Challenges in thoracic imaging for image-guided radiotherapy

Professor Suresh Senan
Radiation oncologist
Disclosure

The VU University medical center has research agreements with Varian Medical Systems (Palo Alto, CA) and Velocity Medical Solutions (Atlanta, GA).
Overview

– Definition of 4-D RT, IGRT
– Motion assessment: Fluoroscopy, slow CT, 4DCT, PET
– Motion of lymph nodes
– Use of FDG-PET scans for target definition
– Baseline shifts in tumor position
– Role of adaptive radiotherapy & replanning
Epidemiology of Cancer in Europe

Distribution of new cancer cases in Europe 2006

Distribution of new cancer deaths in Europe 2006

Karim-Kos 2008
Fang LC, 2006

Fig. 4. Local-regional control for all patients.

Table 4. Pattern of failure

<table>
<thead>
<tr>
<th>Site of failure</th>
<th>All pts., no. of patients (%)</th>
<th>2D, no. of patients (%)</th>
<th>3D, no. of patients (%)</th>
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<tbody>
<tr>
<td>Total failures</td>
<td>95/196 (48)</td>
<td>64/111 (58)</td>
<td>31/85 (36)</td>
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<tr>
<td>Local alone</td>
<td>26 (27)</td>
<td>18 (28)</td>
<td>8 (26)</td>
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<tr>
<td>Regional alone</td>
<td>6 (6)</td>
<td>5 (8)</td>
<td>1 (3)</td>
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<tr>
<td>Locoregional</td>
<td>4 (4)</td>
<td>2 (3)</td>
<td>2 (6)</td>
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<td>DM only</td>
<td>23 (24)</td>
<td>10 (16)</td>
<td>13 (42)</td>
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<tr>
<td>DM + local</td>
<td>20 (21)</td>
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<tr>
<td>DM + regional</td>
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<td>7 (10)</td>
<td>3 (10)</td>
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<tr>
<td>DM + locoregional</td>
<td>6 (6)</td>
<td>5 (8)</td>
<td>1 (3)</td>
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</table>

Abbreviation: DM = distant metastasis; other abbreviations as in Table 1.
Is tumor motion an important cause of local failure?
3D Conformal radiotherapy
(or how we used to work)
Planning CT for the thorax

Conventional (3D) CT image

4DCT reconstruction showing all possible tumour positions
Motion of primary lung tumors

4DCT in 166 tumors

For 95% of the tumors, motion in SI, lat and AP directions is ≤ 1.34 cm, 0.40 cm, and 0.59 cm, respectively.

Liu 2007
First routinely available 4D imaging technique for lung tumors

MULTIPLE “SLOW” CT SCANS FOR INCORPORATING LUNG TUMOR MOBILITY IN RADIOTHERAPY PLANNING

4D imaging using ‘slow’ CT scan

Serial CT slices

4 seconds per slice

Actual tumor

‘Slow’ image

Fast CT

‘Slow’ CT

Lagerwaard 2001
4DCT, or respiration-correlated CT scan

RPM Signal

X-ray on
X-ray off

First couch position
Second couch position
4D image sorting

CT Image Sorting Program

End-expiration

End-inspiration

Full respiratory cycle
4 sec
4D image sorting

Full respiratory cycle
4 sec

End-inspiration

End-expiration

CT Image Sorting Program

Mid-exhale

End-exhale

Mid-inhale

End-inhale

10 respiratory ‘bins’ obtained
Screen-view of 4D viewer

Advantage4D (GE Healthcare)
• **Max Intensity Projection (MIP):** maximum value of a pixel over all phases; indicates any location where tumor is present in any of the phases.

• **Min IP:** minimum value of each pixel over all phases; indicates only those locations where tumor is constantly present over all phases.

• **Mean IP:** mean value of each pixel over all phases; represents the time-weighted location of the tumor.

