



Effect of contrast medium on treatment modalities planned with different photon beam energies: a planning study

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ABSTRACT

Background: Routinely, patient's planning scans are acquired after administration of iodinated contrast media but they will be treated in the absence of that. Similarly, high energy photons have a better penetrating power, while low energy photons will result in tighter dose distribution and negligible neutron contamination. The aim of the study was to investigate a suitable photon beam energy in the presence of intravenous contrast medium.

Materials and methods: An indigenously made original-contrast (OC) phantom was mentioned as virtual-contrast (VC) and virtual-without-contrast (VWC) phantom were generated by assigning the Hounsfield Units (HU) to different structures. Intensity-modulated (IMRT) and volumetric-modulated-arc (VMAT) plans were generated as per criteria of the TG-119 protocol.

Results: It was observed that the maximum dose to the spinal cord was better with 6 mega-voltage (MV) in IMRT. The coverage of Prostate PTV (PR PTV) was similar with all the photon energies and was comparable with TG-119, except for original-contrast (OC) phantom using the VMAT technique. Homogeneity-index (HI) was comparatively better for VMAT plans.

Conclusion: The contrast CT images lower the dose to targets. IMRT or VMAT plans, generated on such CT images will be delivered with higher doses than evaluated. However, the overdose remains non-significant.

Key words: contrast-enhanced CT; AAPM TG119; integral dose

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Introduction

The aim of radiotherapy is to deliver maximum effective unified dose to tumour target while sparing the nearby critical structures or keeping them within their tolerances. As per literature, one should use higher photon beam energy for deeper targets, like carcinoma of cervix and carcinoma prostate. It is generally seen that lateral separation of such patients remains approximately 20 cm or more. As a conventional approach of treatment of such cases,

the combination of 6 MV and 15 MV is used in the box-field technique. The drawback of such technique is less sparing of the organs-at-risk, i.e. the bladder and rectum. In the same manner, achieving the dose to the spinal cord in head-and-neck cases or carcinoma lung is always challenging.

The evolution of technology has changed the scenario by facilitating the planner to use a 3-dimensional conformal-radiation-therapy (3DCRT) approach. The definition of conformality includes the usage of tomographic images for treatment

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planning. Routinely, the tomographic images are acquired after administration of iodinated intravenous contrast media to patients. Contrast enhanced tomographic images help in better delineation of planning target volumes and organs-at-risk.

Although the treatment plans will be generated on contrast-enhanced computed-tomography (CT) images, the treatment will be delivered in the absence of contrast media. This causes a debate among practitioners about the application of intravenous contrast. Undoubtedly, the presence of contrast medium in planning CT enhances the recognition of a tumour target and improves the ability to provide an accurate delineation of structures but conducting a comprehensive study to evaluate the effect of intravenous contrast on the treatment planning is a necessity.

Conformal radiation therapy is widely accepted in the treatment of carcinoma of cervix which is the fourth most common cancer among women [1]. As per report of the World Health Organization (WHO) of 2018, an estimated 570,000 women were diagnosed with cervical cancer worldwide and approximately 300,000 women died from the disease [2]. Radiation related toxicities are one of the reasons for these causalities.

Intensity-modulated-radiation-therapy (IMRT) has come up with major benefits when compared with 3DCRT as this technique facilitates the planner to modify the photon beam fluence in the optimum manner [3]. The upgrade of technology has brought the features of continuous motion of the gantry and MLC to deliver treatment plans with a variable dose rate. This technique is known as 'volumetric-modulated-arc-therapy (VMAT)'.

Generally, the selection of photon beam energy depends on target volume, patient physical size and tumour depth but 6 MV photon beam is a choice of treatment in most of the clinical sites with different advanced modalities. High energy photons have better penetrating power, skin sparing effect and lesser normal tissue doses while the low energy photons will have narrow penumbra and will result in tighter dose distribution around the target, minimum dose to nearby structures, negligible neutron contamination, minimum head leakage and internal scatter.

Higher energy photons tend to increase the risk of induction of secondary malignancies because of greater collimator leakage and scatter, patient scatter

and photo-neutron production [4] whereas the lower energy photons deposit higher doses near beam entry regions and the treatment plan requires greater number of fields, beam segments and monitor units. These adverse skin reactions are major concern in deep seated targets [5]. It has been observed that monitor units and treatment time increases in IMRT as compared to VMAT, which leads to concern about fatal risk of secondary malignancies [6]. It is reported that the risk increases up to 3.4% with 15 MV photons whereas it varies around 1%-3% with 6 MV photon beams [7]. Therefore, the evaluation of choice of optimum photon energy is also mandatory in the ambience of contrast medium.

Hence, the present study focuses on investigating the best suitable photon beam energy in the presence of intravenous iodized contrast medium keeping the hypothesis that contrast media remain insensitive to treatment technique and beam energy.

Materials and methods

Phantom preparation

An indigenously made contrast phantom was used for the study. Phantom was made using Perspex sheets (water equivalent material) and water was poured inside to mimic the patient body. A sleeve was provided to place the ionization chamber at the treatment isocentre. Cylindrical chamber (Active volume: 0.125 cc) was used to evaluate the dose to the isocentre. A vial filled with iodinated contrast, used for patient CT scan, was placed around the ionization chamber sleeve to generate the effect of contrast media. This phantom is called an 'original-contrast (OC)' phantom in the present study as shown in Figure 1 and was scanned on our departmental CT scanner (Somatom Sensation Open, Siemens Medical Solution, Germany). The slice thickness was kept as 0.3 cm and the scan was transferred to Somavision workstation (Varian Medical Systems) in a *dicom* format. The similar phantom was created using software and Hounsfield Units (HU) were assigned to different structures like phantom walls, filled water, contrast vial and ionization chamber sleeve with active volume as shown in Figure 2. This phantom was utilized as 'virtual contrast (VC)' phantom. Additionally, the contrast vial was assigned the HU of water and the same phantom was represented as 'virtual-without-contrast (VWC)' phantom.

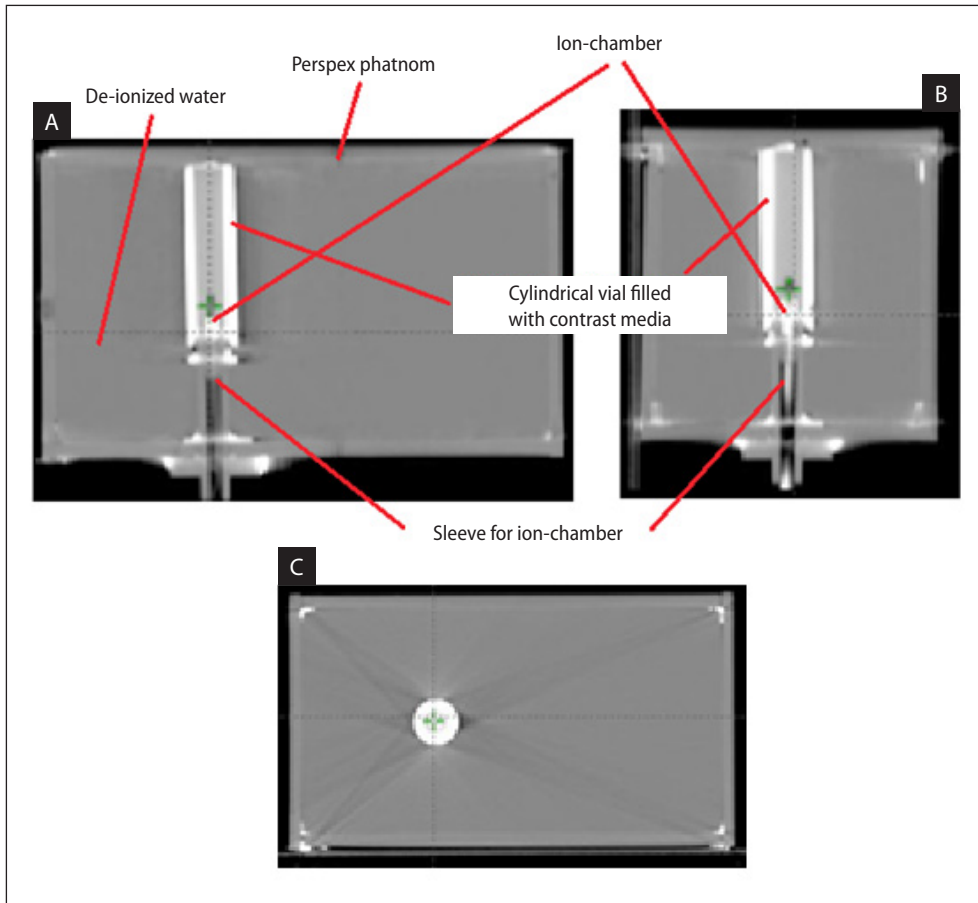


Figure 1. Preparation of phantom. **A.** Coronal view. **B.** Sagittal view. **C.** Axial view

