DELIVERY TECHNIQUES FOR IMRT

Dr Sivananthan Sarasanandarajah (Siva)
B.Sc (Hons, Phys), P.G.Dip.Sc (Distinction, Med.Phys),
M.Sc (Med.Phys), Ph.D.(Med.Phys), MACPSEM

Senior Medical Physicist
Peter MacCallum Cancer Institute
Melbourne, Australia

Regional Training Course on Basics of Intensity Modulated Radiotherapy
Melbourne Australia, 9-13 September 2015
Aim

To distinguish between different IMRT delivery methods and to make appropriate choices
Specific Learning Objectives

• List the different methods of IMRT delivery (compensator-based, static MLC, dynamic MLC, VMAT, helical tomotherapy, CyberKnife)

• Discuss the technical and physical aspects of each method

• Identify the benefits and limitations of the different technologies
3-D Conformal versus Intensity-Modulated Radiotherapy

3-D conformal radiotherapy without intensity modulation

Intensity-modulated radiotherapy
IMRT delivery methods

**Stationary gantry**
- Physical compensators
- Field in field

**Rotational gantry**
- Simplified IMAT
- Tomotherapy (sequential or helical)

**Large fields**
- Physical compensators
- Field in field

**Narrow fields**
- Sliding window

**Segments**
- Step and shoot
- IMAT
Methods of Delivery of IMRT

- Compensator-based
- Step-and-shoot
- Dynamic MLC

- VMAT
- Helical tomotherapy
- CyberKnife
Compensator-based IMRT converts the open-field uniform fluence map to the intended intensity-modulated map via a custom-made compensator. Compensators are solid metal, usually brass or aluminium, and are milled to the patients' tumour size and shape. The compensators are attached individually to the linear accelerator for each beam direction.
Compensator-based
Compensator-based

Characteristics of the method:

- Can be performed with accelerators without MLC
- Not sensitive to temporal fluctuations of smaller sub-fields associated with MLCs and no fraction-to-fraction variability
- Most commercial treatment planning systems offer the compensator-based IMRT option
- Patient-specific QA is similar to MLC-based IMRT
Compensator-based

Disadvantages of the method:

• Difficult to generate very low intensities
• Requires smooth cooperation between the user and the manufacturer of the compensators
• RTTs have to enter the room for each field to place a compensator on the tray
• Special precautions should be made to ensure that the right compensator is used for each patient and each treatment field
• Costs?
MLC-based

IMRT treatments can be delivered with the MLC operating in one of three basic modes:

- **Static MLC (SMLC)** mode in which the intensity-modulated fields are delivered in the form of a sequence of small segments or sub-fields; each sub-field with a uniform intensity.

- **Dynamic MLC (DMLC)** mode in which the intensity-modulated fields are delivered in a dynamic fashion with the leaves of the MLC moving during the irradiation of the patient.

- **Volumetric-modulated arc therapy (VMAT)** mode in which the dynamic approach is used as the gantry rotates around a patient.
Production of IMRT Beams Using MLC-equipped Linear Accelerators

**Static approach** with several static intensity-modulated fields at a specific gantry angle

**Dynamic approach** with intensity-modulation during irradiation at a specific gantry angle
Static MLC

- This is often known as the ‘step-and-shoot’ method
- A sequence of sub-fields is treated one after the other to create the overall fluence. Each sub-field is defined by a different MLC setting
- The injector is switched off between each field and there is no radiation during leaf movement
- Each sub-field can be recorded and verified separately
Static MLC

MLC shape

Fluence
Dynamic MLC

- This technique uses either a ‘closing’ or ‘sliding’ window depending on how each MLC leaf-pair traverses the field.
- In this case, the biggest difference from a static MLC delivery is that radiation is delivered during leaf movement.
- This method has the same challenges as dynamic wedging in the event of a beam interruption and/or termination.
Static MLC versus Dynamic MLC

