Technical aspects of imaging used for IMRT

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Imaging for planning: so much to say…
Local control

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

IMRT

The aim of radiotherapy
The problem with cancer

- Cancer is not ‘one’ disease
- Tumour cells originate from ‘normal’ cells
- The tumour is surrounded by normal tissue
The aim of radiotherapy

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

IMRT

Sine qua non
Creation of a ‘virtual’ patient
Objectives of the presentation

• To introduce basic concepts of imaging for IMRT
• To discuss the role of different imaging methods
• To explore their role in the treatment planning process
What is special with IMRT?

• The computer does the work
• Tight margins
• Sparing of critical structures surrounded by tumour
ICRU report 62: But how tight can our margins be?

- Subclinical involvement
- Internal and set-up margin combined as independent
- Internal margin
- Set-up margin

GTV

CTV

PTV
Imaging for treatment planning

- 3D (at least)
- Geometrically correct
- Related to treatment modality (ie allows dose calculation + creation of reference images for verification)
- Relatively cheap and easy access
X-rays for imaging

Modern computed tomography (CT) scanner, 2005

Roentgen 1895
EMI scanner (1972)
Today’s multi slice CT
CT scanner
Computed Tomography

- Rotating fan beam
- Rotation period 0.4 to 2s
- 180 – 360 degrees (a bit of overscan)
- Fan beam thickness 1 to 10mm
Collimation

slice collimation

scatter collimation
Speed up the acquisition

- Helical CT
  - Fast
  - Breath hold scans
    - Pitch - travel per revolution
    - Pitch factor = pitch/slice thickness (e.g., 5mm pitch/5mm = 1)
    - Typical pitch factor > 1 therefore dose reduction

Reconstruction may involve interpolation of signal from two adjacent helices
CT Multi slice acquisition

- Multi-slice CT
  - Matrix detector
  - Faster - 0.5 s/slice
  - Improved images esp. 3D

Matrix detector

Single slice detector

 Courtesy J Battista
4D CT

• Several methods:
  – Prospective
  – Retrospective
  – Axial
  – Helical

• Typically requires external marker of breathing phase
CT fluoroscopy

• Continuos rotation around the patient
• Typically multi-slice
• Typically reduced mAs
• Last image hold

• Common for biopsy taking
Philips: 16 slice, retrospective helical 4D CT
Breathing period: 3 to 6 seconds
Rotation period: 0.44 seconds
Use projections of 0.22 seconds for reconstruction
Use small pitch factor and multislice
Target definition with 4DCT

MIP

ITV

ITV + 5 mm = PTV

Thanks to Nick Hardcastle
Magnetic Resonance Imaging

• For short MRI
• One of the most important medical imaging tools
• Of particular relevance for soft tissue contrast
Fundamental NMR physics

• Nuclear Magnetic Resonance
• Requires nuclei with a magnetic moment
• Most common:
  – protons, protons, protons, protons, phosphorous
Pulse sequences

• Many options
• Even more acronyms
• Generate many different types of contrast
Magnetic Resonance Imaging

Images are acquired using protons/hydrogen magnetic moments
Contrast options in MRI

- Proton density
- T1
- T2
Contour Example

Blue: MRI - radiologist
Yellow: CT - radiation oncologist
MRI vs CT with Prosthesis
Contrast options in MRI

- Proton density
- T1
- T2
- Flow
- Metabolic activity
- Oxygenation
- Function

four views of the carotid arteries
Contrast options in MRI

- Proton density
- T1
- T2
- Flow
- Diffusion
- Perfusion
- Functional MRI
Functional MRI

with task - no task = fMRI
Functional MR

Activation from bilateral fist clenching...
Nuclear Medicine - the original functional imaging, eg: Positrons (PET)
X-ray CT is the ‘gold standard’ for radiotherapy planning: Three dimensional, high spatial resolution, no distortion and useful for inhomogeneity correction in dose calculations

Courtesy M MacManus
What about spatial resolution?

• In plane 1mm?
• Slice thickness and spacing 3mm?
What about spatial resolution?

- In plane 1mm?
- Slice thickness and spacing 3mm?
- Dose calculation grid 2.5mm?
- Fluence optimisation grid 2.5mm?
- Motion over the course of delivery 2mm (depends)???
CT scan in NSCLC with bland atelectasis: Where is the edge of the tumour?

Courtesy M MacManus
Add PET et voilà…

Courtesy M MacManus
PET for Radiotherapy Target Identification

- Staging - patient selection
- Outlining of target structures
- Assessment of motion/Internal Target Volumes
- Prediction of outcome/biological planning

Mostly FDG PET - from an oncology point of view it is just such a good tracer…
Studies that compare CT based planning with PET or PET/CT based RT planning in NSCLC

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Courtesy M MacManus
PET based outlining reduces inter-observer variability in target volume outlining (Ashamalla IJROBP 2005)

PET target contouring: 6 Observers

Courtesy M MacManus
Target delineation: CT vs CT+PET

Steenbakkers et al., 2006
Many studies from pre-PET/CT era. However, typically combination of anatomical and functional image…
Fusion of images
Fusion of images

Can not always assumed to be perfect in PET CT
Could be affected by motion
May affect also attenuation correction
4D PET could be helpful (PMCC experience in lung, J Callahan)
Interpretation not necessarily easy

Courtesy R Jeraj
Automatic Contouring…

• PET and CT are quantitative!
• Automatic contouring of many structures standard
• Others to come: atlas based segmentation

Davis et al 2006
Radiother. Oncol.
Three clinical examples:
Red - computer
Green - clinician
PET Impact on Radiation Oncology Target Definition

- Diagnosis and Staging
- Target contouring: Lung, Oesophagus, Head and Neck, Lymphomas, ...
- Conformal Avoidance (Brain)
- Advantages: More reproducible, slow scan to avoid motion artefacts
Lung perfusion measured with SPECT for treatment planning

No need to spare this part of the lung!
Just a thought: Tumor growth and shrinkage

Number of cells

Palpable tumor

Tumor growth

Start of radiotherapy

Fractionated treatment

time
Tumor growth and shrinkage

Number of cells

10^{12}

10^{9}

10^{6}

10^{3}

1

Tumor growth

Palpable tumor

Start of radiotherapy

Imaging

Fractionated treatment

time
Tumor growth and shrinkage

Number of cells

Start of radiotherapy

Imaging

Palpable tumor

Fractionated treatment

Treatment success?

Tumor growth

Early detection? Micro metastasis? Microscopic spread --> CTV?
Just a thought: Imaging and immobilisation
Summary

- Imaging has changed the way we think of radiotherapy
  - Planning
  - Treatment
- High quality RT requires high quality imaging
- Exquisite dose distributions can be created using IMRT
- The combination of IMRT + imaging makes modern RT powerful
- Professionals need to acquire new skills

Arcimboldo
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