Imaging and Radiotherapy

Imaging for planning and treatment delivery in EBRT

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Declaration of COI

• Our institution has a research collaboration agreement with Varian Medical Systems
Local control

- Identification of the target
- Delivery of radiation
  - Excellent dose distribution
  - Precision targeting

IMRT

IGRT

The aim of radiotherapy
Local control

- Identification of the target
- Excellent dose distribution
  - IMRT
- Delivery of radiation
  - Precision targeting
  - IGRT

The aim of radiotherapy
Imaging in radiotherapy

- Imaging: any method that relates information pertaining to target identification, (characterization,) and localization to clinicians at any part of the radiotherapy journey
- Planning
- Treatment
- (Follow up)
Objectives

- Discuss challenges and limitations of current imaging
- Consider needs for imaging (and as such what is currently in discussion for imaging of patients)
- Consider the role of biological imaging for planning, IGRT and follow up
- Highlight a few issues that may be of interest in the future

Planning Treatment
Imaging developments are driven by need…

1. Imaging for planning
   - Clinical
     - Better soft tissue contrast
     - Different image contents
     - Faster imaging
     - Lower risk
   - More affordable
   - Wider applicability
   - More sexy
Imaging developments are driven by need…

• 2 IGRT
  • Clinical
    • Better soft tissue contrast
    • Different image contents
    • Faster imaging
    • Lower risk
  • More affordable
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Imaging developments are driven by need...

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  - Clinical
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    - Lower risk
  - More affordable
  - Wider applicability
  - More sexy

NB similar consideration for images in follow up
1. Imaging for planning

- Must allow for identification of the target
1. Imaging for planning

- Must allow for identification of the target
- Should help to characterize the target with information relevant to radiotherapy
  - Motion, size changes

Courtesy N Hardcastle
1. Imaging for planning

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Burridge et al. IJROBP 2006
1. Imaging for planning

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These could often be seen as input for ITVs

Burridge et al. IJROBP 2006
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  - Relevant biology

Courtesy M MacManus
1. Imaging for planning

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Courtesy M MacManus
Biology information needs interpretation

FDG

FLT

CuATSM

Courtesy R Jeraj
Combination of images

- PET/CT
- CT
- PET
- CT/MRI
Future issues 1: deformable registration
Future issues 1: deformable registration

Difficult to have ground truth and validate
1. Imaging for planning

- Must allow for identification of the target
- Should help to characterize the target with information relevant to radiotherapy
  - Motion, size changes
  - Relevant biology: target and organ at risk

CT  VENTILATION  PERFUSION

Courtesy J Callahan and N Hardcastle
Future issues 2: normal tissue biology

Optimal choice of beam angles through non-functional lung

Courtesy J Callahan and N Hardcastle
Future issues 2: normal tissue biology

Optimal choice of beam angles through non-functional lung

MRI fibre tracking

http://sumerdoc.blogspot.com/

Courtesy J Callahan and N Hardcastle
1. Imaging for planning

- Must allow for identification of the target
- Should help to characterize the target and OAR with information relevant to radiotherapy
- Allow dose calculation to be performed
1. Imaging for planning

- Must allow for identification of the target
- Should help to characterize the target and OAR with information relevant to radiotherapy
- Allow dose calculation to be performed

Note that modern dose calculation algorithms (monte Carlo, ACUROS) do not require CT numbers but elemental composition
2. Image guidance requirements

- Link to planning – reference imaging or contours
- Contours can be structures and/or isodose lines
2. Image guidance requirements

- Link to planning
- Integration in treatment machine
  - Readily available
  - Minimise the need to move patient

IGRT (CBCT) at PSI
One of two floor mounted X-ray tubes

X-ray detector panels

Stereoscopic cameras for motion management

Infrared motion marker

Electronic portal imaging device (retracted)

Gantry mounted kV imaging panel

Gantry mounted kV X-ray tube for planar imaging and CBCT

Treatment head with MLC

6D couch adjustment

One of two floor mounted X-ray tubes
2. Image guidance requirements

- Link to planning
- Integration in treatment machine
- Images provide appropriate contrast
MRI the ultimate contrast machine?