Static MLC
- Simple concept
- Generally more MUs compared to 3-D CRT
- Requires high accuracy of leaf position

Dynamic MLC
- Not intuitive
- Much larger number of MUs compared to 3-D CRT
- Requires very high accuracy of leaf position
Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy

C. Yu, 1995

CLINICAL IMPLEMENTATION OF INTENSITY-MODULATED ARC THERAPY

Cedric X. Yu, D.Sc., X. Allen Li, Ph.D., Liun Ma, Ph.D., Donorn Chen, Ph.D., Shahid Naqvi, Ph.D., David Shepard, Ph.D., Mehmed Sarrafz, Ph.D., Timothy W. Holmes, Ph.D., Moran Sutharalagam, M.D., and Carl M. Mansfield, M.D.

Results: By the end of May 2001, 50 patients had completed their treatments with the IMAT technique. Two to five arcs were needed to achieve highly conformal dose distributions. The IMAT plans provided better dose uniformity in the target and lower doses to normal structures than 3D conformal plans. The results varied when the comparison was made with fixed gantry IMRT. In general, IMAT plans provided more uniform dose distributions in the target, whereas the inverse-planned fixed gantry treatments had greater flexibility in controlling dose to the critical structures. Because the field sizes and shapes used in the IMAT were similar to those used in conventional treatments, the dosimetric uncertainty was very small. Of the first 32 patients treated, the average difference between the measured and predicted doses was $-0.54 \pm 1.72\%$ at isocenter. The $80\%-95\%$ isodose contours measured with film dosimetry matched those predicted by the planning system to within 2 mm. The planning time for IMAT was slightly longer than for generating conventional 3D conformal plans. However, because of the need to create phantom plans for the dry run, the overall planning time was doubled. The average time a patient spent on the table for IMAT treatment was similar to conventional treatments.

C. Yu, 2002, The Maryland experience
Helical tomotherapy and volumetric-modulated arc therapy (VMAT) are two arc-based approaches to delivering IMRT. Varian Medical Systems and Elekta developed the first commercially available solutions providing VMAT. Varian’s RapidArc volumetric-modulated arc therapy delivers a complete IMRT treatment in a single rotation of the treatment machine around the patient. The system was engineered to deliver VMAT two to eight times faster than conventional IMRT or helical tomotherapy. With the Elekta VMAT system, single or multiple radiation beams sweep in uninterrupted arcs around the patient. VMAT can be used with complete or partial arcs to reduce treatment times from six to twelve minutes required for conventional IMRT to as few as one to two minutes.
• The solution proposed by Otto is an aperture-based algorithm for treatment plan optimization where dose is delivered during a single gantry arc.
• The technique is similar to tomotherapy in that a full 360 deg of beam directions are available for optimization, but is fundamentally different in that the entire dose volume is delivered in a single source rotation.
• MLC leaf motion and number of MUs per degree of gantry rotation is restricted during the optimization so that gantry rotation speed, leaf translation speed, and dose rate maxima do not excessively limit the delivery efficiency.
• Gantry and MLC position sampling is progressively increased throughout the optimization.
Step-and-shoot IMRT
Step and shoot IMRT

- Multiple fields
- Many segments per field
- Each segment requires information on all leaves and mu
- Rather complex treatment file
Step and shoot IMRT

• Practical issues:
  • What is the minimum field size allowed?
    Typically 2x2cm²
  • What is the minimum number of monitor units per segment?
    Typically 4mu
Step and shoot

• Simple concept
• Some intuitive understanding possible (eg field in field)
• Available by all linac manufacturers
• Available in all IMRT (except HT) planning systems
• May take some time to deliver...
Dynamic treatment techniques

- Arcs
- Dynamic wedge
- Dynamic MLC

↑ increasing complexity with increasing flexibility in dose delivery.
VMAT

- During gantry rotation changes in:
  - segment shape
  - gantry speed
  - dose rate
VMAT treatment of prostate cancer at the Netherlands Cancer Institute

