VMAT Treatment Planning

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Swedish Medical Center

- Founded in 1910 by Dr. Nils Johanson and a group of Seattle's leading Swedish-born businessmen.
- We treat 225 radiation oncology patients each day.

Acknowledgments

- Vivek Mehta
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Disclaimer

- Our IMAT work is sponsored in part through a grant from Elekta.
**Objectives**

1) To provide an overview of VMAT capable treatment planning systems.
2) To review VMAT planning techniques and tools for creating optimal VMAT plans.
3) To examine the quality of plans that can be obtained using VMAT.

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**Treatment plans were developed using forward planning or simple beam shaping based on the patient’s anatomy.**

- Treatment plans with full inverse planning.
- The dose rate varies as the gantry rotates around the patient.

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**First Generation IMAT 2000-2007**

- Treatment plans were developed using forward planning or simple beam shaping based on the patient’s anatomy.
- The dose rate was constant as the gantry rotated around the patient.

**Next Generation IMAT 2008-**

- Treatment plans with full inverse planning.
- The dose rate varies as the gantry rotates around the patient.

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**IMAT Inverse Planning Solutions**

- **Varian** → Eclipse RapidArc
- **Philips** → Pinnacle SmartArc
- **Elekta** → ERGO++
- **Elekta** → Monaco VMAT
- **Nucletron** → Oncentra MasterPlan VMAT
- **Siemens/Prowess** → Prowess Panther
Planning is performed using Direct Aperture Optimization.

Typical plan uses 1 arc with 177 control points.

For some cases, multiple arcs are used to improve the plan quality or provide adequate coverage of large targets.

Varian Eclipse

Direct aperture optimization: A turnkey solution for step-and-shoot IMRT

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The key feature of DAO is that all of the delivery constraints are included directly into the IMAT optimization.

The optimizer starts by matching the shapes to the BEV of the target.

Throughout the optimization, the MLC leaf position are optimized but they are never allowed to violate the delivery constraints.

DAO for IMAT

Inverse planning for intensity modulated arc therapy using direct aperture optimization

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DAO Optimization

- A simulated annealing algorithm is used to optimize the MLC leaf positions and aperture weights.
- After each change in an MLC leaf position, the algorithm checks to see if any of the delivery constraints are violated. If so, the change is rejected.
- Otherwise, the change is accepted based on the rules of simulated annealing.

Eclipse VMAT

- In Otto’s paper, he used DAO to produce IMAT plans.
- Key innovations:
  1. Focused on a single arc approach with more control points in the single arc. Termed “VMAT”.
  2. Progressive sampling was used to improve the speed of the algorithm.
- This is the approach utilized in Eclipse.

Volumetric modulated arc therapy: IMRT in a single gantry arc

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Varian Eclipse

- Composite dose for H&N patient treated at UMMS.
- Initial = 50.4 Gy, SFB1 = 96Gy, SFB2 = 10.86Gy

Courtesy of Warren D’Souza
Varian Eclipse

- Initial plan and SFB1 used 2 arcs, SFB2 used 1 arc
- Delivery time = 1.5 minutes per arc

Prostate and seminal vesicles plotted with 97% iso-cloud.
- 1 arc, 652 MUs, 1.7 minute delivery

H&N prescription levels of 54, 59.6, and 70 Gy

- 1 arc, treatment time ≈ 2 minutes
Elekta VMAT

- Anatomy based inverse planning is available (Ergo++).
- Full inverse planning solution is under development (Monaco)

Ergo++ (1)

- Ergo++ is a treatment planning system developed by 3DLine, a company based in Milan Italy.
- Ergo++ was originally designed for planning dynamic arcs delivered using the 3DLine mMLC.
- 3DLine was acquired by Elekta in 2007.

