A dosimetric comparison of 3D DCAT vs. VMAT for palliative and early-stage liver lesions

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I. Abstract

II. Introduction

a. PI: Prominence of liver cancer incidence statistics globally, VMAT is readily chosen over 3D methods, especially for SBRT. (Siegel et al\(^1\))
b. PII: Research/Lit review on the pros (modulation and conformity) and cons (interplay effect during breathing cycles) of VMAT, research on liver movement (Afrin et al\(^2\), Bae et al\(^3\), Tsai et al\(^4\), Lu et al\(^5\), Edvardsson et al\(^6\))
c. PIII: Advantages of DCAT highlighted by previous studies done comparing VMAT and DCAT on lung, new research done comparing VMAT and DCAT for liver SBRT (Pokhrel et al\(^7\), Bokrantz et al\(^8\), Han et al\(^9\), Moon et al\(^10\), Thaper et al\(^11\))
d. PIV: Summarize key points, mention rising cost of IMRT (Piana et al\(^12\), Vermal et al\(^13\), Roach et al\(^14\))

i. **Problem:** The problem is that there is a paucity of literature comparing 3D DCAT to VMAT for early-staged or small metastatic liver lesions

ii. **Purpose:** The purpose of this study is to determine if the conformity of dose, irradiated volume, and dose to OAR are equivalent or improved with the use of 3D DCAT as an alternative method of treatment when compared to standard VMAT for SBRT treatment of liver lesions.

iii. **Hypothesis:** Researchers tested the hypotheses that 3D dynamic conformal arc therapy for liver lesions will achieve a (H1\(_A\)) mean heart, (H2\(_A\)) kidney, (H3\(_A\)) large bowel, (H4\(_A\)) small bowel, and (H5\(_A\)) stomach, (H6\(_A\)) esophagus, ≤ to those created with VMAT; (H7\(_A\)) \(V_{20}\) for the lungs ≤ to those created by VMAT; (H8\(_A\)) \(V_{15} < 700\) cc to the normal liver;
(H9A) conformity index ≥ 1; (H10A) Homogeneity index ≤ 2; and (H11A) volume irradiated by 50% of the dose ≤ to that of VMAT.

III. Materials and Methods
   a. Patient selection and setup
      i. PI: Patient population
         1. 20 early-stage or metastatic liver patients
         2. Inclusion criteria (liver lesion >2 cm and <5 cm, adults aged 18-99, 50 Gy in 5 fractions)
         3. Exclusion criteria (patients not initially planned with VMAT, liver lesions)
      ii. PII: CT simulation and patient immobilization
         1. Civco board, Q-fix knee sponge, arm shuttle, full body vac-loc bag, compression belt
   b. Contouring
      i. PI: Planning objectives, target volumes, and critical structures partly adopted from RTOG 1112 protocol (Dawson15)
   c. Treatment Planning
      i. PI: General planning details
         1. Eclipse treatment planning system with AcurosXB
         2. Varian TrueBeam linear accelerator with 10 MV FFF photons
         3. VMAT plan utilizing 2-3 partial arcs, slight collimator rotations, variable field sizes
         4. DCA plan utilizing 3 partial arcs (one 40-degree arc, 5-degree gap, one 135-degree partial arc, 5-degree gap, another 40-degree partial arc), slight collimator rotations, variable field sizes
            a. Larger arc is weighted more heavily than the other two smaller arcs
         5. Normalized to 100% of prescription dose (50 Gy) covering 95% of the treatment volume
         6. SBRT parameters used for both techniques
      d. PI: Plan Comparison
i. Compared coverage between VMAT and DCA plans
ii. Compared OAR dose metrics between VMAT and DCA plans (heart mean dose, kidney mean dose, stomach mean dose, esophagus mean dose, small bowel mean dose, large bowel mean dose, V20 of lungs, and V15 of liver)
iii. Compared conformity index, and volume irradiated by the 50% isodose line

e. Statistical Analysis (UW-La Crosse Stats Center)
   i. Wilcoxon Test
      1. Mean Heart, Kidney, Large Bowel, Small bowel doses, V20 of lungs
      2. Significance level: $P < 0.05$ is statistically significant
   ii. Paired t-test
      1. $V_{15}$ of the liver, mean dose to esophagus and stomach, CI, HI, $V_{25}$
      2. Significance level: $P < 0.05$ is statistically significant