**EPID movie**

**Dose per control point**

**Accumulated dose**

Single arc

10 MV beam / 80 s delivery time
VMAT

One arc  Two arcs

Higher dose homogeneity in PTV

Courtesy to Wilko Verbakel (VUmc)
VMAT versus IMRT


Intensity modulation with photons for benign intracranial tumours. A planning comparison of volumetric single arc, helical arc and fixed gantry techniques.
A. Fogliata, A. Clivio, G. Nicolini, E. Vanetti, L. Cozzi

<table>
<thead>
<tr>
<th>Organ</th>
<th>Parameter</th>
<th>IMRT</th>
<th>RA_M120</th>
<th>RA_HD120</th>
<th>HT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain Stem</td>
<td>$D_2$ [Gy]</td>
<td>36.1±13.7</td>
<td>34.6±13.4</td>
<td>34.6±13.4</td>
<td>38.2±12.4</td>
</tr>
<tr>
<td></td>
<td>$V_{95}$ [%]</td>
<td>20.0±26.3</td>
<td>23.0±26.9</td>
<td>20.8±26.0</td>
<td>29.6±25.9</td>
</tr>
<tr>
<td>Optic chiasm</td>
<td>$D_2$ [Gy]</td>
<td>32.1±22.6</td>
<td>32.0±24.0</td>
<td>32.0±24.1</td>
<td>35.3±23.3</td>
</tr>
<tr>
<td>Ipsilateral ON</td>
<td>$D_2$ [Gy]</td>
<td>12.6±15.6</td>
<td>13.3±15.0</td>
<td>13.8±15.6</td>
<td>10.8±10.9</td>
</tr>
<tr>
<td>Ipsilateral Eye</td>
<td>$D_2$ [Gy]</td>
<td>12.4±16.6</td>
<td>6.8±3.9</td>
<td>6.8±3.7</td>
<td>9.6±4.7</td>
</tr>
<tr>
<td>Healthy Brain</td>
<td>Mean [Gy ]</td>
<td>2.7±1.9</td>
<td>3.9±2.0</td>
<td>3.1±2.8</td>
<td>3.3±2.8</td>
</tr>
<tr>
<td></td>
<td>$V_{95}$ [%]</td>
<td>3.2±2.5</td>
<td>3.1±2.8</td>
<td>2.8±2.2</td>
<td>3.1±2.8</td>
</tr>
<tr>
<td>Healthy Tissue</td>
<td>Mean [Gy ]</td>
<td>2.5±1.4</td>
<td>3.9±1.6</td>
<td>3.3±1.5</td>
<td>3.9±1.9</td>
</tr>
<tr>
<td></td>
<td>$V_{95}$ [%]</td>
<td>0.4±6.5</td>
<td>0.2±6.1</td>
<td>0.2±6.1</td>
<td>12.1±9.8</td>
</tr>
<tr>
<td>Integral dose</td>
<td>[10^3 Gy cm²]</td>
<td>7.5±3.3</td>
<td>9.7±3.4</td>
<td>8.7±3.4</td>
<td>10.4±4.2</td>
</tr>
</tbody>
</table>

© IC 2008
VMAT versus IMRT

- Higher dose homogeneity in- and outside PTV
- Slightly better sparing of the OAR

Courtesy to Wilko Verbakel (VUmc)
Comparison of number of MUs

Average number of MUs for 200 cGy at isocentre for the treatment of prostate cancer at The Netherlands Cancer Institute

<table>
<thead>
<tr>
<th>Technique</th>
<th>MU open</th>
<th>MU wedge</th>
<th>MU total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-D CRT: 3 beams (+ wedges)</td>
<td>218</td>
<td>302</td>
<td>520</td>
</tr>
<tr>
<td>IMRT: 5 beams (step-and-shoot)</td>
<td></td>
<td></td>
<td>344</td>
</tr>
<tr>
<td>VMAT: 1 arc</td>
<td></td>
<td></td>
<td>310</td>
</tr>
</tbody>
</table>
Comparison of number of MUs

