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ORIGINAL ARTICLE – OPEN ACCESS

Comparison of the Dosimetric Planning Efficiency of Dynamic Conformal Arc and Volumetric Modulated Arc Therapy Techniques for Stereotactic Body Radiotherapy of Lung Cancer Using Internal Target Volume

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ABSTRACT

Objective: This retrospective study constitutes a feasibility assessment of dynamic conformal arc (DCA) therapy as an alternative to volumetric-modulated arc therapy (VMAT) for stereotactic body radiation therapy (SBRT) of lung cancer (LC) with the free breathing technique using internal target volume. DCA is to create a more efficient treatment reducing beam-on time (BOT) and monitor unit (MU) without interplay errors except for complex tumor geometries when compared to volumetric modulated arc therapy (VMAT).

Materials and Methods: CT images and plans of forty patients treated with 50 Gy prescription in four fractions using VMAT technique for SBRT treatment of LC selected. Plans were re-planned with using DCA technique. VMAT and DCA plans compared via The Radiation Therapy Oncology Group (RTOG) Protocol 0915 for conformity and efficient having pass rate of gamma index in quality assurance (QA), MU and BOT.

Results: The study included 40 patients. The mean value of QA pass rate 99.10±1.49 in DCA and 92.34±1.96 in VMAT. The rate was higher in DCA ($p<0.001$ and $t=8.98$). The values of BOT and MU were 4.68 min and 3296 in the VMAT technique and they were 3.58 min and 2395 in DCA. These values were significantly improved with DCA ($p<0.001$ and $p<0.001$).

Conclusion: DCA can potentially minimize multi-leaf collimator errors from respiratory motion and small-field dosimetry. It delivery similar doses of treatment quality to tumor while providing faster treatment by significantly reducing MU and BOT compared to VMAT and moreover offers same-day SBRT treatments without the need for specific QA.

Keywords: Dynamic conformal arc, lung cancer, stereotactic body radiotherapy, treatment technique, volumetric modulated arc therapy

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INTRODUCTION

Stereotactic body radiation therapy (SBRT) has been more preferred for the treatment of various diseases in recent years (1, 2). SBRT is the first choice for standard curative therapy, especially for patients with early-stage inoperable non-small cell lung cancer (NSCLC) because it provides a high cure rate and minimizes treatment-related toxicity (3–6). Radiation dose delivery with high accuracy and precision has been a major challenge in SBRT therapy, which is based on the delivery of high doses in very small fractions of lung tumors with regular moving targets (7). The report of the American Association of Physicists in Medicine Task Force 76 recommends the management of respiratory techniques when tumor movement is present or normal tissue preservation is important (7, 8). Due to technological advances in radiotherapy, many other devices and strategies are available for use in the treatment of regular or irregular movements of tumors, including free breathing, gating, and tracking techniques. SBRT treatments using four-dimensional computed tomography (4D-CT) simulation systems that account for motion during a respiratory cycle and generate an internal target volume (ITV) based on the entire range of motion are preferred by most treatment centers (7, 9). There is no consensus on the solution, treatment technique, or planning of problems that may result from tumor movement (7, 8), despite the rapid development of SBRT and motion management techniques with a wide variety of application tools.

Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) are frequently preferred in the treatment of SBRT of extra-cranial tumors in recent years (1, 10). VMAT, which is the most widely used technique in SBRT treatment, has a complex geometry that allows the movement of multi-leaf collimator (MLC) leaves, dose rate and gantry rate to be synchronized during delivery of the treatment. (1, 10, 11). Regular tumor movement created by the respiratory cycle in SBRT of NSCLC is the reason for the uncertainty in the dose calculation and dose delivery. However, the highly modulated VMAT technique with a complex structure is sensitive to the calculation and delivery uncertainties in treatments of small moving areas (12). For the moving target, the interaction between the movement of MLC leaves and the target allows overdose or under dose of the treated volume and healthy tissue (12–14). Ehler ED. et al. (15) have been showed that the dose delivered to a moving target varies due to the interaction of MLC and organ movement. In many studies examining the interaction effect caused by small area and tumor

