Patient-based Quality Assurance for IMRT

CE-IMRT2

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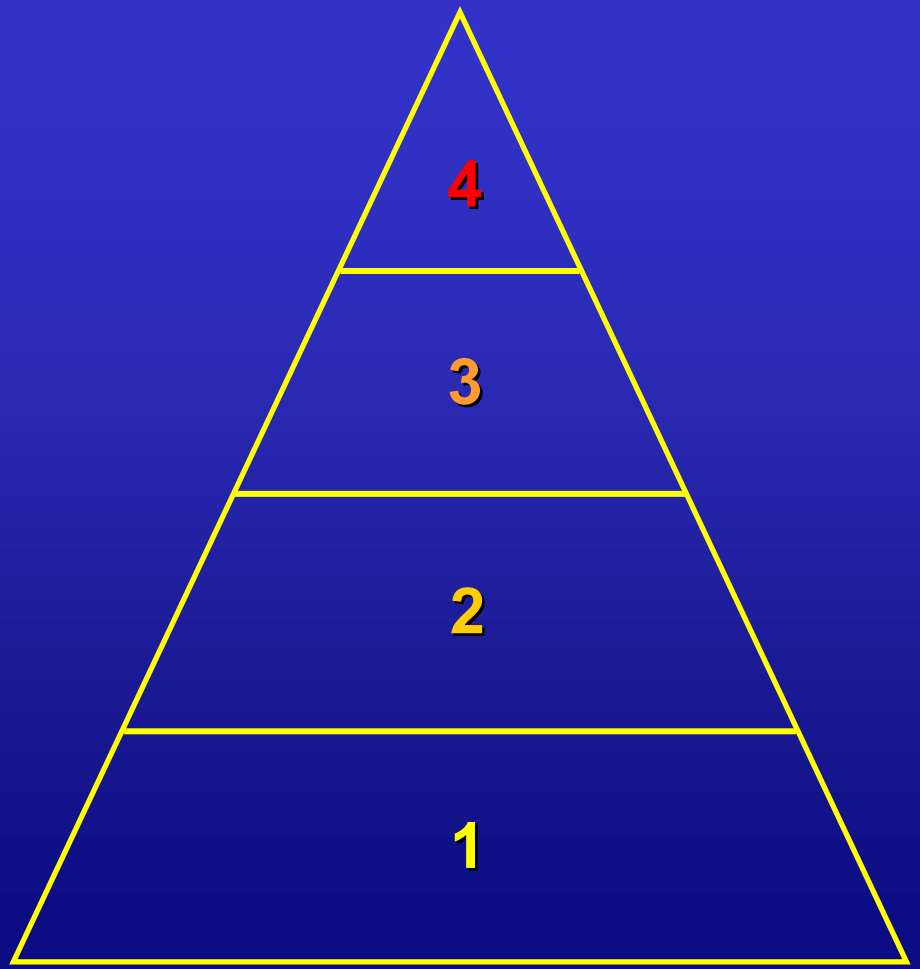
Outline

- Customize your QA procedure
- Tools, an overview:
  - Dosimetry
  - Phantoms
- Hazard analysis, some examples
- Discrepancy analysis, some examples
- Beware of what is not verified by your procedure
- Target localization

Customize

- How to get comfortable?
- What is recommended/required “officially”?
  - Verify each field
  - Verify composite treatment
  - Absolute dose check
- Create an efficient QA-procedure
  - Don’t drown in film measurements
  - Efficient processing required

QA for IMRT: 4 levels



- Pre-clinical verification of IMRT treatment (Patient related)
- Verification of fluence maps, individual IMRT fields on water phantom
- Small-field dosimetry
- Basic QA (linac, MLC)

Level 1: Basic linac QA

- Tests for Validation and after every accelerator check
  - MLC calibration and alignment
  - Speed Stability
  - Beam on/off stability
  - Gravity test
  - MLC reliability test
- Weekly test
  - Garden fence test

Level 2 and 3

- Level 2: *Small field dosimetry*
  - Commissioning
  - Acceptance
- Level 3: *Verification of IMRT delivery*
  - “Chair”
  - Geometric fluence profile
  - Irregular test profile

