Image guided Radiation Therapy (IGRT) - a perspective

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University of Michigan

Has financial interest in Calypso Medical Technologies
What is image guidance?

Broadly stated, IGRT involves any use of imaging to aid in decisions in the radiotherapy process

- Decision of whether/how to treat
- Delineation of structures of interest
- Aid in positioning, verification, and monitoring
- Assessment and prognosis of outcome

Although significant work is happening in all areas, a few areas have received the most recent attention

- in-room imaging and localization techniques
- “4D” characterization and management for breathing
- “molecular” imaging
- “adaptive” therapy
Need for accurate target definition!

Conventional

High precision
Need for accurate target definition!
distribution is achieved with angled beams. Here, the need for tissue compensation overrides the need to compensate for the expected hot spot of the apex of the overlap region. Thus, the wedges must be reversed from their usual placement.

Finally, Figure 11 shows an example of what can be achieved by optimization programs. In this case, the target volume is almost exactly covered by the 90% isodose line and the dose at the center, marked by the X, was limited to 50%. This 18 field plan with two isocenters and field sizes conforming to the shape of the target volume can be executed by some modern computer controlled treatment machines with only one patient setup.

Work is underway at some centers to develop schemes for optimizing treatments which take into account the variation in the size and shape of the target volume in three dimensions. Although the three dimensional target volume has an irregular shape in most cases, radiotherapists frequently draw the target area as a circle, square, or rectangle, since those are the shapes of the isodose curves usually obtained by standard plans. The use of optimization would allow the radiotherapist to define the target volume more precisely, based on the characteristics of the tumor rather than on the characteristics of the treatment machine.
CT is the most dominant imaging modality

While CT provides useful information, a number of parameters need consideration for optimizing the use of this modality

- Resolution versus SNR
- Contrast and contrast timing
- Effects of geometry and heterogeneities on image quality
Dynamic contrast enhancement – time series of differential uptake in the liver

Y. Cao, University of Michigan
Optimizing contrast - timing

Early Arterial  Late Arterial  Venous

Hepatocellular Carcinoma: Optimal Contrast Strategies for Detection and Staging Using Multislice CT
By Janio Szklaruk PhD, MD, Paul Silverman MD
CT angiography of an AVM - continuous infusion during scanning

Neurovascular Applications of CT Angiography
Prashant G Shetty, KS Jhaveri
Ind J Radiol Imag 2000; 10:
Impact of breathing-related motion on CT

AAPM TG76 report (Keall et al)
Warning: Choking Hazard
Not for treatment planning systems over 3 years old!

Modern Radiotherapy - the “4D” era?
4D CT: Coronal View

Amplitude sorting  
Phase sorting

Dan Low, Washington University
4DCT used to create an ITV

0% 20% 50% 70% 90%

Courtesy of Peter Balter, MDA
What happens when you don’t look?

It is likely that models of the patient will need to include variations in estimated movement beyond those directly observed.

MRI aids in target delineation

Y Cao, University of Michigan
Prostate MRI (L Chen, Fox Chase Cancer Center)
Can distortion be handled effectively?

L Chen, FCCC
Who knows how to optimize imaging for target definition?

Research and development in imaging systems has focused heavily on sensitivity and specificity of DIAGNOSIS.

The concept of border delineation has not been a major area of R+D effort, and is a far more complex issue to resolve.
Motion studies with MRI

Superior soft tissue contrast
Not necessarily faster than CT
Arbitrary planes
Other tricks to improve speed
The potential of multimodality-imaging in RT

- PET
- F-miso
- Hypoxia

- MRI/MRS
- choline/citrate
- Tumor burden

- PET
- IUdR
- Tumor growth

- Biological Eye View

- Biol. Tgt. Volume

Grigsby et al, JCO, 2001

Courtesy of Sasa Mutic, Wash U

PET

n = 256

7%

18%

64%

CT

0%

6%

20%
FDG-PET for target definition in the thorax
(F Kong, University of Michigan)

Differentiating tumor from collapsed lung

Detecting CT missed nodes
What is the tumor boundary from PET?

Outlining the tumor target
Lesion/background ratio
SUV cut-off method (2.5)
Threshold method

Which one is correct?