Underberg R. IJROBP 2005
Mean single phase volume = 16.3 cc +/- 0.6 cc

Underberg, 2005
Limitations of using MIPs

- **Caution** with MIP's for tumors adjacent to mediastinum or diaphragm
- Review target volumes at extreme phases of a 4DCT scan

Underberg 2005
Other developments to facilitate use of 4DCT data
4DCT: Color intensity projections

Cover, Lagerwaard, Senan. IJROBP 2006

Color encoding of time period a structure is present at that location
• **Composite CIP images** calculated on a pixel-by-pixel basis; component phase images windowed and images scaled linearly. Max., mean, and min. intensity for each pixel over all phases calculated. **Hue-saturation-brightness (HSB)** for each pixel of CIP image calculated.

• Pixels **unchanged** in all bins appear **uncoloured**.

• Color encoding of period of **time** a **structure** present at location.

• **CIP** implemented as written plug-in to ImageJ (1.31v), a Java based image processing package (http://rsb.info.nih.gov/ij/)
Panel showing grayscale image at all phases
TARGET VOLUME DELINEATION IN STAGE I LUNG CANCER:

COMPARISON OF MAXIMAL INTENSITY PROJECTIONS (MIP) VS DEFORMABLE REGISTRATION TOOL FOR PROPAGATING GTV CONTOURS

J.R. van Sörnsen de Koste¹, I.E. van Dam¹, G.G. Hanna², R. Muirhead³, B.J. Slotman¹ and S. Senan¹

¹ Dept. of Radiation Oncology, VU University medical center, Amsterdam, The Netherlands
² Center for Cancer Research and Cell Biology, Queen's University Belfast, N. Ireland
³ The Beatson, West of Scotland Cancer Center, Glasgow, United Kingdom
• We assumed deformable image registration tool could avoid some drawbacks associated with contouring MIP.

• Our study compared target definition using MIP modified by 4DCT end-respiratory phases with contour propagation in all phases of 4DCT using a deformable registration tool.
4DCT planning scans of 6 patients (varying tumor sizes, locations, radiological appearances and extent of tumor motion.

3 observers contoured visible tumor (GTV) on end-inspiration CT scan and again after two weeks; 2 observers contoured GTVs on all CT images of 4DCT and all MIPs.

Contoured end-inspiration GTVs were propagated over 9 other 4DCT phases using a deformable registration tool (Modified Bspline algorithm combined with Mattes formulation, Velocity Medical Systems)
• Intra- and inter observer variations in end-inspiration GTV determined for volumetric coverage and Dice volume similarity Coefficients (DC):

\[
\text{Dice's Coefficient} = \frac{2(A \cap B)}{A + B}
\]

• GTV motions and shapes were evaluated from contoured 4DCT scan (2 observers) and using deformable registration (1 observer).

• Routine MIP-based ITV definition compared to deformably reconstructed ITVs.
Contoured GTV in all patients

• Intra-clinician GTVs reproduced better than inter-clinician GTVs: 92.9% (4.2%, 1SD) Vs. 86.0% (10.6%, 1SD) [P< 0.02, T-test].
• Mean DC numbers indicate same trends: 0.93 vs. 0.89 [P<0.02].
Results

Deformable Vs. MIP-based ITV definition

Pat.3  
Window / Level setting - Mediastinum
AV-IP (4DCT)  MIP (4DCT)

"Optimal" ITV  Routine ITV
• Changes in tumor shape occur during respiration; deformable registration may better account for this without the confounding effects of intra-clinician variations in contouring.

• The ‘optimal’ ITV ($ITV_{10\text{def-optimized}}$) was smaller than our routine MIP-based ITV in 2 patients (2-10%) and was larger in 3 (5-10%).

• Manual ITV from all 4DCT phases was larger than ‘optimal’ ITV in 5 of 6 patients (range 1-11%).

