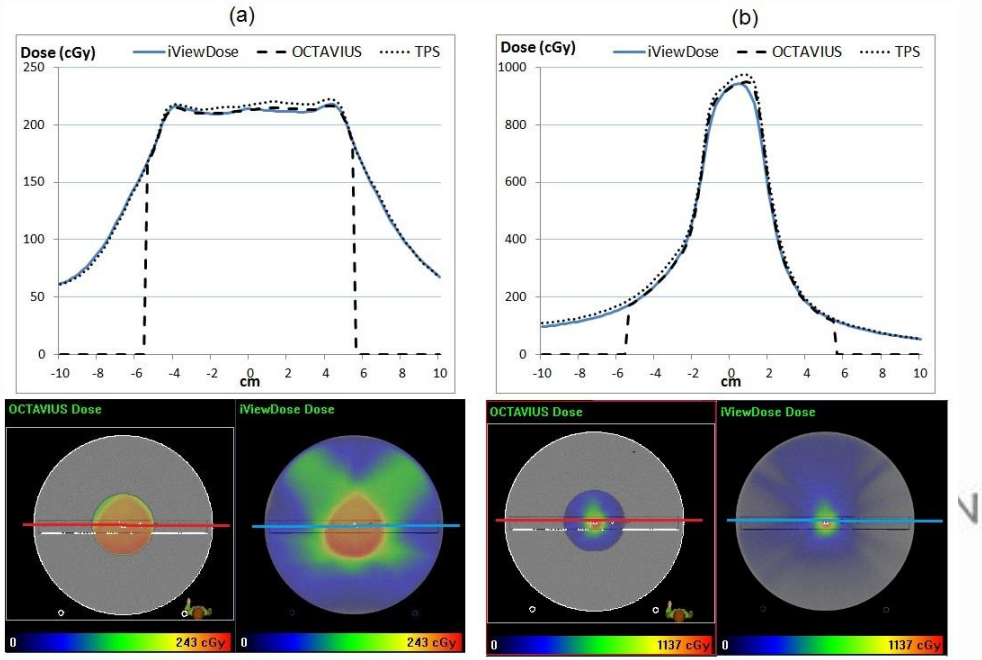
iViewDose

pre-treatment results

- NKI-AVL data iViewDose vs OCTAVIUS 4D System direct comparison

	γ-mean	near γ-max	γ-pass rate	%ΔISOC
7 IMRT	0.35 ± 0.12	1.04 ± 0.17	98.2 ± 2.2	-0.6 ± 1.6
	(0.20, 0.55)	(0.77, 1.22)	(93.6, 100.0)	(-2.8, 1.2)
6 VMAT	0.43 ± 0.09	1.08 ± 0.32	97.5 ± 2.1	-0.2 ± 1.3
	(0.28, 0.53)	(0.53, 1.6)	(95.3, 99.8)	(-2.4, 0.7)



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THANKS BEDANKT GRACIAS

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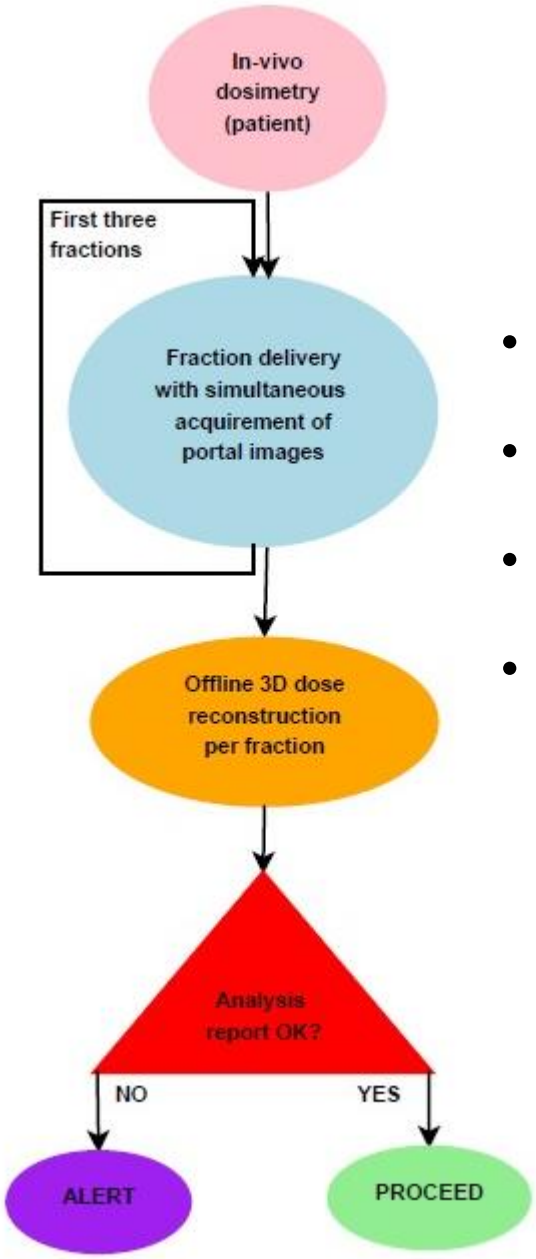

