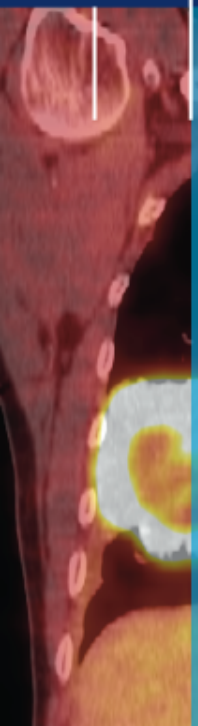
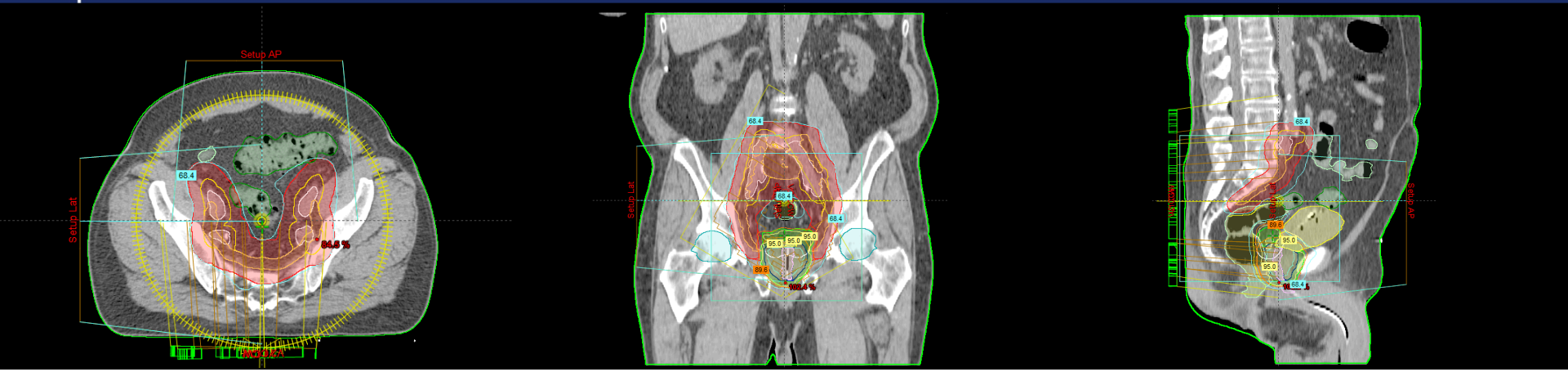
Patient-specific QA using 3D EPID dosimetry: future becomes reality

S.M.J.J.G. Nijsten, MAASTRO CLINIC



Verification of modern radiotherapy techniques

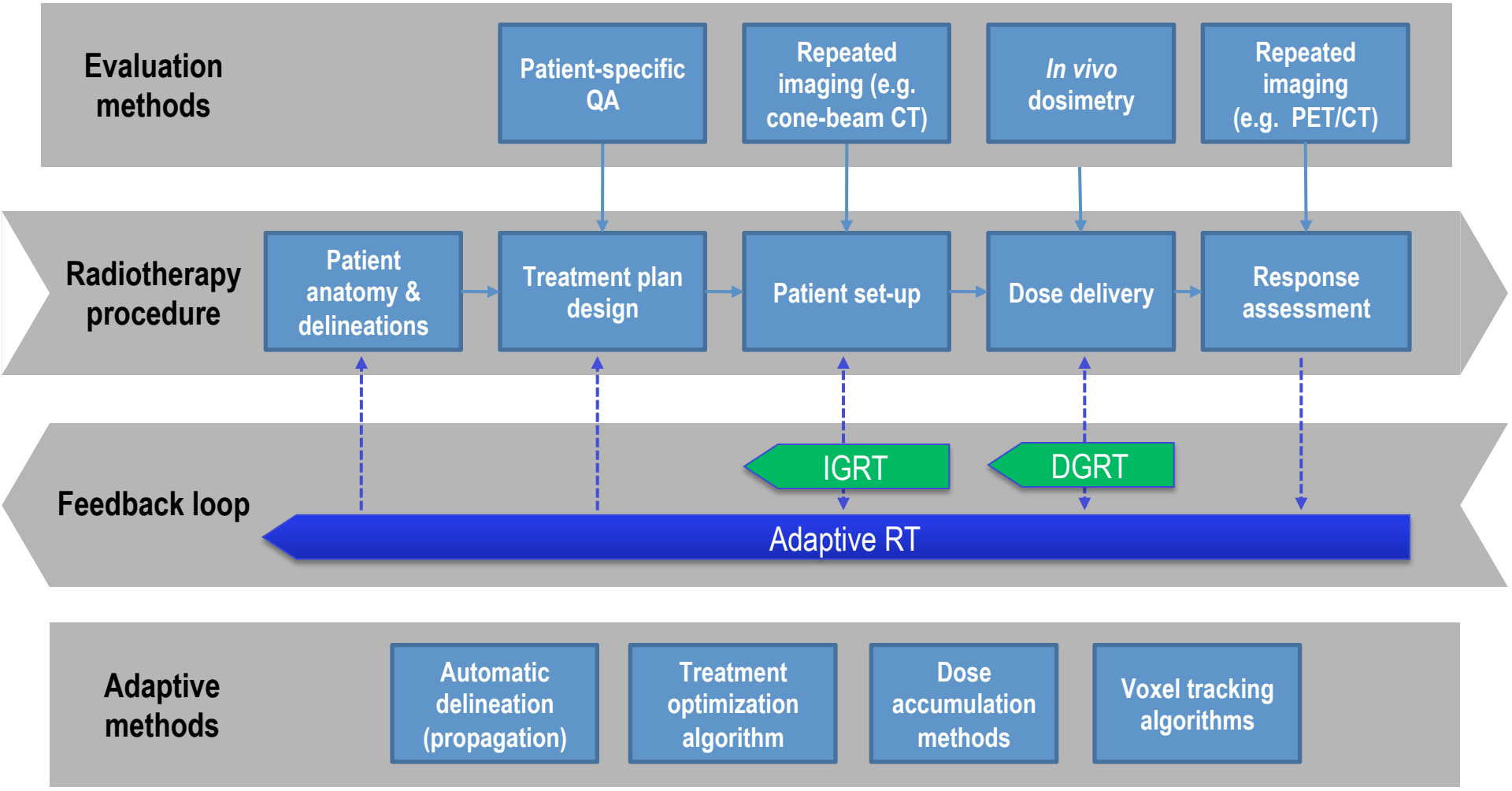


Current modern radiotherapy techniques demand robust and fast dose delivery verification techniques taking into account different uncertainties in dose delivery.

More complex techniques often also require more complex verification techniques which are still under development and are not always commercially available.

The chain of radiotherapy

(Adaptive RT using IGRT and DGRT procedures)



Dose Guided Radiation Therapy (DGRT)

Statement about IGRT

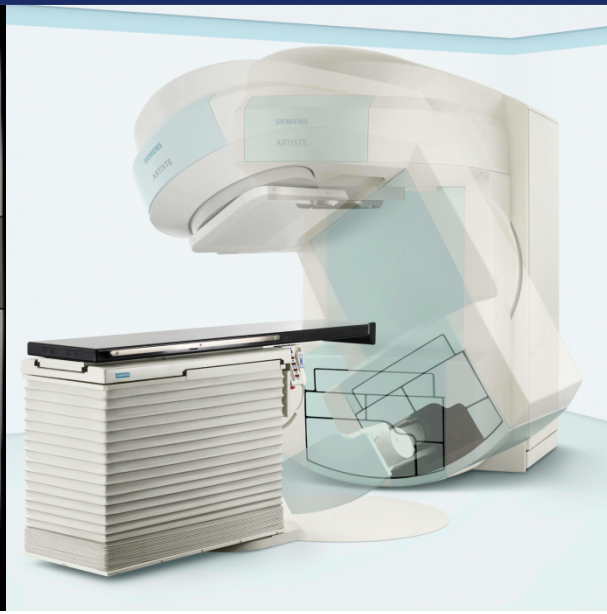
(Lancet Oncology, October 2006)

"Frequent imaging during the course of treatment, or image guided radiotherapy, is becoming a crucial requirement for further innovation in conformal radiotherapy, to ensure that high-precision techniques are delivered as planned."