Treatment of prostate cancer
Average number of MUs for 200 cGy at isocentre

<table>
<thead>
<tr>
<th>Technique</th>
<th>MU total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-D CRT: 4-beams</td>
<td>295.5</td>
</tr>
<tr>
<td>IMRT: 5 beams (sliding-window)</td>
<td>788.8</td>
</tr>
<tr>
<td>Constant dose rate - VMAT: 1 arc</td>
<td>491.6</td>
</tr>
<tr>
<td>Variable dose rate - VMAT: 1 arc</td>
<td>454.2</td>
</tr>
</tbody>
</table>

Helical tomotherapy
Helical tomotherapy

6 MV x-ray source

Primary collimator
(0 to 5.0 cm slice width)

Binary MLC
(64 leaves, each @ 0.6 cm)

CT detector system
The VERO project at UZ Brussels, Belgium

Courtesy BrainLAB AG, Mitsubishi Heavy Industries
Tomotherapy IMRT

- “arc” type dose distribution
- excellent avoidance of normal tissues
- Dose “conforms” to target
- “Hit the tumor and miss the patient”
In comparison with VMAT helical tomotherapy offers the following advantages:

- It is designed specifically for IMRT
- It has less leakage compared to a conventional accelerator
- It presents a complete “turnkey” solution
- It yields for some treatment sites somewhat better dose homogeneity in the target volume and slightly better sparing of organs at risk
- It has online MV imaging
Helical tomotherapy

In comparison with VMAT helical tomotherapy has the following disadvantages:

– It requires special hard- and software; i.e., the whole infrastructure just for one machine (planning system, server, etc)
– It requires re-planning at another TPS if a patient is exchanged for a treatment at a conventional accelerator (in case of long maintenance periods)
– It requires longer irradiation times compared to VMAT performed with a conventional accelerator (about 5 min compared to 1.5 min for a 200 cGy prostate treatment)
– It requires longer times for 3-D setup verification compared to other in-room imaging systems such as cone-beam CT (about 11 min compared to 4.5 min for a head-and-neck treatment)
CyberKnife

Miniature linac mounted on a robotic arm
CyberKnife

Miniature linac mounted on a robotic arm
In comparison with other radiosurgical techniques the CyberKnife offers the following advantages:

- It allows frameless radiosurgery, *i.e.*, it dispenses with the need for a rigid and invasive stereotactic frame.
- It monitors and tracks the patient’s position continuously and uses on-line images for finding the exact position of the target in the treatment room coordinate system.
- It aims the radiation beam into the on-line determined target position and achieves a dose delivery accuracy of the order of 1 mm through this image-guided dose delivery method.
- It allows for frameless radiosurgical dose delivery to extracranial targets, such as the spine, lung and prostate.
In comparison with other frameless radiosurgical techniques the CyberKnife has the following disadvantages:

– It requires special hard- and software
– It can only be used for specific treatment techniques
– It requires much longer irradiation times compared to VMAT performed with a conventional accelerator, and is mainly suitable for hypo-fractionated treatments
– It allows verification in two planes and is therefore less suitable for 3-D setup verification compared to other in-room imaging systems
Final comments

It is important to note that there are many issues that determine the choice of a specific IMRT delivery technique. These include:

- plan quality
- the efficiency of planning, delivery, and quality assurance
- the complexity and reliability of delivery
- the total number of monitor units required to deliver the prescribed dose
- costs
Many thanks to:

- Kin Yin Cheung
- Lucca Cozzi
- Andrea Holt
- Anton Mans
- Jake Van Dyk
- Wilko Verbakel
- Dirk Verellen
- Jochem Wolthaus
- Tomas kron

for borrowing their slides!