IMRT vs VMAT

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Disclosure

– Some content/figure are taken from internet
– Reference text books/publications
– Training materials from vendors
What is VMAT?

- Rotational IMRT implemented on conventional linacs
- MLC Leaves move during gantry rotation
- Leaves do not necessarily conformal to target volume
- Leaves move in and out of the projected target volume (i.e., beam’s eye view)
- Gantry speed and dose rate may vary during VMAT
- Achievable modulation depends on leaf speed, gantry speed
VMAT

- Varian → RapidArc
- Elekta → PreciseBeam VMAT
- Both are using the term volumetric modulated arc therapy (VMAT).
How does RapidArc / VMAT Work

- Allows intensity within the aperture to be varied relative to BEV
- Enabled by variable dose rate and gantry speed, which are linked to MLC speed
- Original algorithm by Otto*

*Volumetric modulated arc therapy: IMRT in a single gantry arc
Karl Otto\textsuperscript{ai} Med. Phys. 35 (1), January 2008
PRO - Progressive Resolution Optimizer

- Creates dose-dynamic arc (RapidArc) plans based on dose-volume objectives
- Optimization is based on simulated annealing algorithm
- Determines the optimal dose-dynamic arc field with DMLC, variable dose rate and variable gantry speed
Progressive Resolution Optimizer

Representation of an arc - Control points
- An arc is approximated by number of control points
- Control point = Static field covering specific angular range

Lower number of points
- Low accuracy
- High flexibility
- Shorter optimization

Higher number of points
- High accuracy
- Low flexibility
- Long optimization
PRO

Initial optimization
  • Arc sampled with control points
  • Fit the MLC aperture
  • Dose calculation
  • Calculation of penalty function
Resolution levels

- Optimization performed in 5 resolution levels-first level starts with few [10] control points
- Each level the control points are increased [2n+1]
  - 1st level - 10
  - 2nd level - 21
  - 3rd level - 43
  - 4th level - 87
  - 5th level - 177

[additional 2 points for first and last position]
Multi-resolution dose calculation

- During each level a maximum fixed number of iteration is performed. A maximum of 7 random MLC shape are optimized (sub-process stops when good shape is found) for each CP

- Calculate dose and update cost function after each modification

- Accept or reject modifications based on cost change and/or violation of linac limitations
Multi-resolution dose calculation

- Introduce more control points as the cost is reduced

- A fast multi-resolution dose calculation (MRDC) is performed for each CP: it is based on multi-resolution 3D convolution of Monte Carlo generated point-spread function kernels. MLC configuration and dose rate are converted in a fluence (which models the leakage from rounded leaf ends and transmission)
Final dose calculation

- Transition fluence use the model motion of leaves and dose rate modulation within the angular range represented by control points.

- MLC transmission, rounded leaf edges and tongue & groove effect included in all dose calculations.

- Final calculation performed with AAA algorithm
  - Dose is calculated for each control point

- Final dose distribution is a sum of dose distribution for each control point.
Rapid arc treatment delivery

- Single/Multiple arc rotation
  - Dose
  - Gantry angle
  - MLC shape

- Dose Vs Gantry Vs MLC
  - Dose Vs Gantry angle
  - MLC shape Vs Gantry position
Rapid arc treatment delivery
Constraints for treatment delivery

- **Gantry speed** - Max. 65 secs per rotation [5.5 deg/sec]
- **Leaf speed** - Max speed < 2.5cms/sec [0.5 cm/deg]
- **Dose rate** - Max dose rate of the field
- **Dose / degree SRS system** - Max 20 MU/deg - 60 MU/deg for trilogy
  - Min 0.1 MU/deg
- **Maximum MU** - 3000 MU, 6000MU for trilogy SRS
- **Efficiency possible** - Gantry moves at max speed as much as
Segmented treatment table (STT)

- Arc
  - Gantry rotation Vs MU
- DW & EDW
  - Jaw position Vs MU
- Static gantry IMRT
  - MLC shape Vs MU
- Conformal arc
  - MLC shapes Vs Gantry angle
- Rapid arc
  - Dose Vs Gantry position and Gantry position Vs MLC shape
Rapid ARC treatment delivery
Advantages and disadvantages of IMRT