DGRT allows for monitoring and adapting a treatment based on the **measured** delivered dose to a patient.

MAASTRO uses electronic portal imaging devices (EPIDs) for this purpose.

Equipment



LINACs

- Siemens Oncor/Artiste, Varian TrueBeam, Elekta Synergy
- Energy: 6/10/15 MV X-rays

a-Si EPIDs

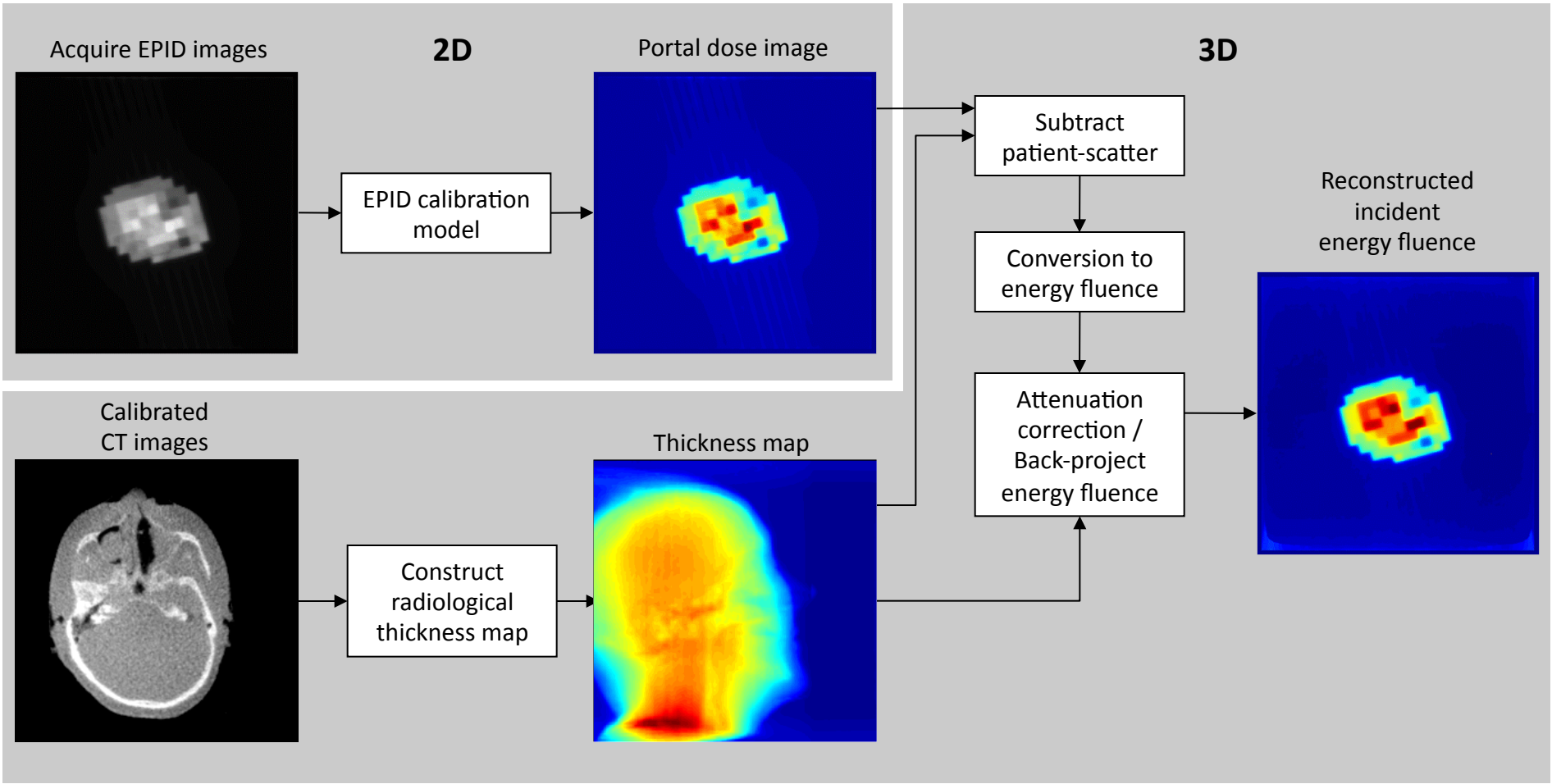
- Siemens OptiVue (AL7/AG9/AN9)
- Varian aS1000
- Elekta iView *GT*

Overview of DGRT

DGRT @ MAASTRO CLINIC

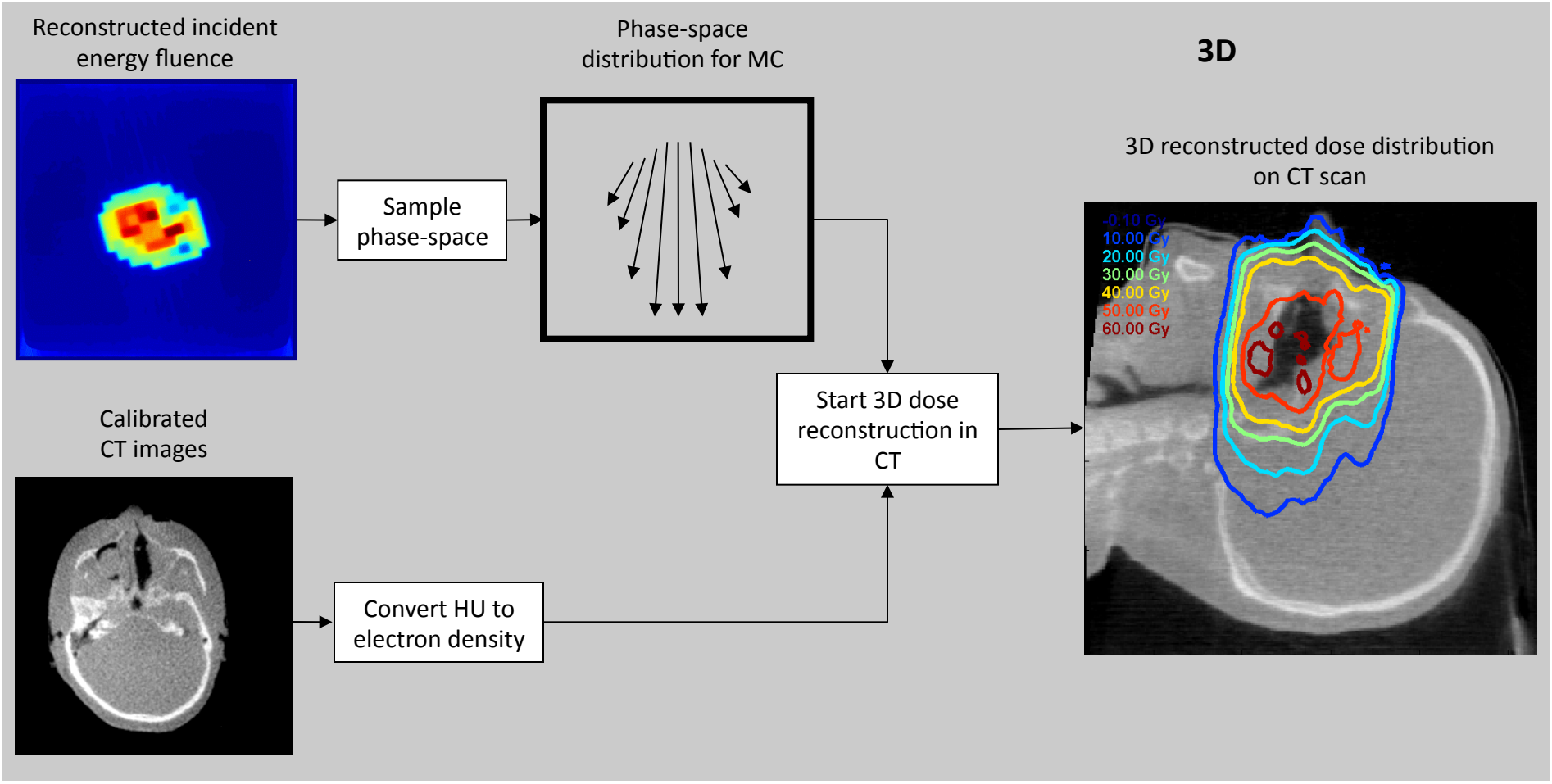
- EPID dosimetry (CCD-based EPID research started in 2000)
- Point dosimetry (clinically used from 2002 to 2006)
- 2D dosimetry
  - Flat-panel dose calibration (for *a-Si* EPIDs started in 2005)
  - Pre-treatment (in clinical use from June 2006 – present)
  - Transit dosimetry (in clinical use from December 2006 – present)
- 3D dosimetry
  - Pre-treatment (in clinical use from July 2012)
  - Dose Recalculation (in clinical use from July 2012)
  - *In-Vivo* dosimetry (in clinical use from July 2012)
- Time-resolved dosimetry
  - Under investigation

