A dosimetric comparison of 3D DCAT vs. VMAT for palliative and early-stage liver lesions
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Abstract
Volumetric modulated arc therapy (VMAT) and 3D dynamic conformal arc therapy (DCAT) are 2 methods proven useful for the clinical implementation of stereotactic body radiation therapy (SBRT) for lung lesions however, similar comparisons of SBRT liver lesions are lacking. The purpose of this study was to determine if the conformity of dose, irradiated volume, and dose to organs at risk (OAR) are equivalent or improved with the use of DCAT as an alternative treatment method when compared to standard VMAT for SBRT delivery of palliative and early-stage liver lesions. Twenty patients with liver lesions sized 2.0-5.0 cm were selected for this study. Plans were created with both DCAT and VMAT techniques for each patient. Metrics evaluated included the mean heart, kidney, large bowel, small bowel, esophagus, and stomach doses, the lung volume receiving 20 Gy (V_{20}), the volume of the normal liver receiving 15 Gy (V_{15}), conformity index (CI), heterogeneity index (HI), and the irradiated volume or volume receiving 25 Gy (V_{25}). The P-values for the mean dose to kidneys, small bowel, esophagus and the lung V_{20} were greater than 0.05, and no statistical difference could be determined between DCAT and VMAT. The P-values for the mean heart, large bowel, stomach, and liver V_{15} were less than 0.05, indicating statistical significance and superiority of VMAT for minimizing dose to these organs, especially V_{15} of the liver. The DCAT technique produced CI greater than 1.0 for all patients proving superior coverage, while standard VMAT produced significantly improved V_{25} with P-values less than 0.0001, and consequently higher HI.

Keywords: VMAT, DCAT, liver cancer, SBRT, palliative care, metastatic disease

Introduction
The liver is a precarious site for various comorbidities and metastatic diseases alike as a major recipient of damage from conditions ranging from obesity, viruses, and excessive alcohol consumption to advanced colorectal cancer. An aggregation of 2020 cancer statistics showed a consistent, yearly increase of primary liver cancer incidence by 2.0 – 3.0%, with death rates also following a similar trend.¹ Advancements in radiation oncology have played a critical role in the selection of volumetric modulated arc therapy (VMAT) over 3D-conventional radiation therapy (3D-CRT) in an effort to treat liver lesions and spare normal tissue. Dynamic conformal arc
therapy (a form of 3D-CRT) and VMAT methods are popular researched techniques being clinically applied for SBRT of the lung, with some even suggesting a hybrid of the two to maximize benefits of each method. However, there is a lack of direct comparisons, consensus, and analysis regarding the 2 methods for SBRT of the liver.

The advantages and disadvantages of VMAT and DCAT differ in that the former method uses optimization of multi-leaf collimators (MLCs) while the latter does not. The primary advantages of VMAT include the ability to achieve dose conformity, lower overall toxicity, and better spare OAR including non-liver organs and those low dose tolerances such as the lung. However, IMRT methods are also known to produce an increase of low dose, including the volume of the normal liver receiving 15 Gy ($V_{15}$), which is thought to be one dosimetric indicator for predicting radiation induced liver disease (RILD). Volumetric modulated arc therapy is also associated with increased interplay effect caused by the motion of the liver during breathing cycles and is reported to result in significant intra-fraction variability (> 3.0 mm), exacerbated by flattening filter free (FFF) beams and smaller clinical target volumes (CTV).

Alternatively, DCAT compensates for the disadvantages of VMAT, but does have clear disadvantages in clinical application of treatments involving irregularly shaped target volumes because intensity modulation is not utilized.

Specific to SBRT lung treatments, comparisons using VMAT and DCAT have shown that DCAT had similar conformity and coverage of the tumor, with slightly better avoidance of OAR which included the lung volume receiving 20 Gy ($V_{20}$), tighter 50% isodose lines, and a significant reduction of monitor units (MUs). Segment weight optimized (SWO) DCAT produced dosimetrically similar plans to VMAT in favorable conditions where the tumor was not directly adjacent to OAR. In addition to its technical simplicity, DCAT is more likely to be approved by insurance in general due to the rising cost-benefit ratio of VMAT, and therefore provides timely palliative treatment of the liver. Currently, there is a lack of accessibility to policies and comparison data needed to draw a consensus on insurance coverage of the liver with different modes of radiation delivery.

