The University of Manchester Manchester Cancer Research Centre

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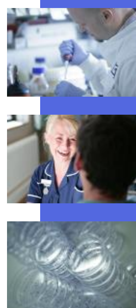
R.I.P. ITV

Marcel van Herk,
Paul Keall and Dan Low



•The MCRC is a member of the Manchester Academic Health Science Centre (MAHSC)

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- Marcel van Herk
  - Is ITV the correct motion encompassing strategy?
- Paul Keall
  - Make margins simple: Use real-time target tracking
- Dan Low
  - Gating is the best ITV killer

Margin simulation and discussion

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Is ITV the correct motion encompassing strategy?

Marcel van Herk
University of Manchester
Christie NHS trust

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Disclosure

- Our department has a research collaboration with Elekta Oncology Systems

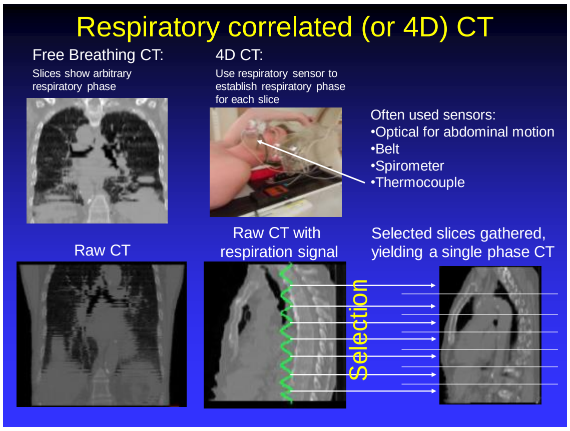
The issue: lung tumor motion

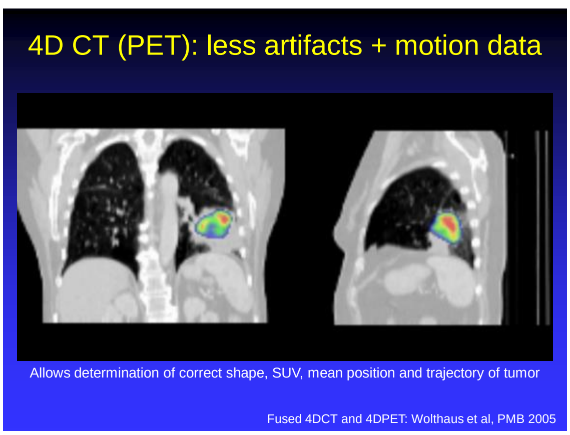
60% lung tumors move less than 1cm
35% between 1 and 2 cm
5% more than 2 cm
Motion increases towards diaphragm, largest in liver

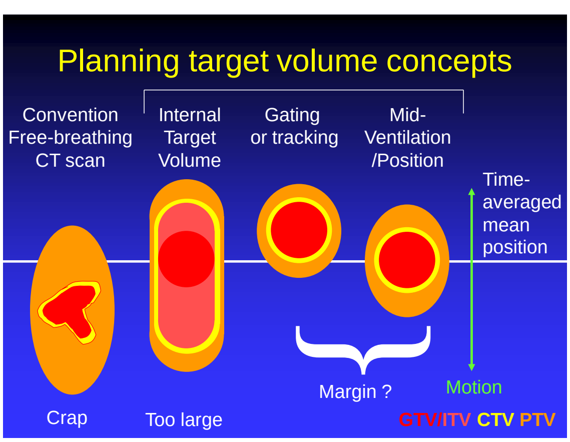
Seppenwoolde et al, 2001

How to minimize the margin?

- 4D imaging for planning
  - All abdominal (lung, liver) cancer patients
- Good delineation protocols and tools
- 4D image guidance
  - Beneficial for peak-peak motion > 1 cm
- Gating and tracking
  - Beneficial for peak-peak motion > 2 cm


Respiratory correlated (or 4D) CT
Free Breathing CT:
Slices show arbitrary respiratory phase
4D CT:
Use respiratory sensor to establish respiratory phase for each slice
Often used sensors:
•Optical for abdominal motion
•Belt
•Spirometer
•Thermocouple
Raw CT
Raw CT with respiration signal
Selected slices gathered, yielding a single phase CT
Selection


4D CT (PET): less artifacts + motion data
Allows determination of correct shape, SUV, mean position and trajectory of tumor
Fused 4DCT and 4DPET: Wolthaus et al, PMB 2005


Planning target volume concepts
Convention Free-breathing CT scan
Internal Target Volume
Gating or tracking
Mid-Ventilation /Position
Time-averaged mean position
Crap
Too large
Margin ?
Motion
GTV/ITV CTV PTV