EPID dosimetry
(2D and 3D verification methods)



van Elmpt et al., A Monte Carlo based three-dimensional dose reconstruction method, Med. Phys. 33(7), 2006
Nijsten et al., A global calibration model for a-Si EPIDs used for transit dosimetry, Med. Phys. 34(10), 2007

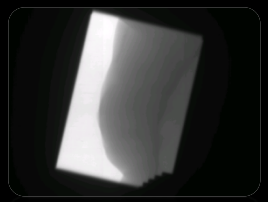
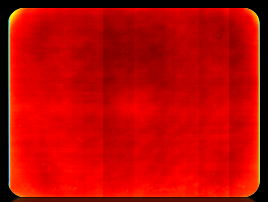
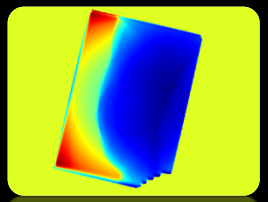
EPID dosimetry
(2D and 3D verification methods)

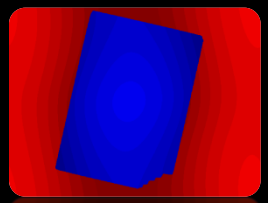
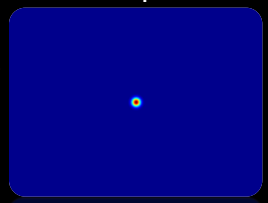
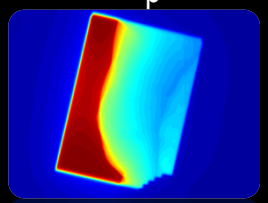


van Elmpt et al., A Monte Carlo based three-dimensional dose reconstruction method, Med. Phys. 33(7), 2006
Nijsten et al., A global calibration model for a-Si EPIDs used for transit dosimetry, Med. Phys. 34(10), 2007

Dosimetric calibration model

(Including off-axis panel shifts)

$$D_p = c_F^{-1} \times G(t_{rad})^{-1} \times$$  $$\times$$  $$^{-1} \times$$  $$^{-1} \times \ldots$$

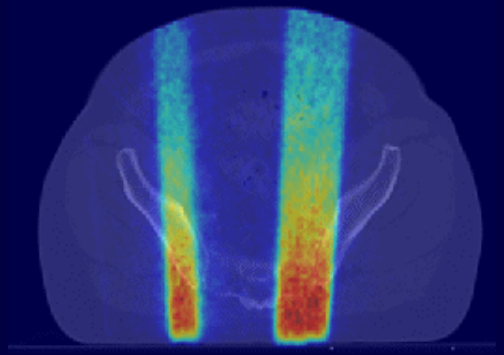
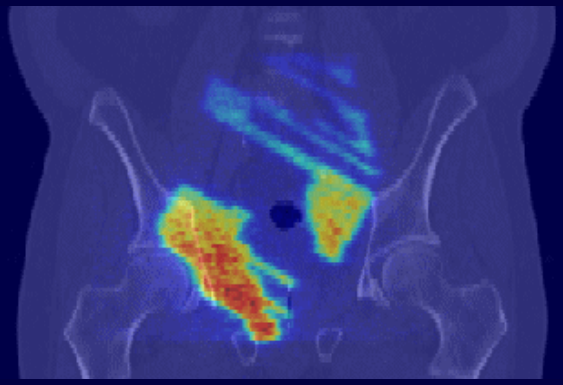
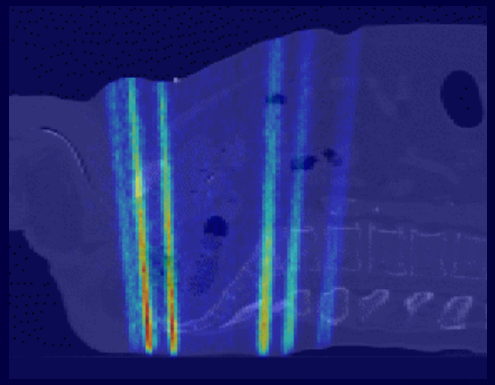
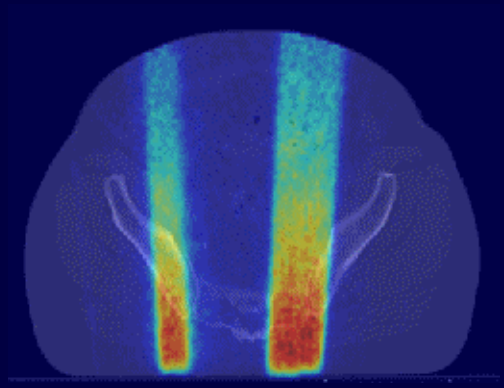
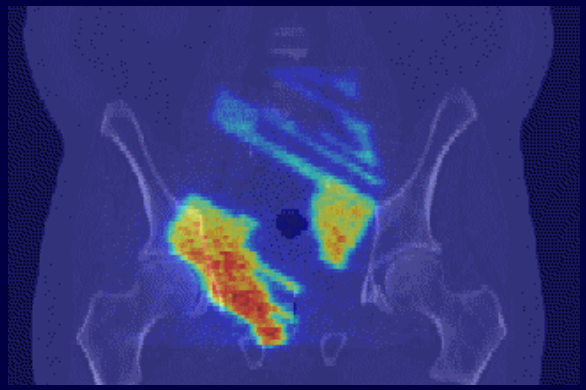
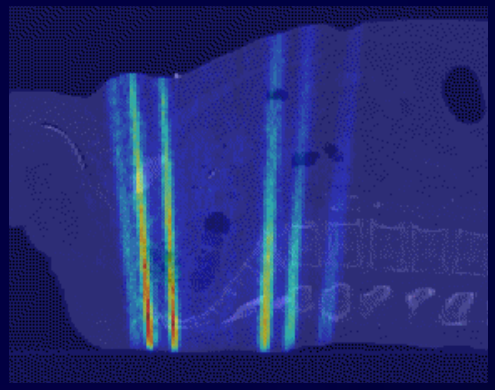
$$\ldots$$  $$^{-1} \otimes^{-1}$$  $$=$$ 

G' is corrected for back scatter (Varian only), dark field and dead pixels.