Advantages:
• More conformal dose, better sparing of OAR
• Several dose (intensity) levels for PTV

Disadvantages:
• More static beams,
• Larger MU (machine dose)
• More time for planning and for delivery
• Higher peripheral dose far from PTV (proportional to MUs)
Rapid Arc advantages

Shorter treatment times

• \( \approx 2 \text{ min (Rapid arc). vs. 8 to 15 min (IMRT)} \)
• Reduced patient motion during treatment
• Increased patient comfort /patient throughput
• VMAT is a more efficient delivery technique due to the continuous nature of the delivery
• Shorter time performing patient specific quality assurance
Head and neck IMRT

Volumetric modulated arc radiotherapy for carcinomas of the oro-pharynx, hypo-pharynx and larynx: A treatment planning comparison with fixed field IMRT

Eugenio Vanetti a, Alessandro Clivio a, Giorgia Nicolini a, Antonella Fogliata a, Sarbani Ghosh-Laskar b, Jai Prakash Agarwal b, Ritu Raj Upreti b, Ashwini Budrukkar b, Vedang Murthy b, Deepak Dattatray Deshpande b, Shyam Kishore Shrivastava b, Ketayun Ardeshir Dinshaw b, Luca Cozzi a,*

a Oncology Institute of Southern Switzerland, Radiation Oncology Department, Bellinzona, Switzerland
b Departments of Radiation Oncology & Medical Physics, Tata Memorial Hospital, Mumbai, India
Aim and Methods

- A planning study was performed to evaluate the performance of volumetric modulated arc radiotherapy on head and neck cancer patients.
- Conventional fixed field IMRT was used as a benchmark.
- CT datasets of 29 patients with squamous cell carcinoma of the oro-pharynx, hypo-pharynx and larynx were included.
- Plans for fixed beam IMRT, single (RA1) and double (RA2) modulated arcs with the RapidArc technique were optimized.
Methods

• Dose prescription was set to 66 Gy to the primary tumour (at 2.2 Gy/fraction), 60 Gy to intermediate-risk nodes and 54 Gy to low-risk nodal levels.

• The planning objectives for PTV were minimum dose >95%, and maximum dose <107%.

• Maximum dose to spinal cord was limited to 46 Gy, maximum to brain stem to 50 Gy.

• For parotids, mean dose <26 Gy (or median <30 Gy) was assumed as the objective.

• The MU and delivery time were scored to measure expected treatment efficiency.
Results

• Target coverage and homogeneity results improved with RA2 plans compared to both RA1 and IMRT.

• All the techniques fulfilled the objectives on maximum dose, while small deviations were observed on minimum dose for PTV.