PET target compared to CT volume

<table>
<thead>
<tr>
<th>Study</th>
<th>Method of Delineation</th>
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<tbody>
<tr>
<td>Erdi et al, 1997 &amp; 2002</td>
<td>40% threshold</td>
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<td>Kiffer et al, 1998</td>
<td>Visual interpretation</td>
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<td>Mah et al, 2002</td>
<td>50% threshold</td>
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<td>Vanuytsel et al, 2000</td>
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<td>Nestle et al, 2005</td>
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<td>Bradley et al, 2004</td>
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<td>Deniaud-Alexandre et al, 2005</td>
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<td>Brianzoni et al, 2001</td>
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<td>Ashamalla et al, 2005</td>
<td>Visual interpretation</td>
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F Kong, U of Michigan
Altered/Escalated Dose Distributions
$^{60}$Cu-ATSM (Hypoxia) - Guided IMRT

Mutic et al, Washington University

Incorporation of MRSI data into Treatment Planning for RT of a GBM

T2 hyperintensity outside CNI 2

CNI3 outside CE

A Pirzkall, UCSF
Contouring

For the SAME contrast and image information, target delineation may significantly vary between experts.

This target definition variability is a critical source of uncertainty in Radiation Oncology today.
3-D median surface with local SD

Van Herk et al (NKI)

LOCAL SD (mm)

- 0.0 – 0.5
- 0.5 – 1.0
- 1.0 – 1.5
- 1.5 – 2.0
- 2.0 – 2.5
- 2.5 – 3.0
- 3.0 – 3.5
- 3.5 – 4.0
- 4.0 – 4.5
- 4.5 – 5.0
- 5.0 – 5.5
- 5.5 – 6.0
- 6.0 – 6.5
- 6.5 – 7.0
- 7.0 – 7.5
- > 7.5
Imaging for treatment verification

1980’s – port films
1990’s - emergence of MV portal imagers
  in-room ultrasound localization
  marker-based localization
  Fluoroscopic tracking
2000’s – flat panel imaging
  KV digital imaging
  CBCT
  MV CBCT
  CT “on rails”
Emerging - Electromagnetic localization and tracking
  surface tracking
  in-room MRI
Considerations of appropriate use of in-room imaging

Localization – As surrogate anatomy approaches the true target through improved visualization, uncertainty reduces in tumor location.

Caveat – Improved direct tumor visualization is currently not amenable to real-time localization and action, thus:

- surrogates are more likely to be needed for rapid monitoring for the moment
- sampling the patient in the treatment room still requires a tie to immobilization and residual uncertainty analysis
CBCT - the ugly...
CBCT - the bad...
CBCT - the good...
Proper use of imaging requires infrastructure, skill sets, and role consideration

Understanding limits and optimal use of imaging systems
Proper QA procedures (relationships of image quality to functional use)
Understanding and routine use of alignment tools
Data management – Who uses what data where, when, and how, and how much infrastructure is needed to support use?
“targeting” moving into the hands of a larger population of users with variable training
Potential for plan modification – benefit not fully defined, heavy reliance on relationships between sampled data sets and understanding of what may be true but not sampled
Use of rule-based strategies for intervention – acceptance of statistical models over the last image seen

…
Dealing with Imaging in Radiation Therapy - AAPM efforts

This Summer school

Scientific Program Committee – Joint topics and sessions

Educational program at AAPM

Science council:

Therapy physics committee

Therapy Imaging Subcommittee

  WG on imaging for treatment planning
  WG on imaging for treatment verification
  WG on imaging for treatment assessment
  WG on molecular imaging in clinical radiation oncology
Major topics of the IGRT section of this workshop:

Imaging for treatment planning
   Concerns in optimizing imaging and contouring
   Imaging technology (CT, PET, MRI)
   Related tools (image alignment)

Imaging for treatment verification
   Technology (Radiograph, ultrasound, (CB)CT)
   Tools (Alignment, tracking)
   Decision support (adaptive methods)
   Support issues (QA, commissioning, safety, infrastructure)

YOUR QUESTIONS AND DISCUSSIONS ARE THE MOST IMPORTANT COMPONENT OF LEARNING!
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Due to a scheduling conflict, the Imaging for patient modeling talks on PET and MRI will be held today at 1:30-3:30, and the CT talks will be held tomorrow from 8:00-10:00. The schedule is correct in the handout, but the CME reviews are not. Please fill out the appropriate box for review. Thank you!