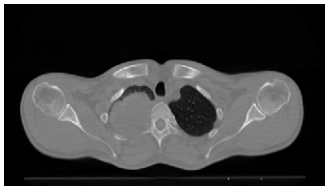
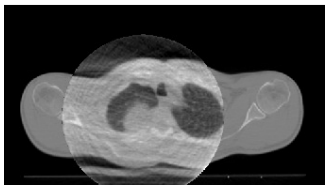
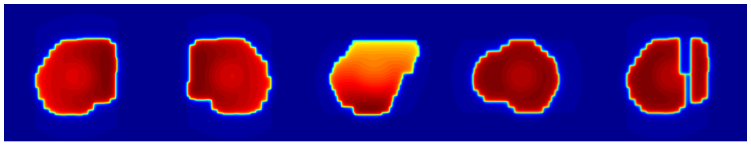
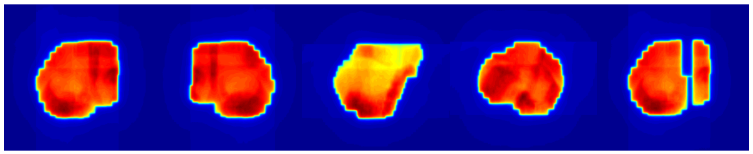
P. Greer, Med. Phys. 32(12), 2005
S.M.J.J.G. Nijsten et al., Med. Phys. 34(10), 2007
P. Rowshanfarzad et al., Med. Phys. 37(5), 2010

3D EPID dosimetry

(Dose reconstruction based on transit dosimetry and planning CT anatomy)

	Axial reconstruction	Coronal reconstruction	Sagittal reconstruction
Dose per segment			
Integrated dose			

Verification scenarios during 3D portal dosimetry

	Planning CT 	CT/CBCT 
Pre-treatment PDIs 	*3D pre-treatment verification* - Prior to first treatment, check of LINAC, QA - Adaptation by designing new treatment plan	*3D dose recalculation* - Prior to treatment, check of dose in patient - Adaptation by incorporating anatomy changes
Transit PDIs 		*3D in vivo dosimetry* - During treatment, delivered dose in patient - Adaptation by incorporating anatomy changes and dose delivery differences

Patient-specific QA with MatriXX and EPID

(Some specifications)

MatriXX detector array in MULTICube phantom

Number of chambers: 1020
Active area: 24.4x24.4 cm^2
7.62 mm center-to-center distance

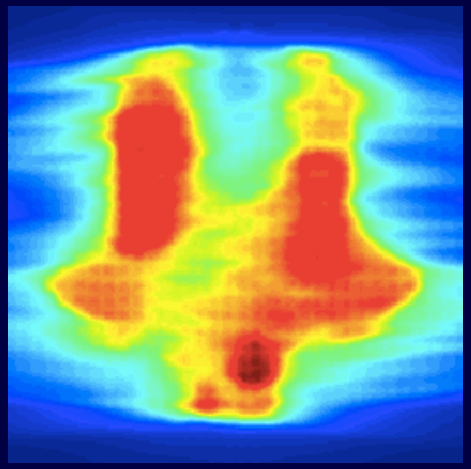
Varian MV EPID @ TrueBeam LINAC

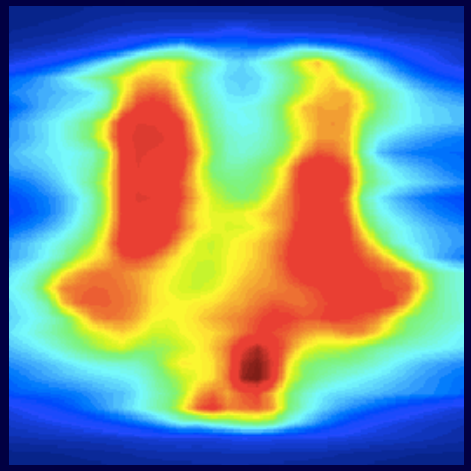
Number of pixels: 196608
Active area: 40.1x30.1 cm^2
0.78 mm center-to-center distance

Cumulative gamma histograms for MatriXX and EPID

(Cut-off isodose values of 0,20,50,80,100%)

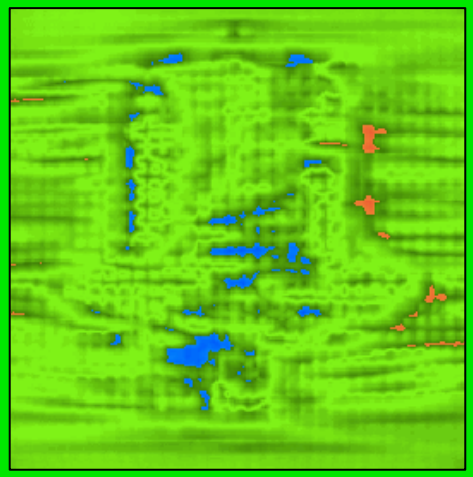
3D dose MatriXX

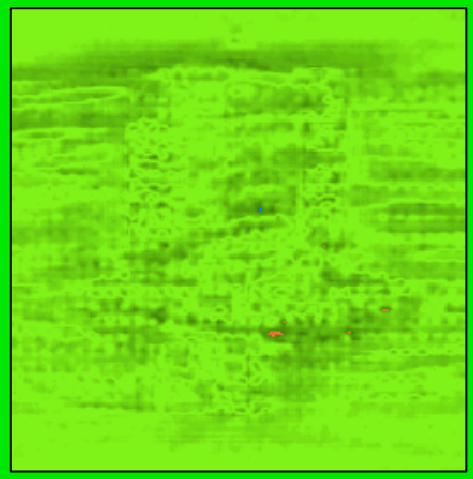




3D dose EPID

3D gamma MatriXX

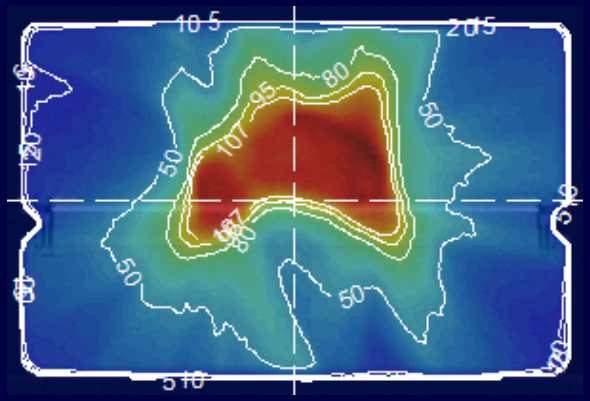
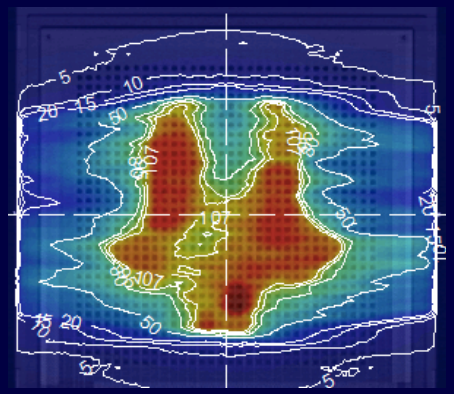
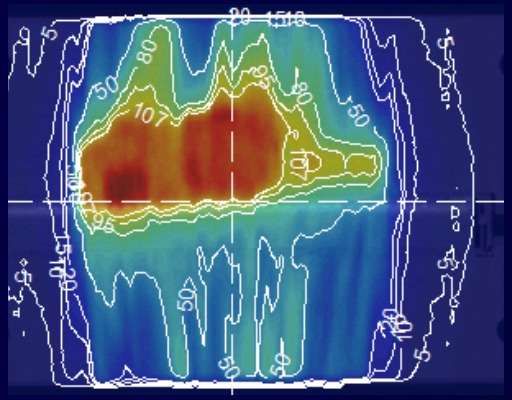
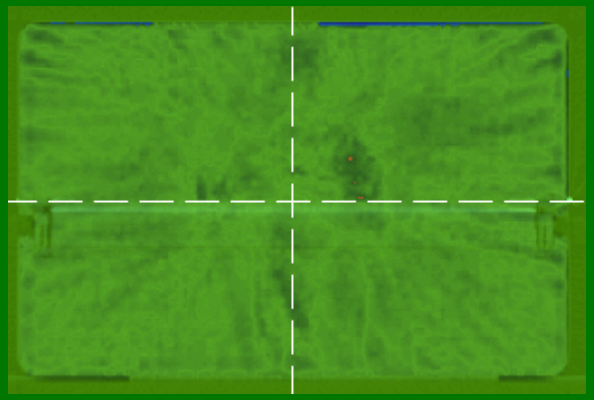
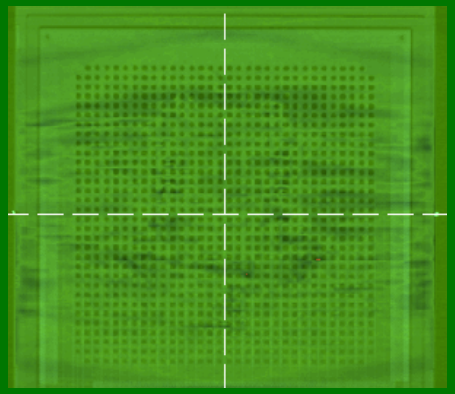
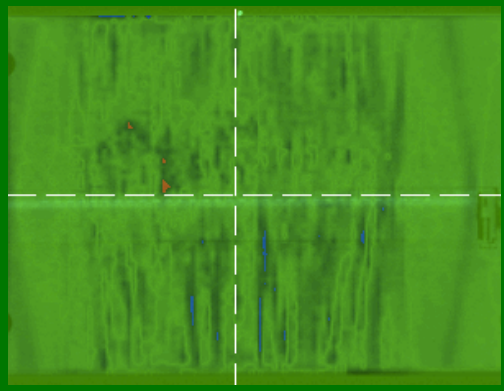