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary of the dosimetric results for the three PTVs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Objective [%]</th>
<th>IMRT</th>
<th>RA1</th>
<th>RA2</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PTV66</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean [%]</td>
<td>100</td>
<td>100.0 ± 0.0</td>
<td>100.0 ± 0.0</td>
<td>100.0 ± 0.0</td>
<td>n/a</td>
</tr>
<tr>
<td>D_{2%} [%]</td>
<td>107</td>
<td>105.4 ± 1.1</td>
<td>106.2 ± 1.4</td>
<td>104.9 ± 1.2</td>
<td>a,b,c</td>
</tr>
<tr>
<td>D_{98%} [%]</td>
<td>95</td>
<td>92.4 ± 1.2</td>
<td>91.7 ± 1.6</td>
<td>93.2 ± 1.5</td>
<td>a,b,c</td>
</tr>
<tr>
<td>D_{5%} - D_{95%} [%]</td>
<td>–</td>
<td>9.9 ± 1.6</td>
<td>11.1 ± 2.4</td>
<td>8.8 ± 2.0</td>
<td>a,b,c</td>
</tr>
<tr>
<td><strong>PTV60</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean [%]</td>
<td>100</td>
<td>100.3 ± 1.6</td>
<td>100.8 ± 1.3</td>
<td>100.7 ± 1.2</td>
<td>–</td>
</tr>
<tr>
<td>D_{2%} [%]</td>
<td>107</td>
<td>105.9 ± 2.0</td>
<td>106.4 ± 1.6</td>
<td>105.4 ± 1.6</td>
<td>C</td>
</tr>
<tr>
<td>D_{98%} [%]</td>
<td>95</td>
<td>92.3 ± 2.3</td>
<td>92.5 ± 2.3</td>
<td>93.6 ± 2.3</td>
<td>b,c</td>
</tr>
<tr>
<td>D_{5%} - D_{95%} [%]</td>
<td>–</td>
<td>10.5 ± 1.8</td>
<td>10.6 ± 2.0</td>
<td>8.7 ± 1.9</td>
<td>b,c</td>
</tr>
<tr>
<td><strong>PTV54</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean [%]</td>
<td>100</td>
<td>100.0 ± 2.2</td>
<td>100.0 ± 1.3</td>
<td>99.5 ± 1.6</td>
<td>C</td>
</tr>
<tr>
<td>D_{2%} [%]</td>
<td>107</td>
<td>106.2 ± 3.4</td>
<td>106.4 ± 1.7</td>
<td>105.2 ± 1.5</td>
<td>C</td>
</tr>
<tr>
<td>D_{98%} [%]</td>
<td>95</td>
<td>92.1 ± 2.8</td>
<td>91.8 ± 2.7</td>
<td>92.1 ± 2.7</td>
<td>–</td>
</tr>
<tr>
<td>D_{5%} - D_{95%} [%]</td>
<td>–</td>
<td>10.5 ± 2.2</td>
<td>10.6 ± 2.3</td>
<td>9.0 ± 2.1</td>
<td>b,c</td>
</tr>
</tbody>
</table>

Statistical significance ($p < 0.05$) is reported between couples from paired t-test analysis; $^a$: IMRT vs RA1, $^b$: IMRT vs RA2, $^c$: RA1 vs RA2.
patients.

Fig. 2. Mean DVHs for the three PTVs for the global cohort of patients.
Fig. 1. Dose distributions on axial, coronal and sagittal views for one representative case.
• RA2 allowed a reduction of D2% to spinal cord of 3 Gy compared to IMRT (RA1 D2% increased it of 1 Gy).
• On brain stem, D2% was reduced from 12 Gy (RA1 vs. IMRT) to 13.5 Gy (RA2 vs. IMRT).
• The mean dose to ipsi-lateral parotids was reduced from 40 Gy (IMRT) to 36.2 Gy (RA1) and 34.4 Gy (RA2).
• The mean dose to the contra-lateral gland ranged from 32.6 Gy (IMRT) to 30.9 Gy (RA1) and 28.2 Gy (RA2).

