IGRT: an opportunity to learn, to improve practice and to generate evidence

T Kron, C Fox, F Foroudi, J Thomas, A Thompson, R Owen, A Herschtal, A Haworth, KH Tai

Peter MacCallum Cancer Centre
Melbourne
Image Guidance

• First X-ray in Australia (July 25, 1896)
• Bathurst: Father Slattery takes image of Eric Thomson’s hand.
• Eric Thomson had accidentally be wounded by a spring gun
Local control

- Identification of the target
- Delivery of radiation
- Excellent dose distribution
- Verifying delivery

IMRT

IGRT
Objectives of the presentation

• Introduce the concept of image guided radiotherapy
• Illustrate the opportunities arising from prospectively collecting relevant information
• Discuss some examples in the context of using daily IGRT for urological malignancies
Attempt a definition for radiotherapy

• IGRT consensus workshop Melbourne February 2008

• “Radiotherapy based on data pertaining to spatial geometry acquired at the point of treatment delivery with the intent to ensure accuracy of radiation delivery appropriate to the clinical scenario”
The problem

- Linac co-ordinate system fixed in the room (about 1mm accuracy!)
Imaging for MV RT units

• X-rays:
  • MV Portal Imaging
  • kV imaging
  • Cone Beam CT
  • Other CT
• Ultrasound
• MRI?
• Fiducial markers
Fiducial markers

- Once implanted very easy to localize daily
- Since March 2007 all prostate cancer patients treated with radical intend have three fiducial gold seeds implanted
- Daily imaging for patient positioning:
  - 2 orthogonal EPI or
  - 2 orthogonal kV image with OBI
2D/2D match

- Two orthogonal (or non-orthogonal) MV or kV images
- Good software
- Provides necessary 3D couch shifts
- Used routinely at Peter Mac
Image guidance process

1. Treatment Planning
   - Reference Image
     - Image Guidance
       - Action protocol

2. Treatment Delivery
   - Move patient
Image guidance process

Treatment Planning

Reference Image

Image Guidance

Action protocol

Data collection

Treatment Delivery
Database

- All data recorded in Impac Record and Verify system
- To date:
  - >500 prostate cancer patients
  - 4 different sites (all Varian equipment but different imaging)
  - >12000 image sets
Multistep process to extract data (no SQL database)

- Crystal reports (x3)
- MS Excel (x3)
- In-house software Chris Fox (x3)
- Access database – all information combined
Imaging pre- and post-treatment

Patient set-up to external marks

Imaging 1

Adjust patient position by set-up difference

Treatment

Imaging 2

Outcome 1: Set-up difference

Outcome 2/3: Quality Assurance and Intra-fraction variation
Outcomes?

• Quality assurance - has patient position been adjusted correctly?
• Research/learning
  • EPI vs OBI
  • Intrafraction motion
  • Predictive patient parameters:
    • BMI
    • Rectal filling at planning
• Change of clinical practice:
  • Patient selection
  • Margins
Outcomes?

• Quality assurance - has patient position been adjusted correctly?
• Research/learning
  • EPI vs OBI
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  • Predictive patient parameters:
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• Change of clinical practice:
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  • Margins
How long does it take?

$kV$ imaging is faster than EPI

EPI - 40 patients: 1125 image pairs
OBI - 102 patients: 2809 image pairs

median OBI = 6.3min

median EPI = 8.4min
Time savings

- Typical treatment time slot 15 min - saving creates about 4 to 5 more patient treatment appointments per day…

- In Australian context kV on-board imaging is borderline cost effective over 8 years (even if we ignore better treatment outcomes)
Consider OBI only (all displacements are corrected)

- Two orthogonal kV images pre-treatment
- Treatment (eg. 5 fields)
- Two orthogonal kV images post-treatment

Time between images

Image analysis and action

Time

Peter Mac
EXCELLENCE INNOVATION COMPASSION
Distribution of intra-fraction dislocations (QA measure in itself)
Is there any preferential direction (systematic error)?