3D gamma EPID

global γ: 3%, 3 mm

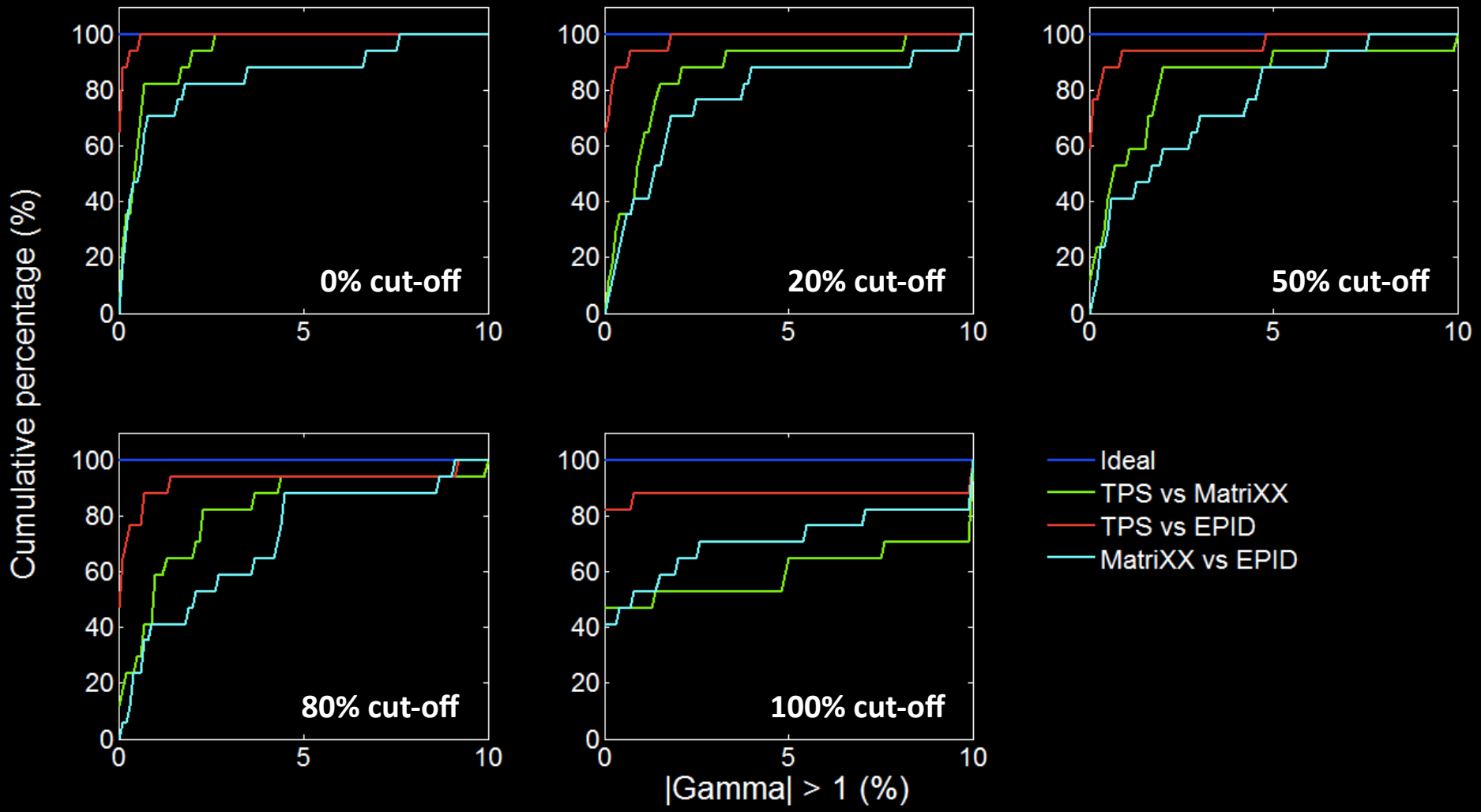
Full 3D dose verification using EPID dosimetry

	Axial reconstruction	Coronal reconstruction	Sagittal reconstruction
3D dose EPID			
3D gamma EPID			

global γ: 3%, 3 mm

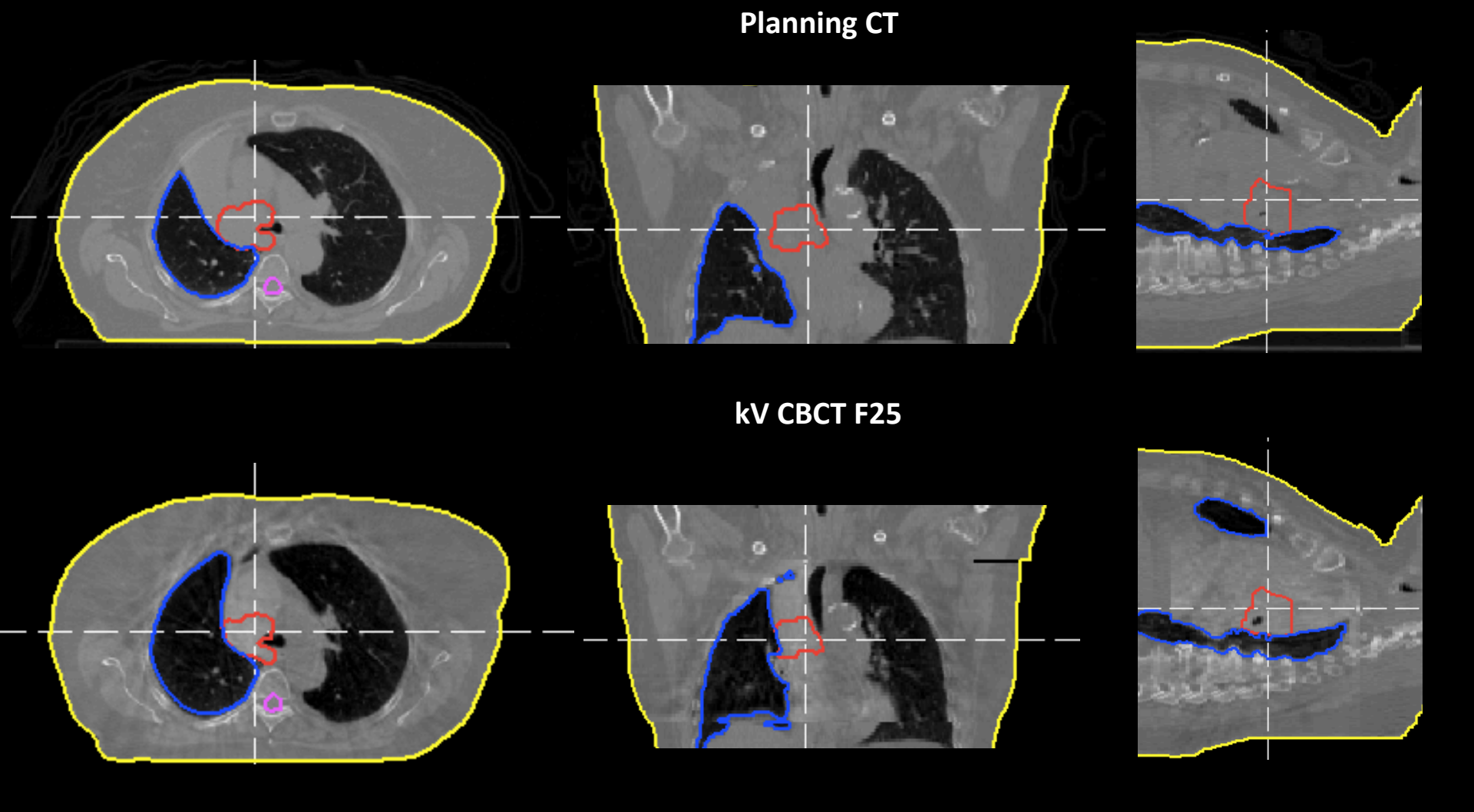
Cumulative gamma histograms for MatriXX and EPID