- RTTs extract panel for detection
- Automatic acquisition of portal image data
- *iViewDose* in batch mode
- Results automatically available minutes after delivery

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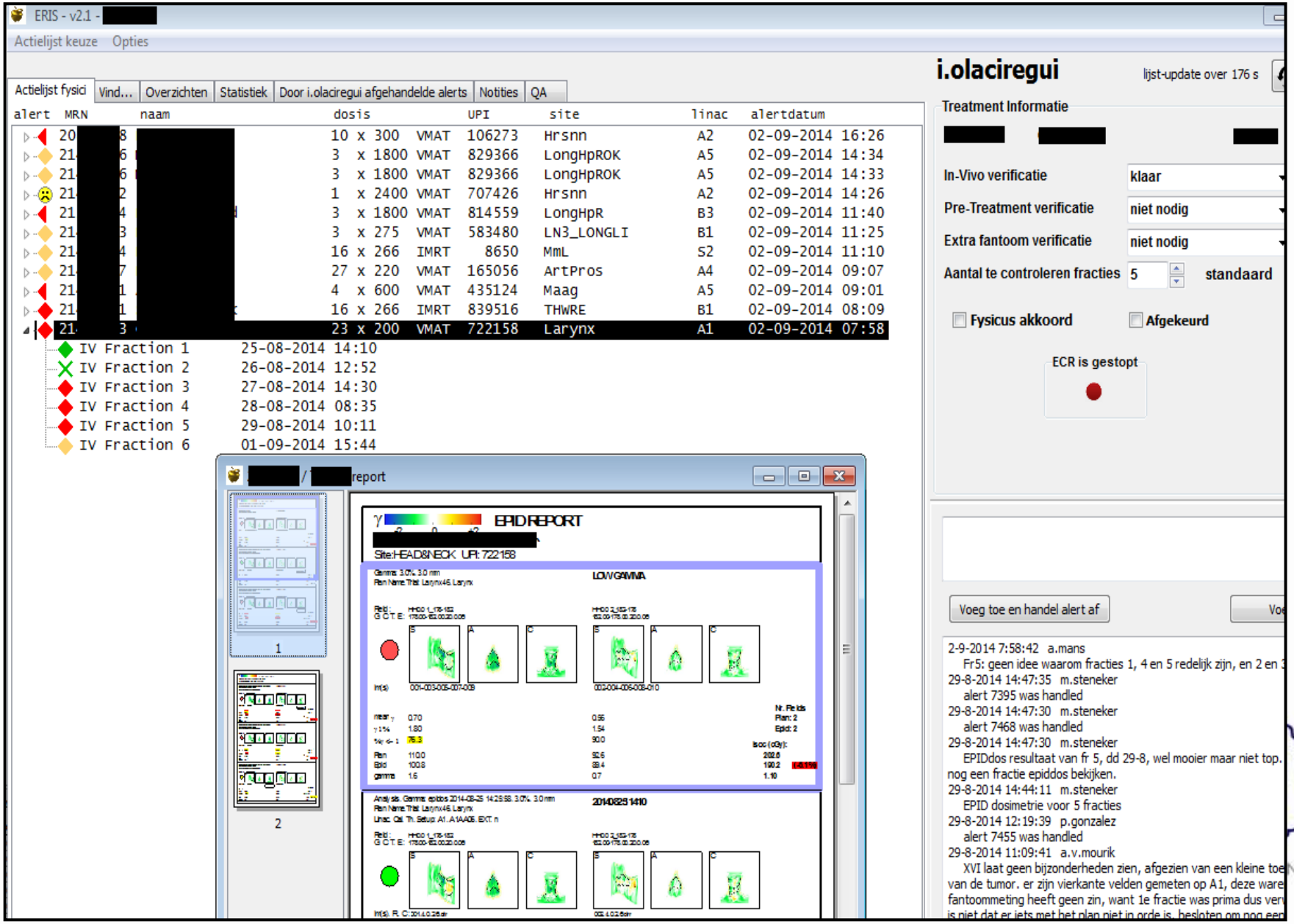
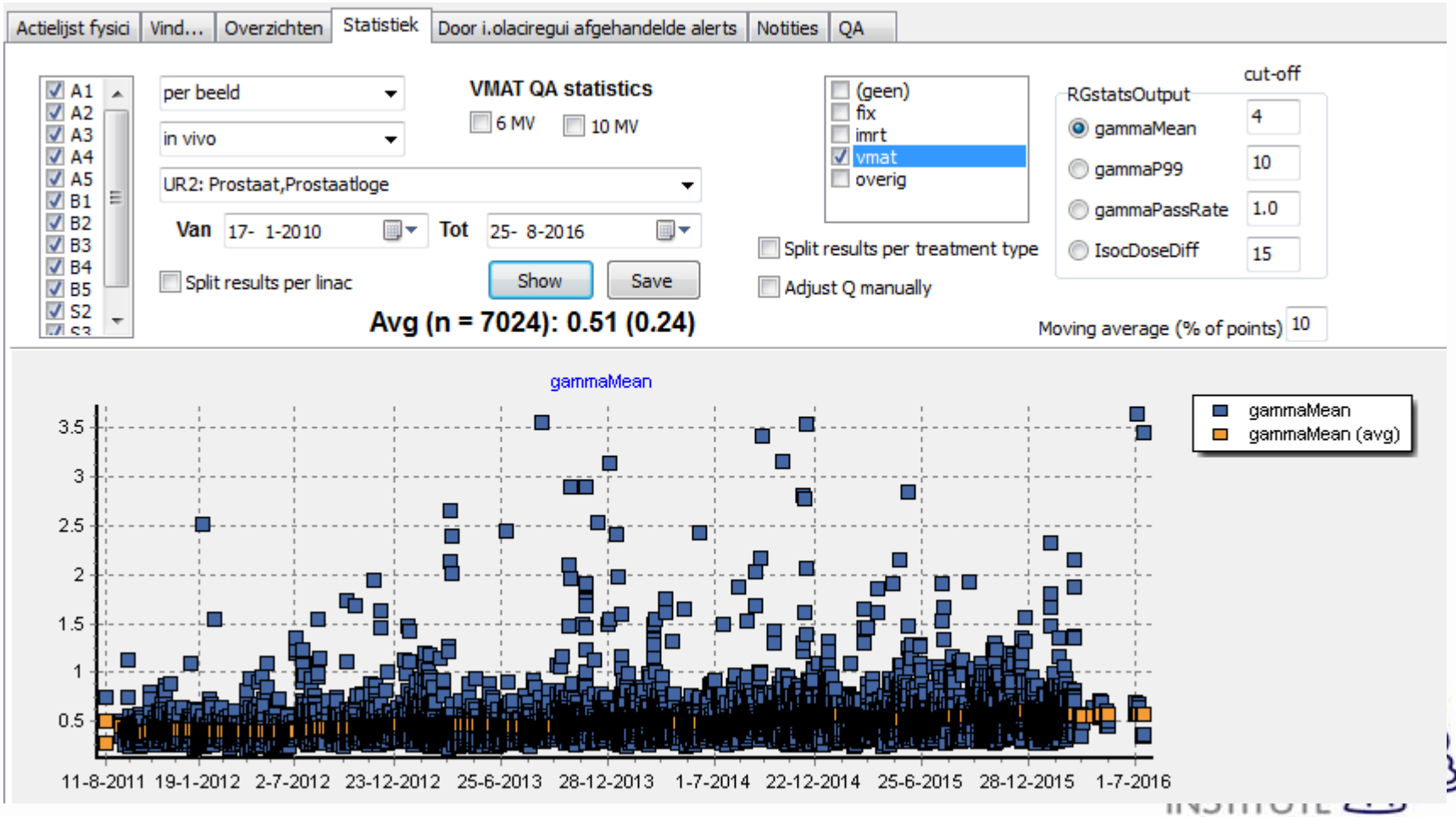
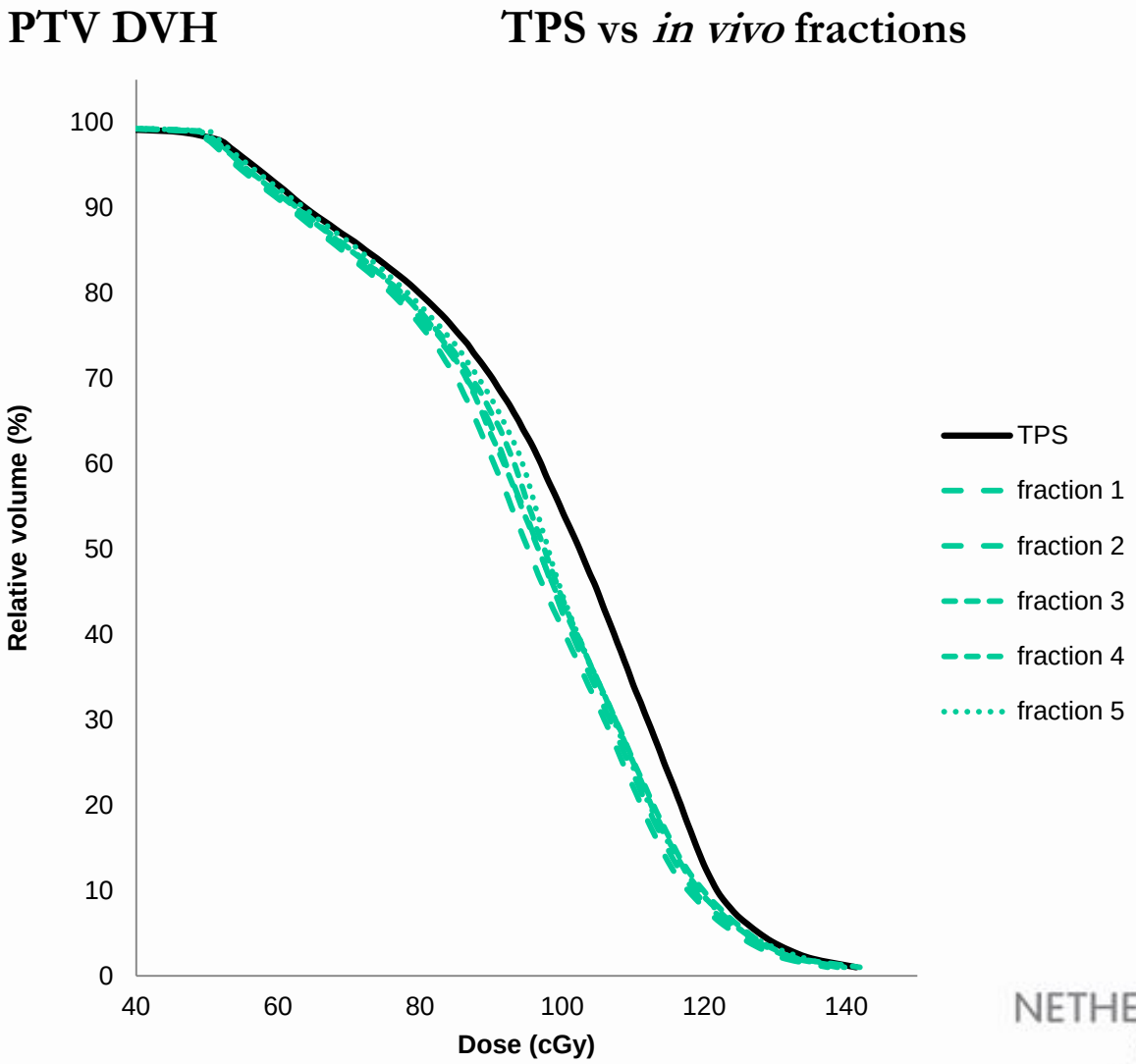
iViewDose R&D