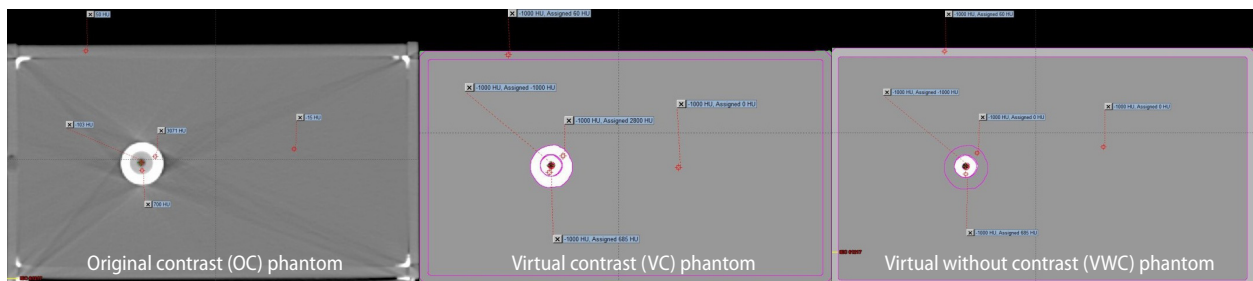


Figure 2. Assigned Hounsfield Units (HU) in different parts of phantoms

Contouring

The structure set provided in recommendations of task group No. 119 of the American Association of Physicists in Medicine (AAPM) was imported from the AAPM website i.e. www.aapm.org and used for planning. This structure set contains four test targets, i.e. Mock head-and-neck, C-shaped target, multi-target (superior-centre-inferior; cylindrical structure of

2 cm radius and 4 cm length each) and mock prostate target. Avoidance structures were the bilateral parotids, spinal cord in mock head neck target; bladder, rectum in mock prostate target and a cylindrical core (2 cm diameter with a 0.5 cm gap between the target and core) in a C-shaped target. All the test target cases, as shown in Figure 3, were imported to all three phantoms for generating the plans.

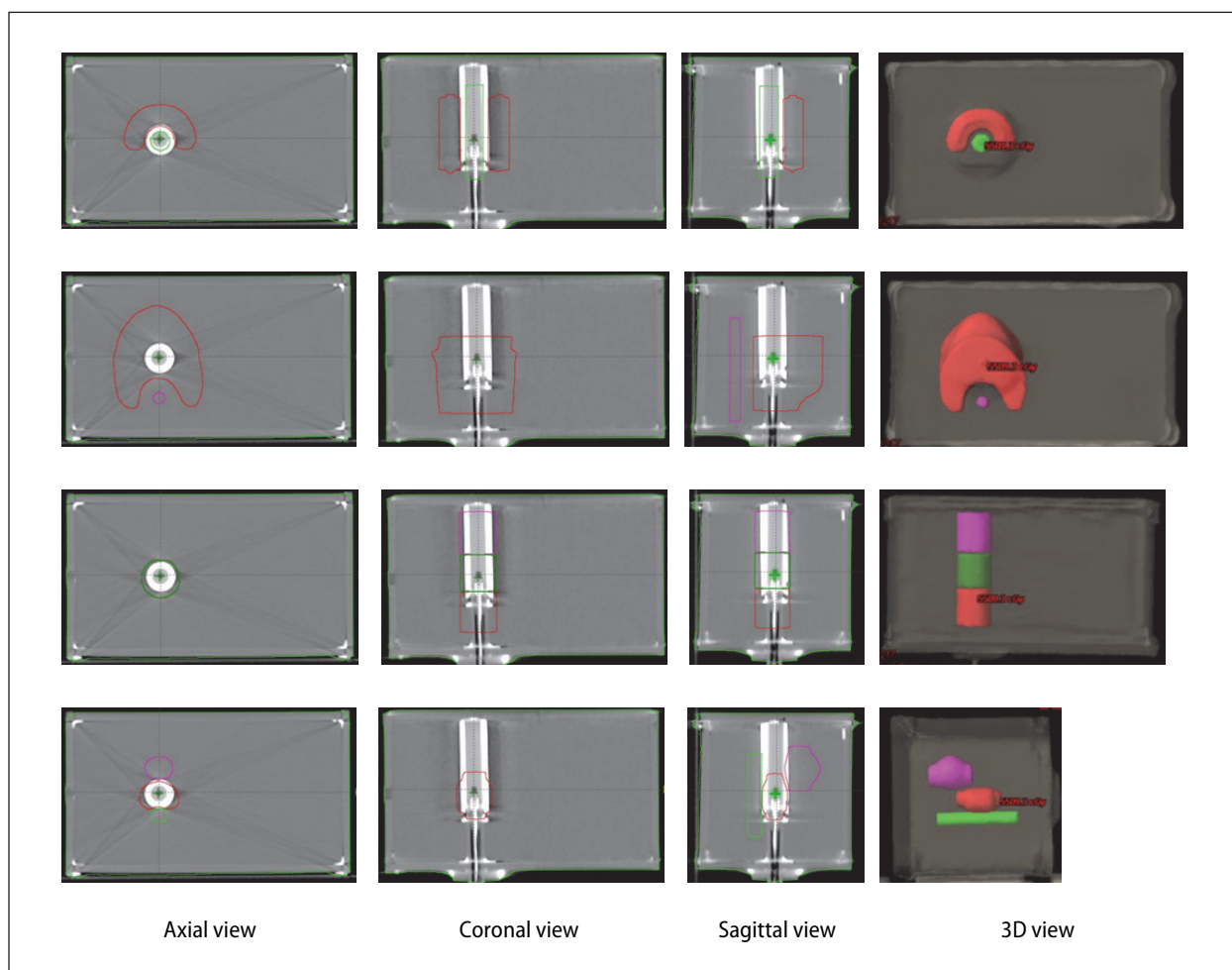


Figure 3. Test targets as per the TG-119 of the American Association of Physicists in Medicine (AAPM TG119) recommendations. **A.** C-shaped target; **B.** Head and neck test target; **C.** Multi-target; **D.** Prostate test target

Treatment planning

Treatment plans were generated on Eclipse (Varian Medical Systems, Version 11.0) treatment planning system (TPS) and were delivered on TrueBeam (Varian Medical Systems, Palo Alto, CA, USA; Version 1.6) linear accelerator (linac). Eclipse TPS uses Progressive Resolution Optimization (PRO) algorithm for optimizing the plans and calculates the same using the Analytical Anisotropic Algorithm (AAA) after leaf-motion-calculation. TrueBeam linac is equipped with three flattened photon beam energies, i.e. 6 MV, 10 MV, 15 MV, and two flattening-filter-free (FFF) energies, i.e. 6 FFF & 10 FFF. Removal of a flattening filter from the beam path increases the dose rate up to 1400 MU/min and 2400 MU/min for 6 FFF and 10 FFF photon beam, respectively. Multi-leaf-collimator (MLC) are attached at a tertiary level in Varian's TrueBeam linac and are characterized by spatial

resolution of 0.25 cm at the isocentre for the central 32 pairs of leaves and 0.5 cm in the outer 28 pairs of leaves.