IV. Results
   a. PI: Evaluate mean dose of heart, kidneys, large bowel, small bowel, stomach, esophagus ($H_{1A}$-$H_{6A}$); Refer to the average difference and standard deviation of the mean dose to OAR produced by VMAT vs DCAT (Table 1)
      i. Evaluate mean dose of heart ($H_{1A}$)
         1. $P$ value = 0.0046
         2. Reject null hypothesis that there is no difference between DCAT and VMAT in respect to mean heart dose
         3. Mean dose to heart statistically lower with VMAT
      ii. Evaluate mean dose of kidneys ($H_{2A}$)
         1. $P$ value = 0.0696
         2. Fail to reject null hypothesis
         3. DCAT is effective in producing mean kidney dose $\leq$ to that of VMAT
      iii. Evaluate mean dose of large bowel ($H_{3A}$)
         1. $P$ value = 0.0023
2. Reject null hypothesis that there is no difference between DCAT and VMAT in respect to mean large bowel dose
3. Mean large bowel dose statistically lower with VMAT

iv. Evaluate mean dose of small bowel (H4A)
   1. $P$ value = 0.3223
   2. Fail to reject null hypothesis
   3. DCAT is effective in producing mean small bowel dose $\leq$ to that of VMAT

v. Evaluate mean dose of stomach (H5A)
   1. $P$ value = 0.0353
   2. Reject null hypothesis that there is no difference
   3. Mean dose of stomach statistically lower with VMAT

vi. Evaluate mean dose of esophagus (H6A)
   1. $P$ value = 0.792
   2. Fail to reject null hypothesis that there is no difference
   3. DCAT is effective in producing mean kidney dose $\leq$ to that of VMAT

b. PII: Evaluate critical metrics for liver SBRT plans that will determine safety of the overall plan, and deliverability. (Table 2)
   i. Evaluate $V_{20}$ of the lungs (H7A)
      1. $P$ value = 0.2622
      2. Fail to reject null hypothesis that there is no difference
      3. Answer: DCAT produces $V_{20}$ of lungs is $\leq$ to those created by VMAT

   ii. Compare $V_{15}$ of the liver (H8A)
      1. Indicate if $V_{15}$ of liver is < 700 ccs for both plans
      2. $P$ value < 0.0001
      3. Reject null hypothesis
      4. VMAT produces significantly less $V_{15}$ (cc’s) of the liver

   iii. CI
      1. $P$ value <0.0001
2. Reject null hypothesis
3. CI for VMAT is statistically lower than that of DCA

iv. HI
1. $P$ value = 0.0479
2. Cannot reject null hypothesis
3. $P$ value still < 0.05; HI for VMAT is statistically lower than that of DCA

v. $V_{25}$
1. $P$ value <0.0001
2. Reject null hypothesis
3. $V_{25}$ statistically lower with VMAT than with DCA

V. Discussion
VI. Conclusion
References


11. Thaper D, Kamal R, Singh G *et al.* Dosimetric comparison of dynamic conformal arc integrated with segment shape optimization and variable dose rate versus volumetric


### Tables

**Table 1.** Mean difference averaged from all patients’ VMAT and DCAT plans, standard deviation, and *P*-value for heart, kidneys, large bowel, small bowel, stomach, esophagus, lungs, and liver.

<table>
<thead>
<tr>
<th>OAR</th>
<th>Mean Difference</th>
<th>Standard Deviation</th>
<th><em>P</em>-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart</td>
<td>-26.30</td>
<td>48.24</td>
<td>0.0046</td>
</tr>
<tr>
<td>Kidneys</td>
<td>-1.01</td>
<td>7.50</td>
<td>0.0696</td>
</tr>
<tr>
<td>Large Bowel</td>
<td>-32.88</td>
<td>59.15</td>
<td>0.0023</td>
</tr>
<tr>
<td>Small Bowel</td>
<td>-2.82</td>
<td>17.29</td>
<td>0.3223</td>
</tr>
<tr>
<td>Stomach</td>
<td>-37.5</td>
<td>74.01</td>
<td>0.0353</td>
</tr>
<tr>
<td>Esophagus</td>
<td>-4.81</td>
<td>80.41</td>
<td>0.792</td>
</tr>
</tbody>
</table>

VMAT = Volumetric modulated arc therapy; DCAT = Dynamic conformal arc therapy; OAR = Organs at Risk

**Table 2.** Mean difference averaged from all patients’ VMAT and DCAT plans, standard deviation, and *P*-value for CI, HI, and V₂₅ of the treatment volume.

<table>
<thead>
<tr>
<th>Critical Metrics</th>
<th>Mean Difference</th>
<th>Standard Deviation</th>
<th><em>P</em>-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{20} ) of Lungs</td>
<td>-0.06</td>
<td>0.41</td>
<td>0.2622</td>
</tr>
<tr>
<td>( V_{15} ) of Liver</td>
<td>-61.73</td>
<td>42.66</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CI</td>
<td>-0.18</td>
<td>0.06</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>HI</td>
<td>0.06</td>
<td>0.13</td>
<td>0.0479</td>
</tr>
<tr>
<td>( V_{25} ) of treatment volume</td>
<td>-46.30</td>
<td>31.09</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

VMAT = Volumetric modulated arc therapy; DCAT = Dynamic conformal arc therapy; \( V_{20} \) = volume receiving 20 Gray; \( V_{15} \) = volume receiving 15 Gray CI = conformity index; HI = homogeneity index; \( V_{25} \) = total volume receiving 25 Gray