In 2 emerging studies, researchers have observed VMAT versus DCAT for a variety of SBRT liver treatments. Moon et al showed that the DCAT plan met planning goals set by the Radiation Therapy Oncology Group (RTOG) SBRT liver protocols; although VMAT was slightly superior in dose distributions to some organs. Researchers also emphasized that, with DCAT, there is less chance of miss because the tumor is in an open field, and there is less
concern with quality assurance, calculation, and interplay effect of the MLC leaves.\textsuperscript{11} Although the study by Moon et al\textsuperscript{12} demonstrated the coverage, conformity, and doses to some OAR using VMAT and DCAT for liver lesions varying in size and number, the authors did not investigate the dose to the kidneys, bowels, lung, and $V_{15}$ of the normal liver, which is critical for safe deliverability of a SBRT liver treatment. Thaper et al\textsuperscript{13} also observed a reduction in MU with DCAT but did not find the use of segment shape optimized (SSO) DCAT as advantageous in their clinical evaluation of DCAT versus VMAT for SBRT treatment of the liver; especially for larger planning target volume (PTV) sizes. With recent studies showing the ability of modified 3D-CRT methods such as the use of DCAT to mimic the results of VMAT plans, additional research is required to evaluate the efficacy and applicability of traditional 3D DCAT for SBRT delivery to treat limited sized liver tumors and compare the dose to nearby structures such as the gastrointestinal organs, normal liver, kidneys, heart, and lung are affected.

Dynamic arc conformal therapy is used for both early-staged and palliative lung tumors due to the physical similarity in size. However, it is possible that the same is true of VMAT for early staged or small metastatic lesions in the liver. It would be beneficial to understand the differences of DCAT and VMAT in the treatment of liver lesions, especially with the increasing demand for optimization and inverse planning which contributes to increasing costs for IMRT as well as cost discrepancies between VMAT and 3D planning.\textsuperscript{14} The problem is that there is a paucity of literature comparing 3D DCAT to VMAT for early-stage or small metastatic liver lesions. Therefore, the purpose of this study was 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. Researchers tested the hypotheses that 3D DCAT for liver lesions will achieve mean doses to (H$_1$A) the heart, (H$_2$A) kidney, (H$_3$A) large bowel, (H$_4$A) small bowel, (H$_5$A) stomach, and (H$_6$A) esophagus, $\leq$ to those created with VMAT; (H$_7$A) $V_{20}$ of the lungs will be $\leq$ those created by VMAT; (H$_8$A) $V_{15} < 700 \text{ cc}$ to the normal liver; (H$_9$A) conformity index (CI) $\geq 1$; (H$_{10}$A) homogeneity index (HI) $\leq 2$; and (H$_{11}$A) total irradiated volume or the volume receiving 25 Gy ($V_{25}$) $\leq$ that of VMAT.

**Methods and Materials**

**Patient Selection**

Twenty patients with early-stage liver cancer or metastatic liver lesions from a single institution were retrospectively selected for this study. Inclusion criteria were patients between
the ages of 45 and 85 years old and liver lesions measuring between 2.0 and 5.0 cm in the
greatest dimension. Patients with lesions smaller or greater than 2.0 and 5.0 cm were not
included in the study. Of the 20 patients selected, 13 had early-stage liver cancer and 7 had
metastatic liver lesions.

Patient Setup

Due to the location and type of treatment performed, extensive immobilization was used
during CT simulation and throughout treatments to minimize internal organ motion. Use of
increased immobilization allowed for treatment margins to be drawn tighter around tumors,
helping to reduce potential dose to surrounding critical structures. During CT simulation, a Civco
board was attached to the simulation table which was used to secure immobilization devices for
SBRT. A Q-Fix knee sponge was indexed on the board for patient comfort and to keep the
patient’s lower anatomy stable. An arm shuttle was placed superiorly to the trunk of the patient,
with the patient’s head resting on the head rest of the arm shuttle, and their arms bent superiorly
to the patient’s head to keep them out of treatment fields. A full body vacuum bag was placed
under the patient’s entire body, from about mid-thigh to their arms. The vacuum bag was
immobilized completely around the patient to refrain the patient from any movement during
treatment. Finally, a compression belt was used to apply pressure to the patient’s abdominal
region to shrink the range of motion of the abdomen and chest during the breathing cycle, thus
reducing internal motion of organs. Breathing cycles were also tracked using 4D motion sensors;
however, the plan was contoured, planned, and treated using the average of this cycle.

