RESEARCH ARTICLE

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Comparison between Volumetric Modulated arc Therapy based Coplanar and Noncoplanar Planning for Stereotactic Body Radiation Therapy of Liver

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Abstract

Background: The study aims to investigate potential dosimetric benefits between non-coplanar and coplanar beam arrangements of Volumetric-Modulated Arc Therapy (VMAT) plans for liver stereotactic body radiotherapy (SBRT). **Methods:** Thirteen patients who had undergone liver SBRT treatment in our department were chosen retrospectively for the study. Two sets of SBRT-VMAT plans namely, non-coplanar (NC-VMAT) and Coplanar (C-VMAT) were generated in Monaco(v5.11) planning system for Elekta Versa HD Linac using unflatten 6MV photon. The NC-VMAT plans were created by two/three non-coplanar partial arcs with couch rotation of $\pm 15^0$ and had an arc span of 130^0 to 160^0 whereas the C-VMAT plans consisted of a full arc. Both plans were compared by statistically analyzing various dosimetric and technical parameters. **Results:** There is no statistically significant difference observed between the C-VMAT and NC-VMAT plans for planning target volume (PTV) coverage. However, the spine dose (D1cc) was much less in the NC-VMAT plan compared to the C-VMAT plan, with mean values of 6.127 ± 3.08Gy and 9.058 ± 4.76Gy, respectively (p-value=0.002). The low dose spillage to the healthy tissue was compared by the volume receiving 5Gy (V5Gy) and 10Gy (V10Gy). V5Gy of the NC-VMAT plan was 2399.23±1870.76cc while that of C-VMAT plans was 2835.36±1930.20cc with the p-value <0.001. Moreover, the monitor units(MU) were less with NC-VMAT than with C-VMAT SBRT plans (p=0.015). **Conclusion:** The plan quality of NC-VMAT plans was favorable compared to C-VMAT plans for liver SBRT especially in reducing spine dose, low dose spillage to healthy tissue, and MU.

Keywords: SBRT- Liver cancer- non-coplanar VMAT- coplanar VMAT

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Introduction

Liver cancer is one of the worldwide challenges. Based on statistics from 2020, liver cancer ranks third in terms of cancer-related deaths and is the sixth most common cancer occurrence [1]. Liver malignancies can either be primary or metastases. The two most frequent types of primary liver cancer are hepatocellular carcinoma (HCC) and cholangiocarcinoma. Liver transplantation is considered the best cure with more than a 70% chance of 5-year survival [2]. The other option is surgical resection which gives 5-year survival rate of around 50% to 60% but there is a high chance of recurrence (usually >50%) [3]. Moreover, a very small fraction of patients with cirrhosis and HCC are suitable for surgical resection [4]. Stereotactic Ablative Radiotherapy (SABR) or stereotactic body radiotherapy (SBRT) is one of the alternative treatment modalities for treating liver cancer patients who are ineligible to undergo surgery or ablation [5]. Hypo-fractionated SBRT is one form of external beam radiation therapy (EBRT), for extracranial irradiation that delivers ultra-high doses over a smaller number of fractions. These features made SBRT a standard treatment modality for several primary as well as metastatic liver cancer [6,7].

SBRT is a treatment plan that delivers a highly conformal dose to the tumor with a steep dose falloff around it to spare the surrounding organs. The precision of SBRT delivery is enhanced by advancements in Image guidance technology allowing for the accurate visualization of the tumor and surrounding structures before as well as during treatment. The breath-holding techniques used for intrafraction target/organ motion management increase the precision of SBRT treatment delivery [8,9]. Studies have demonstrated that VMAT plans are highly conformal compared to IMRT and 3D-CRT with shorter delivery times, making it a better radiotherapy technique for SBRT [10-12]. Recently, SBRT

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using the Volumetric-Modulated Arc Therapy (VMAT) mode of treatment delivery with Flatten Filter Free(FFF) photon beam has become increasingly common [13,14].