Ergo++ (2)

- Elekta modified Ergo++ to provide VMAT planning capabilities.
- For VMAT, Ergo++ designs the beam shapes based simply on the patient’s anatomy.
- The beam weights within a given arc are then optimized.
Ergo++ - Pancreas

Anatomy Based Inverse Planning
Plan Quality

Fig. 1: MC dose maps of eight beam angles with the use of the anatomy-based VMAT plan for a pancreas case (Case 2). Red: PTV, Green: Aorta, Purple: Splenic Artery.
Anatomy Based Inverse Planning
Plan Quality

Ergo++

- As an anatomy based solution, Ergo++ is not as sophisticated as a full inverse planning tool such as found in Eclipse.
- It can, however, match the plan quality of fixed field IMRT for convex target shapes.
The use of anatomy based inverse planning for IMAT:

0% 1. Directly optimizes the MLC leaf positions
0% 2. Provides plan quality consistently better than fixed field IMRT.
0% 3. Should provide high quality dose distributions for convex targets.
0% 4. Requires progressive sampling
0% 5. Utilizes a sweeping window delivery technique.

Answer:

- Anatomy based inverse planning should provide high quality dose distributions for convex targets.

Monaco Background (1)

- Markus Alber, a researcher at the University of Tübingen developed a treatment planning system called Hyperion.
- Two key feature of Hyperion are: (1) Monte Carlo based dose calculation and (2) Biology based IMRT optimization.
- Computerized Medical Systems (CMS) licensed the Hyperion system and created a commercial version called Monaco.
Monaco Background (2)

- Monaco 1.0 was released July 2007 as an IMRT-only planning system.
- In 2008, Elekta acquired CMS and began work to put a VMAT inverse planning solution into Monaco.
- Beta versions of the VMAT solution shipped in spring of 2010.

Monaco VMAT Algorithm

- First optimized fluence maps are produced at a series of discrete beam angles.
- These optimized fluence are then converted into deliverable VMAT arcs.

Monaco - Sweeping Window

- Monaco produces plans using a "sweeping leaf sequencer" where the leaves move unidirectionally across the field.
- The leaf movement continues to alternate between sectors of the arc.

Monaco VMAT

Case #1 - Brain

- 180 cGy/fraction, 320 MU
- Delivery time = 4 min. 40 sec.
Monaco VMAT
Case #1 - Brain

Monaco VMAT
Case #2 - Prostate

- 180 cGy/fraction, 678 MU
- Delivery time = 3 min 54 sec
Monaco VMAT
Case #2 - Prostate

Monaco VMAT
Case #3 – Pelvic Mass

- 180 cGy/fraction, 463 MU
- Delivery time = 4 min 40 sec
Monaco VMAT
Case #3 - Pelvic Mass
- Pelvis: 180cGy/fx (5940), 463MU
- Delivery time = 4min 40sec

Monaco VMAT
Case #4 - H&N
- 200 cGy/fraction, 847 MU
- Deliver time = 12 min 44 sec
Monaco - Summary

- Monaco will serve as Elekta’s VMAT planning solution.
- Monaco VMAT is in Beta testing.
- Initial results are promising, but it is unclear if Monaco VMAT works well for the most complex cases.

Philips Pinnacle - SmartArc

- SmartArc is an extension of the DMPO planning functionality in Pinnacle.
- The SmartArc planning tools were developed by RaySearch (Stockholm).
**SmartArc Features**

- Works with VMAT-capable Varian and Elekta linacs
- Plans can be created with constant or variable dose rates
- Single or multiple arcs covering 90 to 360°
- Dose objectives can be changed during optimization
- Coplanar or non-coplanar plans

**SmartArc Planning Steps**

1. Add a dynamic arc beam
2. Specify couch, collimator, and beam angles
3. Specify dose objectives
4. Specify SmartArc optimization parameters
5. Optimize
6. Compute final convolution dose

**SmartArc Optimization (1)**

1. Beams are generated at the start and the stop angles and at 24° increments from the start angle.
2. A fluence map optimization is performed.
3. The fluence maps are sequenced and filtered so that there are only 2 control points per initial beam angle.

**SmartArc Optimization (2)**

4. These control points are distributed to adjacent gantry angles and additional control points are added to achieve the desired final gantry spacing.
5. All control points are processed to comply with the motion constraints of VMAT.
SmartArc Optimization (3)

6. The DMPO algorithm is applied with an aperture based optimization that takes into account all of the VMAT delivery constraints.
7. The jaws are conformed to the segments based on the characteristics of the linac.

SmartArc Plan Quality

- An alpha version of the SmartArc module was installed in our clinic in February 2009.
- For a series of cases, the accuracy of the predicted dose was verified using the IBA MatriXX 2D ion chamber array inserted in a MULTICube Phantom.