Level 4: different philosophies

- Every day ↔ Every patient ↔ Class solutions
  - QA procedure largely dependent on approach
- Top-down ↔ Bottom-up

- **Comprehensive**
- **Discrepancy analysis complicated**

- **Detailed, analysis straightforward**
- **Time consuming**

QA in IMRT: an example

- Comprehensive test for class solution with anthropomorphic phantom (pre-clinical verification)
  - e.g. every 10 patients
- Comprehensive test for IMRT delivery capability
  - Fluence map created by TPS, transferred and delivered
    - Chair
    - Geometric dose distribution
  - e.g. every week
- Regular detailed QA of linac and MLC (basic verification)
  - e.g. every month

QA in IMRT: customize

- Dosimetry
- Phantom
- Hazard analysis
  - Find weak links
  - Define control points
- Intuition/experience from conventional RT is lost
- Beware of what is not verified in your QA
- Discrepancy analysis

Absolute dose and MU validation

- MU validation requires either
  - Direct measurement of dose using TPS MUs and fluences
    - Time-intensive
      - Temporal
      - High dose gradients
      - Small field dosimetry
    - Currently most thorough method of validation
  - Independent computation of dose
    - Most efforts still single point
    - Ideally, recompute entire 3D dose

Dosimeters

- Integrating
  - TLD chips
  - Alanine chips
  - MOSFET
  - Radiographic film
  - Radiochromic film
  - Gel
- Non-integrating
  - Ionization chamber (conventional, micro, pin-point)
  - diodes
  - diamond
  - Linear array detectors

Dosimetric verification

- Down scaling of Monitor units
  - Losing small segments
  - Underestimation of scatter and leakage dose
- Small field dosimetry
- Temporal dose delivery:
  - integrating dosimeters (TLD, alanine, film, gel)
  - non-integrating (ionization chamber, …)

Dosimeters

- 0 dimensional
  - Ionization chamber
    - Conventional
    - Micro, diamond, …
  - Diodes
  - MOSFET
  - Diamond
  - TLD, alanine
- 1 dimensional
  - Stack of TLD chips
  - Linear array detectors
- 2 dimensional
  - Film
  - EPID
  - Array of TLD chips
- 3 dimensional
  - Gel
  - Stack of film
  - 3D-array of TLD chips