IMRT plans were generated with gantry angles 0° , 51° , 102° , 153° , 204° , 255° and 306° with collimator/ couch 0° for all the test cases. However, two full-arcs ranging from 181° to 179° clockwise and anti-clockwise, were used in VMAT plans.

Comparative evaluation

The plans were generated as per criteria of the TG 119 protocol and a comparative evaluation was done by qualitative as well as quantitative methods. The plans were evaluated for different test cases on the following parameters — Table 1.

Plan quality indices, like conformity index and homogeneity index, were also evaluated for selected test cases using the ICRU-83 protocol and the following formula:

Table 1. Parameters in the plans evaluated for different test cases

Test target	Parameter/structure	D _{99%}	D _{98%}	D _{95%}	D _{90%}	D _{50%}	D _{30%}	D _{20%}	D _{10%}	D _{5%}	D _{2%}	D _{max}
Mock Head neck	HN PTV	X	X		X	X		X			X	
	Cord											X
	Bilateral Parotids					X						
Mock multi-target	PTV Centre	X							X			
	PTV Superior	X							X			
	PTV Inferior	X							X			
Mock C-shaped	CS PTV		X	X		X			X		X	
	Core									X		
Mock prostate	PR PTV		X	X		X				X	X	
	Bladder						X		X			
	Rectum						X		X			

PTV — planning target volume; CS — C-shaped; PR — prostate

$$\text{Conformity Index (CI98) [8]:} \\ \frac{\text{Volume of 98\% isodose curve (in cc)}}{\text{Volume of PTV (in cc)}}$$

$$\text{Homogeneity Index (HI) [9]:} \\ \frac{(D_{2\%} - D_{98\%})}{D_{50\%}}$$

Dose spillage to nearby normal tissues remains a concern for the planners and, hence, the integral dose to normal tissues [10] for the structure ‘body-PTV’, was calculated using the following formula:

Normal-tissue-integral-dose (NTID): Mean dose (in Gy) x Volume of structure (in cc)

Statistical analysis

Data collected was validated with other published data and AAPM TG 119 values were taken as a standard. Inter-comparison test was performed to analyze the data to find out statistically significant results for better interpretation. The formula used was:

$$\text{Percentage deviation} = \frac{(\text{Measured value})}{(\text{AAPM TG 119 limiting value})}$$

Results

Dosimetric deviation of IMRT and VMAT plans in VWC phantom with published studies for TG 119 recommendations with 6 MV photon beam energy was calculated and tabulated in Table 2. It is mentioned that the present study in without con-

trast phantom has significant correlation with other published data which was performed in a similar ambience, i.e. in the absence of contrast media. This experimental data was analyzed to make a resemblance with published data and made a comparison with results of AAPM TG 119 [11], Mynampati et al. [12], Nithya et al. [13], Lalit et al. [14] and Kaushik et al. [15].

Further, the plans were generated with varying photon beam energies mentioned above, and the results were tabulated in Table 3. The dose coverage (95% of maximum prescribed dose) to PTV for different test cases in all the three views (axial, coronal and sagittal) are shown in Figure 4 for different techniques and photon beam energies in selected phantoms.

Mock head and neck case

For the head and neck test case, the HN PTV target coverage to 99% of volume was in comparison with TG 119 results. It was observed that the maximum dose to the spinal cord was better with 6 MV photon beam energy in the IMRT technique and tabulated in Table 3 and Table 4.

Mock multi-target case

In this case, all the parameters of target coverage were achieved, except for the inferior target in VMAT cases with all energies. Also, the D_{10%} for the central target was not achieved in most of the contrast phantoms. Mynampati et al. [12] and Ezzell et al. [11] also reported the higher D_{10%} for the central target in their studies. However, the

Table 2. Dosimetric deviation of intensity-modulated-radiation-therapy (IMRT) and volumetric-modulated-arc therapy (VMAT) plans with other studies for TG-119 structures using 6 MV

Structure	Para-meters	TG-119		Mynampati et al.		Nithya et al.		Lalit et al.		Kaushik et al.		Present study (VVC phantom)		IMRT versus		VMAT versus			
		Goal	Results	IMRT	VMAT	IMRT	VMAT	IMRT	VMAT	IMRT	VMAT	IMRT	VMAT	TG 119	Mynam-pati et al.	Lalit et al.	Kaushik et al.	TG 119	Mynam-pati et al.
Mock head and neck target																			
HN PTV	D _{99%} [Gy]	> 50.0	50.28 ± 0.58	50.57	50.00	50.07	50.15	50.01	50.33	51.24	51.06	1.02	1.01	1.02	1.02	1.02	1.02	1.02	1.02
	D _{95%} [Gy]	> 46.5	47.04 ± 0.52	46.70	48.40	46.56	46.98	48.49	48.95	47.97	48.57	1.02	1.03	1.03	1.03	0.99	0.98	1.03	1.00
	D _{20%} [Gy]	< 55.0	52.99 ± 0.93	52.16	52.00	53.12	53.49	51.43	51.73	54.64	53.14	1.03	1.05	1.03	1.06	1.06	1.00	1.02	0.99
Cord	D _{max}	< 40.0	37.41 ± 2.50	38.34	37.90	39.28	38.12	34.17	38.47	29.73	35.77	0.79	0.78	0.76	0.87	0.77	0.96	0.94	0.94
Rt. Parotid	D _{50%}	< 40.0	17.98 ± 1.84	18.65	17.98	17.80	19.05	17.45	19.42	16.63	17.05	0.92	0.89	0.93	0.95	0.86	0.95	0.95	0.90
Lt. Parotid	D _{30%}	< 40.0	17.98 ± 1.84	19.15	19.25	17.70	19.33	17.23	19.42	16.74	17.35	0.93	0.87	0.95	0.97	0.86	0.96	0.90	0.90
MUs						952	1134			2114	759			2.22					0.67
Mock multi target																			
Center	D _{99%} [Gy]	> 50.0	49.55 ± 1.62	50.07	50.00	49.58	49.05	49.78	50.32	46.16	48.56	0.93	0.92	0.93	0.93	0.92	0.98	0.97	0.99
	D _{10%} [Gy]	< 53.0	54.55 ± 1.73	53.58	53.52	54.04	54.45	52.88	52.47	52.46	52.62	0.96	0.98	0.97	0.99	1.00	0.96	0.98	0.97
Superior	D _{99%} [Gy]	> 25.0	25.16 ± 0.85	26.21	26.87	24.71	24.93	25.99	25.59	24.75	24.29	0.98	0.94	1.00	0.95	0.97	0.97	0.90	0.97
	D _{10%} [Gy]	< 35.0	34.12 ± 3.04	32.43	31.33	32.62	32.82	29.35	33.62	25.96	25.32	0.76	0.80	0.80	0.88	0.77	0.74	0.81	0.77
Inferior	D _{99%} [Gy]	> 12.5	14.07 ± 1.85	13.64	13.67	15.14	14.13	12.96	13.12	12.12	10.66	0.86	0.89	0.80	0.94	0.92	0.76	0.78	0.75
	D _{10%} [Gy]	< 25.0	24.18 ± 2.72	19.60	19.04	21.06	24.82	16.66	17.96	13.54	12.74	0.56	0.69	0.64	0.81	0.75	0.53	0.67	0.51
MUs						492	607			862	564			1.75					0.93
Mock C-shaped target																			
CS PTV	D _{95%} [Gy]	> 50.0	50.10 ± 0.17	50.00	50.04	50.09	50.01	50.04	50.16	49.95	49.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	D _{10%} [Gy]	< 55.0	54.40 ± 0.52	54.82	54.93	54.88	54.72	52.44	52.42	53.95	53.66	0.99	0.98	0.98	1.03	1.03	0.99	0.98	0.98
Core	D _{3%} [Gy]	< 25.0	22.00 ± 3.14	15.85	16.77	24.98	24.74		23.39	26.08	22.78	1.18	1.65	1.04		1.12	1.03	1.36	0.92
MUs						898	607			1677	830			1.87					1.37
Mock prostate target																			
Prostate PTV	D _{95%} [Gy]	> 75.6	75.66 ± 0.21	75.67	75.64	75.64	75.86	75.84	75.72	76.26	76.01	1.01	1.01	1.01	1.01	1.01	1.00	1.00	1.00
	D _{3%} [Gy]	< 83.0	81.43 ± 1.56	81.46	82.30	81.57	81.59	79.94	78.30	78.81	79.43	0.97	0.97	0.97	0.99	1.01	0.98	0.97	0.97
Bladder	D _{30%} [Gy]	< 70.0	65.36 ± 2.97	54.55	56.12	54.89	54.27	27.61	43.94	11.98	15.94	0.18	0.22	0.22	0.43	0.27	0.24	0.28	0.29
	D _{10%} [Gy]	< 75.0	73.03 ± 1.50	71.40	72.12	73.97	74.03	48.57	62.69	27.86	32.01	0.38	0.39	0.38	0.57	0.44	0.44	0.44	0.43
Rectum	D _{30%} [Gy]	< 70.0	43.94 ± 8.78	37.85	31.30	51.07	46.77	46.62	65.36	47.19	47.23	1.07	1.25	0.92	1.01	0.72	1.07	1.51	1.01
	D _{10%} [Gy]	< 75.0	62.69 ± 8.15	59.44	52.47	69.54	69.53	73.84	73.03	66.11	63.01	1.05	1.11	0.95	0.90	0.91	1.00	1.20	0.91
MUs						499	532			675	593			1.35					1.11