- Soft tissue contrast
- Imaging independent of treatment beam
- Possibly fast – motion management
- Potential for functional imaging
- Reference images from MR simulator

Elekta/Philips collaboration

ViewRay – Co MRI
2. Image guidance requirements

• Link to planning
• Integration in treatment machine
• Images provide appropriate contrast
• Fast to be commensurate with time scales of patient changes
Radiotherapy time-scales

Intra-fractional time scale
- respiratory motion
- cardiac motion
- digestive system motion

1 second 1 minute 1 hour

Inter-fractional time scale
- bowel/bladder filling
- random/systematic setup errors
- tumor growth and shrinkage
- weight gain and loss

1 day 1 week

Motion Management

Setup Verification

Adaptive
Radiotherapy time-scales

**Intra-fractional time scale**
- Automated simple decision making
- Respiratory cardiac motion

**Inter-fractional time scale**
- On line IGRT, set-up correction, plan of the day
- Random/systematic setup errors
- Bowel/bladder filling
- Tumor growth and shrinkage
- Weight gain and loss

**Motion Management**
- Setup Verification
- Adaptive
Complex IGRT – re-planning?

Start of treatment
7 days later
2 weeks later
3 weeks later
1 month later

Courtesy of Tim Holmes, St. Agnes Cancer Center, Baltimore, MD
Replanning or multiple pre-planning?

Burridge et al IJROBP 2006
Replanning or multiple pre-planning?

<table>
<thead>
<tr>
<th>CBCT each Fraction</th>
<th>Conventional Plan</th>
<th>Adaptive Plan</th>
<th>Select best plan based on image of the day</th>
</tr>
</thead>
</table>

2. Image guidance requirements

- Link to planning
- Integration in treatment machine
- Images provide appropriate contrast
- Fast to be commensurate with time scales of patient changes
- Simple and easy to interpret (if on line)
2. Image guidance requirements

- Link to planning
- Integration in treatment machine
- Images provide appropriate contrast
- Fast to be commensurate with time scales of patient changes
- Simple and easy to interpret (if online)

Courtesy P Keall, N Hardcastle
2. Image guidance requirements

- Link to planning
- Integration in treatment machine
- Images provide appropriate contrast
- Fast to be commensurate with time scales of patient changes
- Simple and easy to interpret (if on line)
- Low risk and dose

Ultrasound
Daily CT for adaptive radiotherapy

Week 1

3cGy + 3cGy + 3cGy + 3cGy + 3cGy + …..

Week 2

3cGy + 3cGy + 3cGy + 3cGy + 3cGy + ... + 3cGy + …..
More on dose...

- Scatter is very significant (>50% of dose)
- Shutter reduction reduces dose
- Dose higher in outer part of the phantom
- Dose higher in full fan and small objects...
- Dose cannot be accounted for in planning (yet)
More imaging versus smaller fields...

Conventional

One of the adaptive plans

Daily CT for adaptive radiotherapy
Difference in dose

Adaptive RT gives less dose

Conventional RT less dose

- Total volume
- Volume - CTV
Biological images for verification of treatment

Pre-treatment

Mid-treatment (1 wk of XRT)

Courtesy R Jeraj
Biological images for verification of treatment

Pre-treatment

Mid-treatment (1 wk of XRT)

Courtesy R Jeraj
Biological images for verification of treatment
Biological images for verification of treatment

![Image of biological images](image)

**Fig. 4.** Serial images of the patient designated as Case 1, demonstrating the distribution of $^{18}$F-3'-deoxy-3'-fluoro-l-thymidine ($^{18}$F-FLT PET) in tumor and bone marrow at three time points: baseline before commencement of therapy (top row), 20 h after administration of 2 Gy (middle row), and 72 h after 10 Gy (bottom row). Red arrows in the right-hand column denote the upper and lower boundaries of the radiation fields. L = liver; M = bone marrow; T = tumor.
Summary

• Imaging is an essential part of radiation oncology – it is required for (diagnosis/staging), planning, treatment delivery, adaptation and (follow up)

• Future issues are
  1. Deformable registration
  2. Critical structure defined planning
  3. Interpretation of biological images
  4. Automation and motion management
  5. Adaptive radiotherapy
Acknowledgement

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