movement, it has been emphasized that the mean dosimetric uncertainty may be more than 20% in intensity-modulated radiation-based therapies such as IMRT/VMAT (16, 17). Huesa-Berral C. et al. (13) have shown that the uncertainties in the mean dose for gross target volume (GTV) tended to increase exponentially with decreasing field size because of the interaction between the action of the multi-leaf collimator and the respiratory movement in lung stereotactic body radiation therapy. Most studies to minimize or eliminate concerns of the interplay effect caused by MLC movement in small fields with breathing cycle recommend DCA, which is more efficient treatment technique as an alternative technique to VMAT/IMRT (10, 18).

The aim of this study was to interpret whether the dose distribution in the DCA technique was clinically acceptable as an alternative to VMAT technique. We evaluated that DCA technique for SBRT of NSCLC treatment could provide reduction treatment time with lower radiation output avoiding interplay errors compared to VMAT.

MATERIALS and METHODS

Patients and Data Collection

A retrospective study was designed with CT images taken for radiotherapy simulation of 40 patients who received SBRT treatment with the diagnosis of lung cancer in American Hospital of VKV Koç Health Institutions and were prescribed a total treatment dose of 50 Gy in 4 fractions. The ethics board of Koç University Committee on Human Research, 34450 Sarıyer /İstanbul, Turkiye (date: 12.06.2021, number: 2021.439.IRB1.128) approved the design of the current dosimetric retrospective study prior to obtaining any patient information data, and each participant, provided written informed consent either by themselves or by their legally authorized representatives, for publication of their results. The University's review board approved the design of the current dosimetric retrospective study prior to obtaining any patient information data, and each participant, provided written informed consent either by themselves or by their legally authorized representatives, for publication of their results. While retrospective patient CT images were obtained using 4D-CT simulation of Philips Brilliance Big Bore CT scanner (Philips Medical Systems Inc., Cleveland, OH), patients of early-stage I-II-III NSCLC (Table 1) with a target volume of less than 10cc including motion with breath were selected retrospectively from a pool of 4D-CT simulation data treated using the VMAT treatment technique, regardless of patient information. All patients were simulated in the supine position with their arms above their heads using special fixation beds. Maximum intensity projection, average intensity projection, and a total of 10 phase images of the entire breath cycle were transferred from Philips Pinnacle Treatment Planning System 9.10 (TPS) for creating tumor volumes on images, where all clinical target volumes as GTVand ITV having included moving of the tumor with breath cycle was defined according to RTOG 0915. PTV is created with add 0.5 mm isotropic margins from ITV in our clinical. Our goal is to cover the prescribed dose of 50Gy by 97% of the PTV volume. Our first goal to have similar PTV coverage for plans made with both techniques, and then second goal was to ensure that specific volumes to which the healthy lung (healthy lung=Lung-ITV) was exposed to doses of radiation were lower than the desired values (Volume of healthy lung receive 5Gy dose is lower than 40% = V5Gy <40%, volume of healthy lung receive 10 Gy dose is lower than 30% = V10Gy <30%, volume of healthy lung receive 20Gy dose is lower than 20% = V5Gy <20%).

Table 1. Patient's characteristics

1 Gender	
Male	27
Female	13
2 Location	
Left lobe	22
Right lobe	18
3 Mean PTV (cc)	13.20
4 Mean ITV (cc)	9.29
5 Mean lung volume (cc)	3782

cc: Cubic centimeter-volume; PTV: Planning target volume; ITV: Internal target volume

Treatment Planning

Plans of both treatment technique were recreate with using collapse cone convolution algorithm on the Philips Pinnacle TPS for treatment device of Varian TrueBeam Linac (Varian Medical Systems, Palo Alto, CA). The same number and the same isocenter were selected for the arcs created by considering the tumor location in all plans. For right lobe; four partial arcs of clockwise and counter clockwise from 182° and 0°, for left lobe; four partial arcs of clockwise and counter clockwise from 0° and 178°. For comparison, VMAT plans in all patients were retrospectively replanned using the DCA technique for dose calculation. DCA plans were produced by utilizing double partial arcs with 1mm MLC opening around the PTV. Since there is no intensity-modulated treatment in DCA plans, there is no blocking due to MLC modulation on the target as shown in Figure 1 that VMAT has some MLC leaves covering the target, whereas for DCA the leaves match the shape of the target.