PTV — planning target volume; HN — head and neck; CS — C-shaped; PR — prostate; MU — monitor unit; VVC — virtual without contrast

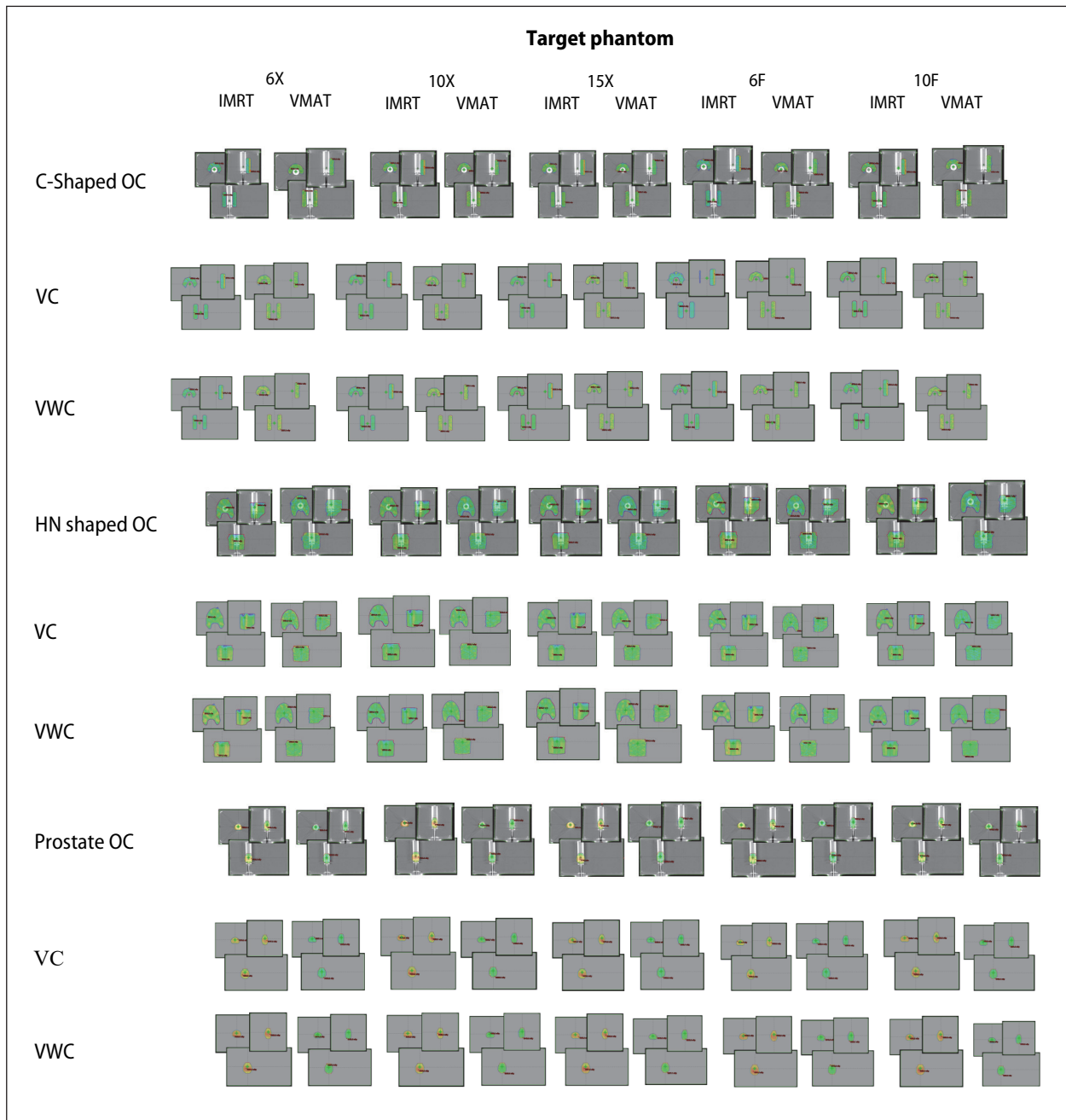


Figure 4. PTV dose coverage (95% of maximum prescribed dose) of test cases for different techniques and photon beam energies in different phantoms. OC — original contrast; VC — virtual contrast; VWC — virtual without contrast

present data demonstrated better results for $D_{10\%}$ for the inferior target for all the available energies in both techniques as compared to the TG 119 result (24.18 Gy).

Mock C-shaped target case

For the C-shaped target case, the dose to 95% volume of CS PTV (i.e. C-shaped Planning Target Volume) was comparable with all the photon beam energies and phantoms and was closer to

values achieved by TG 119. The dose received by 5% volume of the ‘core’ structure was observed as exceeded in IMRT plans from the prescribed limit ($D_{5\%} < 25$ Gy) and shown an upward trend with increasing photon beam energies. The results were tabulated in Table 5 and Table 6.

Mock prostate case

For the prostate test target, the coverage of PR PTV (i.e. Prostate PTV) was similar with all the

Table 3. Evaluation of plan parameters for different photon energies using intensity-modulated-radiation-therapy (IMRT) technique