Contouring

After CT simulation, the datasets were imported into Varian Eclipse Treatment Planning
System (TPS) for contouring and fusions with other imaging studies to aid in delineation of the
target volumes for the radiation oncologist. Contouring and fusions were done on the average
breathing cycle from the 4D scan. Planning objectives, target volumes, and critical structures
were partly adopted from RTOG 1112 protocol; therefore, the OAR contoured were the kidneys,
small bowel, large bowel, esophagus, stomach, heart, and lungs.15

Treatment Planning

Treatment planning for each technique was consistent for all patients. AcurosXB version
13.7 of Varian Eclipse TPS was utilized for the planning aspect of each patient’s conformal and
VMAT plans. Treatments were planned for a Varian TrueBeam linear accelerator with 120 HD
MLCs. Both VMAT and DCA plans were designed using the energy 10 MV FFF for each field.
Stereotactic body radiation therapy treatment parameters were used for both techniques. Both VMAT and DCA plans were planned for 50 Gy in 5 fractions. Based on the location of the tumor, beam arrangements for VMAT and DCA techniques slightly differed for each patient to avoid excessive radiation to normal structures. The VMAT plans were designed with 2 - 3 partial arcs approximately 200 - 220° each. Slight collimator rotations were used to maximize MLC blocking based on the tumor volume. The size of the treatment volume also led to variable field sizes between patients. The DCA plans were also designed consistently, with slight variance between patients due to tumor location. The DCA plans were designed to use 3 partial arcs. The order of the partial arcs was a 40° arc, a 5° gap, a 135° arc, another 5° gap, and a 40° arc. The weighting for the 135° arc was weighted 65 - 70% of the total dose. The weighting for the 40° arcs were equally weighted with the remaining dose. Collimator rotations and variable field sizes were also used based on the tumor volume and location. Both planning techniques were normalized to 100% of the prescription dose covering 95% of the treatment volume.

**Plan Comparison**

After retrospectively planning VMAT and DCA techniques for each patient, coverage of the treatment volume was compared between the 2 techniques by analyzing the isodose lines and dose volume histogram (DVH). Since both techniques were normalized to the same value, the isodose lines and dose fall off were considered and compared between the 2 plans. Conformity index and V25 of the treatment volume were both calculated through Eclipse treatment planning software for each plan. Homogeneity index (HI) for each plan were derived from the equation:

\[ HI = \frac{\text{maximum dose}}{\text{prescription dose}} \]

Dose metrics were also compared between the VMAT and DCA plans. The comparative dose metrics included: the mean dose of the heart, kidney, stomach, esophagus, small and large bowel; the V20 of the lungs; and the V15 of the liver. For each plan using either VMAT or DCA technique, the dose metrics and dose values were acquired and compared.

**Statistical Analysis**

The raw data for all patients in the study were congregated to find the mean difference and standard deviation resulting from VMAT and DCA plans. The mean difference was defined as the average difference of either dose, volume, or index values that resulted from VMAT minus DCAT. To test the significance of the mean difference values, a Wilcoxon test and paired t-test were performed. The Wilcoxon test was used to calculate the P values for mean doses to the heart, kidney, large bowel, small bowel, and also the V20 of the lungs. The paired t-
test was used to calculate the $P$ values for mean doses to the esophagus and stomach, $V_{15}$ of the liver, CI, HI, and $V_{25}$ of the treatment volume.