It is evident from the past studies that, SBRT plans that are generated with non-coplanar beam arrangements help in improving the dose conformity and minimize the irradiated volume of healthy tissue. Dong et al, reported that noncoplanar IMRT is dosimetrically superior compared to VMAT in Liver SBRT [15]. The optimal noncoplanar beam arrangements for SBRT plans have been studied, and are generally incorporated with several static IMRT beams, thus the planning and treatment delivery become a tedious process. In contrast, the coplanar full arc SBRT VMAT planning involves a simple beam arrangement but increases the irradiated volume. Some studies have compared NC-VMAT with C-VMAT for various sites like the lung, Brain, and Nasopharynx which showed the benefit of NC-VMAT plans over C-VMAT plans [16-18]. However, to the best of our knowledge, the application of manually selected beam orientation in VMAT plans generated with a limited number of ipsilateral partial arcs to avoid the possibility of gantry collision with the couch for liver SBRT has not been well studied. Thus, the aim of this study was to compare the plan quality dosimetrically as well as the technical feasibility between the non-coplanar partial arc and coplanar full arc VMAT plans for liver SBRT.

Materials and Methods

Planning CT (Computed Tomography) images of 13 patients who underwent VMAT-based SBRT to the liver at our department between 2019-2022 were retrospectively included in this study. Table 1 shows the details of selected patients.

Immobilization and image acquisition

All the patients were immobilized using a vaculock along with the Deep Expiration/Inspirational Breath Hold technique (DEBH/DIBH) with Active Breathing control technology (ABC, Elekta). A similar patient positioning was reproduced in the Philips Brilliance Big Bore CT scanner for image acquisition. Planning CT images of 2mm slice thickness were acquired in both free breathing (FB) as well as breath hold conditions. These images were then transferred to the Treatment Planning System named MONACO (TPS) (Version 5.11) for delineation of target volume and organs at risk. The image obtained from contrast-enhanced CT as well as MRI (Magnetic Resonance Image)/PET(Positron Emission Tomography) scans were used to locate the tumour volume. The FB and breath-hold images were fused to generate the Internal Target Volume (ITV). The Planning Target volume (PTV) with the margin ranging between 2-4mm from ITV and Organs at risk(OARs), such as the spinal cord, oesophagus, duodenum, stomach, healthy liver(liver - Gross Tumor Volume), and right and left kidneys were delineated.

Treatment Planning

Two sets of VMAT SBRT plans, non-coplanar and coplanar, were made for each patient using 6MV flattening-filter-free (FFF) photon energy provided by Elekta VersaHD Linear Accelerator with agility collimator head. The coplanar plans (C-VMAT) consist of one full arc of 360^0 while the non-coplanar(NC-VMAT) plans consist of either two or three partial arcs of an arc span of 130^0 to 160^0 with $\pm 15^0$ couch angle. The angles are selected by ensuring the non-collision of the gantry with the couch and ABC breath hold tool placed on the patient's surface, from the perspective of the Beam's Eye View (BEV). The plan isocentre was placed at the PTV center and the collimator angle was kept at zero degrees for all cases. The planning objective was to achieve 95% of the prescription dose (P.D) coverage to 95% of the PTV (PTV95% RX=95%) and 99% of the PTV receive the 90% of the prescribed dose (PTV90%RX> 99%). A hotspot of up to 120%-130% of the prescribed dose was accepted within the GTV(Gross Tumour Volume)to allow dose heterogeneity. The dose constraints to Liver-GTV were, the mean dose was 15Gy and V10Gy below 70%, Spinal Cord D_{1cc} was 11Gy, Bilateral Kidneys mean dose was 10Gy and Chest wall D0.5cc was 40(Gy). Planning objectives for PTV and OARs dose constraints are based on Radiation Therapy Oncology Group (RTOG) 1112 [19] and Quantitative Analyses of Normal Tissue Effects in the Clinic (QUANTEC) [20] guidelines. The plan optimization was done in Monaco TPS using a Monte Carlo dose calculation algorithm with a calculation grid of 2mm. Until an acceptable treatment plan is generated with satisfied plan evaluation criteria, various priorities were kept on altering in the planning trial during the segmentation optimization phase in MONACO TPS.

Plan Evaluation

The monitor units were acquired for each plan. All plans were evaluated by comparing the Dose Volume Histogram (DVH) metrics of PTV coverage and OARs. The dosimetric parameters of PTV coverage selected for comparison were PTV95% and PTV90%. V100% (Volume receiving 100% of P.D), V50%(Volume receiving 50% of P.D), and PTV volume were used for calculating the conformality index (CI) and Gradient Index(GI) as follows.

CI = V_{PI}/PTV Volume [21]

Where V_{PI} is Volume receiving prescription isodose.

