IMAGE-GUIDED RADIATION THERAPY:

Benefits and limitations

Ref: Khan: The Physics of Radiation Therapy, 4th Ed. (2009), Ch. 25
Khan (ed.): Treatment Planning in Radiation Oncology, 2nd Ed. (2007), Ch. 12

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Image-Guided Radiation Therapy (IGRT)

- Radiotherapy that uses image guidance procedures to:
  - delineate target volume and organs at risk
  - Identify and correct problems arising from inter- and intrafractional variation in patient setup, anatomy, target volume, and organs at risk
IGRT Technologies

- Radiographic simulator
- CT simulator
- PET CT
- Portal imager
- In-room CT scanner
- Kilovoltage cone-beam CT
- Megavoltage cone-beam CT
- Helical tomotherapy
- Ultrasound
Radiographic Simulator
Portal Imager
(EPI D)
CT Simulator
In-Room CT scanner

- 3-D volumetric data in treatment coordinates. Neither the couch nor the patient is moved relative to the treatment isocenter.
Kilovoltage Cone-Beam CT (kVCBCT)

- On-board kV imaging. Capabilities: Radiography (2-D), fluoroscopy (2-D), cone-beam CT (3-D)
Megavoltage Cone-beam CT (MVCBCT)

Accelerator equipped with electronic portal imaging device (EPID) with a-Si flat-panel detector:

- MV portal images (2-D)
- MV cone-beam CT (3-D)
ADVANTAGES
MVCBCT over kVCBCT

- No artifacts due to metallic objects
- CT numbers correlate with e-density
- Calculation of imaging dose possible
ADVANTAGES
KVCBCT over MVCBCT

- Better contrast and spatial resolution
- Better soft-tissue visibility at much lower imaging doses
- Better compatibility with reference treatment plan
- Combination of radiography, fluoroscopy, and CBCT for the same source and detector provides greater flexibility
Helical Tomotherapy

- Combines linac and helical CT scanner for IMRT delivery
- The problem of interslice match line is minimized
- MVCT images with low scan dose (1-2 cGy)
- MVCT images suitable for treatment plan verification
Helical Tomotherapy

(a) Tomotherapy Unit
(b) Spiral Scan
Ultrasound

- Noninvasive, nonradiographic, real-time imaging. EXAMPLE: BAT System by Nomos
- Basic problem – poor image quality
- Anatomic distortion is another problem
- 3-D ultrasound system is a definite improvement. EXAMPLE: 3-D Ultrasound Target Localization System: SonArray by Zmed, Inc.
Management of Respiratory Motion
[Ref: AAPM TG-76 (2006)]

4-D CT (the fourth dimension being time).

- EXAMPLE: Varian’s RPM Gating System

- Gating thresholds are set when the target is in the desired position of the respiratory cycle

- Treatment beam turned on and off in accordance with the programmed gating thresholds
Management of Respiratory Cycle
(Real-time Tumor Tracking)

Fluoroscopy-based tracking system

EXAMPLE: ExacTrac/Novalis body system by BrainLab, AG

- Optical tracking [IR reflectors on surface, two IR cameras in the ceiling]
- Stereoscopic imaging [two x-ray tubes mounted in the floor and two opposing aSi detector panels in the ceiling]
- X-ray imaging and IR tracking fully integrated
Management of Respiratory Cycle (Real-time Tumor Tracking)

ExacTrac/Novalis Body System

Automatic steering of treatment couch to match treatment isocenter with linac isocenter
Management of Respiratory Cycle (Real-time Tumor Tracking)

CyberKnife (Accuray, Inc)

- Image-guided frameless stereotactic radiosurgery system for treating cranial and extracranial lesions
Management of Respiratory Cycle
(Real-time Tumor Tracking)

Electromagnetic Field Tracking
(Calypso 4-D Localizing System)

- Real-time localization of electromagnetic transponders (beacons) implanted into the tumor
Management of Respiratory Cycle
(Real-time Tumor Tracking)

MRI-guided IGRT
(Renaissance system by ViewRay, Inc.)