Integration with R&V




Actielijst fysici
Vind...
Overzichten
Statistiek
Door i.olaciregui afgehandelde alerts
Notities
QA
A1
A2
A3
A4
A5
B1
B2
B3
B4
B5
S2
per beeld
in vivo
UR2: Prostaat,Prostaatloge
VMAT QA statistics
6 MV
10 MV
Van 17- 1-2010
Tot 25- 8-2016
Split results per linac
Show
Save
Avg (n = 7024): 0.51 (0.24)
(geen)
fix
imrt
vmat
overig
Split results per treatment type
Adjust Q manually
cut-off
RGstatsOutput
gammaMean 4
gammaP99 10
gammaPassRate 1.0
IsocDoseDiff 15
Moving average (% of points) 10
gammaMean
gammaMean
gammaMean (avg)
3.5
3
2.5
2
1.5
1
0.5
11-8-2011
19-1-2012
2-7-2012
23-12-2012
25-6-2013
28-12-2013
1-7-2014
22-12-2014
25-6-2015
28-12-2015
1-7-2016



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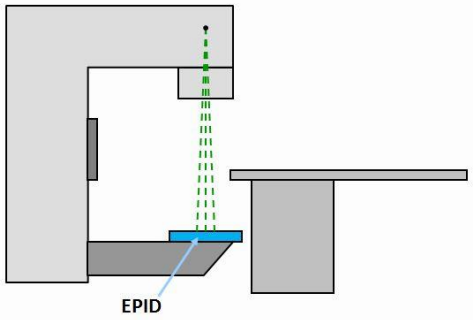
iViewDose R&D

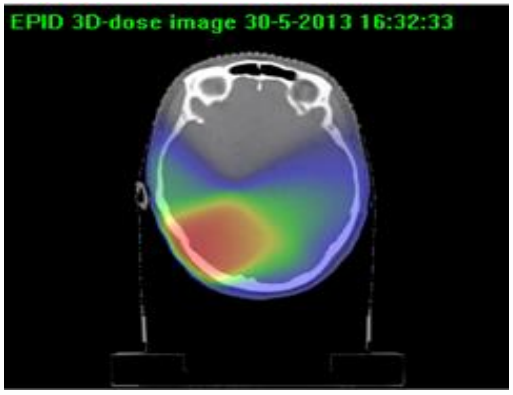
Virtual patient 3D dose reconstruction



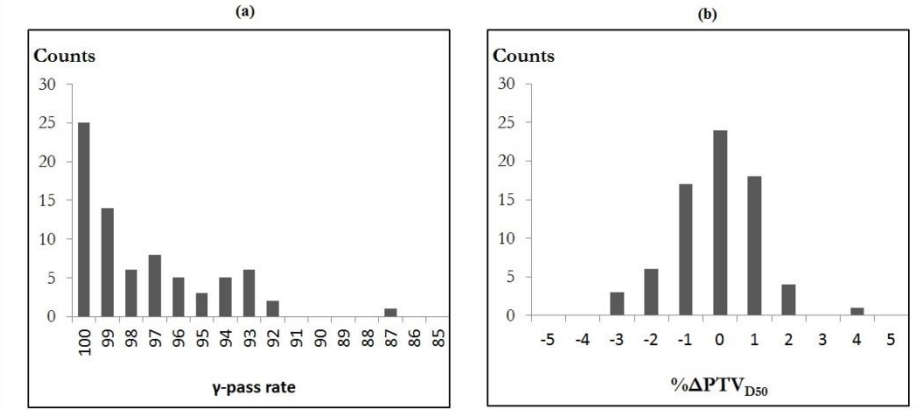
$$Pr_{ij}^{EPID,in\ air}$$

Predicts the 3D dose to be delivered to the patient using in air EPID measurements