<table>
<thead>
<tr>
<th>Organ</th>
<th>Parameter</th>
<th>Objectives [Gy]</th>
<th>IMRT</th>
<th>RA1</th>
<th>RA2</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal cord</td>
<td>Mean [Gy]</td>
<td>–</td>
<td>30.8 ± 3.4</td>
<td>28.2 ± 3.7</td>
<td>25.3 ± 3.1</td>
<td>a,b,c</td>
</tr>
<tr>
<td></td>
<td>D2% [Gy]</td>
<td>46</td>
<td>42.8 ± 2.1</td>
<td>43.7 ± 4.1</td>
<td>39.0 ± 2.6</td>
<td>b,c</td>
</tr>
<tr>
<td>Brain stem</td>
<td>Mean [Gy]</td>
<td>–</td>
<td>13.1 ± 10.4</td>
<td>10.4 ± 8.4</td>
<td>9.9 ± 8.6</td>
<td>a,b</td>
</tr>
<tr>
<td></td>
<td>D2% [Gy]</td>
<td>50</td>
<td>38.2 ± 15.3</td>
<td>26.5 ± 16.9</td>
<td>24.8 ± 16.3</td>
<td>a,b,c</td>
</tr>
<tr>
<td>Ipsi-lateral parotid</td>
<td>Mean [Gy]</td>
<td>&lt;26</td>
<td>40.1 ± 11.6</td>
<td>36.2 ± 10.8</td>
<td>34.4 ± 11.1</td>
<td>a,b,c</td>
</tr>
<tr>
<td></td>
<td>D50% [Gy]</td>
<td>&lt;30</td>
<td>40.4 ± 13.8</td>
<td>34.8 ± 14.3</td>
<td>32.0 ± 15.2</td>
<td>a,b,c</td>
</tr>
<tr>
<td></td>
<td>D23% [Gy]</td>
<td>–</td>
<td>51.0 ± 12.0</td>
<td>46.4 ± 13.3</td>
<td>44.7 ± 14.5</td>
<td>a,b,c</td>
</tr>
<tr>
<td></td>
<td>D66% [Gy]</td>
<td>–</td>
<td>30.1 ± 15.6</td>
<td>25.0 ± 13.8</td>
<td>22.2 ± 14.6</td>
<td>a,b,c</td>
</tr>
<tr>
<td>Contra-lateral parotid</td>
<td>Mean [Gy]</td>
<td>&lt;26</td>
<td>32.6 ± 8.4</td>
<td>30.9 ± 7.7</td>
<td>28.2 ± 6.8</td>
<td>b,c</td>
</tr>
<tr>
<td></td>
<td>D50% [Gy]</td>
<td>&lt;30</td>
<td>30.1 ± 10.4</td>
<td>28.4 ± 9.1</td>
<td>24.1 ± 7.5</td>
<td>a,b,c</td>
</tr>
<tr>
<td></td>
<td>D23% [Gy]</td>
<td>–</td>
<td>41.9 ± 10.5</td>
<td>38.6 ± 12.1</td>
<td>36.0 ± 12.1</td>
<td>a,b,c</td>
</tr>
<tr>
<td></td>
<td>D66% [Gy]</td>
<td>–</td>
<td>21.2 ± 10.8</td>
<td>20.1 ± 6.3</td>
<td>15.5 ± 4.0</td>
<td>b,c</td>
</tr>
<tr>
<td>Healthy tissue</td>
<td>Mean [Gy]</td>
<td>–</td>
<td>12.2 ± 2.9</td>
<td>11.5 ± 2.4</td>
<td>11.4 ± 2.3</td>
<td>ab</td>
</tr>
<tr>
<td></td>
<td>V10Gy [%]</td>
<td>–</td>
<td>33.1 ± 8.4</td>
<td>30.9 ± 8.0</td>
<td>31.0 ± 8.0</td>
<td>ab</td>
</tr>
<tr>
<td></td>
<td>DoseIntegral [10^4 Gy cm²]</td>
<td>–</td>
<td>9.4 ± 3.4</td>
<td>8.7 ± 2.2</td>
<td>8.7 ± 2.2</td>
<td>ab</td>
</tr>
</tbody>
</table>

Statistical significance (p < 0.05) is reported between couples from paired t-test analysis: a: IMRT vs RA1, b: IMRT vs RA2, c: RA1 vs RA2.
Conclusions

RA1 and RA2 showed some improvements in organs at risk and healthy tissue sparing, while only RA2 offered improved target coverage with respect to conventional IMRT.
### Table 3. Comparative planning studies in head and neck cancer