Prostate Example

- 1 arc, 180 cGy/fraction
- 480 monitor units, 1.75 minutes
After extensive testing and validation, we began using SmartArc clinically in June 2009 under an IRB protocol.

- We began using it more frequently after the official release of Pinnacle 9.0.
Pancreas Case – Treated with SmartArc

- 4500 cGy delivered in 25 fractions
- 1 arc, 338 MUs, Delivery time = 1.6 minutes

Liver
Lt. Kidney
Sp. Cord
Rt. Kidney
Summary of SmartArc Clinical Cases

- 30 patients treated covering a variety of treatment sites including lung, head-and-neck, liver, pancreas, esophagus, brain, and chest wall.
- 1 arc used in 19 cases
- 2 arcs used in 11 cases.
- Average delivery time: 1 arc cases = 1.9 minutes, 2 arc cases = 3.9 minutes.

Nucletron – Oncentra VMAT

- The Oncentra VMAT module was developed by RaySearch Laboratories, a software development company located in Stockholm.
- RaySearch also developed the SmartArc module for Pinnacle.
- The underlying VMAT planning engine is the same.
Nucletron – Oncentra VMAT

Prostate Verification

H&N Verification

Nucletron – Oncentra VMAT

- Oncentra VMAT was released in December 2009.
- 14 sites have been installed in Europe (non are clinical).
- No sites in the U.S. at this time.
Siemens/Prowess CBT

- Prowess' Direct Aperture Optimization algorithm is used to develop VMAT plans for delivery on Siemens linacs.
Commercial Solutions - Summary

- The availability of fully dynamic rotational IMRT delivery capabilities of conventional linacs has allowed us to fully realize the capabilities of IMAT.
- This has also been made possible through the availability of the first robust commercial inverse planning solution for IMAT.

VMAT Planning – Key Questions

- Single arc vs. Multi-arc delivery
- Coplanar vs. Noncoplanar

Single vs. Multi Arc

- Increasing the number of arcs provides additional flexibility in shaping the dose distribution.
- The key questions are which cases benefit from the use of multiple arcs and what number of arcs should be used.
1 arc vs. 2 arcs

Solid lines: 2 arcs
Dashed lines: 1 arc

Delivery time: 1 arc = 124 sec, 2 arcs = 181 sec

2 arcs vs. 3 arcs

Solid lines: 2 arcs
Dashed lines: 3 arcs

Delivery time: 2 arcs = 181 sec, 3 arcs: 293 sec
What treatment site would most likely see a dosimetric benefit to increasing the # of VMAT arcs to more than 1?

0% 1. Lung
0% 2. Prostate
0% 3. Brain
0% 4. Pancreas
0% 5. Head & Neck

Answer:

• Due to the complex target volumes and the frequent use of multiple prescription levels, head & neck cases are most likely to see significant dosimetric improvement when using more than 1 VMAT arc.

Coplanar vs. Noncoplanar VMAT

• An advantage of VMAT relative to tomotherapy is the availability of non-coplanar arcs.
• Initial VMAT work has focused almost exclusively on coplanar delivery...

Planning Parameters

• 1 arc is sufficient for simple cases such as prostate, but 2 arcs are needed for more complex cases such as H&N.
• Coplanar versus non-coplanar...
Dosimetric Comparison of IMAT with Conventional IMRT Delivery Techniques

With the latest advances in IMAT planning and delivery, we can now test if IMAT can serve as a true alternative to tomotherapy in terms of plan quality and delivery efficiency.

Arc Sequencer

- We developed an algorithm that can convert optimized fluence maps into deliverable IMAT plans.
- Using this algorithm we compared the plan quality for IMAT with that for helical tomotherapy.
- At the time, however, no machine existed capable of delivering the plans.
New Study: VMAT vs. Tomotherapy

- Collaborative study between Swedish Cancer Institute and University of Virginia.
- 6 prostate, 6 head-and-neck, and 6 lung cases were selected for this study.
- Fixed field IMRT, VMAT, and Tomotherapy were compared in terms of plan quality, delivery time, and delivery accuracy.
- Delivery time for VMAT plan was 2.04".
- Delivery time for the Tomotherapy plan was 5.44".
- Delivery time for fixed field IMRT was 7.26".