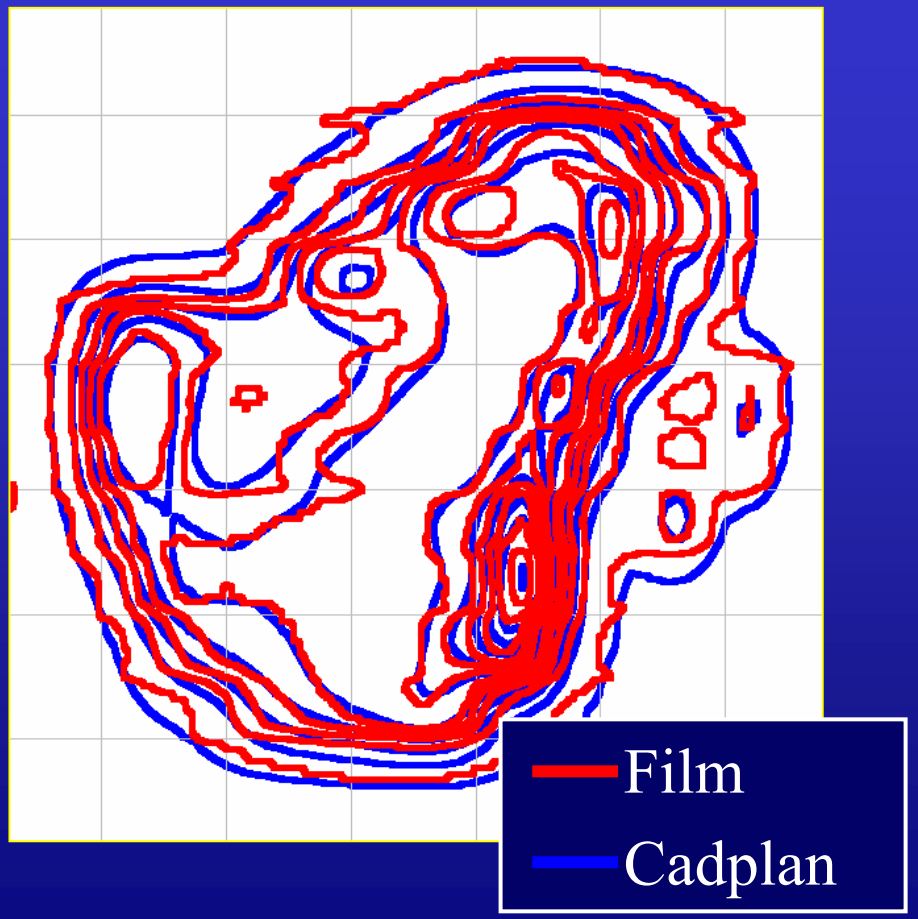
Phantoms

- Generally 3 types
  - Anthropomorphic
    - Internal heterogeneities are anatomically relevant
    - Multiple dosimeter comparison difficult
    - Geometric alignment cumbersome
  - Geometrically regular
    - Internal construction precise
    - Multiple dosimeters possible
    - Alignment straightforward
  - Geometrically irregular
    - Create fluence map to obtain a homogeneous dose distribution
    - Easy for analysis

Phantom Verification

- Necessary tools:
  - Dose Export of a defined area or plane into file or clipboard (ASCI)
  - Export of data to beam shaper for 2D phantom verification at specified depth
  - Independent registration of measurement and calculation needed

Film Dosimetry



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EPID & Gamma Evaluation

Gamma comparison at University Hospital Leuven:

clinical implementation of gamma algorithm
on dosimetry with PortalVision:

- pre-treatment evaluation:
  EPID versus TPS

- treatment evaluation:
  EPID versus TPS
  EPID versus EPID

- error detection

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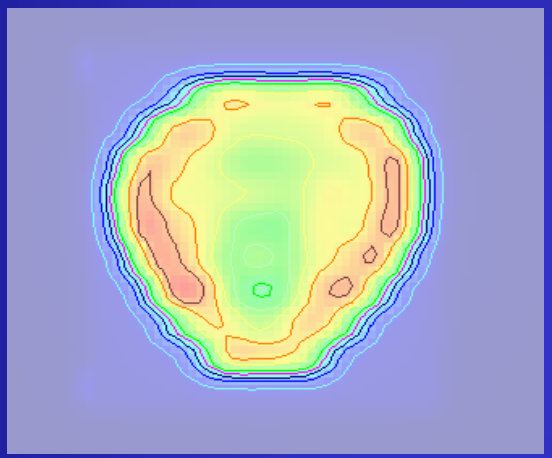
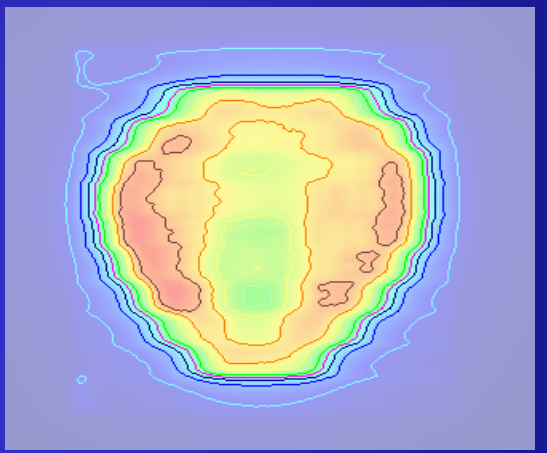
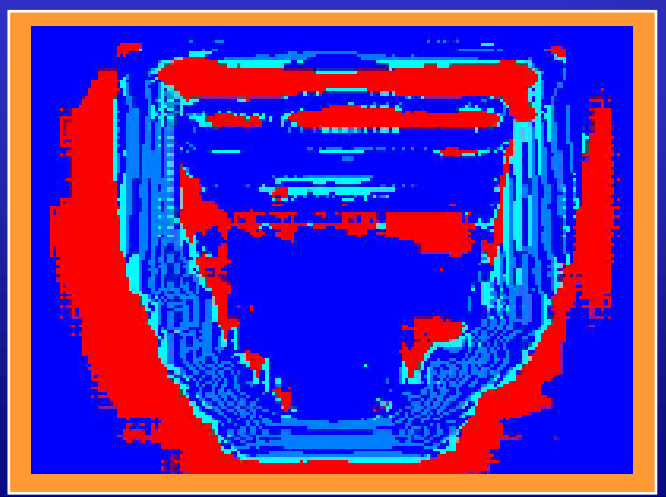
EPID & Gamma Evaluation