- Low-field open MRI unit + three cobalt-60 sources each equipped with computer-controlled MLCs to deliver IMRT
MRI-guided IGRT

(Renaissance system by ViewRay, Inc.)
Management of Imaging Dose

[Ref: AAPM TG-75 (2007)]

Imaging Dose Specification

- Entrance skin dose or air kerma (planar kV)
- Air kerma at the axis of rotation (CT).
- Computed tomography dose index (CTDI) – integrated dose in a single slice.
- Dose area product (DAP): product of dose and area exposed (in planar imaging)
- Dose length product (DLP): product of dose and axial length imaged (in axial imaging)
Effective dose \((E)\) is mathematically defined as:

\[
E = \sum_T w_T H_T
\]

where \(H_T\) is the average organ dose to tissue \(T\) for a given imaging procedure and \(w_T\) is the weighting factors representing relative sensitivities of the organs.
Practical effective dose equation:

\[ E = D \cdot F \]

where \( D \) is the imaging dose and \( F \) is the pre-calculated conversion factor for a given imaging modality, considering patient age, sex, and the region imaged.
Currently it is not possible to compare or combine effective doses from imaging and therapeutic procedures.

The AAPM TG-75 states:

“Because this comparison appears to be of great interest to the radiation therapy community, we consider that theoretical and/or empirical estimates of effective dose from the therapy beam during treatment should be made.”
Two general categories: stochastic (all or none) and nonstochastic (deterministic) effects

No threshold dose can be predicted for stochastic effects

It is possible to set threshold limits for nonstochastic effects
Risks From IGRT Procedures
(EXAMPLE)

- Skin injury risks associated with image-guided interventional procedures.

<table>
<thead>
<tr>
<th>Effects</th>
<th>Threshold</th>
<th>Time of Onset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early transient erythema</td>
<td>2000 mGy</td>
<td>2–24 h</td>
</tr>
<tr>
<td>Temporary epilation weeks</td>
<td>3000 mGy</td>
<td>1.5</td>
</tr>
<tr>
<td>Main erythema</td>
<td>6000 mGy</td>
<td>3 weeks</td>
</tr>
<tr>
<td>Permanent epilation weeks</td>
<td>7000 mGy</td>
<td>3 weeks</td>
</tr>
<tr>
<td>Dermal necrosis weeks</td>
<td>15,000 mGy</td>
<td>&gt;52</td>
</tr>
<tr>
<td>Eye lens opacity (detectable)</td>
<td>&gt;1000 mGy</td>
<td>&gt;5 years</td>
</tr>
<tr>
<td>Cataract (debilitating)</td>
<td>&gt;5000 mGy</td>
<td>&gt;5 years</td>
</tr>
</tbody>
</table>

Conclusions

- IGRT is a young and evolving technology.
- Currently, the potential benefits of IGRT are theoretical.
- Well-designed clinical trials are needed to demonstrate its advantages on a scientific basis.
- Motion management and tumor tracking will make sense only if there is a high-degree of certainty in delineating target volumes and organs at risk as well as their localization on-line.
Conclusions (Contd.)

- Excessive dose from intensive imaging procedures is a serious problem in IGRT.

- There is a need to evaluate stochastic as well as nonstochastic risks involved in all the imaging procedures used in radiation therapy.

- Imaging doses must be balanced with demonstrable improvements in the delivery of therapeutic dose.
Accurate delineation of GTV, CTV, PTV, and organs at risk is pre-requisite for realizing potential benefits of IGRT.

Caution: Too much emphasis on dose conformity can backfire, resulting in inadequate target coverage or increase in normal tissue complication, especially when following aggressive dose-escalation schemes.
Conclusions
(Contd.)

It is expected that the enthusiasm for IGRT will continue to grow and eventually its benefits will outweigh the technical challenges
Recommended Reading

Thank You