(Based on 17 coronal measurements through isocenter for different cut-off dose values)



kV CBCT for soft tissue visualization and dose reconstruction

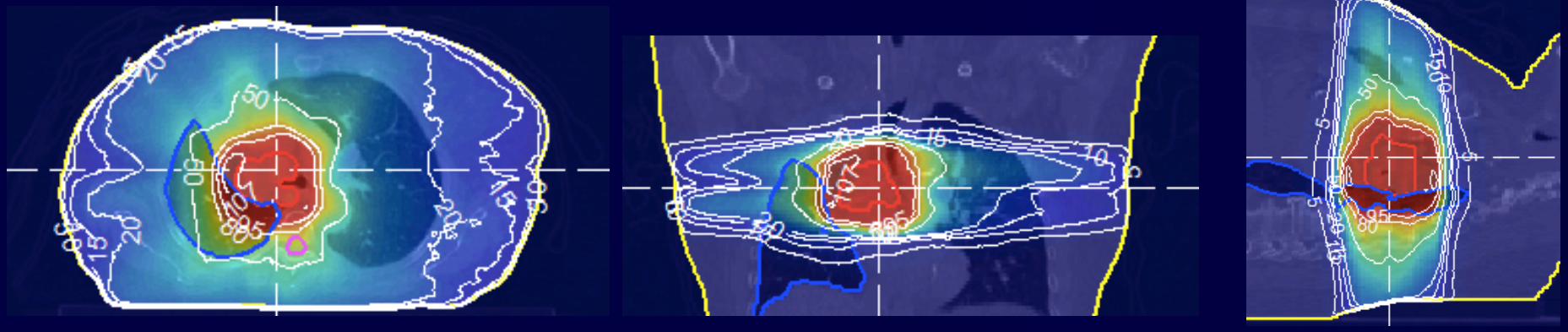
(Redelineation)



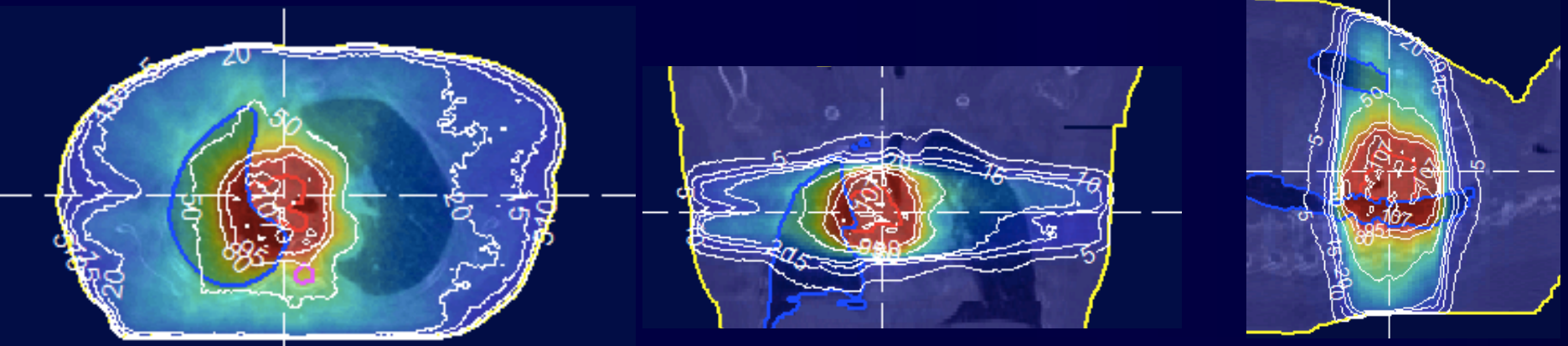
kV CBCT for soft tissue visualization and dose reconstruction

(Dose reconstruction based on transit dose measurements)