reference image



measured image

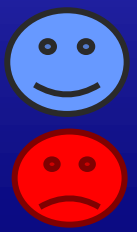




acceptance criteria:

ΔD_{max} (e.g. 1 %)

DTA (e.g. 1 mm)



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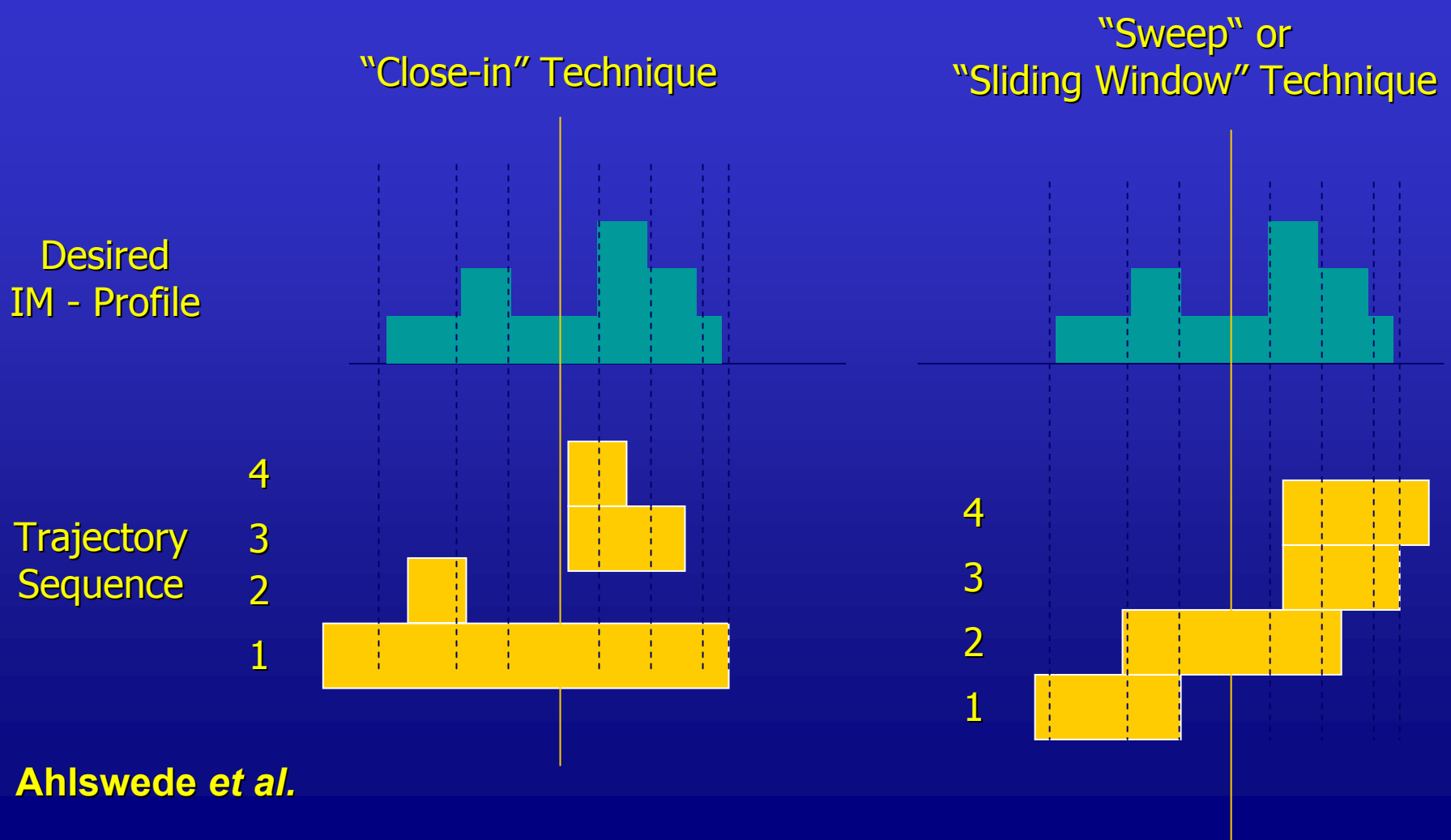
Hazard analysis