Structure	Parameters	VWC phantom						OC phantom						VC phantom					
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF			
Mock head and neck target																			
HN PTV	D _{95%} [Gy]	47.93	51.25	50.96	50.98	51.01	50.18	50.65	50.41	49.96	50.36	50.68	51.11	50.87	51.03	50.74			
	D _{98%} [Gy]	48.98	49.09	48.86	48.68	48.96	48.04	48.65	48.27	47.78	48.29	48.04	48.93	48.65	48.81	48.73			
	D _{90%} [Gy]	51.25	48.02	47.81	47.59	47.95	46.99	47.61	47.37	46.55	47.33	46.98	47.96	47.58	47.82	47.63			
	D _{50%} [Gy]	53.82	53.53	53.27	53.54	53.41	52.58	52.99	52.85	52.49	52.86	53.61	53.28	53.28	53.53	53.11			
	D _{20%} [Gy]	54.64	54.29	54.03	54.39	54.29	53.43	53.77	53.61	53.39	53.74	54.49	54.04	54.02	54.41	53.98			
	D _{2%} [Gy]	55.55	55.13	54.98	55.39	55.34	54.44	54.71	54.56	54.46	54.75	55.49	54.95	54.92	55.49	54.98			
Cord	D _{max} [Gy]	29.73	30.11	30.06	29.91	29.81	29.13	30.12	29.66	29.11	30.75	30.10	30.38	29.92	29.05	29.78			
Rt. Parotid	D _{50%} [Gy]	16.63	17.76	17.68	15.82	17.51	16.83	18.26	18.42	16.04	17.75	16.73	17.66	17.79	15.92	16.76			
Lt. Parotid	D _{50%} [Gy]	16.76	18.28	18.24	15.65	17.96	17.07	18.59	18.71	15.91	17.75	16.79	18.21	18.29	16.08	17.14			
MU		2114	1865	1642	2189	2365	2143	1716	1755	2391	2205	2179	1808	1620	2258	2056			
Mock multi target																			
Centre	D _{95%} [Gy]	45.78	46.28	46.34	46.58	46.84	47.23	46.08	46.11	45.16	44.71	45.99	46.92	46.41	46.23	46.74			
	D _{10%} [Gy]	52.46	52.56	52.22	52.46	52.51	54.63	54.74	54.76	54.66	55.22	52.73	52.88	52.12	52.69	52.39			
Superior	D _{95%} [Gy]	24.79	24.49	23.89	24.54	24.28	26.24	25.09	24.49	25.24	25.13	25.42	24.98	24.62	25.03	24.69			
	D _{10%} [Gy]	25.96	26.15	26.13	25.61	25.67	27.64	28.21	28.03	26.86	27.25	26.31	26.25	25.81	25.93	25.54			
Inferior	D _{95%} [Gy]	12.14	12.12	12.22	12.05	12.75	13.85	14.38	12.53	12.98	13.94	12.51	12.69	12.42	12.63	12.72			
	D _{10%} [Gy]	13.54	13.67	13.85	13.21	13.56	14.91	15.77	15.39	13.99	15.22	13.94	13.99	13.89	13.59	13.57			
MU		862	690	687	866	802	1610	1371	1007	1156	1162	1119	831	717	1314	840			

PTV — planning target volume; HN — head and neck; MU — monitor unit; VWC — virtual without contrast; OC — original contrast; VC — virtual contrast

Table 4. Evaluation of plan parameters for different photon energies using volumetric-modulated-arc therapy (VMAT) technique

Structure	Parameters	VVC phantom					OC phantom					VC phantom				
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF
Mock head and neck target																
HN PTV	D _{99%} [Gy]	48.61	48.64	48.65	47.89	48.96	48.77	48.55	48.68	48.61	48.49	48.49	48.05	48.57	48.39	47.96
	D _{98%} [Gy]	49.18	49.22	49.26	48.51	49.55	49.39	49.23	49.33	49.29	49.16	48.76	48.61	49.09	49.03	48.55
	D _{90%} [Gy]	51.06	51.06	51.13	50.46	51.48	50.81	50.77	50.85	50.75	50.69	50.69	50.49	50.98	50.92	50.44
	D _{50%} [Gy]	52.51	52.51	52.53	51.99	53.07	52.04	52.06	52.07	52.06	52.08	51.94	51.97	52.51	52.49	51.97
	D _{20%} [Gy]	53.14	53.11	53.11	52.66	53.69	52.71	52.69	52.66	52.77	52.79	52.79	52.61	53.14	53.23	52.66
	D _{2%} [Gy]	54.02	54.01	54.01	53.64	54.68	53.75	53.66	53.67	53.84	53.87	53.57	53.54	54.05	54.23	53.64
Cord	D _{max} [Gy]	35.77	36.49	35.93	36.72	37.04	32.61	33.16	32.73	32.87	33.29	36.35	36.26	36.58	36.39	
Rt. Parotid	D _{50%} [Gy]	17.02	17.63	17.93	17.39	18.76	13.69	15.37	15.82	12.88	14.51	16.83	17.84	17.32	17.81	
Lt. Parotid	D _{50%} [Gy]	17.36	18.36	18.34	17.28	18.78	14.51	16.39	16.37	13.57	15.04	17.22	18.59	17.25	18.03	
MU		759	700	650	792	877	773	644	669	861	818	660	649	831	835	
Mock multi target																
Centre	D _{99%} [Gy]	48.42	47.86	47.81	48.53	47.86	45.52	47.03	47.21	46.06	46.46	48.05	48.35	48.13	48.56	47.89
	D _{10%} [Gy]	52.62	52.43	52.76	52.63	52.43	55.41	53.41	53.98	54.31	54.71	52.82	53.41	53.33	52.81	52.77
Superior	D _{99%} [Gy]	24.31	23.92	24.07	24.18	24.09	23.31	24.20	24.33	22.32	22.76	24.15	24.41	24.51	24.18	24.18
	D _{10%} [Gy]	25.33	25.16	25.28	25.21	25.16	26.57	25.89	36.18	26.15	26.43	25.25	25.62	25.67	25.36	25.32
Inferior	D _{99%} [Gy]	10.67	11.02	11.04	10.61	10.67	10.14	10.18	10.15	10.15	10.01	10.76	10.86	10.74	10.76	10.43
	D _{10%} [Gy]	12.74	12.63	12.73	12.68	12.67	13.96	13.54	13.68	13.67	13.97	12.76	12.95	12.99	12.75	12.81
MU		564	480	442	570	533	729	533	481	759	767	537	477	612	523	

PTV — planning target volume; MU — monitor unit; VVC — virtual without contrast; OC — original contrast; VC — virtual contrast

Table 5. Evaluation of plan parameters for different photon energies using intensity-modulated-radiation-therapy (IMRT) technique

Structure	Parameters	VVC phantom					OC phantom					VC phantom				
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF
Mock C-shaped target																
CS PTV	D _{98%} [Gy]	48.91	49.05	48.98	48.69	49.11	48.84	50.04	50.69	48.06	49.44	49.05	49.25	49.29	49.42	49.31
	D _{95%} [Gy]	49.94	50.09	49.97	49.71	50.12	49.81	50.96	51.63	49.03	50.44	49.97	50.15	50.19	50.11	50.16
	D _{90%} [Gy]	52.61	52.71	52.59	52.41	52.72	52.46	53.56	54.26	51.81	53.03	52.41	52.53	52.54	52.03	52.53
	D _{10%} [Gy]	53.94	53.84	53.74	53.77	53.97	53.91	54.78	55.41	53.34	54.33	53.77	53.71	53.61	53.14	53.75
	D _{2%} [Gy]	54.76	54.61	54.51	54.68	54.78	54.79	55.46	56.18	54.32	55.14	54.59	54.35	54.31	53.82	54.48
Core	D _{5%} [Gy]	26.09	26.65	26.86	25.83	26.94	26.23	27.21	27.75	25.66	27.11	26.01	26.64	26.79	25.07	26.96
MU		1677	1484	1367	1878	1729	1712	1528	1425	1934	1721	1683	1463	1348	1779	1693
Mock prostate target																
PR PTV	D _{98%} [Gy]	75.35	74.83	74.95	75.16	74.89	72.89	73.48	73.26	72.71	72.61	74.73	74.96	75.19	74.73	74.76
	D _{95%} [Gy]	76.31	75.76	75.82	76.07	75.81	75.83	76.47	76.33	75.48	75.69	76.81	75.85	76.16	75.62	75.57
	D _{90%} [Gy]	78.26	77.79	77.81	77.96	77.72	75.93	76.48	76.06	75.62	75.57	77.84	78.03	78.53	77.75	77.73
	D _{5%} [Gy]	78.81	78.35	78.54	78.39	78.26	76.32	76.91	76.67	76.08	76.06	77.63	78.66	79.31	78.55	78.38
	D _{2%} [Gy]	78.89	78.42	78.61	78.46	78.34	76.82	77.25	76.85	76.71	76.48	78.79	78.76	79.48	78.69	78.49
Bladder	D _{90%} [Gy]	11.83	11.62	11.83	12.52	12.09	10.73	11.41	10.39	12.35	12.69	11.07	11.11	10.49	10.98	10.62
	D _{10%} [Gy]	27.89	27.72	28.51	29.43	28.86	26.72	27.96	26.75	28.47	29.28	26.95	26.91	26.22	26.33	25.74
Rectum	D _{90%} [Gy]	47.17	46.91	46.99	48.23	47.44	45.63	46.38	45.41	46.46	46.91	46.89	46.52	46.13	46.16	45.62
	D _{10%} [Gy]	66.08	65.87	65.57	66.57	65.82	64.39	64.92	63.87	65.16	65.27	65.31	65.33	65.15	64.67	64.29
MU		675	623	574	677	611	726	620	586	715	570	671	601	592	727	631