Conclusion

• MIP-based ITV definition differ by up to 10% versus ‘optimal’ ITVs derived using deformable registration.
Local-, regional- and distant failure

N= 402 patients with single T1-T2 tumor
Median follow-up 24 months (range 3-56 months)

Local Failure N=7 (1.7%)
Median time to LF 10 months

Actuarial local failure:
@1 year: 2.1%
@2 years: 2.7%
@3 years: 4.8%

Regional Failure N=26 (6.5%)
Median time to RF 8 months

Actuarial regional failure:
@1 year: 5.7%
@2 year: 12.0%
@3 year: 12.0%

Distant Failure N=52 (12.9%)
Median time to DF 8 months

Actuarial distant failure:
@1 year: 11.1%
@2 year: 21.2%
@3 year: 25.9%
### Stage I NSCLC: Toxicity of stereotactic RT

**Lagerwaard, 2008**

**Acute and subacute**

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<td>Fatigue</td>
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<td>12%</td>
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<td>Nausea</td>
<td>9%</td>
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<tr>
<td>Dyspnea</td>
<td>6%</td>
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<tr>
<td>Cough</td>
<td>6%</td>
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<td>Hemoptysis</td>
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<tr>
<td>Palpitations</td>
<td>1%</td>
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</table>

**Late**

- Radiation pneumonitis: 9 (3%)
- Thoracic wall pain: 6 (2%)
- Rib fracture: 4 (1%)
- Pleural effusion: 4 (1%)

ELCC-ESMO 2008
4-dimensional radiotherapy (4DRT)

- ‘explicit inclusion of the temporal changes in anatomy during the imaging, planning and delivery of radiotherapy’
- In principle, 4D radiotherapy is intuitive and simple.
- In practice, 4D radiotherapy is a very difficult problem, with many levels of complexity.

Keall P, 2004
4D radiotherapy for lung cancer

IGRT for lung cancer

4D imaging
- 4DCT
- ‘Slow’ CT scans
- Fluoroscopy
- PET-CT scans (?)gated

Treatment Planning & delivery

4D verification

Intervention
- (yes/no; threshold ??)

No intervention
- (time-trends)

Intervention
- (adaptive radiotherapy)

Reproducibility of intervention or respiratory pattern

Lagerwaard 2007
Image-guided radiotherapy

1. Frequent imaging during radiotherapy

2. Use of the images to improve precision and accuracy of radiation delivery

(reduced set-up errors = small radiation fields)
• 29 peripheral lung tumors
• 4 clinicians scored mobility on fluoroscopy
• Contours in 4DCT used to measure mobility
• Motion estimates not possible in 8 pts
• Mobility overestimated using fluoroscopy
• Mean ITVs derived with fluoroscopy are 52% larger than if 4DCT contours used
Use of ITV approach

- Mageras G, 2004 (MSKCC)
- Underberg R, 2004 (VUMC)
- Takayama K, 2005 (Kyoto U.)
- Hodge W, 2006 (Wisconsin U.)
- Bradley J, 2006 (Wash U.)
- Rietzel E, 2008 (MGH)
- Chang J, 2008 (MDAH)

Requires ‘10 mins’
Stage I NSCLC – contouring guidelines

Radiation Oncology

Study protocol
Recommendations for implementing stereotactic radiotherapy in peripheral stage IA non-small cell lung cancer: report from the Quality Assurance Working Party of the randomised phase III ROSEL study
Coen W Hurkmans*1, Johan P Cuijpers2, Frank J Lagerwaard2, Joachim Widder3, Uulke A van der Heide4, Danny Schuring1 and Suresh Senan2
**PTV based on the ITV concept**
For 4D CT scans, the ITV can be derived from the union of GTV delineations on all breathing phases or alternatively, from contouring on a maximum intensity projection (MIP) CT-dataset [28,29]. The appropriateness of the MIP-delineation should at least be confirmed by a visual inspection of the projected ITV contours on the CT-datasets of the end-inspiration and end-expiration phase bins using axial, sagittal and coronal views. In addition to the

**PTV based on the mean tumour position**
As an alternative to the ITV concept, planning and irradiation based on the time-averaged mean position of the tumour has been developed [32]. In contrast to the ITV to PTV margin discussed previously, the CTV to PTV margin needed here should take the tumour motion into account. However, similar to the reasoning given for the ITV to PTV margin, a minimum margin of 3 mm should be used for the incorporation of the other uncertainties.
4D radiotherapy for lung cancer

IGRT for lung cancer

4D imaging
- 4DCT
- ‘Slow’ CT scans
- Fluoroscopy
- PET-CT scans (gated)

Treatment Planning & delivery

4D verification

Intervention
(yes/no; threshold ??)