- Leaf calibration
  - e.g. OF can change with 7% for 0.1 cm difference in small field sizes for an Elekta linear accelerator.
  - Leaf sequence important
- Tertiary collimator
  - Alignment
  - Leaf sequence, abutting slices?

Leaf Sequencing



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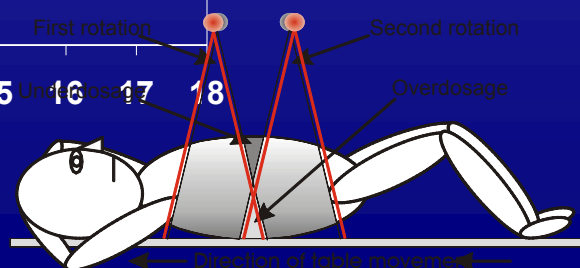
“Sequential” Tomotherapy: *The match line*

Index +1mm



Discrepancy analysis

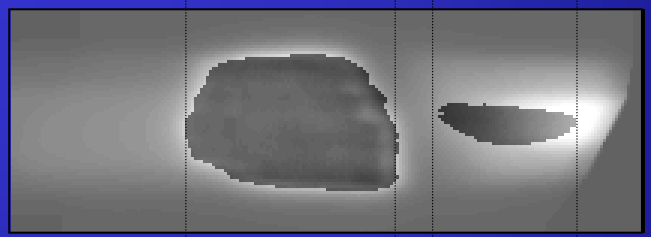
- TPS:
  - Basic beam data (PDD, OF, leaf offsets, penumbra)
  - Linac model
  - Dose calculation algorithm
  - Leaf sequencing algorithm
  - …
- Experiment:
  - TLD calibration
  - MLC data transfer
  - Experimental set-up (many things can go wrong: MU, positioning, gantry, … typically after-hours)
  - …

Discrepancy analysis (cont'd)

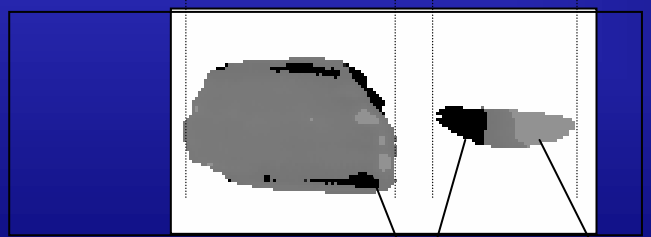
- Delivery
  - MLC calibration
  - Linac operation
  - …
- Analysis
  - Incorrect registration
  - Down-scaling of MU
    - Losing small segments
    - Underestimating leakage/transmission dose
  - …

Discrepancy analysis

R2 = 1/T2



Planning minus gel



Planning minus gel

< -5%

> +5%

De Wagter *et al.*

Discrepancy analysis

The relationship between measured versus calculated dose in function of increased constraints to the OAR while maintaining the prescribed target dose at 1.00 Gy

	Prescribed		Calculated		Measured		Meas/Calc		MU/^{o}
	T (Gy)	OAR (Gy)	T (Gy)	OAR (Gy)	T (Gy)	OAR (Gy)	T (Gy)	OAR (Gy)	
Case 1	1.00	0.25	1.08	0.32	1.08	0.34	1.00	1.04	0.79
Case 2	1.00	0.10	1.07	0.19	1.09	0.19	1.02	0.98	0.81
Case 3	1.00	0.06	1.17	0.05	1.09	0.09	0.94	1.83	1.30
Case 4	1.00	0.03	1.15	0.03	0.94	0.08	0.82	2.92	1.40