<table>
<thead>
<tr>
<th>Paper [ref]</th>
<th>VMAT commercial system</th>
<th>Number of patients</th>
<th>Primary tumour site</th>
<th>Comparison</th>
<th>PTV</th>
<th>OAR</th>
<th>MU per fraction</th>
<th>Treatment time per fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbakel et al [91]</td>
<td>RapidArc</td>
<td>12</td>
<td>Nasopharynx, oropharynx and hypopharynx</td>
<td>IMRT (7F,SW) vs VMAT (SA) vs VMAT (DA)</td>
<td>Similar PTV coverage. DA VMAT better than SA VMAT and IMRT for homogeneity</td>
<td>No significant difference. Parotid dose lower with DA VMAT (by average 2 Gy) compared with SA VMAT and IMRT</td>
<td>VMAT (SA), 439; VMAT (DA), 459; IMRT, 1108</td>
<td></td>
</tr>
<tr>
<td>Vanetti et al [92]</td>
<td>RapidArc</td>
<td>29</td>
<td>Oropharynx, hypopharynx and larynx</td>
<td>IMRT (7−9F,SW) vs VMAT (SA) vs VMAT (DA)</td>
<td>Similar PTV coverage and conformity. DA VMAT better than SA VMAT and IMRT for homogeneity (SA VMAT slightly inferior to IMRT)</td>
<td>VMAT better than IMRT at sparing spinal cord (D2%, mean dose), brainstem (D2%, mean dose) and parotid glands (mean dose). DA VMAT better than SA VMAT. VMAT – lower integral doses to body</td>
<td>VMAT (SA), 463; VMAT (DA), 584; IMRT, 1126</td>
<td></td>
</tr>
<tr>
<td>Johnston et al [93]</td>
<td>RapidArc</td>
<td>10</td>
<td>Nasopharynx and oropharynx</td>
<td>IMRT (9F,SW) vs VMAT (DA)</td>
<td>Similar PTV coverage IMRT slightly better than VMAT for conformity and homogeneity</td>
<td>No significant differences for spinal cord, brainstem doses. VMAT better than IMRT for contralateral parotid gland sparing</td>
<td>VMAT, 529; IMRT, 1628</td>
<td></td>
</tr>
<tr>
<td>Guckenberger et al [94]</td>
<td>SmartArc</td>
<td>15 (of 20)</td>
<td>Post-operative pharynx/larynx, primary pharynx, paranasal sinus</td>
<td>IMRT (9F,SS) vs VMAT (1−3 arcs)</td>
<td>For PTV coverage and homogeneity: (post-operative pharynx/larynx) SA VMAT inferior to IMRT, DA VMAT = IMRT TA VMAT better than IMRT; (primary pharynx) SA and DA VMAT inferior to IMRT TA VMAT = IMRT; (paranasal sinus) All VMAT plans inferior to IMRT; (decreased coverage between orbits)</td>
<td>No significant difference (SA VMAT inferior to DA VMAT; TA VMAT and IMRT) (paranasal sinus) All VMAT plans inferior to IMRT for lens sparing</td>
<td>VMAT, 430−688; VMAT (SA), 358−440; VMAT (DA), 460−519; VMAT (TA), 506−560</td>
<td></td>
</tr>
<tr>
<td>Bertelsen et al [95]</td>
<td>SmartArc</td>
<td>25</td>
<td>Oropharynx and hypopharynx</td>
<td>IMRT (5−7F,SS) vs VMAT (SA)</td>
<td>Similar PTV coverage and homogeneity. VMAT better than IMRT for elective PTV coverage and conformity</td>
<td>VMAT better than IMRT at sparing spinal cord, parotid glands, submandibular glands at high dose levels. VMAT – lower volumes of normal tissue (outside PTV) irradiated to higher doses</td>
<td>VMAT, 460; IMRT, 503</td>
<td></td>
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<tr>
<td>Alvarez-Moret [96]</td>
<td>Oncentra Masterplan</td>
<td>4</td>
<td>Oral cavity, hypopharynx, nasoal cavity</td>
<td>IMRT (7−9F,SS) vs VMAT (SA) vs VMAT (DA)</td>
<td>IMRT and DA VMAT similar PTV coverage, homogeneity (SA VMAT inferior to IMRT and DA VMAT)</td>
<td>VMAT inferior to IMRT at sparing normal tissue (SA VMAT inferior to IMRT and DA VMAT)</td>
<td>VMAT (SA), 4913; VMAT (DA), 596.4; IMRT, 575.4</td>
<td></td>
</tr>
</tbody>
</table>

Teoh M et al, BJR, 84 (2011)
Thank you for your kind attention