4DCT and respiratory motion management strategies in lung cancer radiotherapy

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Outline – Respiratory Motion Management / 4DCT

• Background to respiratory motion issues

• Respiratory Motion - Extent of the problem

• Relevance to radiotherapy planning

• Specific methods of dealing with respiration motion during radiotherapy imaging and treatment delivery
Reasons for failure
Post Radical RT in Lung Cancer

- Inadequate Radiation dose

- Geographic miss
  - Presence of undetected nodal or distant metastases
  - Failure to accurately identify disease
    - Inter-observer variation
    - Limitations of imaging modalities
  - Failure to deliver treatment to planned target
    - Failure to estimate intra and inter fraction tumour motion
Geometric Uncertainties in Radiotherapy Delivery

- Set-up Error
- Target volume delineation (inter-observer variation)
- Tumour changes during treatment
- Respiratory Motion

Will IGRT live up to its promise?

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].

Van Herk V. Acta Oncologica 2008;47:1186-1187
Primary Tumour Motion

Average Motion:
Sup-Inf: 12±2mm
Rad: 2±1mm

Fig. 4. Orthogonal projections of the trajectories of the 21 tumors on (left) the coronal (LR-CC) and (right) the sagittal (AP-CC) plane. The tumors are displayed at the approximate position, based on the localization mentioned in the treatment chart. Tumors that were attached to bony structures are circled.

Primary and nodal motion

3D Displacement:
Average: 0.68cm
range: 0.17-1.64cm

Variation in Respiratory Pattern

Impact of Respiratory Motion on Radiotherapy

• Image acquisition limitations:
  – Diagnostic
  – Treatment planning
  – IGRT

• Treatment planning limitations:
  – Will need margins to account for this (large PTVs)
  – Inaccurate dose calculation

• Radiation delivery limitations:
  – Intrafractional and Interfractional Motion
ICRU Target Volume Definitions

- **GTV** – Clinically apparent disease
- **ITV** – margin added to include all respiratory or cardiac motion
- **CTV** – margin added to include subclinical microscopic disease
- **PTV** – margin added to include set-up uncertainties
Benefits of Reducing Respiratory Motion Uncertainties

- Reduction of treated volume
- Reduced pulmonary toxicity
  - Reduce CTV-PTV expansion
- May permit dose escalation
- Improved delivery of concurrent chemotherapy
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Methods for dealing with Respiratory Motion

- Motion encompassing techniques
- Respiratory gating techniques
- Breath hold techniques
- Forced shallow breathing (abdominal compression)
- Real time tumour tracking
Methods for dealing with Respiratory Motion

- **Motion encompassing techniques**
  - Fluoroscopy
  - Slow CT
  - Inhalation / Exhalation breath hold CT
  - Mid ventilation CT
  - 4-Dimensional / Respiration Correlated CT (4DCT)
  - **Purpose is creation of an ITV**

- **Respiratory gating techniques**
- **Breath hold techniques**
- **Forced shallow breathing (abdominal compression)**
- **Real time tumour tracking**
Fluoroscopy
Fluoroscopy
Slow CT

Respiration Correlated CT/ 4DCT

Respiratory Cycle

Phases of respiratory cycle

0 10 20 30 40 50 60 70 80 90

SINGLE TABLE POSITION

4DCT SORTING ALGORITHM

Table Position 1
Table Position 2
Table Position 3
etc...

Phase 0
Phase 10
Phase 20
etc......
Phase 90

Retrospective Gating
External triggers for respiration correlation

- These provide a representation of the respiratory cycle to synchronise the CT Data to
- Acquire data in list mode and retrospectively bin

Varian RPM  Thermistor  Respiratory belt
RPM System
Patient Set-up
RPM Respiratory Trace

Inspiration: 2.0 sec.
Expiration: 2.0 sec.
Breathing Period: 4.0 sec.

Increase Treatment Time by $\times 3.6$ (28% Duty Cycle)

Scale
4 cm

Auto Scale
Gated Motion 2.7 mm

Beam Enabled
Beam Hold
4DCT Outlining

- Raw CT Data
- Respiration Images
  - AveIP
  - MIP
  - Phase 0
  - Phase 50

End inspiration
End expiration

Used to create MIP modified ITV
4DCT Outlining

End inspiration

End expiration

AveIP

MIP

Used for treatment planning – gives better assessment of average tissue density (Contours and OARs exist on this CT)

Used to create MIP modified ITV

Phase 0

Phase 50

CTV

PTV
Target volume definition
Standard Margins versus 4DCT based

Methods for dealing with Respiratory Motion

• Motion encompassing techniques
• **Respiratory gating techniques**
  – Gating using an external respiration signal
  – Gating using internal fiducial markers
• Breath hold techniques
• Forced shallow breathing (abdominal compression)
• Real time tumour tracking
Types of Gating

• Respiratory phase based gating
  – end inspiration gating
  – end expiration gating

• Amplitude monitored gating
Phase Based Gating

Inspiration

Expiration

Threshold for beam on

Time
End Inspiration Gating

Beam on only at these times

Threshold for beam on

Inspiration

Expiration

Time
Amplitude Monitored Gating

Treatment beam is switched off

During Treatment

Time

4DCT Acquisition
Methods for dealing with Respiratory Motion

• Motion encompassing techniques
• Respiratory gating techniques
• **Breath hold techniques**
  – Deep inspiration breath hold
  – Active breathing control
• Forced shallow breathing (abdominal compression)
• Real time tumour tracking
Deep Inspiration Breath Hold

Patient holds a deep breath and is encouraged to keep yellow line above the blue box.

Patient VDU representation

Time (Respiration Trace)
Methods for dealing with Respiratory Motion

• Motion encompassing techniques
• Respiratory gating techniques
• Breath hold techniques
• Forced shallow breathing (abdominal compression)
  – Reduces movement of abdominal organs
  – To minimise intra-thoracic motion
• Real time tumour tracking
Abdominal Compression
Methods for dealing with Respiratory Motion

- Motion encompassing techniques
- Respiratory gating techniques
- Breath hold techniques
- Forced shallow breathing (abdominal compression)
- Real time tumour tracking
Necessary Steps for Real Time Tumour Tracking

1. Identify the tumour position in real time

2. Anticipate the tumour motion to allow for time delays in the response of the beam-positioning system

3. Reposition the beam

4. Adapt the dosimetry to allow for changing lung volume and critical structure locations during the breathing cycle.
Conclusions

Respiratory motion management techniques may reduce dose to normal tissues.

4D Imaging is necessary for successful implementation of stereotactic ablative radiotherapy for early stage NSCLC.

4D imaging may permit dose escalation and more successful delivery of concurrent chemo-radiotherapy in Stage III NSCLC.

4D imaging requires careful QA at all steps of treatment pathway to ensure accurate treatment delivery.