Inefficient use of the beam

Dose (OAR) ↓

&

Dose (Target) remains constant

⇓

The number of available ports ↓

⇓

The number of MU/° or MU/segment ↑

⇓

The contribution of leakage & scatter dose ↑

Discrepancy analysis: *Influence of leakage dose*

- Ionization chamber measurements showed a transmission of 0.5% through the vanes of the MIMiC.
- This enables to calculate an estimated leakage dose based on the total amount of MU delivered during tomotherapy

	Total MU	Leakage (cGy)	Calculated (cGy)	C + L (cGy)	Measured (cGy)	M/C	M/(C+L)
Case 1	458	2.29	32.4	34.7	33.6	1.04	0.97
Case 3	755	3.78	4.67	8.45	8.56	1.83	1.01

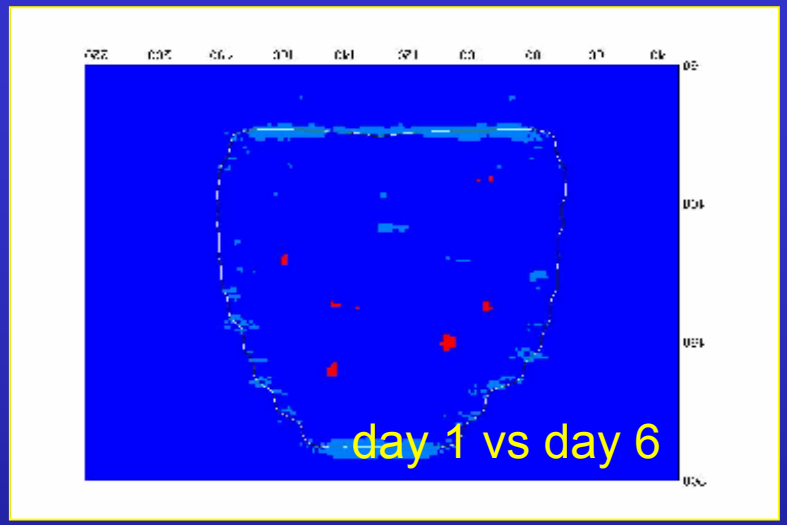
Discrepancy analysis: *Influence of leakage dose*

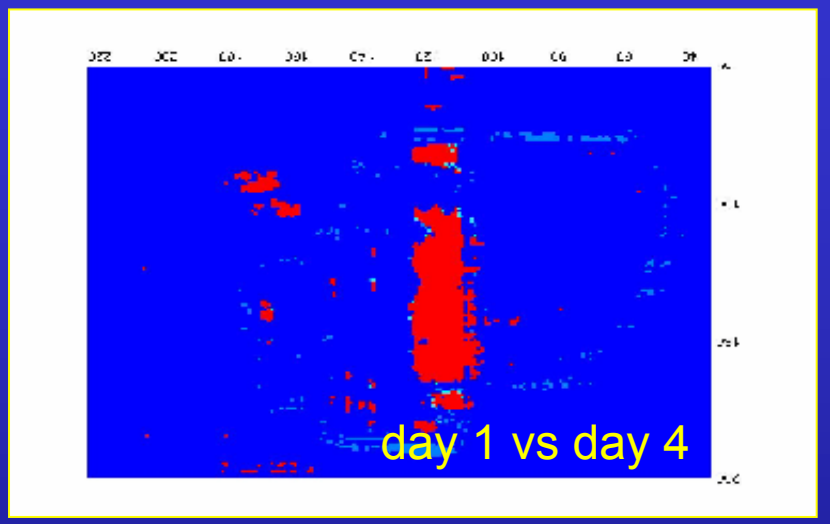
- Phantom measurements (TLD) of the tomotherapy procedure compared to an identical treatment with all vanes closed during treatment