Specific Quality Assurance of Plans

Specific quality assurance (QA) phantom was used to calculate the beam on time (BOT=Treatment Time on Linac), monitor unit (MU=Radiation Output on Linac), and QA pass rate in each treatment plan. Pass rates in radiotherapy QA guidelines were considered for the specific QA pass rate.

Dosimetric Comparison

Dosimetric Comparison; for two techniques, all plans were appropriate in terms of critical organ doses according to RTOG 0915. For dosimetric planning efficiency, V5Gy (%), V10Gy (%) and V20Gy (%) for total lung, D%98 (Gy) as minimum dose, D%2 (Gy) as maximum dose, Dmean (Gy) as mean dose, conformality index (CI) as recommended by ICRU 62 and Gradient Index (GI) as recommended by RTOG for coverage of target (PTV) were compared. Number of monitor unit per fraction (MU: calculated on Pinnacle TPS) and BOT: recorded during phantom QA measurement at the machine) of delivery time per fraction was also compared between two techniques.

Statistical Analysis

In the study, the Shapiro-Wilk test of SPSS version 23.0 (IBM SPSS Statistics for Windows, IBMCorp Version 23.0. Armonk, NY) was used to decide whether all data were parametric or not. All parameters except QA pass rate were found to be non-

Table 2. Total lung and plan quality parameters*

	DCA	VMAT	p DCA vs VMAT
Total lung			
V_{20Gy} (%)	0.44 (0.1–0.63)	0.49 (0.1–0.75)	0.652
V_{10Gy} (%)	3.0 (2.1–3.83)	3.9 (2.8–5.20)	**0.031**
V_{5Gy} (%)	11.2 (8.20–15.42)	15.5 (9.75–18.17)	**0.025**
PTV			
D_{mean} (Gy)	55.16 (51.73–61.16)	54.19 (50.34–62.02)	0.712
$D_{\%98}$ (Gy)	50.13 (48.22–57.62)	49.05 (47.14–58.36)	0.610
$D_{\%2}$ (Gy)	60.14 (55.80–65.15)	59.99 (54.05–66.43)	0.692
Quality parameters			
QA pass rate (%)	99.10±1.49	92.34±1.96	<**0.001**
BOT (min/fx)	3.58 (2.90–4.60)	4.68 (3.70–5.70)	<**0.001**
MU	2395 (1979–3248)	3296 (2639–4205)	<**0.001**
CI	1.28 (1–1.32)	1.27 (1–1.33)	0.884
GI	4.35 (3.57–6.15)	4.22 (3.80–6.03)	0.820

*: Median values (minimum and maximum standard deviation); DCA: Dynamic conformal arc; VMAT: Volumetric-modulated arc therapy; %: Percent volume; VGy: Volume receiving X Gy dose; PTV: Planning target volume; BOT: Beam on time; Gy: Gray; D_{mean}: Mean dose; $D_{\%x}$: Dose on X% volume; min/fx: Minute of per fraction; MU: Monitor units; CI: Conformity index; GI: Gradient index