PTV — planning target volume; CS — C-shaped; PR — prostate; MU — monitor unit; VVC — virtual without contrast; OC — original contrast; VC — virtual contrast

Table 6. Evaluation of plan parameters for different photon energies using volumetric-modulated-arc therapy (VMAT) technique

Structure	Parameters	VVC phantom					OC phantom					VC phantom				
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF
Mock C-shaped target																
CS PTV	D _{98%} [Gy]	49.01	48.96	49.51	48.98	48.98	48.75	48.69	48.81	49.12	48.85	49.33	48.88	49.36	48.79	48.95
	D _{95%} [Gy]	49.85	49.78	50.33	49.85	49.79	49.56	49.51	49.58	49.96	49.64	50.11	49.63	50.11	49.57	49.67
	D _{50%} [Gy]	52.74	52.75	53.25	52.72	52.73	52.18	52.18	52.23	52.16	52.18	52.72	52.17	52.68	52.12	52.11
	D _{10%} [Gy]	53.66	53.62	54.15	53.63	53.66	53.07	53.09	53.11	53.09	53.06	53.63	53.02	53.51	53.06	52.98
	D _{2%} [Gy]	54.13	54.11	54.65	54.15	54.15	53.73	53.63	53.62	53.65	53.61	54.13	53.51	53.99	53.61	53.49
Core	D _{5%} [Gy]	22.77	23.57	23.56	23.06	23.06	24.42	22.13	22.01	22.38	22.09	22.28	21.91	22.05	22.49	21.72
MU		830	770	769	913	955	825	780	753	885	845	770	734	935	956	
Mock prostate target																
PR PTV	D _{98%} [Gy]	75.01	74.95	74.87	75.04	75.33	73.06	72.98	72.87	73.26	73.51	74.76	74.56	74.31	75.04	74.77
	D _{95%} [Gy]	76.01	75.92	75.81	75.98	76.28	73.89	73.85	73.77	74.01	74.34	75.74	75.59	75.39	75.98	75.79
	D _{50%} [Gy]	78.11	78.08	78.14	78.07	78.11	75.91	76.09	76.09	75.99	76.38	77.89	77.84	77.95	77.93	77.89
	D _{5%} [Gy]	79.45	79.35	79.38	79.46	79.32	77.31	77.42	77.46	77.38	77.71	79.35	79.31	79.51	79.26	79.25
	D _{2%} [Gy]	79.96	79.81	79.81	79.94	79.79	77.67	77.75	77.81	77.78	78.04	79.77	79.68	79.87	79.67	79.61
Bladder	D _{30%} [Gy]	15.77	16.98	16.86	15.78	16.65	15.22	16.13	16.42	16.83	15.69	14.37	14.88	15.52	13.71	14.99
	D _{10%} [Gy]	31.94	31.59	31.82	31.26	31.26	29.53	30.74	32.58	31.54	31.89	30.41	29.98	31.26	29.78	29.83
Rectum	D _{30%} [Gy]	47.33	46.36	47.08	47.48	47.52	47.02	46.44	46.91	46.86	46.23	46.35	46.91	46.81	45.98	45.73
	D _{10%} [Gy]	62.99	63.53	63.87	63.86	63.67	60.77	61.91	63.04	60.76	61.91	62.18	62.64	63.19	61.46	62.67
MU		593	521	491	659	557	553	465	452	582	516	575	530	481	640	557

PTV — planning target volume; CS — C-shaped; PR — prostate; MU — monitor unit; VVC — virtual without contrast; OC — original contrast; VC — virtual contrast

photon beam energies and was comparable with TG 119 ($D_{95\%} > 75.6$ Gy), except for OC phantom using the VMAT technique. The results were tabulated in Table 3B and Table 3D. Dose to the bladder and rectum were within the prescribed limit ($D_{30\%} < 70$ Gy, $D_{10\%} < 75$ Gy) and bladder doses were lesser than all selected studies.

Plan quality indices

Homogeneity index (HI) was reported and tabulated in Table 7 and Table 8. It was evident that HI was comparatively better for VMAT plans with all the energies in HN PTV and CS PTV and was comparable with IMRT for PR PTV. Similarly, the conformity index (CI) was evaluated and found better with the VMAT technique.

Integral dose of normal tissue

Dose to normal healthy tissues was calculated and it was found that the IMRT technique deliver more unwanted radiation to body tissues other than tumour target when compared to VMAT plans. It was noted that higher photon energy spills lesser dose to healthy tissues. The dose spillage of 50% of maximum prescribed dose is shown in Figure 5 and Figure 6.

Variation of plan parameters with standard practice

Relative measurement was performed for the collected data with standard limiting values prescribed by TG 119 and the results were tabulated in Table 9 and Table 10. It was evident that we had achieved better coverage for the head and neck test target and prostate test target for all the energies in our study. Also the coverage for the multi-target case and C-shaped target was comparable with TG 119 results for both treatment techniques. Maximum dose to the 'cord' was lesser with IMRT but dose to bilateral parotids was almost similar. Dose to the 'centre target' in multi-target case was below the limiting values for the IMRT technique and also for the 'OC phantom' in the VMAT technique. $D_{10\%}$ to the 'inferior target' was also not achieved and deviated more for the 'OC phantom' in both techniques and varying energies. Dose received by the 'core' structure was better achieved by the VMAT treatment technique and exceeded for IMRT for all the energies. Dose to the bladder and rectum was within the tolerance, recommended by the TG 119 protocol.

Table 7. Plan quality indices for intensity-modulated-radiation-therapy (IMRT) plans with different photon energies

Parameter	Structure	VWC phantom					OC phantom					VC phantom					
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	
HI	HN PTV	0.12	0.11	0.11	0.13	0.12	0.12	0.11	0.12	0.12	0.12	0.12	0.11	0.12	0.12	0.12	0.12
	CS PTV	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.12	0.11	0.11	0.10	0.10	0.08	0.10	0.10
	Prostate	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CI	HN PTV	1.08	1.15	1.13	1.00	1.09	1.02	1.04	1.03	1.01	1.03	1.05	1.14	1.12	1.01	1.07	1.07
	CS PTV	1.09	1.16	1.19	1.05	1.13	1.10	1.17	1.20	1.05	1.14	1.11	1.17	1.20	1.40	1.14	1.14
	Prostate	1.18	1.20	1.15	1.18	1.15	0.94	1.21	1.17	1.16	1.17	1.12	1.13	1.10	1.10	1.09	1.09
NTID (Gy-cm ³) X 10 ³	HN PTV	790.22	769.01	749.38	778.44	764.31	758.64	741.31	737.53	748.84	732.25	789.44	773.73	752.52	781.58	747.02	747.02
	CS PTV	614.81	604.95	600.84	609.06	597.55	604.41	607.58	610.75	594.91	592.53	613.99	604.95	600.84	683.03	597.55	597.55
	Prostate	442.86	424.45	424.45	449.56	424.45	427.87	415.73	411.69	434.34	411.69	430.31	412.72	414.39	432.82	409.38	409.38