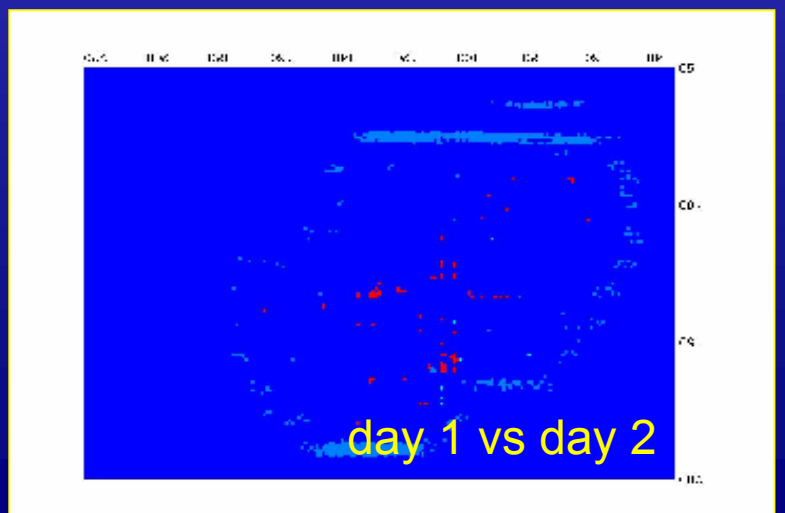
	Total MU	Leakage (cGy)	Calculated (cGy)	C + L (cGy)	Measured (cGy)	M/C	M/(C+L)
Case 1	458	1.60	32.3	33.9	33.6	1.04	0.99
Case 3	755	2.45	4.70	7.15	8.56	1.83	1.20

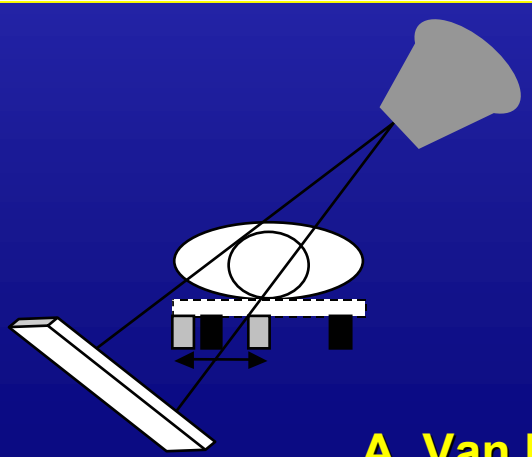
EPID & Gamma Evaluation

ΔD = 1% DTA = 3mm









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Beware of what has not been verified

- Threshold for skin contouring in TPS
- Extra-target dose
- Heterogeneity correction
- Target localization
- …

Extra-target dose

- Any absorbed dose the patient receives outsides the treatment volume must be considered undesirable.
- In addition to the primary beam absorption in overlying and underlying healthy tissue, the major sources are:
  - X-ray leakage
  - photons scattered out of the treatment volume
  - neutrons originating in the treatment head and leaking through the head shielding.

WBED per MU: $H_p(10)_{conv}$ - $H_p(10)_{tomo}$

Estimates of whole-body equivalent dose per MU obtained from TL-badge and neutron bubble detector measurements

	$H_p(10)_{conv}$ (mSv/MU)		$H_p(10)_{IMRT}$ (mSv/MU)	
	photons	neutrons	photons	neutrons
head	1.05×10^{-2}	-	2.73×10^{-2}	0.11×10^{-4}
sternum	1.18×10^{-2}	-	1.55×10^{-2}	0.27×10^{-4}
gonads	0.17×10^{-2}	-	0.31×10^{-2}	0.21×10^{-4}