GI = 50% Prescription Isodose Volume/ Prescription isodose volume [22]

Patient-Specific Quality Assurance (PSQA)

Both groups of VMAT SBRT plans underwent point dosimetry measurement using a pinpoint chamber (PTW, Germany) with slab phantom for the feasibility of treatment delivery and the results were within the 3% difference compared to TPS-generated quality assurance (QA) plans.

Statistical Analysis

Descriptive statistics such as Mean and Standard Deviation (SD) of each dosimetric parameter for both NC-VMAT and C-VMAT plans were estimated. A paired t-test was carried out in Jamovi Software (Version 2.3.28) to investigate the statistical significance difference in the dosimetric parameters for both the NC-VMAT and C-VMAT plan, with p less than 0.05 considered significant.

Results

The isodose distribution and target DVH comparison between NC-VMAT and C-VMAT SBRT plans for a prescription dose of 40Gy is represented for one patient in Figures 1 & 2 respectively. On the axial view of Figure 1, the spillage of the low dose covers a large volume of the healthy tissue for the C-VMAT plan compared to the NC-VMAT plan. In the C-VMAT plan, a similar pattern of low-dose spill is observed, on the sagittal as well as coronal view. The dosimetric matrix of the PTV coverage, PTV95% for the two plans is given in Table 2 which shows that there is no significant difference (p=0.572) between NC-VMAT and C-VMAT SBRT plans. We found that, both the plans could achieve conformal dose coverage to PTV. The CI also does not show any significant differences with average values of 0.904 ± 0.095 for coplanar plans and 0.881 ± 0.101 for non-coplanar plans (p=0.221). The gradient index (GI) of the C-VMAT plan was slightly better with average values of 4.021±1.056 than the non-coplanar plans with average values of 4.337±1.335 but there was no statistically significant difference (p=0.079).

The dose-volumetric parameters of OARs in both plans are shown in Table 2. These results show that there was no difference between the two plans in terms of dose to OARs except the dose to the spine. The average dose to 1 cm3 (D_{1cc}) of the spine in coplanar plans was 9.058±4.76Gy and for non-coplanar plans was 6.127±3.08Gy with a p of 0.002. The Figure 3 compares the D_{1cc} of the spine between C-VMAT and NC-VMAT plans. The dose to 1 cm^3 (D_{1cc}) of the left kidney showed slightly better results in non-coplanar with average values 3.09±2.99Gy in comparison to coplanar with average values 4.10±3.84Gy but the difference is not significant (p=0.077).

The dosimetric parameters of the healthy tissue volume receiving low-dose spillage of 5Gy and 10Gy are given in Table 2. Our results showed that both V_{5Gy} and V10Gy of healthy tissue were less in NC-VMAT compared to C-VMAT SBRT plans. Here, only the V_{5Gy} showed a significant difference between non-coplanar and coplanar plans with a p of <0.001. The Figure 4 compares the V_{5Gy} of healthy tissue volume between NC-VMAT and C-VMAT SBRT plans. For healthy tissue, the average value of V_{10Gy} for C-VMAT plans was 1343.88±1086.57cc and