**Lung Case**

**Prostate Case**

**SmartArc Plan**

**Head & Neck Case #1**

- Two targets with prescription levels of 5040 and 4500 cGy.

**Helical Tomotherapy**

**2-arc VMAT**
Two targets with prescription levels of 5040 and 4500 cGy

- Average V95: Tomotherapy = 98.4% and VMAT = 98.6%
- Max cord dose: Tomotherapy = 34.4 Gy and VMAT = 21.6 Gy
- Mean parotids dose: Tomotherapy = 12.1 Gy and VMAT = 12.6 Gy

Delivery time for VMAT plan was 4'25"
Delivery time for the Helical Tomotherapy plan was 9'07"
H&N Example #2

Solid = SmartArc  Dashed = Tomotherapy

H&N Example #3

SmartArc Plan

Table 3: Lung case 6 (patient): Plan comparison between fixed-field IMRT, VMAT, and HT

<table>
<thead>
<tr>
<th></th>
<th>IMRT</th>
<th>VMAT</th>
<th>HT</th>
<th>Wilcoxon matched-pairs signed-rank test</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV V95 [%]</td>
<td>98.5 (97.0-100)</td>
<td>98.5 (97.0-100)</td>
<td>98.0 (97.7-100)</td>
<td>0.373</td>
</tr>
<tr>
<td>PTV D95 [cGy]</td>
<td>3.1 (2.7-3.1)</td>
<td>3.6 (3.0-3.5)</td>
<td>3.5 (3.2-3.7)</td>
<td>0.438</td>
</tr>
<tr>
<td>Lung V20 (%)</td>
<td>3.8 (2.5-5.2)</td>
<td>5.0 (4.9-5.3)</td>
<td>4.7 (4.3-5.2)</td>
<td>0.844</td>
</tr>
<tr>
<td>Lung D200 [cGy]</td>
<td>15.3 (14.5-16.3)</td>
<td>15.0 (14.8-16.1)</td>
<td>15.1 (14.8-16.3)</td>
<td>0.625</td>
</tr>
<tr>
<td>Cord D2 [%]</td>
<td>10.5 (10.0-11.0)</td>
<td>10.6 (10.0-11.2)</td>
<td>10.5 (10.0-11.0)</td>
<td>0.663</td>
</tr>
<tr>
<td>Cord D90 [%]</td>
<td>5.6 (5.0-6.0)</td>
<td>5.8 (5.3-6.3)</td>
<td>5.5 (5.0-6.0)</td>
<td>0.861</td>
</tr>
<tr>
<td>V95 [%]</td>
<td>99.3 (99.2-99.4)</td>
<td>99.3 (99.2-99.4)</td>
<td>99.3 (99.2-99.4)</td>
<td>0.861</td>
</tr>
</tbody>
</table>

Abbreviations: PTV = planning target volume; V95 = volume of PTV receiving 95% of prescription; D95 = standard deviation of PTV dose; D2 = volume of structure receiving ≥2% DVH. QA passing rate was obtained using gamma analysis with 3 mm/3% limit. Values expressed in mean range (range). The Wilcoxon matched-pairs signed-rank test is based for VMAT vs. HT.
Future Developments

- With the current HiArt system, the jaw width and the couch speed are set to constant values for each plan.
- In 2011, Tomotherapy Inc. will offer a new option with dynamic jaw motion and dynamic couch motion.
- This should improve the efficiency of delivery and the quality of the plans.
Dynamic Jaws/Dynamic Couch

- DJ/DC couch plans were developed for 10 nasopharyngeal patients.
- As compared with the traditional 2.5 cm jaw setting, the mean integral dose was reduced by 6.3% and the average delivery time was reduced by 66%.

VMAT Planning - Summary

1. All major planning vendors now offer inverse planning solutions for VMAT with varying levels of robustness.
2. Initial work on VMAT has largely focused on single arc coplanar delivery. The advantages of using multiple arcs and non-coplanar beams are now being more fully explored.
3. With current technology, VMAT can provide similar plan quality as tomotherapy with a more efficient delivery.