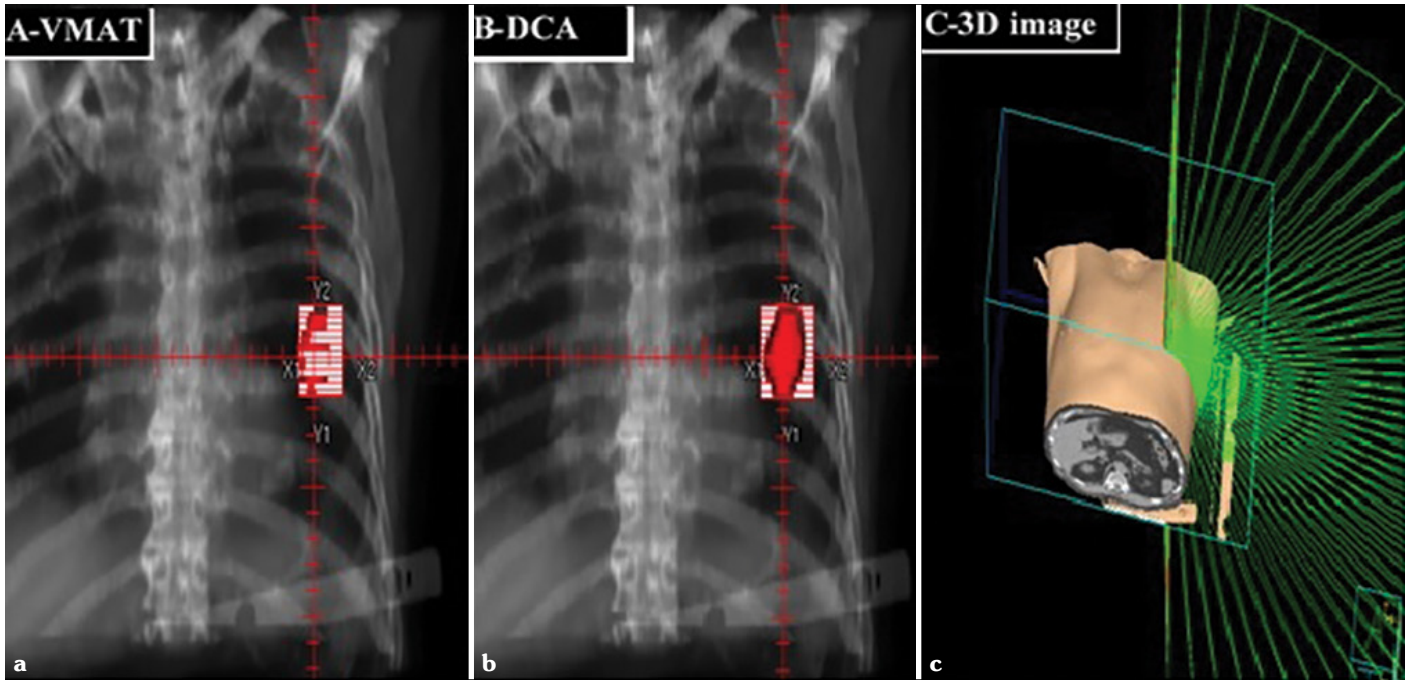

Figure 1. (a) For VMAT technique and (b) For DCA technique; Digitally Reconstructed Radiograph of MLC control point on beam eye view (one control point for arc #1 on each plan). The red color volume represents of tumor. (c) 3D image of arcs on a sample patient. The green color lines represent of beams into body

parametric. Nonparametric data given as median, minimum and maximum values were analyzed with the Mann-Whitney U-statistical test. QA pass rate parametric data, expressed as mean±SD, were performed using the Student t test. A confidence interval of 95% and a p value of <0.050 were accepted as statistically significant differences.

RESULTS

The study included 40 patients. All parameters were detailed in Table 2. Total lung based on dose volume histogram, for DCA vs. clinical VMAT plan, respectively; for V_{20Gy} were 0.44% vs. 0.49% (p=0.652), for V_{10Gy} were 3.0% vs. 3.9% (p<0.050),