Reproducibility of intervention or respiratory pattern

No intervention
(time-trends)

Intervention
(adaptive radiotherapy)

Lagerwaard 2007
## Motion management strategies

<table>
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<th>Method</th>
<th>Technique</th>
<th>Comments</th>
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<td>Incorporate all movements</td>
<td>4DCT or slow CT</td>
<td>May lead to increased risk of normal tissue toxicity</td>
</tr>
<tr>
<td>Freeze movement</td>
<td>Breath hold</td>
<td>Not feasible in all lung cancer patients</td>
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</tbody>
</table>
| Intercept movement: ‘gated’ radiotherapy | Respiratory cycle as surrogate of tumor position | (1) Treatment time increased  
(2) Difficulties in target verification |
| Track or chase tumor        | Implanted markers and specialized treatment delivery | (1) Difficult endobronchial marker insertion  
(2) CT-guided insertion risks pneumothorax  
(3) Markers migrate after insertion  
(4) Difficult to predict normal tissues doses |

Lagerwaard 2007
When to manage respiratory motion?

AAPM Task Group 76: respiratory management techniques should be considered if either of the following conditions occur:

• >5 mm range of motion is observed in any direction; or

• significant normal tissue sparing as determined by your clinic can be gained using a respiration management technique.

Keall 2006
Motion intervention strategy?

Manage motion if in >5 mm [AAPM TG76], …… but what about reproducibility of interventions?

‘Motion may be less than the reproducibility of intervention to reduce motion’ [Dawson ’05]
Is gating needed in stage I NSCLC?

Conventional target volume

Gated target volume
Is gated SRT necessary in stage I NSCLC?

Underberg R, 2005

Analysis of 4DCT scans in 34 patients with stage I NSCLC

- ≥ 50% reduction in PTV achieved in 15% of tumors
- ≥ 30% reduction in PTV achieved in 38% of tumors
Respiratory gating: a warning!

- Respiratory gating... is better than not accounting for motion at all only if it is carried out properly.
- Tight margins increase the risk of geometric misses,.. require accurate treatment delivery.
- Such accurate delivery is not trivial because of inter- and intrafractional variations.

Li X, 2007
Can gating worsen outcomes?

Kato M, 2004

- Stage I NSCLC treated with carbon ion radiotherapy
- Total of 81 patients; 23.2% local recurrences

<table>
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<tr>
<th>Patient</th>
<th>Recurrence pattern</th>
<th>Period (month)</th>
<th>Respiratory-gated irradiation</th>
<th>Provisional target (yes/no)</th>
<th>Fractionation</th>
<th>Total dose (GyE)</th>
<th>Number of irradiation portals</th>
<th>Type of tissue</th>
<th>Locus</th>
<th>Tumor size (mm)</th>
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CLINICAL INVESTIGATION

IMPACT OF AUDIO-COACHING ON THE POSITION OF LUNG TUMORS

CORNELIS J. A. HAASBEEK, M.D., FEMKE O. B. SPOELSTRA, M.D., FRANK J. LAGERWAARD, M.D., Ph.D.,
JOHN R. VAN SÖRNSSEN DE KOSTE, Ph.D., JOHAN P. CUIJPERS, Ph.D., BEN J. SLOTMAN, M.D., Ph.D.,
AND SURESH SENAN, M.R.C.P., F.R.C.R., Ph.D.

doi:10.1016/j.ijrobp.2007.11.061
Starting audio coaching led to displacements in ITV position of ≥5mm in up to 56% of mobile tumors.

Respiratory gating at end-inspiration and end-expiration were equally susceptible to displacements.

Underscores importance of ensuring similar respiratory patterns during imaging and delivery of gated radiotherapy.
• Difficult endobronchial marker insertion
• CT-guided insertion risks pneumothorax
• Markers migrate after insertion
• Difficult to predict normal tissues doses with tracking
• **Imura 2005**: Markers in bronchial tree allow for setup accuracy of ± 2 mm during a 1–2-week treatment period.

• Relationship between markers and tumor can change significantly after 2 weeks.