Planning CT



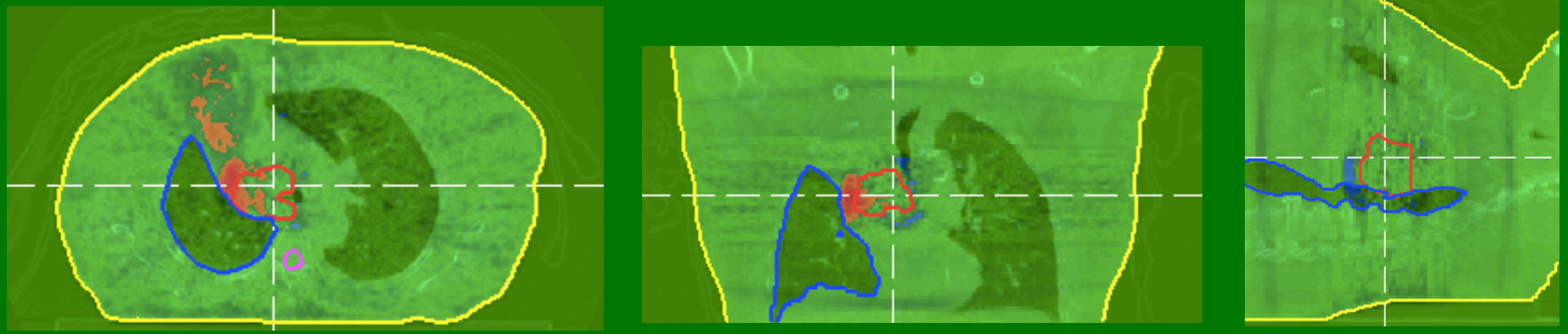
kV CBCT F25



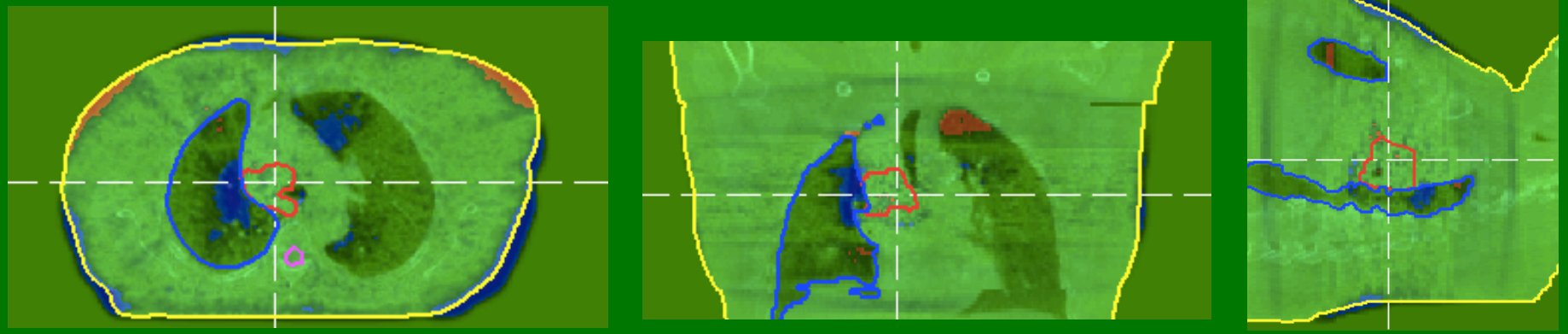
kV CBCT for soft tissue visualization and dose reconstruction

(3D gamma calculation based on transit dose measurements)

Planning CT



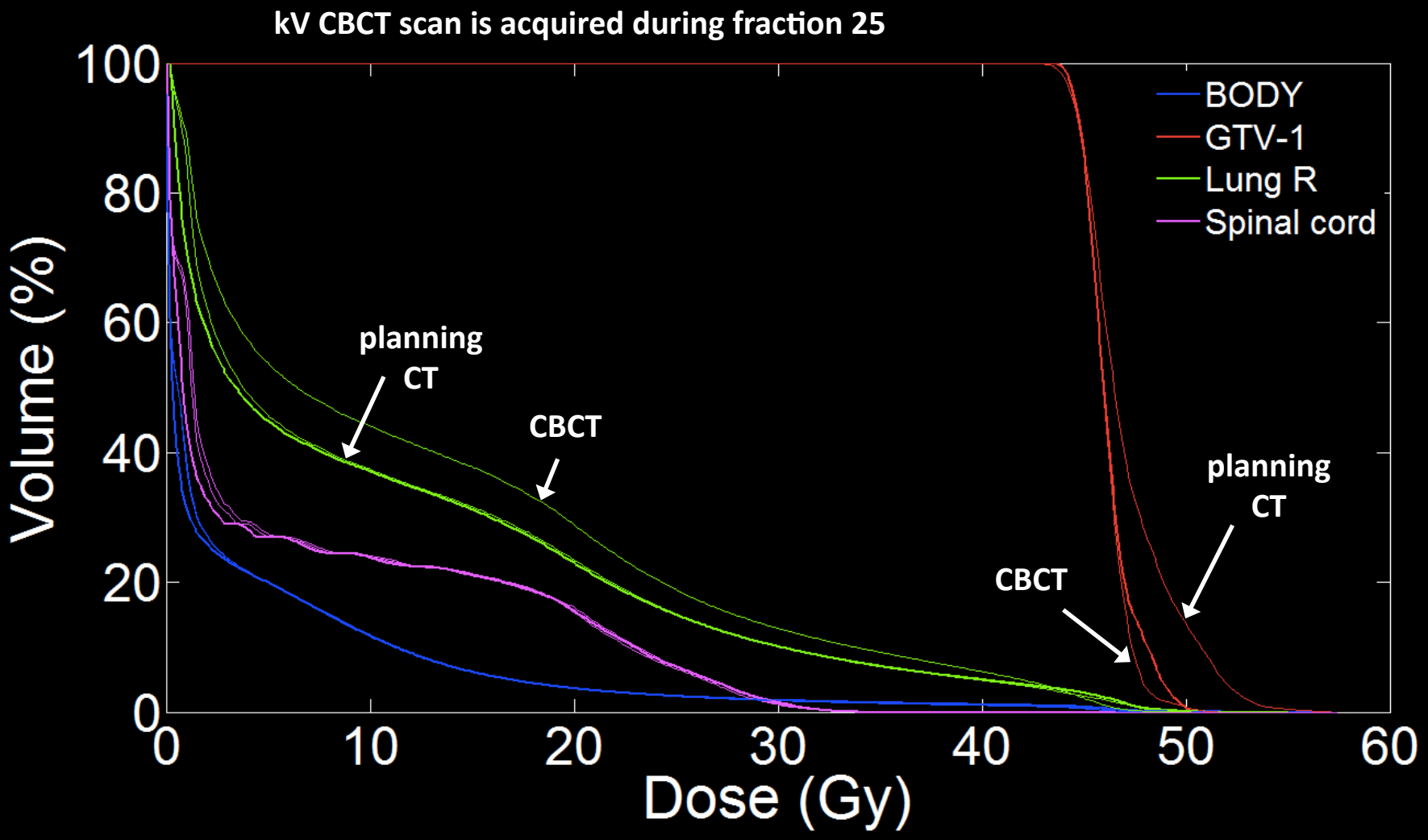
kV CBCT F25



global γ: 3%, 3 mm

kV CBCT for soft tissue visualization and dose reconstruction

(DVH calculations for planning CT and 1 fraction with CBCT based on VIVO)

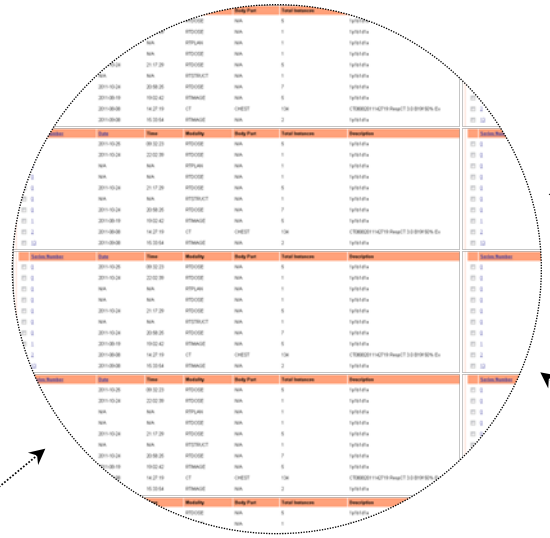


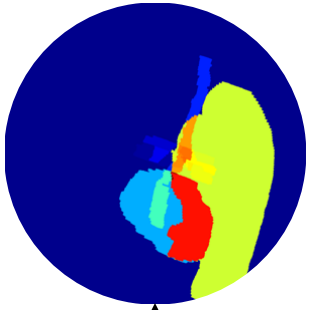
EPID dosimetry

(DGRT workflow prior to treatment)

PACS

Storage of DICOM-RT data used and created by 2D and 3D DGRT procedures

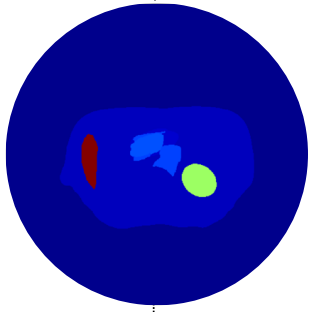




DGRT_CON

Projected structures (ROIS) are created

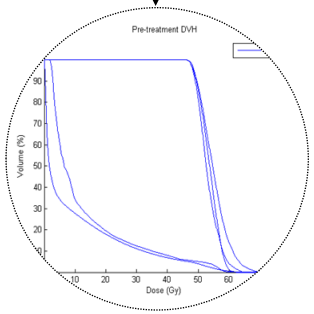
PLAN, VOIS



DGRT_VOI

Volume-of-interests (VOIS) are created

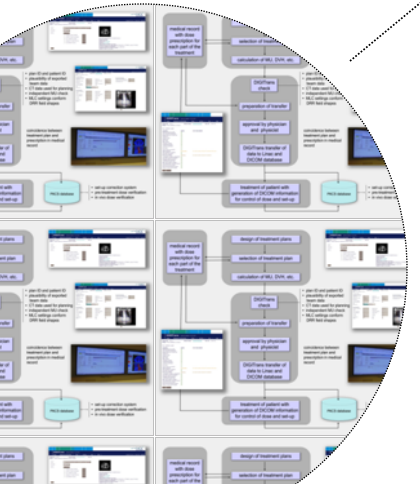
CONTOURS 3D, PLAN, CT TPS



DGRT_DVH

Dose-volume-histograms (DVH PRED) are created

DOSE 3D TPS, VOIS, PLAN



DIGITrans

Treatment planning objects are transferred to central PACS database and the DGRT workflow is started by DGRT_VOI