**Results**

*Mean Dose to Organs at Risk*

The mean dose difference to the heart, kidneys, large bowel, small bowel, stomach, and esophagus resulting from VMAT minus DCAT were -26.30, -1.01, -32.88, -2.82, -37.5, and -4.81 cGy, respectively (Table 1). The higher mean dose difference correlated with a larger range for standard deviation. The greatest mean dose differences were to the heart, large bowel, and stomach resulted in $P$ values of 0.0046, 0.0023, and 0.0353, respectively. These $P$-values ($< 0.05$) indicated statistical significance between the 2 outcomes and that DCAT is not able to produce mean doses equivalent to that of VMAT for the heart, large bowel, and stomach; therefore, the null hypotheses cannot be rejected. Furthermore, the negative values of the mean difference indicated that the VMAT mean dose to the heart ($H_{1A}$), large bowel ($H_{3A}$), and stomach ($H_{5A}$) was statistically lower than that of DCAT. The $P$-values for the kidneys, small bowel, and esophagus were 0.0696, 0.3223, and 0.792, respectively. These $P$-values ($>0.05$) indicated that there was no statistical significance between the VMAT and DCAT plans suggesting that DCAT is not able to produce mean doses equivalent to that of VMAT for the kidneys, small bowel, and esophagus; therefore, the null hypotheses were rejected.

*Critical Metrics*

To determine the overall safety and efficacy of the plan, the $V_{20}$ of the lungs, $V_{15}$ of the liver, CI, HI, and the $V_{25}$ of the total volume was analyzed. The mean dose difference to the $V_{20}$ of the lungs, $V_{15}$ of the liver, CI, HI, and $V_{25}$ of the total volume resulting from VMAT minus DCAT were –0.06, –61.73, -0.18, 0.06, and –46.30, respectively. The $P$-value of the $V_{20}$ of the lungs ($P=0.2622$) indicated that there was no statistical difference between the VMAT and DCAT plans and that DCAT was not able to produce $V_{20}$ of the lungs $\leq$ that of VMAT; therefore, the null hypotheses was rejected. The $P$-value of the $V_{15}$ of the liver ($< 0.0001$) indicated that the $V_{15}$ of the liver ($H_{8A}$) produced by VMAT was statistically lower than that of DCAT. The CI produced by DCAT plans for all patients were $\geq1$, while the CI produced by VMAT plans did not achieve the ideal value of “1” for 17 patients. The HI produced by both VMAT and DCAT achieved a value $<2$, with a $P$-value of 0.0479. The $P$-value of the irradiated volume or $V_{25}$ ($H_{10A}$) was $< 0.0001$, indicating that the null hypothesis, DCAT cannot produce a $V_{25} \leq$ to VMAT, failed to be rejected (Table 2).
Discussion

Organs At Risk

The data from this study indicate that DCAT is effective in producing a mean dose to the kidneys (H2A), small bowel (H4A), and esophagus (H6A) statistically equivalent to that of VMAT, but is not effective in producing the same effect with the heart, large bowel, and stomach. It is important to note that statistical difference does not always imply clinical significance, especially if the mean dose produced overall is low compared to the recommended guidelines and constraints. Although VMAT was superior in reducing average doses to the heart, large bowel, and stomach, both DCAT and VMAT produced acceptable mean doses to these structures. The highest mean dose produced by DCAT was 555.6 cGy, 550.1 cGy, and 898.5 cGy to the heart, large bowel, and stomach, respectively. The highest mean dose produced by VMAT was 500.2 cGy, 518.2 cGy, and 803.5 cGy to the heart, large bowel, and stomach, respectively. The P-values were also just low enough to indicate statistical difference, indicating that statistical difference was not substantial. According to Quantitative Analyses of Normal Tissue Effects in the Clinic (QUANTEC) guidelines, the mean dose to the heart should not exceed 2600 cGy, and the maximum dose to the stomach should not exceed 4500 cGy. For 5 fraction SBRT treatments, it is also recommended that the maximum dose to the colon and stomach should not exceed 3800 cGy and 3200 cGy, respectively. Since DCAT nor VMAT exceeded values and had a very low overall average dose to these structures, it is unlikely that patients receiving SBRT to the liver with either method would experience side effects such as pericarditis, ulceration of the bowels or stomach. Since the mean dose to these structures was minimal, there is no evidence that the relative statistical difference of the two plans would make a clinical difference.