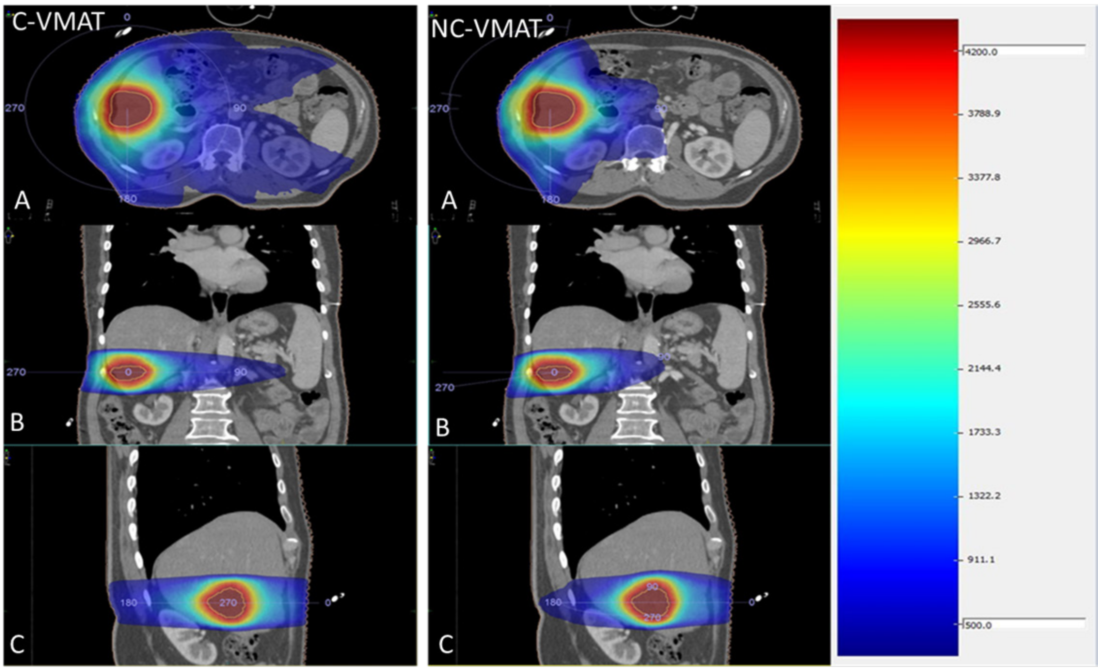

Figure 1. The axial(A), Coronal(B), and Sagittal views of C-VMAT Plan and NC-VMAT SBRT Plans with Isodose Colour Wash Ranging between 5Gy to 42Gy.

Table 1. Summary of Selected Patients

No. of patients	13
Gender	12 Men and 1 Woman
Age	52-70 years
Stage	5 with HCC- (Barcelona Clinic Liver Cancer) BCLC A and B 8 with Stage IV Liver Metastasis
Dose prescription	Ranging between 6Gy to 16Gy per fraction
PTV volume(cc)	Ranging between 15cc to 480cc

Table 2. Dosimetric Parameters Comparison for PTV and OARs Planned with NC-VMAT and C-VMAT SBRT Techniques.

Parameters		Mean ± SD		p-value
		C-VMAT	NC-VMAT	
PTV95% (%)		98.091 ± 1.894	98.323 ± 1.741	0.572
PTV90% (%)		99.535 ± 1.088	99.696 ± 0.801	0.171
CI		0.904 ± 0.095	0.881 ± 0.101	0.221
GI		4.021 ± 1.056	4.337 ± 1.335	0.079
MU		2728.885 ± 1000.11	2410.815 ± 786.46	0.015
Liver-GTV Mean dose (Gy)		9.55 ± 5.47	9.62 ± 5.20	0.784
Oesophagus $D_{0.5cc}$ (Gy)		10.64 ± 12.27	8.81 ± 11.35	0.128
Stomach D_{1cc} (Gy)		14.60 ± 9.42	14.50 ± 9.95	0.859
Duodenum $D_{0.5cc}$ (Gy)		12.437 ± 9.50	13.171 ± 9.51	0.329
Right kidney	Mean dose (Gy)	2.37 ± 2.49	2.28 ± 2.40	0.528
	D_{1cc} (Gy)	9.14 ± 7.18	8.08 ± 6.79	0.165
Left kidney	Mean dose (Gy)	1.12 ± 1.09	1.09 ± 1.24	0.905
	D1cc (Gy)	4.10 ± 3.84	3.09 ± 2.99	0.077
Spinal Cord D_{1cc} (Gy)		9.058 ± 4.76	6.127 ± 3.08	0.002
Heart D_{30cc} (Gy)		6.20 ± 9.98	6.46 ± 10.13	0.74
Chest wall $D_{0.5cc}$ (Gy)		31.86 ± 13.85	32.30. ± 13.33	0.546
Common Bile Duct D0.5cc (Gy)		18.59 ± 14.94	18.10 ± 15.73	0.605
Skin $D_{0.5cc}$ (Gy)		23.65 ± 8.47	24.69 ± 903	0.403
Healthy tissue V_{5Gy} (cc)		2835.36 ± 1930.20	2399.23±1870.76	<0.001
Healthy tissue V_{10Gy} (cc)		1343.88 ± 1086.57	1202.38±958.77	0.097

Paired t test, P-value<0.05

1202.38±958.77cc for NC-VMAT plans (p-value 0.097).

In the technical parameter aspect, the average values of monitor unit (MU) for coplanar and non-coplanar VMAT plans were 2728.885 ± 1000.11 and 2410.815 ± 786.46 respectively showing that the total MU is lesser for NC-VMAT with a significant difference of p=0.015. The Figure 5 shows the differences in total MU between the NC-VMAT and C-VAMT plans.