*6 MV photon beam

WBED for a 70 Gy target dose

- $H_{p,conv}(70\ Gy) = 1.18 \times 10^{-2} \times 35 \times 585 = 242$ mSv

  $\therefore$ probability coeff. $= 1.2 \times 10^{-2}$

- $H_{p,tomo}(70\ Gy) = 1.55 \times 10^{-2} \times 35 \times 3630 = 1969$ mSv

  $\therefore$ probability coeff. $= 9.9 \times 10^{-2}$

Comparison *w literature*

	Verellen *et al*	Followill *et al*	Mutic *et al*
MU_{conv}	20475	8400	-
MU_{IMRT}	127050	67900	94500
ratio	6.2	8.1	-
$H_p(10)_{conv}$	1.18×10^{-2} mSv/MU	0.8×10^{-2} mSv/MU	-
$H_p(10)_{IMRT}$	1.55×10^{-2} mSv/MU	0.8×10^{-2} mSv/MU	0.4×10^{-2} mSv/MU
$H_{p,conv}$(70 Gy)	242 mSv	67 mSv	-
$H_{p,IMRT}$(70 Gy)	1969 mSv	543 mSv	406 mSv
ratio	8.1	8.1	-
Prob. $coeff_{conv}$	1.2×10^{-2}	0.4×10^{-2}	-
Prob. $Coeff_{IMRT}$	9.9×10^{-2}	2.8×10^{-2}	2.0×10^{-2}
ratio	8.3	7.0	-

WBED for a prostate case

- Assuming identical scatter conditions:

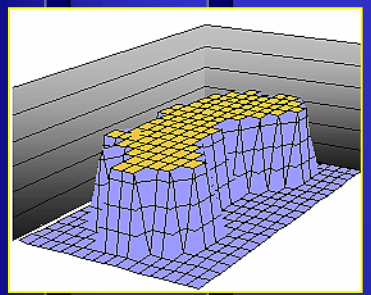
  $H_p(10) = 1.55 \times 10^{-2}$ mSv/MU

  $H_p(70\ Gy) = H_p(10) \times \#MU \times \#fractions$

  - serial tomother. (654 MU, 5 arcs): 1774 mSv
  - IMRT 1 (490 MU, 6 fields): 1595 mSv
  - IMRT 2 (128 MU, 6 fields): 417 mSv
  - Dynamic arc (292 MU, 1 arc): 158 mSv

Target Localization

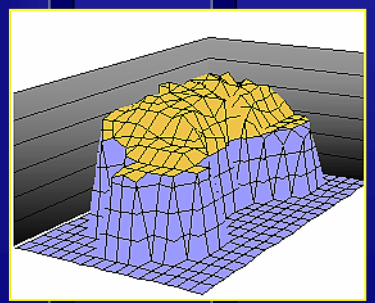
- Conformal Dose distribution



  - High dose volume is shaped to the volume occupied by the target.
  - Don't miss the target!

∴ PTV and PRV should reflect set-up accuracy!!!

- Temporal Intensity Modulation



  - Optimization based on snap-shot.
  - Target displacement/movement influences dose distribution.

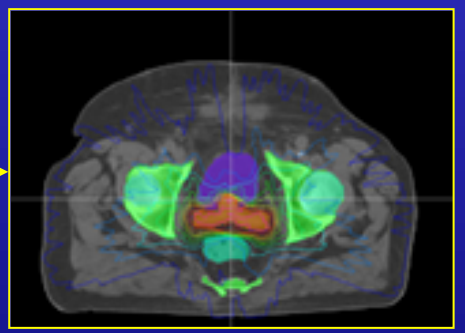
∴ Real-time knowledge of anatomy required!!!

The radiotherapy chain

Physical patient

- CT room coords
- Lasers
- Skin markers
- Images
- Bone
- Tumor
- Delineation
- Margin
- Planned beam

- Treatment room coords
- Lasers
- Skin markers
- Bone
- Tumor



- Beam
- Linac
- Treatment room

Van Herk *et al.*

Virtual patient

17 possibilities for geometrical errors

Solutions

- Tomotherapy
- EPID
- Ultra sound
- Cone beam CT
- Real-time infrared guidance
- Stereoscopic X-ray imaging

Conclusions

- Analyze the chain of events in your IMRT treatment procedure
  - Hazard analysis: define control points
  - Customize QA/QC procedure
  - Get comfortable with each step
- Complementary dosimetry
- QA procedure should be efficient
- Training of personnel!

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