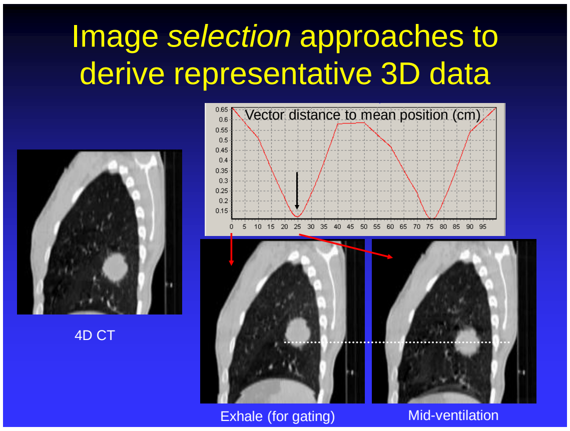
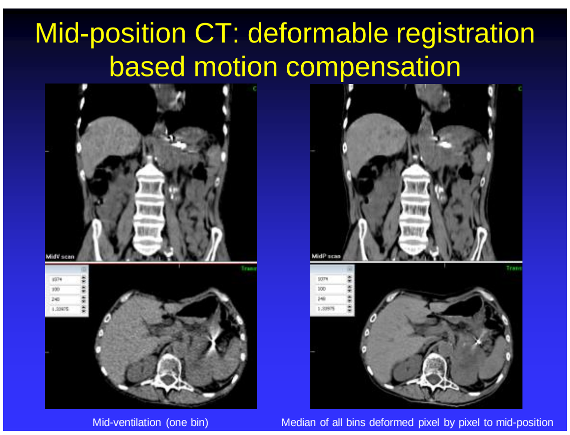
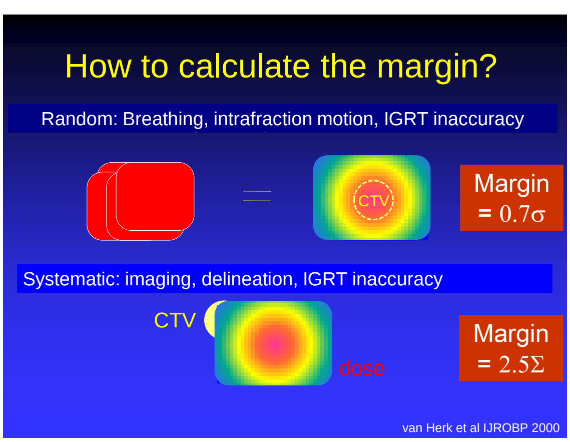


Image *selection* approaches to derive representative 3D data
Vector distance to mean position (cm)
4D CT
Exhale (for gating)
Mid-ventilation


Mid-position CT: deformable registration based motion compensation
Mid-ventilation (one bin)
Median of all bins deformed pixel by pixel to mid-position


How to calculate the margin?
Random: Breathing, intrafraction motion, IGRT inaccuracy
CTV
Margin = 0.7σ
Systematic: imaging, delineation, IGRT inaccuracy
CTV
dose
Margin = 2.5Σ
van Herk et al IJROBP 2000

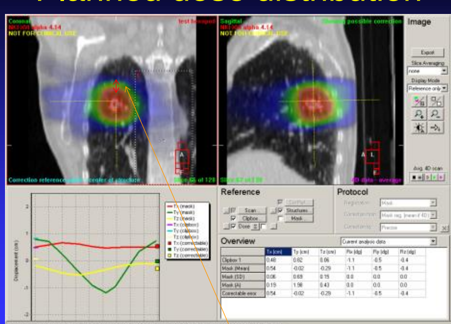
A physicists thought (≠ 2.5Σ + 0.7σ)

$$M = 2.5\Sigma + 0.84\sqrt{(\sigma_p^2 + \sigma^2)} - 0.84\sigma_p$$

- In plain language:
  - The required safety margin depends mostly on systematic errors (Σ), things that are reproducibly shifted for this patient
  - In photon radiotherapy, the margin for 'random' errors (σ) can be very small as long as the mean error is zero and $\sigma < \sigma_p$

van Herk et al, IJROBP 2000

Planned dose distribution



Dose is extra 'blurry' in lung: smaller margin required

σ_p ~6 mm in lung; ~3 mm in liver

Required margin: (σ_p = 6 mm, 5 fractions, prescribed at 80% isodose line, NO IGRT)

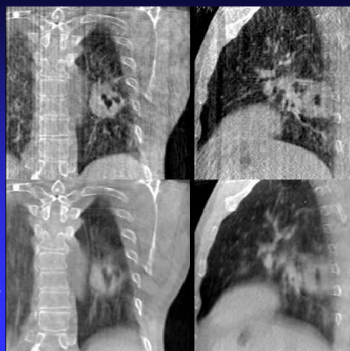
Error	Random errors	Systematic errors
Delineation uncertainty		
Setup error	4 mm	4 mm
Organ motion (baseline shift)	3 mm	3 mm
Intrafraction motion	1 mm	1 mm
Respiration	*10 mm*	*10 mm*
Margin	**3 mm**	**15 mm**