HI — homogeneity index; CI — conformity index; NTID — normal tissue integral dose; VWC — virtual without contrast; OC — original contrast; VC — virtual contrast

Table 8. Plan quality indices for volumetric-modulated-arc therapy (VMAT) plans with different photon energies

Parameter	Structure	VWC phantom					OC phantom					VC phantom					
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	
HI	HN PTV	0.09	0.09	0.09	0.10	0.10	0.08	0.09	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10
	CS PTV	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	Prostate	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
CI	HN PTV	1.00	1.00	1.00	0.99	1.00	1.06	1.04	1.06	1.05	1.06	1.05	1.06	1.05	1.06	1.00	1.00
	CS PTV	0.96	0.99	0.99	0.99	0.99	1.01	1.01	1.01	1.01	1.08	1.02	1.01	1.01	1.00	1.01	1.01
	Prostate	1.06	1.06	1.06	1.08	1.07	0.92	0.93	0.92	0.93	0.93	0.96	1.05	1.04	1.06	1.05	1.05
NTID (Gy-cm ³) X 10 ³	HN PTV	758.80	750.16	748.59	747.02	744.66	815.20	800.12	794.84	780.51	772.22	756.45	751.73	745.45	748.59	737.59	737.59
	CS PTV	595.91	584.39	589.33	594.26	572.89	588.57	571.93	566.39	589.36	561.63	593.44	584.39	581.11	589.33	572.07	572.07
	Prostate	380.91	371.70	371.71	384.26	372.54	370.44	359.92	357.49	374.48	362.35	374.22	359.15	357.47	379.24	359.15	359.15

HI — homogeneity-index; CI — conformity index; NTID — normal tissue integral dose; VWC — virtual without contrast; OC — original contrast; VC — virtual contrast

Total monitor units

Total monitor units were calculated summing monitor units of individual fields of each plan and noted in Table 3. It was evident that requirement of MUs decreases with increasing photon beam energies and it was much less for the VMAT technique, which is shown in Table 11 and Table 12.

Discussion

Accuracy of treatment delivery depends on accurate dose computation. The use of contrast-enhanced images for treatment planning and delivery of those treatment plans on non-contrast tissues was always a matter of concern for radiotherapy practitioners. The contrast agent includes high-Z radio-opaque materials which attenuate the X-rays more than the normal tissues. This situation increases the CT number (or Hounsfield Units, i.e. HU) and, hence, the electron density in that voxel temporarily which could result in altering photon beam dosimetry [16, 17].

We have used test case targets provided by AAPM TG 119 and validated the same with the Eclipse treatment planning system. It was noted in our study that PTV coverage achieved in all the test cases was more than the limiting values and increased with higher photon energy. However, a little difference was observed with contrast-enhanced phantom images for target coverage. Our results are in agreement with results published by Haghparast et al. [18]. Moreover, to relate the photon beam energies with intravenous contrast, Ramm et al. [19] conducted their study. They used a cylinder of barium sulfate (diameter 3 cm) in a water phantom and irradiated the same with either 6 MV or 25 MV photon beam energies to evaluate the effect of CT contrast on dose calculation in a three-dimensional planning technique. They concluded that the effect of contrast was very small if the planner increased the number of beams and a dose difference of 2.7% and 1.8% was found for 6 MV and 25 MV, respectively, for a standard four-field technique due to cylinder of contrast but the dose perturbation was not clinically significant.

Jing et al. [20] highlighted the underestimation of dose due to intravenous contrast was slight and was moderate due to an oral contrast agent. But, Weber et al. [21] reported a slight reduction of dose to the

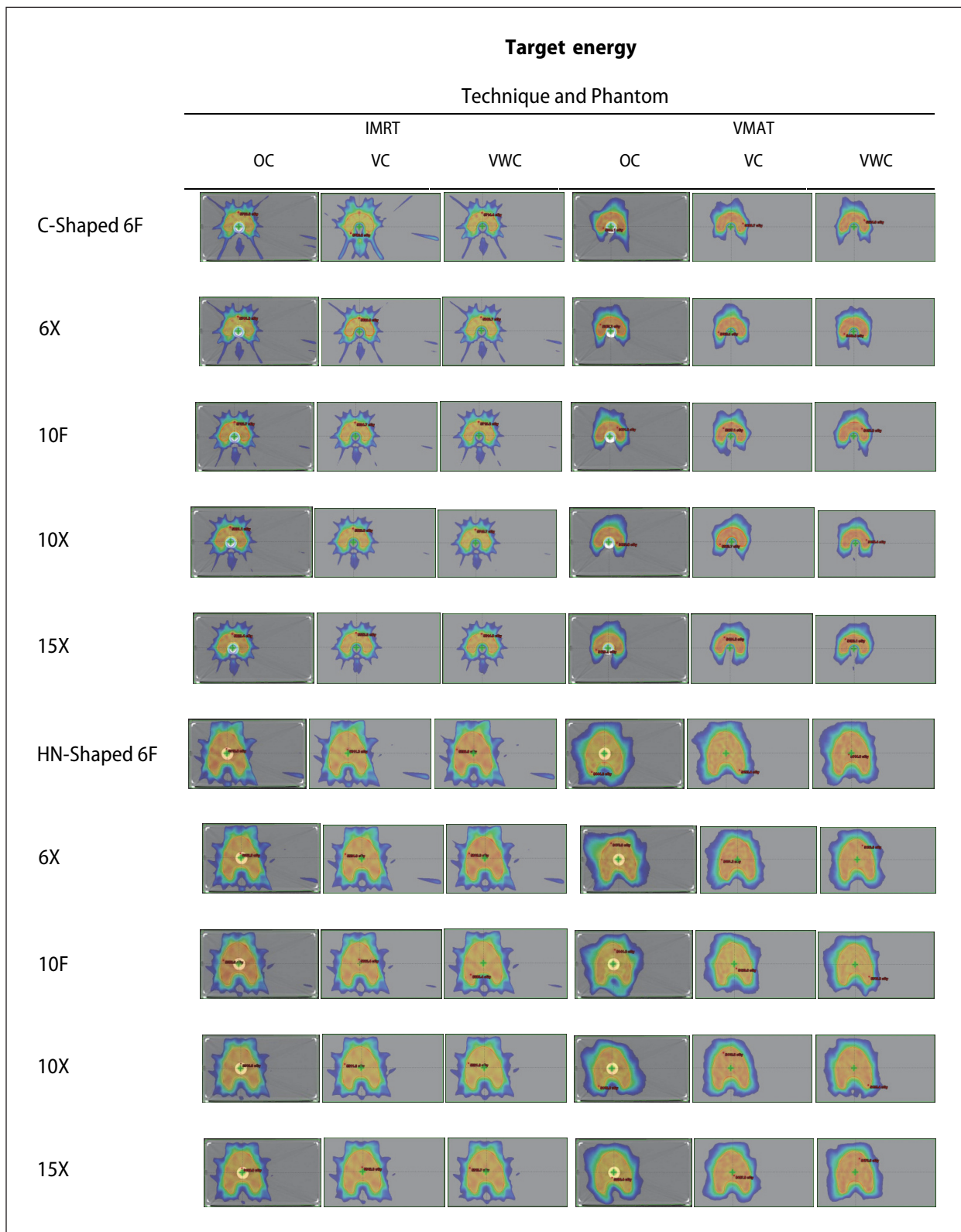


Figure 5. Spillage of 50% of prescription dose in C-shaped and head-and-neck-shaped test cases (Axial view)

prostate target (0.03–0.14%) and rectum (1.13%) while studying the effects of bladder opacification on dose calculations with a 6-field conformal plan

for prostate cancer patients. In a similar manner, the higher tail-region was reported for the ‘central’ target in our study.