For more radiosensitive structures such as the lung and the normal liver, it is critical to reduce dose to these structures to avoid RILD and radiation induced pneumonitis. The V20 of the lungs were minimal (< 7.1% for VMAT, <7.6% for DCAT) and were statistically equivalent between the two methods, proving that DCAT technique was effective in producing a statistically equivalent dose to the V20 of the lungs when compared to VMAT (H7A). However, the volume of the normal liver receiving 15 Gy proved to be a concerning metric, as DCAT was not able to produce optimal results compared to VMAT. Volumetric modulated arc therapy was able to produce V15 of the liver less than 700 cc for 18 patients, while the medical dosimetrist struggled with 2 patients and 1 additional patient for DCAT. The statistical analyses also
concluded that VMAT was significantly superior in reducing $V_{15}$ of the liver. In most SBRT cases concerning the liver, this critical metric assumes that a fractionated 15 Gy will produce a lower biologically equivalent dose, and that 500 cc are the minimum volume of normal liver required post resection for sufficient functioning of the organ. The $V_{15}$ of the liver being < 700 cc is a widely accepted factor that has been documented to limit hepatic injury such as RILD, and a predictor for patient recovery from radiation induced toxicity to the liver within the first 3 months post radiation.\textsuperscript{18} Based on the foundations of this established metric; it can be concluded that the statistical significance between VMAT and DCAT for $V_{15}$ of the liver is also clinically relevant - VMAT is superior and produces improved clinically acceptable plans compared to that of DCAT (Figure 1). Previous researchers did not evaluate the $V_{15}$ of the normal liver; however, the $V_{30}$, $V_{20}$, and $V_{10}$ were also significantly higher in DCAT compared to those of VMAT.\textsuperscript{12}

**Conformity, Homogeneity, and Irradiated Volume**

Based on the results, DCAT achieved a better CI and HI than the VMAT plans, while VMAT was able to achieve a lower $V_{25}$ compared to DCAT. The ideal value for CI is 1, and a CI $\geq 1$ indicated that DCAT had better overall coverage of the PTV. The miniscule $P$-value ($<0.0001,$) indicates strong statistical evidence that DCAT was superior in achieving a CI greater than or equal to 1 (H$_{9A}$). A CI of $< 1$ was achieved for 18 patients planned with VMAT. This decreased PTV coverage in the VMAT plans could be due to several factors, including the interplay of MLCs during modulation to minimize average doses to OAR. There is increased internal organ motion due to the proximity of the liver to the diaphragm, requiring more stringent immobilization and/or QA to decrease the chance of geometric miss and deliver accurate dosage. The HI helps to measure the overall safety of SBRT plans and ensures that the plan is not excessively over-dosed. The acceptable range for this metric varies depending on treatment site and desired coverage. In general, SBRT plans are known to be less homogeneous within the PTV due to its ablative nature and tightening of the prescription line with minimal to no margin in order to prioritize conformity of dose to the target and minimize dose to OAR.\textsuperscript{19} An HI $< 2$ ensures that the plan is not excessively high in dose. Although both DCAT and VMAT plans were able to achieve HI $< 2$, the $P$-value indicated enough statistical evidence to infer that DCAT was superior in producing a lower HI value.