Discussion

Hypo-fractionated SBRT, delivers ultra-high fractional doses in minimal fractions to result in a high biologically effective dose(BED) and the majority involves the treatment of the liver and lung [23]. As these sites involve organ motion, the high-precision treatment is of major concern in SBRT. Modern linear accelerators with image-guided radiotherapy facilities have made it practically

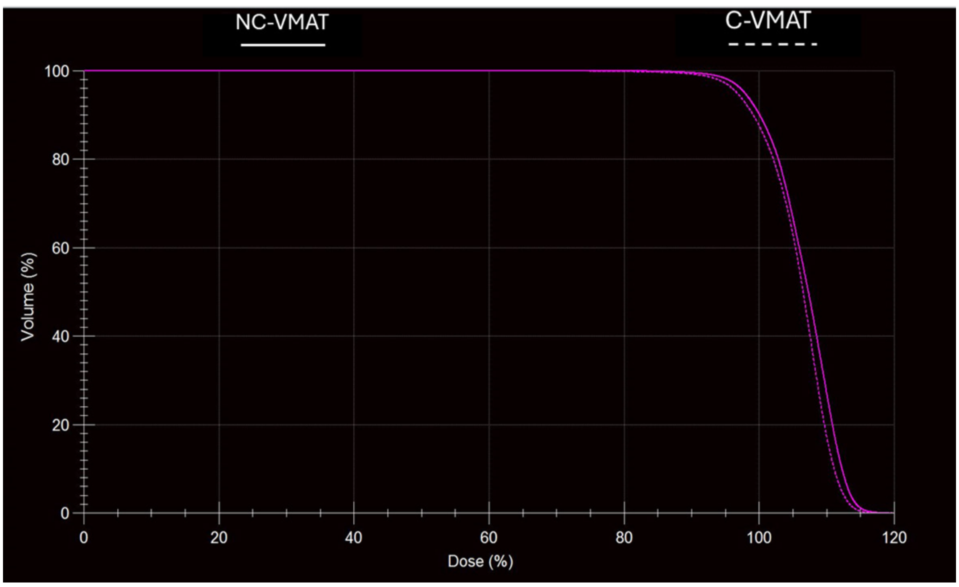

Figure 2. Target Dose Volume Histogram Comparison of C-VMAT and NC-VMAT SBRT Plans

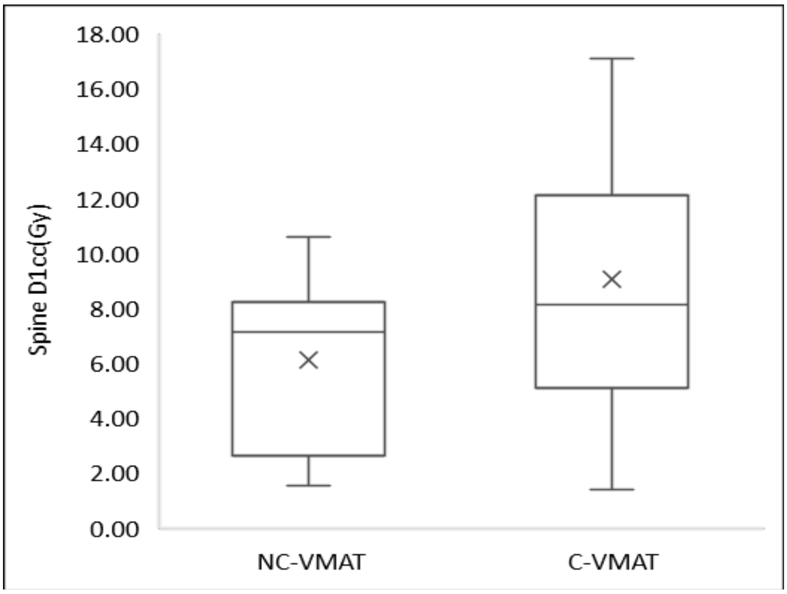

Figure 3. Maximum Dose Comparison for Spine D_{1cc} (Gy) between NC-VMAT and C-VMAT SBRT Plan.

possible. In the case of liver SBRT, conformal treatment delivery helps in reducing the irradiated volume of a healthy liver and hence radiation-induced liver diseases [24]. In addition, the lesion is off-centered, hence most of the studies in the literature have recommended noncoplanar IMRT fields to achieve high dose conformality to the target and improved organ sparing [15]. In past decades, VMAT has emerged as a significant contributor to the advancement in radiotherapy, hence several studies have recommended VMAT with FFF photons which resulted in a time-efficient technique [25,26].