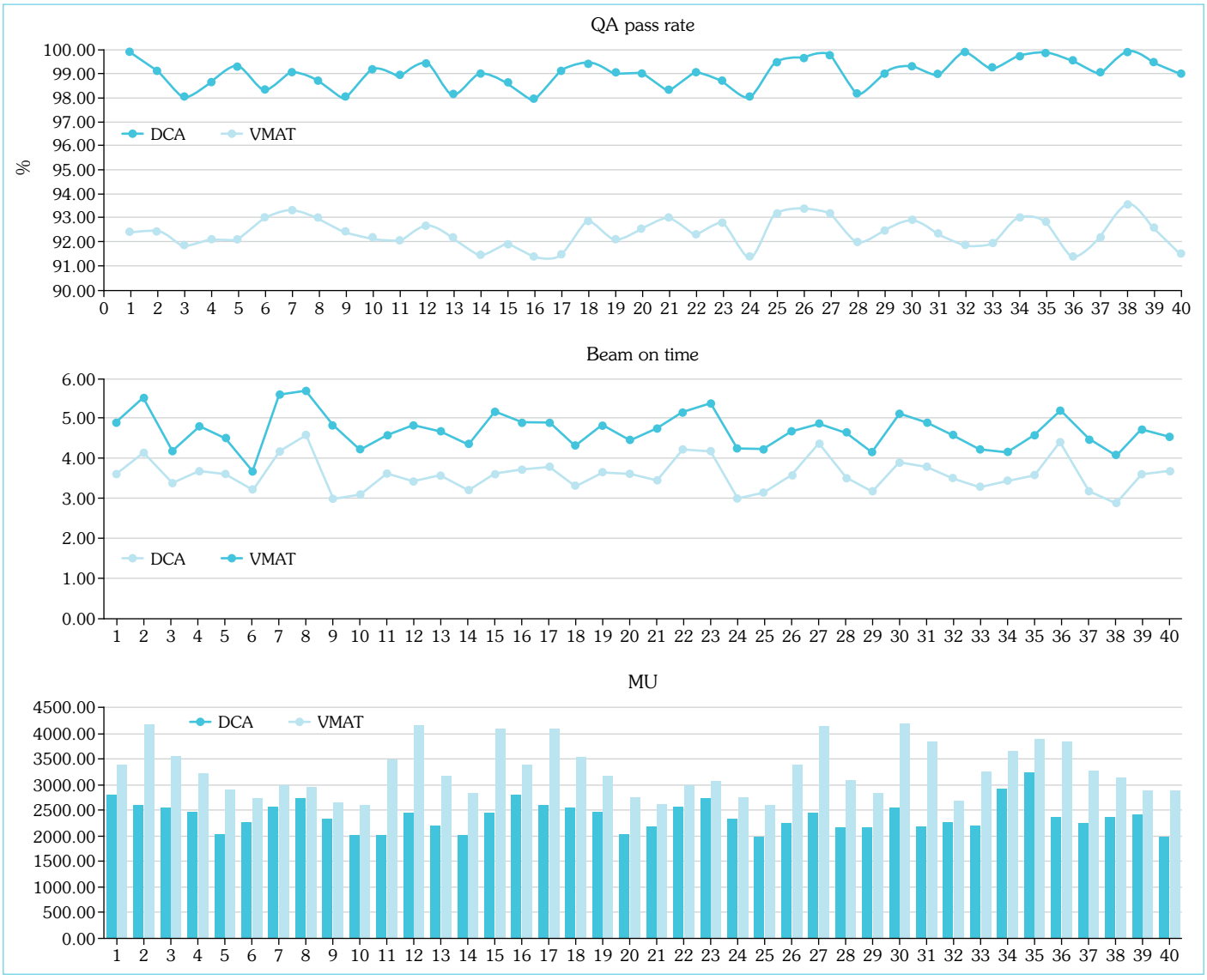

Figure 2. For DCA vs VMAT plans, Distribution of QA pass rate, BOT and MU on histogram graphics of each patient

for V_{5Gy} were 11.2% vs. 15.5% (p<0.050). All plans of DCA and VMAT techniques were at least 95% of PTV received 95% of the prescribed dose, and values of PTV minimum ($D_{\%98}$; 50.13 Gy vs 49.05 Gy; p=0.610), maximum ($D_{\%2}$ Gy; 60.14 vs 59.99 Gy; p=0.692) and mean (D_{mean}; 55.16 Gy vs 54.19 Gy; p=0.712) were similar.