The $V_{25}$ of the PTV volume helps to measure the difference of conformality of the prescription dose based on the PTV volume.\textsuperscript{20} The data provided robust evidence of statistical difference between VMAT and DCAT for this outcome with $P < 0.0001$; VMAT was superior to
DCAT in producing a smaller irradiated volume. The metrics CI, HI, and $V_{25}$ are correlated, and changing one can affect the other parameters. The VMAT plans had a lower $V_{25}$ or the irradiated volume, resulting in a tighter 50% IDL. Consequentially, this produces increased hot spots and therefore a higher HI while lowering the CI for the VMAT plans (Figure 2 & 3). Since the CI, HI, and $V_{25}$ are correlated because one can affect the other, it may be up to the discretion of the physician to decide if the irradiated volume takes priority over coverage and/or homogeneity of dose to minimize dose to the OAR. Pokhrel et al\textsuperscript{8} compared DCAT vs VMAT for SBRT of lung tumors and demonstrated that simple DCAT based plans were able to improve target coverage with acceptable dose to OAR. However, the lack of density of the lung may contribute to the key difference in the ability of the DCAT plan to maintain a tighter intermediate dose spillage ($V_{50\%}$) in the lung, whereas tissue density in the abdominal region led to slightly increased intermediate dose spillage with DCAT in this study. This is further supported in the Moon et al\textsuperscript{12} study, where DCAT for the liver produced higher CI but also consequently a higher D$_{50\%}$. There is an agreement of the CI and its effect on intermediate dose spillage with the use of DCAT between both studies. The improvement of the CI and HI of the DCAT plans, and consequently the expansion of the lower doses resulting in increased irradiated volume in the DCAT plans may also be a contributing factor for the slight increase of mean dose to the heart, large bowel, and stomach. The $V_{15}$ of the liver may have been one of the organs affected by the $V_{25}$ or intermediate dose spillage.

**Conclusion**

The research problem was the paucity of literature comparing 3D DCAT to VMAT for early-stage or small metastatic liver lesions. The purpose of this retrospective study was 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. While modulation with VMAT did show advantages in sparing some critical structures such as the heart, large bowel, and stomach, there was not a large degree of statistical significance in this study, and clinical significance is questionable. Dynamic conformal arc therapy was superior in producing CI $> 1$ and HI $< 2$ when compared to VMAT, but the increase in total irradiated volume was a consequential effect that may be linked to the increased dose in the heart, large bowel, and stomach. The $V_{15}$ of the liver was the most concerning metric, as it determines the deliverability and safety of the plan. In this
study, the $V_{15}$ of the liver was greatly improved using VMAT when compared to DCAT. Based on this evaluation, it was concluded that VMAT was superior to DCAT for this study.

The limitations of this study included the data collected at a single institution with a small sample size of 20 patients. Incorporating multiple institutions and a higher number of patients would improve the external validity and robustness of statistics within this study. Especially for certain metrics, such as $V_{15}$ of the liver, the superiority between the 2 plans was determined by a difference of 1 patient. By creating a multi-institutional study, a larger number of patients with the same size tumor and location in the liver would help reduce the effect of confounding factors during the statistical analyses. Confounding factors can include different algorithms used in certain TPS, which may or may not affect the result of these plans. The patients in this study were limited to a diagnosis of early-stage or metastatic liver lesions within 2.0 - 5.0 cm. Future studies should include the evaluation of different size ranges or locations to stratify which patients may significantly benefit from VMAT. In addition, it may also be beneficial to evaluate the gradient index to further determine if DCAT is superior or equivalent to VMAT. Since this study concludes that doses to certain structures were statistically distinguished due to the $P$-value but may not be clinically significant, future studies may be needed to evaluate the clinical impact.

**Acknowledgments**

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References


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17. Mobius Medical Systems, 3D Dose Volume Histogram poster


Figures

Figure 1. Dose volume histogram comparison for the $V_{15}$ liver metric for VMAT and DCAT plan for patient 16.

Figure 2. Isodose distribution showing the conformality around the PTV at isocenter for patient 19. Figure (A) shows the DCAT plan and Figure (B) shows the VMAT plan.
Figure 3. Homogeneity index and maximum dose for Figure A showing the DCAT plan and Figure B showing the VMAT plan.
Tables

Table 1. Average mean difference of all 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 (cGy)</th>
<th>Standard Deviation</th>
<th>$P$-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>

* = $P$-value of mean difference is statistically significant, VMAT < DCAT

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

Table 2. Average mean difference of all patient VMAT and DCAT plans, standard deviation, and $P$-value for CI, HI, and $V_{25}$ of the treatment volume.

<table>
<thead>
<tr>
<th>Critical Metrics</th>
<th>Mean Difference</th>
<th>Standard Deviation</th>
<th>$P$-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 cc</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 cc</td>
<td>31.09</td>
<td>&lt; 0.0001*</td>
</tr>
</tbody>
</table>

* = $P$-value is statistically significant

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; cc = cubic centimeters.