A few studies in the literature have dosimetrically compared VMAT and noncoplanar IMRT in Liver SBRT. Woods et al, recommended an optimum beam arrangement named the 4Π method over full arc C-VMAT and NC-VMAT in liver SBRT, which contained 20 noncoplanar intensity-modulated fields [27]. The study concluded that the 4Π method showed significant dosimetric benefits in PTV coverage and OAR sparing, without many changes in conformality and homogeneity among all the plans. The overall time to deliver 20 beams in the 4Π method was almost 45 minutes, whereas it was within 10 minutes for the other two plans. In contrary, Tahibult et al, investigated various combinations of partial arcs with single full arc C-VMAT against the 8 fields IMRT technique in liver SABR using 6MV photon energy [28]. Their results showed better dose conformity in VMAT compared to IMRT plans and sparing of normal liver was gradually improved in VMAT planning. They found that a combination of a full arc C-VMAT with ipsilateral partial arc and additional NC-VMAT partial arcs showed promising results in both HCC and Liver metastasis patients with single lesions.

Shafro et al, proposed a hybrid treatment method called VMAT plus to enhance BED in liver SBRT [29]. This method has combined C-VMAT with computer-

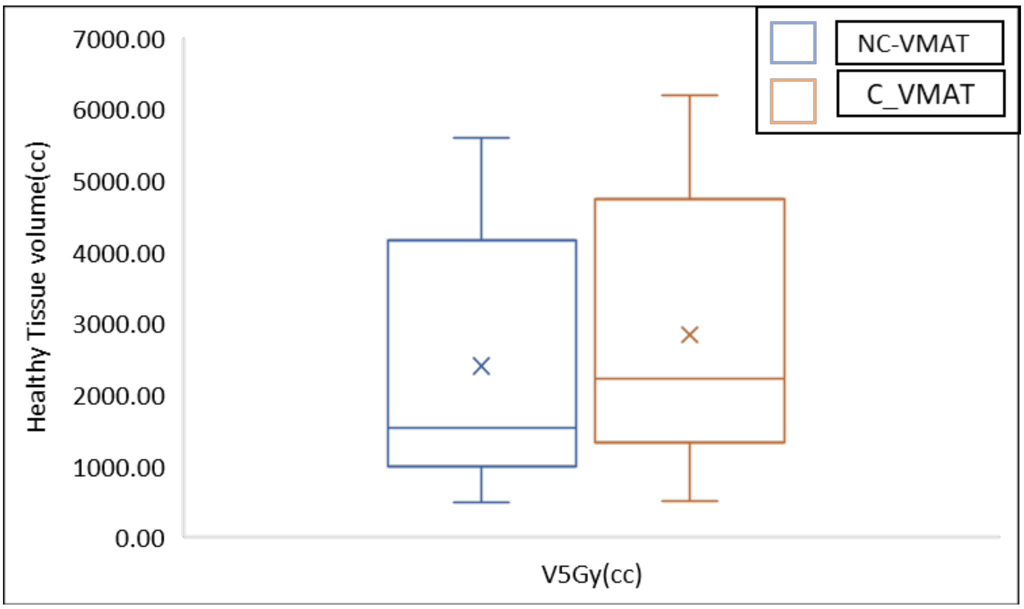

Figure 4. Comparison between NC-VMAT and C-VMAT SBRT Plans forV_{5Gy} of Healthy Tissue.