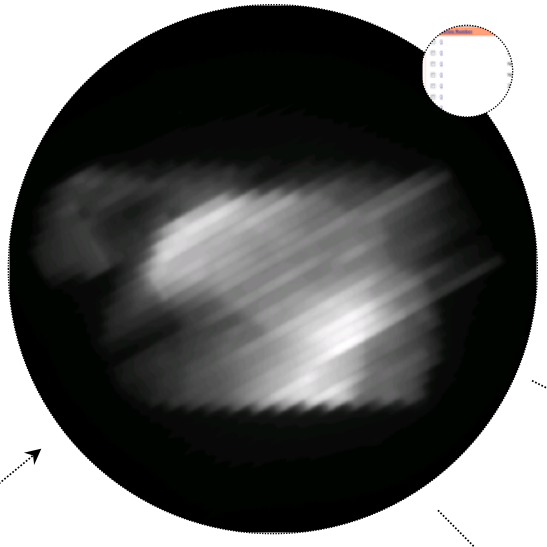
EPID dosimetry

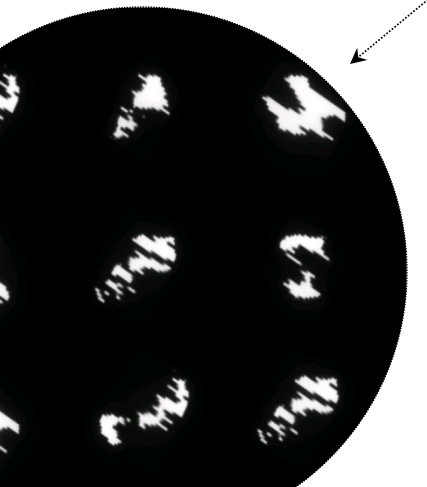
(DGRT workflow during treatment)

DGRT_ACQ

Generation of multi-frame DICOM-RT Image object based on individual dark field corrected frames

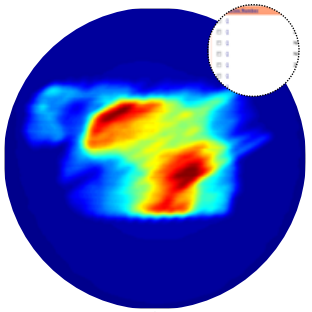
***SYNC DB**, PLAN*

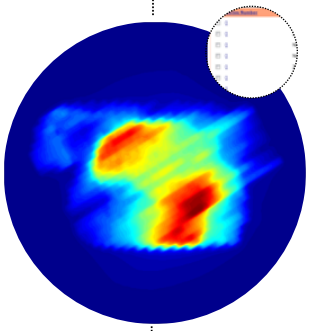


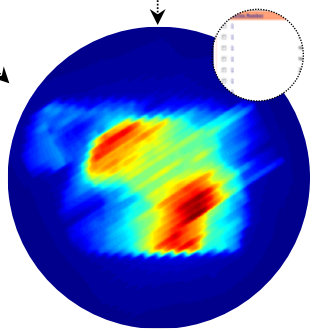


iTools

Individual frames are captured and stored to local disk







DGRT_VIV

Transit portal dose images (PDI PRED T) are predicted

PDI PRET P, PLAN, VOIS, CT TPS

DGRT_PRE

Pre-treatment portal dose images (PDI PRED P) are predicted

PORTAL IMAGE, PLAN

DGRT_EPD

Portal dose images (PDI MEAS) are calculated

PORTAL IMAGE, PLAN, (PDI PRED P)

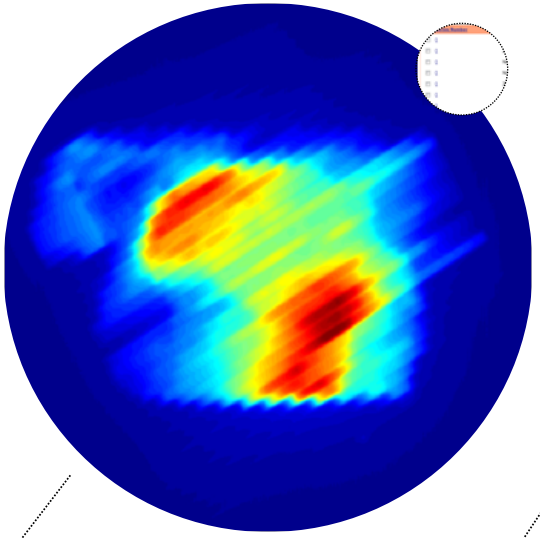
EPID dosimetry

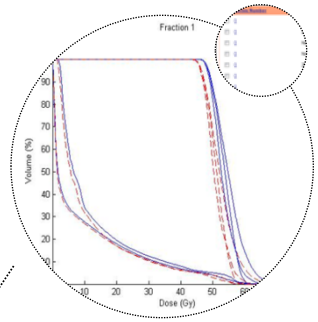
(DGRT workflow during treatment)

DGRT_EPD

Portal dose images (PDI MEAS) are calculated

PORTAL IMAGE, PLAN, (PDI PRED P)

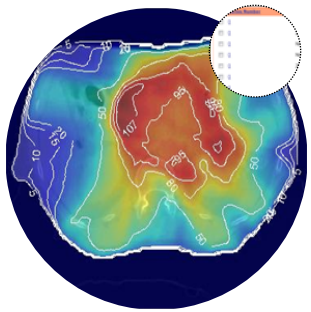




DGRT_DVH

Dose-volume-histograms (DVH MEAS) are created

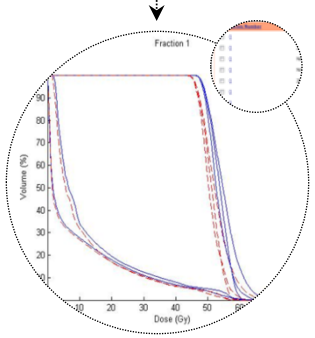
DOSE 3D MEAS, VOIS



DGRT_RECON

3D dose reconstructions (DOSE 3D MEAS) are performed

PDI MEAS, VOIS, PLAN, DOSE 3D TPS, CT TPS



DGRT_GAM3D

3D gamma distributions (GAMMA 3D) are created

DOSE 3D MEAS, DOSE 3D TPS, VOIS, PLAN

DGRT_EV2D

(+ DGRT_REP)

PDF reports are generated based on 2D DGRT results

PDI MEAS, VOIS, PDI PRED, PLAN, ROIS, DRRS

DGRT_EV3D

(+ DGRT_REP)

PDF reports are generated based on 3D DGRT results

DOSE 3D MEAS, DOSE 3D TPS, DVH, GAMMA 3D, VOIS, PLAN, CT TPS

Conclusions

- *a*-Si EPIDs can be accurately calibrated for dosimetric purposes and included as dosimeter in verification procedures of modern complex radiotherapy techniques

- Patient-specific QA using 3D EPID dosimetry can replace existing pre-treatment verification methods offering a high verification accuracy and minimizing workload

- 3D EPID dosimetry makes it possible to apply Dose Guided Radiation Therapy during clinical routine and allows for documentation, adaptation and individualization of patient treatments

> ***Patient-specific QA using 3D EPID dosimetry is no longer future but reality***

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