• **Nagata 2005**: Only 14% of Japanese centers use fiducial markers
Pneumothorax rates

- Choi CM, 2004: 22% of 458 pts; but was delayed in 3.3% (pneumothorax not developing later than 3h was defined as a delayed pneumothorax).

- Geraghty PR, 2003: 38% of 324 patients after use of 18-gauge needles and 23% of 522 after use of 19-gauge needles.
Is a single 4D imaging scan sufficient?

‘Baseline shifts’ in tumor position?
Reproducibility of 4DCT

Haasbeek CJA, 2007

- 60 tumors (59 patients) using 4DCT scans repeated after 2 or more fractions of stereotactic radiotherapy.
- Repeat scans performed at a mean of 6.6 days (range 2–12 days) after the first fraction.
- Original SRT plan applied to PTV_{4DCT2}, and coverage by the 80% prescription isodose determined.
Mean 3D displacement between center of mass of both PTVs was 2.0 mm.

Initial 80% prescription isodose ensured a mean coverage of 98% for repeat PTVs.

80% isodose encompassed repeat ITV in all but 1 tumor**.

**“Inadequate” coverage caused by new area of atelectasis adjacent to tumor on the repeat 4DCT.
Reproducibility in target position using repeat CBCT imaging (n= 8 patients)

Purdie TG 2007
New Eclipse optimisation algorithm that *simultaneously* changes 3 parameters during treatment

- shape of treatment aperture
- delivered dose intensity
- speed of gantry rotation
VUmc RapidArc

Rapidly changing dose rate throughout a continuous range allows greater variation in intensity levels at different gantry angles.

Example of critical structure avoided by traversing leaf pairs across it while dose rate is reduced to nearly zero.
Daily setup based on tumor position

SBRT delivery in <12 mins using RapidArc [Verbakel W, 2009]
Role of FDG-PET for target definition

- Established role for in PET staging
- PET for defining target volumes?
- PET for ‘adaptive radiotherapy’?
CAN PET PROVIDE THE 3D EXTENT OF TUMOR MOTION FOR INDIVIDUALIZED INTERNAL TARGET VOLUMES? A PHANTOM STUDY OF THE LIMITATIONS OF CT AND THE PROMISE OF PET

CURTIS B. CALDWELL, PH.D.,*† KATHERINE MAH, M.SC.,‡§ MATTHEW SKINNER, M.SC.,‡ AND CYRIL E. DANJOUX, M.D.†§

Fig. 4. AP maximum pixel ray trace $^{22}$Na-PET images of the same sphere while (a) stationary and moving 25 mm in the (b) longitudinal and (c) transaxial directions. The period was 4 s, and the images were acquired over 30 min. The graphical overlay represents the region localized using a threshold defined by 15% of the maximum voxel value. These images illustrate that the time-averaged, capsule-shaped geometry that the moving sphere traces is better represented by PET compared with spiral CT.
• 70 surgical specimens; mean microscopic tumour extension of 2.69 mm (adenocarcinomas) and 1.48 mm (squamous cell)

• To account for 95% of all microscopic extension, use of margins of 8 mm (adenoc.) and 6 mm (squamous)

Giraud 2000
AAH: atypical adenomatous hyperplasias

Number of cancer cells needed for detection?

3 human cancer cell lines [glioblastoma and 2 subtypes of SCLC] in concentrations $10^4$ - $10^7$ were seeded on 6-well plates or plastic tubes and treated with FDG-glucose in vitro.

FDG retention measured in a PET/CT scanner and in a calibrated well counter. Clinical situation simulated using a cylinder phantom with a background concentration of FDG.

**Theoretical detection limit** was around $10^5$ **malignant cells**. In a **cylinder phantom** the detection limit was **increased** by a factor of 10. FDG retention measured by PET and a gamma counter was closely correlated to the number of cells and a linear relationship was found.

**Detection limit of PET** is in magnitude of $10^5$ to $10^6$ malignant cells.

Fischer BM. 2006
Optimal Distance of Malignant Negative Margin in Excision of Nonsmall Cell Lung Cancer: A Multicenter Prospective Study

Sawabata 2004, N = 118 cases of NSCLC

Conclusions. Malignant positive margins were not found when the margin distance was greater than the maximum tumor diameter, which was considered to be the optimal margin distance for prevention against margin relapse.