3 mm SD

3D versus 4D CBCT

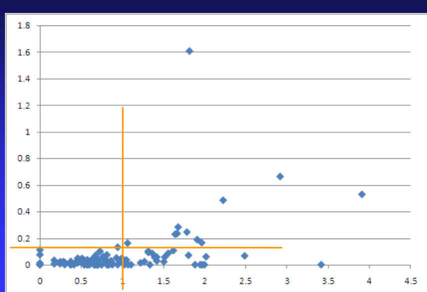
- 4D Data set
- 8 x 84 projections

- 3D Data set
- 670 projections



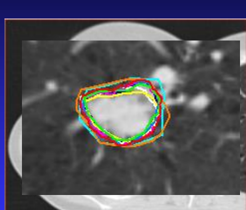
When is 4D guidance needed ?

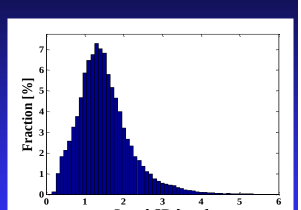
Error vector length (cm) →



Amplitude (cm) →

Target definition uncertainty must not be forgotten !





16 patients
10 radiation oncologists

RMS = 2 mm (1SD)

Required Margin (σ_p = 6 mm, 5 fractions, prescribed at 80% isodose line, IGRT)

Error	Random errors	Systematic errors
Delineation uncertainty		***2 mm***
Setup error	~~4 mm~~	~~4 mm~~
Organ motion (baseline shift)	~~3 mm~~	~~3 mm~~
Intrafraction motion	1 mm	1 mm
Respiration	*10 mm*	~~10 mm~~
Margin	**1 mm**	~~20 mm~~ → **5 mm**

Simulated dose distributions IGRT without tracking

A = 10 mm, M = 6 mm

Margin simulation (σ_p = 6 mm, 3 fractions, prescribed at 80% isodose line, IGRT&tracking)

Error	Random errors	Systematic errors
Delineation uncertainty		*2 mm*
Setup error	~~4 mm~~	~~4 mm~~
Organ motion (baseline shift)	~~3 mm~~	~~3 mm~~
Intrafraction motion	1 mm	1 mm
Respiration	~~*10 mm*~~ → *1 mm*	~~10 mm~~
Margin	~~3 mm~~ → **0 mm**	~~20 mm~~ → **5 mm**

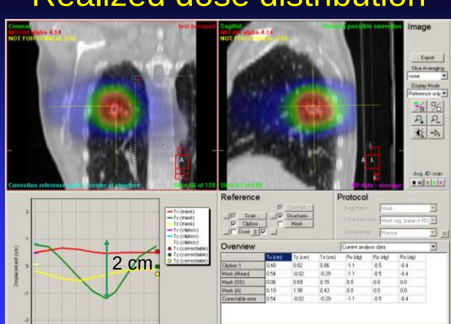
Where is the ITV ?

Respiration motion causes a dose blurring that is easily compensated with a very small margin

Lung: margin is 1 mm for 10 mm pp amplitude

Planned dose distribution

Realized dose distribution



2 cm tumor motion → 3 mm extra margin

Clinical results with mid-V

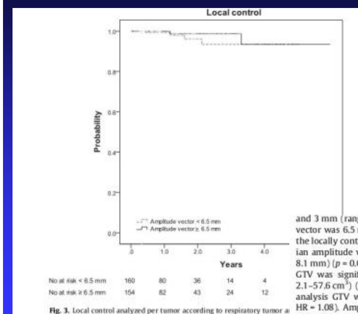


Fig. 3. Local control analyzed per tumor according to respiratory tumor a

and 3 mm (range 0–18 mm), respectively. The median amplitude vector was 6.5 mm (range 0–39 mm) for all tumors as well as for the locally controlled tumors. In case of local recurrence, the median amplitude vector was significantly *smaller*: 3.0 mm (range 1–8.1 mm) ($p = 0.04$). In patients with a local recurrence the median GTV was significantly larger with a volume of 16.0 cm^3 (range 2.1–57.6 cm^3) ($p = 0.04$). In univariate continuous Cox-regression analysis GTV was predictive for local recurrence ($p < 0.001$ and HR = 1.08). Amplitude vector was borderline significant ($p = 0.08$ and HR = 0.77). ROC analysis revealed an optimal cut-off for amplitude vector of 3.5 mm. Additional Cox-regression was significant

Peulen et al, R&O 2014

Conclusions

- Respiration has only a small effect of dose delivery in lung cancer
- Main uncertainty remaining after full IGRT is delineation variability M>5mm
- Depending in amplitude I suggest:
  - A<1 cm: 4D CT and 3D IGRT M<1mm
  - 1cm<A<2cm: 4D CT and 3D IGRT M<3mm
  - A>2cm: gating or tracking M>3mm
- This approach is clinically proven

Thank you for your attention