The mean values of QA pass rate for all plans were 99.10±1.49 and 92.34±1.96 in DCA and VMAT techniques, respectively. The rate was higher in DCA (p<0.001 and t=8.98). For DCA technique, the values of BOT and MU were 3.58 (2.90–4.60) and 2395 (1979–3248), respectively. For VMAT technique, the values of BOT and MU were 4.68 (3.70–5.70) and 3296 (2639–4205), respectively. These values were found to be higher in VMAT (p<0.001 and p<0.001). For values of CI were 1.28 (1.0–1.32) in DCA technique and 1.27 (1.00–1.33) in VMAT technique (p=0.884), respectively. Figure 2 presented the comparison of QA pass rates, BOT, and MU on a patient basis in detail and Figure 3 showed the planning dose distribution for both techniques on example patient images, while values of GI were 4.35 (3.57–6.15) in DCA technique and 4.22 (3.80–6.03) in VMAT technique (p=0.820), respectively. No statistical difference was found for the two parameters.

DISCUSSION

SBRT, which is more preferred in recent years, has been adopted as the standard treatment option for patients with inoperable in NSCLC (19, 20). We investigated the clinical applicability of the DCA technique, which is a more efficient treatment technique by reducing the treatment time and MU, compared to the VMAT technique in NSCL cancer. The arcs of the DCA plans delivered the same treatment dose with less complex geometry, reduced MU and BOT without on-target beam modulation than in VMAT. In addition, since the QA pass rate approaches 100%, it can eliminate the requirement for patient specific QA before treatment. These results revealed the effectiveness of DCA plans for the treatment of four-fraction SBRT of NSCLC.

Since SBRT based on delivering the high treatment dose in a single or several fractions (≤5 fractions) to the target volume, the need

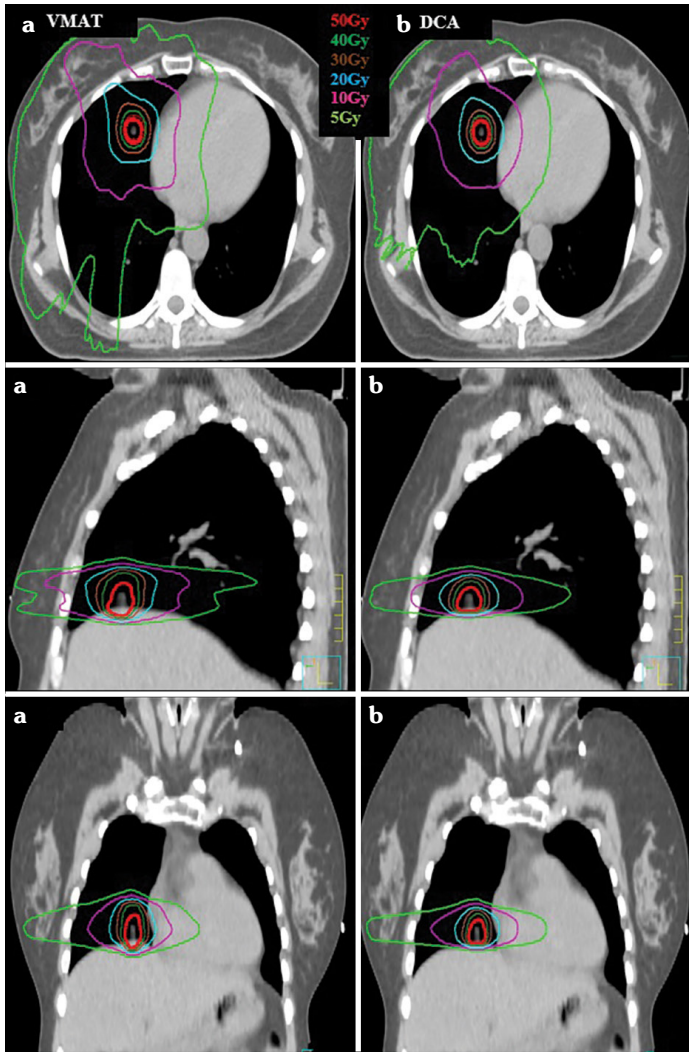

Figure 3. Images from top to down in axial, sagittal and coronal views of dose distribution with isodose lines on the sample patient for (a) VMAT (left), (b) DCA plan (right)

