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Margin simulation and discussion

Is ITV the correct motion encompassing strategy?

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Christie NHS trust
Disclosure

• Our department has a research collaboration with Elekta Oncology Systems

The issue: lung tumor motion

60% lung tumors move less than 1 cm
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

Raw CT

4D CT: Use respiratory sensor to establish respiratory phase for each slice

Raw CT with respiration signal

Selected slices gathered, yielding a single phase CT

Often used sensors:
- Optical for abdominal motion
- Spirometer
- Thermocouple

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

Margin ?

GTV = ITV CTV PTV

Crap Too large
**Image selection approaches to derive representative 3D data**

- Mid-ventilation
- Exhale (for gating)
- 4D CT

**Mid-position CT: deformable registration based motion compensation**

- Median of all bins deformed pixel by pixel to mid-position
- Mid-ventilation (one bin)

**How to calculate the margin?**

**Random: Breathing, intrafraction motion, IGRT inaccuracy**

- Margin = 0.7\(\sigma\)

**Systematic: imaging, delineation, IGRT inaccuracy**

- Margin = 2.5\(\Sigma\)

"van Herk et al IJROBP 2000"
A physicist's thought ($\neq 2.5 \Sigma + 0.7 \sigma$)

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

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

van Herk et al, IROBP 2000

Planned dose distribution

Dose is extra ‘blurry’ in lung: smaller margin required.

<table>
<thead>
<tr>
<th>Error</th>
<th>Random errors</th>
<th>Systematic errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delineation uncertainty</td>
<td>4 mm</td>
<td>4 mm</td>
</tr>
<tr>
<td>Setup error</td>
<td>3 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td>Organ motion (baseline shift)</td>
<td>1 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Intrafraction motion</td>
<td>10 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>Margin</td>
<td>3 mm</td>
<td>15 mm</td>
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</tbody>
</table>

Required margin: ($\sigma_p = 6$ mm, 5 fractions, prescribed at 80% isodose line, NO IGRT)
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** ($\sigma_p = 6 \text{ mm}, 5 \text{ fractions}, \text{ prescribed at 80\% isodose line, IGRT})

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</tr>
<tr>
<td>Respiration</td>
<td>10 mm</td>
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</tr>
<tr>
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<td>1 mm</td>
<td>20 mm $\rightarrow$ 5 mm</td>
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**Simulated dose distributions**

**IGRT without tracking**

- A = 10 mm, M = 6 mm

**Margin simulation** ($\sigma_p = 6 \text{ mm}, 3 \text{ fractions}, \text{ prescribed at 80\% isodose line, IGRT\&tracking})

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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.
Conclusions

- Respiration has only a small effect of dose delivery in lung cancer
- Main uncertainty remaining after full IGRT is delineation variability M>6mm
- 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