No
Is there a relationship between directions of intra-fraction displacement?
Is daily imaging useful?

- Patient set-up to external marks
- OBI imaging 1
- Adjust patient position by set-up difference
- Treatment
- OBI imaging 2

Outcome 1: Set-up difference

Outcome 2: Intrafraction variation
Is daily imaging useful?

- Patient set-up to external marks
- OBI imaging 1
- Adjust patient position by set-up difference
- Treatment
- OBI imaging 2

Outcome 1: Set-up difference
Mean set-up vector: 4.9 +/- 3.0mm

Outcome 2: Intrafraction variation
Mean displacement: 2.2 +/- 2.0mm
Relationship bet. Time and 3D Displacement

Increase of displacement with time between image sets
Distribution of displacements for times between images of

<table>
<thead>
<tr>
<th>Percent of time group</th>
<th>3D Displacement (cm)</th>
</tr>
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<tbody>
<tr>
<td>&lt; 7 mins</td>
<td>7 to 14 min</td>
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<tr>
<td>&gt; 14 mins</td>
<td></td>
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</table>
With treatment times of 15 minutes a 5mm 3D margin does not cover all prostate movements in a 30 fraction treatment.
“Real” prostate motion (Calypso 4D tracking system, Kupelian et al 2007)

Fig. 6. Examples of behaviors observed in the continuous tracking data: (a) continuous target drift; (b) transient excursion; (c) stable target at baseline; (d) persistent excursion; (e) high-frequency excursions; (f) erratic behavior. Red: vertical, green: longitudinal, blue: lateral, black: vector length.
Impact/Significance of IGRT

- Clinical practice
  - Better patient set-up
  - Quality assurance
  - Margin design - use margin recipe
  - Workflow/resources
  - Hypo-fractionation (PROFIT trial)

- Patient selection
- Adaptive radiotherapy

Like most veterinary students, Doreen breezes through Chapter 9.
Examples of variations between patients

- Large intra-fraction motion
- Very stable

- patient A
- patient B
- patient C
- patient D
Number of patients with a certain average 3D displacement

Individual Means of 3D Displacement

Should these patients have the same margin or the same optimisation?
Classification from 1st Five Fractions:
- Small
- Medium
- Large
Classification of patients based on the first five fractions appears to be possible....

Hope for adaptive radiotherapy
Patient selection?

- No association of systematic and random prostate motion with
  - Body mass index
  - Rectal filling at time of treatment planning
Conclusion

- Image guidance provides us with a lot of data (that should be prospectively collected)
- Evaluation of the data allows improvement of individual patient’s treatment as well as improvement of departmental protocols
- A margin for prostate cancer patients smaller than 5mm appears to be not compatible with intrafraction motion patterns
Acknowledgements

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Cone beam CT

- Each OBI is one ‘multi’ slice CT projection
- Slow scan – motion artefacts
- Field of View limited
- Scatter affects accuracy of CT numbers
On-line adaptive RT for bladder cancer patients

- Could be easy or hard:
  - Send patient to void
  - Choose the best from several plans
  - Replan daily

- Challenges:
  - Interpretation of complex images in limited time
  - Selection of appropriate actions
  - Training requirements
  - Documentation
Creation of Conventional and 3 Adaptive Plans

- Planning CT
- 5 Daily CBCTs Week 1

Options:
- Conventional
- Small
- Average
- Large
### Online Bladder Protocol Process

<table>
<thead>
<tr>
<th>Week</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
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<td>Adaptive Plan*</td>
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<td><img src="image7.png" alt="Circle" /></td>
<td><img src="image8.png" alt="Circle" /></td>
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*Adaptive Plan based on Planning CT and first 5 CBCT
Axial CBCT Showing first 5 bladder contours from CBCTs
Preliminary Results

- 27 patients enrolled in adaptive RT trial
- Include imaging after RT to ensure volume is still covered
- Reduction of effective margin by 10mm!!!
- Clear dosimetric advantage for the patient
- Less integral dose to the patient?
- Adaptive RT possible
  - Need equipment
  - Time
  - Training