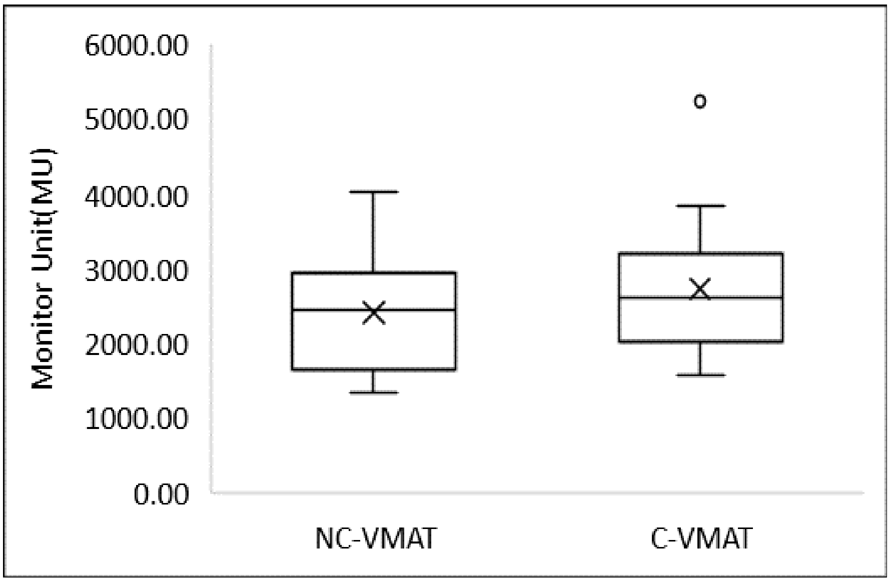

Figure 5. Comparison of Total Monitor Units(MU) between the NC-VMAT and C-VAMT SBRT Plans.

optimized noncoplanar IMRT fields(<5 fields). The results showed VMAT+ plans had comparable results with 25 noncoplanar IMRT plans in PTV coverage and organ sparing. The monitor units and treatment time were considerably high in VMAT plus compared to VMAT as well as IMRT plans. In a recent study, Ma et al, proposed and investigated an NC-VMAT plan for HCC patients, based on a cage-type radiotherapy setup to avoid the possible gantry collision [30]. The cage-type NC-VMAT plan significantly reduced the dose to the volume of liver-PTV compared to NC-VMAT and C-VMAT except for lung as well as heart dose.

Most of the LINAC-based dosimetric comparison studies on noncoplanar VMAT plans in liver SBRT are based on computer-optimized beam orientations that utilize many beams and are performed on photon energies of 6MV or greater. Thus, the planning and treatment delivery has become a tedious process. In this study, we have compared manually selected noncoplanar partial arc VMAT with coplanar full arc VMAT in hypo fractionated liver SBRT using 6MV FFF photons. The novelty of the present work is that we have used simpler ipsilateral NC-VMAT partial arcs based on BEV (Beam's Eye View) to avoid the possibility of gantry and couch collision. We compared several dosimetric and technical parameters between non-coplanar and coplanar VMAT plans to evaluate the plan quality. The PTV coverage was similar with both the plans as well as the sparing of OARs as stated by the previous studies [13,17]. The D_{1cc} of the spine was much lesser with the non-coplanar plans. A significant difference was observed in the low-dose spillage volume of the normal tissues with non-coplanar plans showing much less spillage for volume receiving 5Gy. This is possible because of the use of ipsilateral partial arcs in the non-coplanar plans. The technical parameter, Monitoring Units delivered was also less with the non-coplanar plans. The PSQA results were also similar between the two groups of plans.

Although a non-coplanar plan using many beams generally achieves equivalent PTV coverage and protection of organs at risk (OAR) compared to coplanar delivery, several factors hinder its broader adoption. These factors include increased complexity in treatment planning, heightened potential for setup errors, a higher risk of collisions, and longer treatment duration. Thus, the use of a limited number of non-coplanar arcs can be preferred when there is a potential benefit over coplanar arcs.

In conclusion, The NC-VMAT plan using two to three manually selected ipsilateral partial arcs for liver SBRT, reduced the planning complexity and showed similar target coverage, and the OARs sparing as that of the full arc C-VMAT plan. In addition, the dose reduction for the spine is observed in the non-coplanar plans. Moreover, the reduction in low-dose spillage to normal tissues in non-coplanar plans is its major advantage. Time is also a major concern in the SBRT treatment, the significant reduction of monitor units in the NC-VMAT plan might be considered as a benefit in comparison to the C-VMAT plan as it improves the patient comfort during treatment.

Author Contribution Statement

Anjum Nisha, Data Collection and Article Drafting; Shambhavi C, Concept and design of the work, Data collection, Data analysis and interpretation, article drafting, and critical revision; Jyothi Nagesh, Critical revision of the article; Sarath S Nair, Critical revision of the article.

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If it was approved by any scientific body/ if it is part of an approved student thesis

The study is approved by the institutional research committee.

Ethical Declaration

Not Applicable (The study is conducted retrospectively and does not contain any human participants or animals).

Conflict of interest

All authors declare no conflict of interest.

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