- No phantom re-planning or positioning
- Pre-treatment with DVH analysis



25 IMRT and 50 VMAT treatments (vs TPS)



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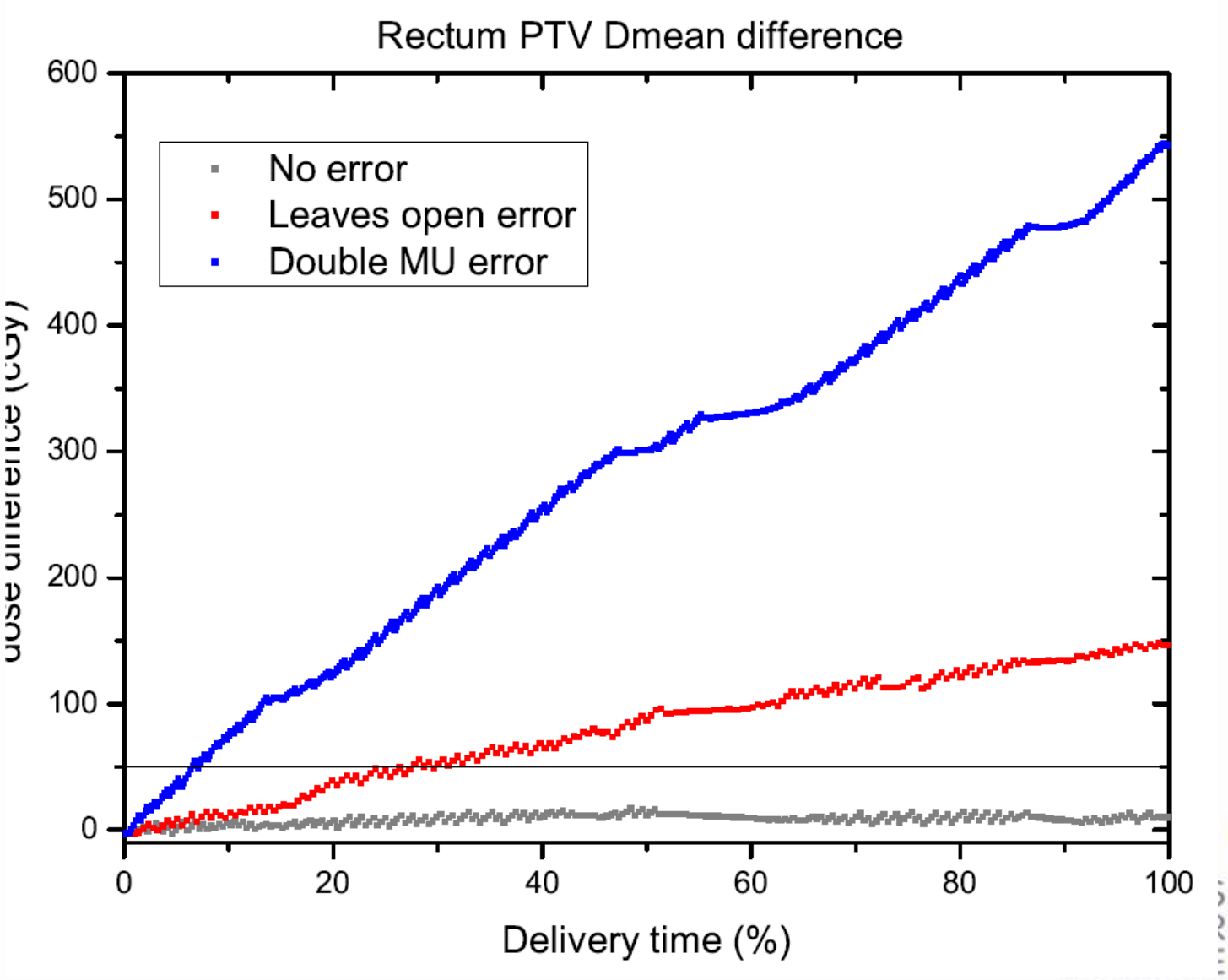

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