Intensity Modulated Arc Therapy

History and Principles

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Arc therapy

Takahashi S. “Conformation Radiotherapy, rotation techniques as applied to radiography and radiotherapy of cancer”. *Acta Radiol Suppl* 142, 1965

- Introduces conformal therapy: MLC-shaped fields matches the beams-eye-view of target
- Describes conformal arc therapy using MLC to outline the tumour through $360^\circ$ rotation.
IMRT Inverse Planning

Rotational IMRT

What is IMAT?

ARC 1
ARC 2
ARC 3
IMAT

- Take a NOMOS tomo plan, convert to 36 2D intensity maps
- Sequence the intensity maps to overlapping apertures
- Convert overlapping apertures into multiple arcs, and
- Deliver by arcing and dynamic MLC motion

From Yu 1995 PMB
No. 1 Principle of IMAT

“The DVHs or subsequently derived biological scores depend on the total number of strata, which is defined as the product of the number of beams and the intensity levels within each beam. As the number of beams increases, the number of intensity levels required to obtain optimal dose distribution should be reduced.”


What matters is the total number of shape changes! Where to place these apertures does not matter.
Works on single arc IMAT

Commercial Adoption

- Varian first commercialized Otto’s VMAT with RapidArc
- Elekta Developed their single arc solution and call it VMAT
- Philips has recently announce their solution called SmartArc
- Other acronyms: AMAT (aperture modulated arc therapy), AMRT (arc-modulated radiation therapy)
1. Compare single arc, multiple arc, and 7-field IMRT

All optimized with the same planning system, with the same objectives, the same Monte-Carlo based calculation, and the same DVH analysis.
Planning

1. IMRT Plan on 36 fields, export the plan
   • Convert to deliverable single arc IMAT
   • Convert to deliverable multi-arc IMAT
2. IMRT Plan on 7 fields
3. Dose calculation with Monte-Carlo method
4. Import doses into Pinnacle for DVH analysis
Results – Brain
Same objectives, same dose engine

Brain case 2

- IMRT
- IMAT
- AMRT

Volume (%)

Dose (cGy)

GTV
PTV
Brainstem
Cord
LtOpticNerve
Results - lung

Lung case 2

Volume (%) vs. Dose (cGy)

- IMRT
- IMAT
- AMRT

- GTV
- PTV
- LtLung
- RtLung
- Cord
- Heart
Results – H&N

Head and Neck case 1

- IMRT
- IMAT
- AMRT

Volume (%)

Dose (cGy)

- PTV
- CTV
- LtParotid
- RtParotid
- Chiasm
Results – H&N 2

Head and neck case 3

- IMRT
- IMAT
- AMRT

- Nodal_CTV
- PTV
- Brainstem
- Cord
- Larynx
- Lt_Parotid

Dose (cGy) vs. Volume (%)
Results - Prostate

Prostate case 1

- IMRT
- IMAT
- AMRT

Volume (%) vs. Dose (cGy)

GTV
PTV
Bladder
Rectum
Compare IMAT and IMRT for 10 Cases

- Multiple arc IMAT wins every time

- Single arc IMAT performs better than 7-field IMRT in most of the cases
Multi-arc to Single arc

Converting multiple arcs to a single arc ...
Converting multiple arcs to a single arc ...
Stacked -> Spaced

Same total number of strata (shape change), same plan quality
Stack v.s. Spaced DVH

![Graph comparing Stack and Spaced DVH](image)
Stacked v.s. Spaced

Same number of apertures, same plan quality
Observation:

Rotational IMRT is insensitive to small angular errors
Understanding Single Arc

- By using large number (100+) of shape variations, intensity modulation is effectively achieved at the target level.
- It is, therefore, capable of achieving IMRT-like plan quality for simple as well as complex cases.

so,

Is it the same as 36 beam IMRT?

In principle: Yes.
In practice: No quite.
This picture ignored deliverability!

Delivery Requirements

- Neighboring shapes must be geometrically connected.
  - Because deliverability takes priority, shapes are forced to connect in the optimization process, leading to lower plan quality

- Dose rate has to vary in order to maintain (more or less) constant gantry speed.
What if I have a fast MLC and fast dose rate variation?
Static Planning for Dynamic Delivery

- All aperture shapes and weights are optimized at fixed angles.
- At delivery, the shape is changing continuously, and the dose rate varies to deliver the MUs.

Therefore, an optimized shape only appear at an instant, and the MUs for the aperture is delivered through different aperture shapes.
Continuous v.s. static beams

Static beam’s Ripple artifact
Some Cases – noticeable Differences

Plan B
Some Cases – Large Differences
Reason 1: Too much MLC movement
Reason 2: Too Much Dose Rate Variation
No.2 Principle of IMAT

Large MLC motion and dose rate variation can cause:

Delivered $\neq$ Planned

Your machine can do it does not mean you should allow it!
2. Compare RapidArc™ with Tomotherapy™

Double-blinded, two institution study
<table>
<thead>
<tr>
<th>Patients</th>
<th>Targets</th>
<th>Volume (cc)</th>
<th>Prescriptions (Gy)</th>
<th>Fraction dose (Gy)</th>
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<tr>
<td>UMM</td>
<td>Brain A (SEQ)</td>
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<td>PTV</td>
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SEQ: sequential boost; SIB: simultaneous in-field boost
(a) (b)

(c) (d)

- HT (2.5 cm FW)
- RA (1 arc)

- Rectum
- Bladder
- Lt & Rt femoral heads
- Small bowel
## MUs and Beam-on Time

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<td>1</td>
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<td>2.93</td>
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<td>329</td>
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<td>3579</td>
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<tr>
<td><strong>Average over 16 cases</strong></td>
<td><strong>485</strong></td>
<td><strong>1.40</strong></td>
<td><strong>4081</strong></td>
<td><strong>4.83</strong></td>
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<td><strong>Standard deviation</strong></td>
<td><strong>185</strong></td>
<td><strong>0.44</strong></td>
<td><strong>1517</strong></td>
<td><strong>1.73</strong></td>
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</table>
**No.3 Principle of IMAT**

- For a given problem, there are preferred angles and locations to take advantage of the planning geometry.
- Intensity modulation within a field is one way, but not the only way, to achieve such angular and location preferences.
Question 1:

A key principle of IMAT is:

0% 1. The use of arcs reduces the integral dose delivered to the patient.

0% 2. Patient specific QA measurements are no longer required.

0% 3. Increasing the total number of shape changes results in improved plan quality.

0% 4. Aperture shapes should track the shape of the target during rotation.

0% 5. Neutron dose to the patient is reduced as compared with fixed field IMRT.

Answer:

References:
Question 2

In single arc IMAT delivery, intensity modulation is effectively achieved at the target level by all of the following except:

1. By using large number (100+) of shape variations
2. Delivery of overlapping shapes from each beam angle
3. Varying the dose rate
4. Dynamic motion of the MLC leaves

Answer:

References:

Conclusion

- IMAT has been proven to improve efficiency without sacrificing quality for both simple and complex cases.
- The success lies in the large number of aperture variations (or strata) and the increased freedom through dose rate or angular spacing variation.
- Plan with static beams may not accurately approximate dynamic delivery, if large MLC travel and dose rate fluctuation are allowed.
- Delivery is not less reliable than dynamic IMRT, but careful commissioning and regular QA is needed.