Belief in PET-based target volumes?

“When the tide goes out, we find out who’s been swimming without a bathing suit.”

Warren Buffett, 2007
Stereotactic RT (SRT): PET-only target definition

- SRT planning performed using BrainSCAN 5.31 to total dose of 60Gy (8×7.5Gy / isocenter)

- Planning spiral CT performed in shallow tidal breathing.

- FDG-PET scan in treatment position and images co-registered with CT

- Delineated tumor volume based on CT and FDG-PET information to compensate for internal motion

Bral S, 2007
In-field tumor progression-free probability at 2 years was only 64.7%

Bral S, 2007
PET heterogeneity versus pathology

N=5 patients

Fig. 1. Visualization of the total procedure: Total surgical specimen (a), specimen sectioned in parallel slices of 1 cm thickness ready to be scanned (b), delineation of tumour heterogeneity in E-soft with regions with 80% (pink line), 50% (green line) and 20% (red line) of maximal uptake of FDG (c) and biopsies from the different regions (d).

van Baardwijk 2008
PET heterogeneity versus pathology

<table>
<thead>
<tr>
<th></th>
<th>Low uptake</th>
<th>Median uptake</th>
<th>High uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainly vital tumour (&gt;75%)</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Mainly fibrosis (&gt;75%)</td>
<td>3*</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Combination of vital tumour, fibrosis and/or inflammation or necrosis</td>
<td>2</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

No significant differences in distribution patterns were observed ($p = 0.16$).

* Two samples showed no vital tumour cells.

Van Baardwijk 2008 (N= 5 patients)
Use of FDG-PET to define target volumes?

- **Methods**: SRT target volumes (TV) using 4DCT were compared to 6 different approaches for PET TV’s in 7 patients with stage I NSCLC.
- Dice similarity coefficient used to assess volume, shape and positional change in PET-generated TVs versus 4DCT TVs.
- **Conclusion**: Conventional PET-TVs do not correspond to MIP-based TVs commonly used for SRT, and all were significantly smaller.

Conformality (Dice coeff) of PET outlining techniques with MIP-modified volumes in 7 patients

Hanna GG, *submitted*
Stereotactic RT aims to **cure** stage I disease.

Focus on FDG-PET as a means of reducing inter-clinician variability may have reduced cure rates at some institutes.
New International Lymph Node Map

IASLC Lung staging project
[Rusch V, 2009]
Stage III nsclc – Delivery of higher doses

IMRT-based approaches allowing delivery of 66 Gy
Availability of better dose constraints for standard CT-RT
# Defining nodal GTVs

<table>
<thead>
<tr>
<th>Nodal Diameter (short-axis)</th>
<th>Approach</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 cm &amp; PET +ve</td>
<td>Include in GTV</td>
<td>High positive predictive value of PET scan</td>
</tr>
<tr>
<td>&lt; 1 cm &amp; PET –ve</td>
<td>Exclude from GTV</td>
<td>Only if dedicated PET scan was used</td>
</tr>
<tr>
<td>&gt; 1 cm &amp; PET +ve</td>
<td>Include in GTV unless representative cytology from the node is negative</td>
<td>EUS-guided aspiration cytology has sensitivity of 88% &amp; accuracy of 91%</td>
</tr>
<tr>
<td>1-1.5 cm &amp; PET -ve and if no cytology available</td>
<td>If primary PET+ve, exclude node from GTV unless cytologically +ve</td>
<td></td>
</tr>
<tr>
<td>≥ 1.5 cm &amp; PET –ve and if no cytology available</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**VUmc scheme** [Modified from Senan 2004]

- 21% probability of **N2** disease [meta-analysis, de Langen 2006]
Liu et al, IJROBP 2007
166 lung tumors, 48% Stage III

Proportion of primary tumors with motion > 0.5 cm during normal breathing:
SI axis: 39.2%
ML axis: 1.8%
AP axis: 5.4%
No involved-field radiotherapy without 4DCT
In 11 of 16 patients, ≥1 malignant node moved more than primary tumor.