for very high focus accuracy and very rapid dose reduction have led to the development of techniques different from conventional treatments. For this reason, the search for different treatment methods to develop a more efficient SBRT treatment technique has become an important and current issue, especially for the lung treatment area where tumor movement occurs (4, 21). Suhong Yu. et al. (22) investigated VMAT and CyberKnife techniques in terms of dosimetric and planning efficiency for lung SBRT cases. Their work concluded that VMAT could achieve comparable plan quality for lung SBRT in a more efficient manner than CyberKnife. In another study, Damodar Pokhrel et al. (23) compared the DCA-based VMAT with the VMAT, which is mostly the clinical standard treatment technique, for ten early-stage I-II NSCLC patients. While in our study, we compared the DCA treatment technique with VMAT, which is our standard treatment technique, and found that it is a more effective treatment method for NSCLC These results, these results of Damodar Pokhrel et al. (23) emphasized that the DCA-based VMAT technique improved the plan quality by simplifying the VMAT complex structure, and speeding up the treatments by reducing the irradiation time.

The VMAT treatment technique, which is the most clinical and first choice treatment technique for SBRT treatments, is one of the most interesting research topics (1, 24). Geoffrey G Z. et al. (25) have been contrasted the VMAT technique with the 3D technique in the treatment of SBRT and showed that the VMAT technique allowed high doses to be administered in a much shorter time, and got better adherence to the target, sharper dose reduction in normal tissues. In addition, the most preferred VMAT treatment technique for SBRT using small areas has been emphasized in many studies that it is highly sensitive to dose variation caused by the MLC positions on the target due to modulation during tumor movement in the respiratory cycle (12, 26). For SBRT of NSCLC, which is usually a few fractional treatments, dose variation or uncertainty in the VMAT technique is important for treatment accuracy. Although in many studies in the literature, it has been reported that the standard or modified alternative techniques such as DCA is effective and clinically appropriate for SBRT of NSCLC, as it eliminates or reduces the concerns about the interaction effect, which is the MLC position specificity during tumor movement (18, 24), Court L. et al. (27) have been showed on study during tumor movement based on respiratory cycle with VMAT technique that in VMAT plans with a target motion of 2 cm, the dose error could be >5% on 40% area in the target. In our study, using the DCA treatment technique with the same arc count as clinical VMAT, treatments administered were faster (mean treatment time 35% lower than clinical VMAT) and more accurate since the absence of MLC moving on PTV (QA pass rate approximately 99%). In addition, DCA minimizes carriage errors for small areas of dose calculation and MLC errors due to tumor movement with breath cycle.

Possible problems arising from respiratory movement in the radiotherapy of lung tumors have been the subject of important investigation (7, 8, 28). Purdie TG et al. (28) have been emphasized that the importance of treatment duration in SBRT treatments to prevent the possibility of intrafractional tumor displacement. They have shown that the uncertainty due to tumor movement increases with the respiratory cycle and the duration of treatment is important, especially in VMAT treatments with MLC modulation on the tumor. Soyoung Lee et al. (29) have been show that DCAT having active breath-hold method provide plan quality with higher delivery efficiency for varying tumor sizes and motions, compared with VMAT. DCA technique in this study, the mean delivery time for SBRT of NSCLC treatment using the four-fraction internal target volume method with free breathing was found to be 3.58 min. Since this treatment time is approximately 1 minute and 30% less than VMAT on average (VMAT: 4.68–DCA: 3.58 min, $p<0.001$), uncertainties due to small area dosimetry in respiratory motion and VMAT complex geometry can be minimized.

CONCLUSION

Our results clinically validated DCA technique as an acceptable, safe and efficient treatment compared with our standard VMAT technique in SBRT for NSCLC. As it reduces the uncertainty of small-field dosimetry & MLC interplay effect and provides better QA transition rates, it could be used in addition as the first treatment option in clinics that do not use a breath cycle management system, while DCA further provided excellent plan quality while better preserving healthy lungs and further significantly reduced delivery time and MU, enabling faster treatment delivery.

Ethics Committee Approval: The Koç University Clinical Research Ethics Committee granted approval for this study (date: 12.06.2021, number: 2021.439.IRB1.128).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Conflict of Interest: The author have no conflict of interest to declare.

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