In 6 patients with “immobile” lung tumors, 4 had nodes with motion > 0.5 cm.

No correlation between 3D motion of primary tumor and nodal motion.
• “Use of new image-guidance technologies to visualize changes in tumour size, shape and position

• Allow for planning adjustments to be made during a course of radiotherapy in order to improve both target coverage and normal tissue avoidance”

Verellen 2007
Primary tumor and nodes may not move in phase.
Change in internal target volumes for 21 patients between time of simulation and at 30 Gy full-dose CT-RT.

Degree of dosimetric miss for 21 patient PTVs observed at 30 Gy CT-RT.
Cone-beam CT images
Cone-beam CT images
CLINICAL INVESTIGATION

COMPARISON OF SPINE, CARINA AND TUMOR AS REGISTRATION LANDMARKS FOR VOLUMETRIC IMAGE-GUIDED LUNG RADIOThERAPY

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*Radiation Medicine Program and ‡Department of Biostatistics, Princess Margaret Hospital, Toronto, ON, Canada; †University of Toronto, Toronto, ON, Canada; and §St. James Institute of Oncology, Leeds Teaching Hospitals, National Health Service Trust, Leeds, England

Purpose: To assess the feasibility, reproducibility, and accuracy of volumetric lung image guidance using different thoracic landmarks for image registration.

Methods and Materials: In 30 lung patients, four independent observers conducted automated and manual image registrations on Day 1 cone-beam computed tomography data sets using the spine, carina, and tumor (720 image registrations). The image registration was timed, and the couch displacements were recorded. The intraclass correlation was used to assess reproducibility, and the Bland-Altman analysis was used to compare the automatic and manual matching methods. Tumor coverage (accuracy) was assessed through grading the tumor position after image matching against the internal target volume and planning target volume.

Results: The image-guided process took an average of 1 min for all techniques, with the exception of manual tumor matching, which took 4 min. Reproducibility was greatest for automatic carina matching (intraclass correlation, 0.90-0.93) and lowest for manual tumor matching (intraclass correlation, 0.07-0.43) in the left-right, superoinferior, and anteroposterior directions, respectively. The Bland-Altman analysis showed no significant difference be-

Conclusion: For advanced lung cancer, the spine or carina can be used equally for cone-beam computed tomography image registration without compromising target coverage. The carina was more reproducible than the spine, but additional analysis is required to confirm its validation as a tumor surrogate. Soft-tissue registration is unsuitable at present, given the limitations in contrast resolution and the high interobserver variability. © 2008 Elsevier Inc.
EDITORIAL

Will IGRT live up to its promise?

MARCEL VAN HERK

Finally, the increased complexity of IMRT and IGRT therapy makes it more error-prone, while anatomical guidance fails to validate the complex beam delivery. I therefore think we should rethink verification, and build in independent verification of the entire chain, otherwise big errors that occur in a small fraction of patients may go unnoticed. For that reason, we have implemented a portal dosimetry program that validates the treatment of each curative patient efficiently (in vivo) [3].
Smaller PTVs using 4D techniques

Individualized (4DCT-based)

Use of ‘standard’ margins

4DCT-based ‘gated’ delivery

Pantarotto & Senan, *in press*
Audio-coached gated radiotherapy

Motion (all phases of respiration)

Residual motion in 3 phases

RPM waveform during gating

Spoelstra F, 2008
Intra-fraction motion assessment

MV ciné images & marker-less tracking

PORTALVISION MV imaging system

Muirhead R, submitted
MV ciné images & marker-less tracking

Carina visible in 81% of cine-images; tumor mass in 77%; hilar lesion in 15%

In 7% of internal structures, observed motion exceeded that seen at 4DCT.

Impaired ability to identify structures include treatment bed bar, use of wedge angles >60°, fields < 6cm in size, and delivery of <50 monitor units.

*Muirhead R, submitted*
Overview

– Definition of 4-D RT, IGRT
– Motion assessment: Fluoroscopy, slow CT, 4DCT, PET
– Motion of lymph nodes
– Use of FDG-PET scans for target definition
– Baseline shifts in tumor position
– Role of adaptive radiotherapy & replanning