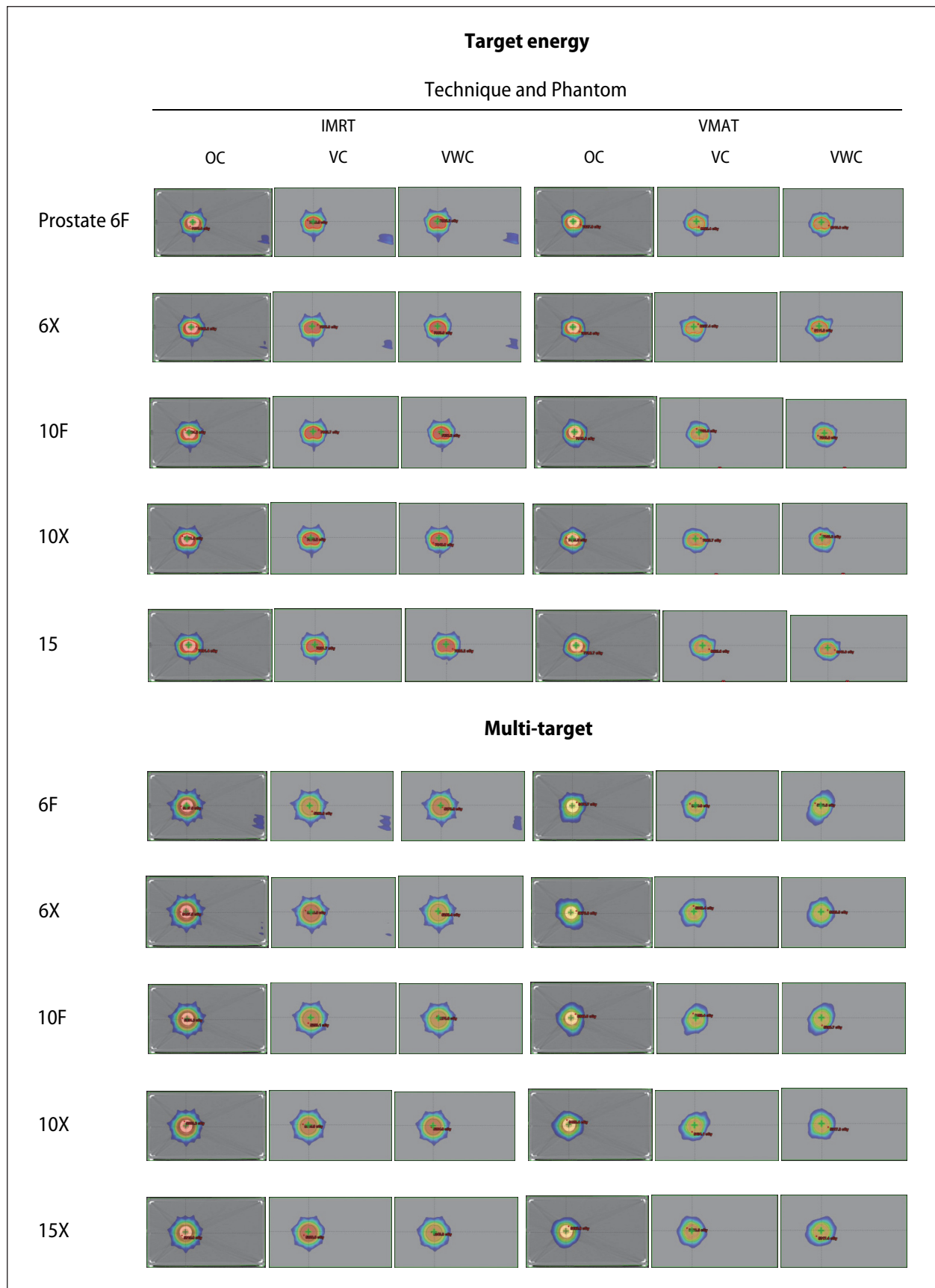


Figure 6. Spillage of 50% of prescription dose in Prostate-shaped and Multi-target test cases (Axial view)

Table 9. Variation of plan parameters from standard TG-119 limiting values for intensity-modulated-radiation-therapy (IMRT)

Structure	Parameters	VVC phantom					OC phantom					VC phantom					
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	
Mock head and neck target																	
HN PTV	D _{95%} [Gy]	1.03	1.03	1.03	1.02	1.03	1.01	1.02	1.02	1.02	1.01	1.01	1.02	1.03	1.02	1.03	1.02
	D _{90%} [Gy]	1.03	1.03	1.02	1.02	1.02	1.00	1.01	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.01
	D _{20%} [Gy]	0.99	0.99	0.98	0.99	0.99	0.97	0.98	0.97	0.97	0.98	0.99	0.98	0.98	0.98	0.99	0.99
Cord	D _{max} [Gy]	0.74	0.75	0.75	0.75	0.75	0.73	0.75	0.74	0.73	0.73	0.75	0.76	0.75	0.75	0.73	0.74
	D _{50%} [Gy]	0.42	0.44	0.44	0.40	0.44	0.42	0.46	0.46	0.44	0.44	0.42	0.44	0.44	0.44	0.40	0.42
Lt. Parotid	D _{50%} [Gy]	0.42	0.46	0.46	0.39	0.45	0.43	0.46	0.47	0.40	0.40	0.42	0.46	0.46	0.46	0.40	0.43
Mock multi target																	
Centre	D _{95%} [Gy]	0.92	0.93	0.93	0.93	0.94	0.94	0.92	0.92	0.90	0.92	0.92	0.94	0.92	0.93	0.92	0.93
	D _{10%} [Gy]	0.99	0.99	0.99	0.99	0.99	1.03	1.03	1.03	1.03	1.04	1.03	0.99	0.99	0.98	0.99	0.99
Superior	D _{95%} [Gy]	0.99	0.98	0.96	0.98	0.97	1.05	1.00	0.98	1.01	1.01	1.02	0.99	0.98	0.98	1.00	0.99
	D _{10%} [Gy]	0.74	0.75	0.75	0.73	0.73	0.79	0.81	0.81	0.77	0.78	0.75	0.75	0.74	0.74	0.74	0.73
Inferior	D _{95%} [Gy]	0.97	0.97	0.98	0.96	1.02	1.11	1.15	1.00	1.04	1.12	1.00	1.02	1.02	0.99	1.01	1.02
	D _{10%} [Gy]	0.54	0.55	1.11	1.06	1.08	1.19	1.26	1.23	1.12	1.22	1.12	1.12	1.12	1.11	1.09	1.09
Mock C-shaped target																	
CS PTV	D _{95%} [Gy]	0.99	1.00	0.99	0.99	1.00	0.99	1.02	1.03	0.98	1.02	0.99	1.00	1.00	1.00	1.00	1.00
	D _{10%} [Gy]	0.98	0.98	0.98	0.98	0.98	0.98	0.99	1.01	0.97	0.98	0.98	0.98	0.98	0.97	0.97	0.98
Core	D _{5%} [Gy]	1.04	1.07	1.07	1.03	1.08	1.05	1.09	1.11	1.03	1.04	1.04	1.07	1.07	1.00	1.08	1.08
Mock prostate target																	
PR PTV	D _{95%} [Gy]	1.01	1.00	1.00	1.01	1.00	1.00	1.01	1.01	0.99	1.02	1.02	1.00	1.00	1.01	1.00	0.99
	D _{5%} [Gy]	0.95	0.94	0.95	0.94	0.94	0.92	0.93	0.92	0.92	0.92	0.94	0.95	0.95	0.96	0.95	0.94
Bladder	D _{30%} [Gy]	0.17	0.17	0.17	0.18	0.17	0.15	0.16	0.15	0.18	0.16	0.16	0.16	0.16	0.15	0.16	0.15
	D _{10%} [Gy]	0.37	0.37	0.38	0.39	0.38	0.36	0.37	0.36	0.38	0.36	0.36	0.36	0.36	0.35	0.35	0.34
Rectum	D _{30%} [Gy]	0.67	0.67	0.67	0.69	0.68	0.65	0.66	0.65	0.66	0.67	0.67	0.66	0.66	0.66	0.66	0.65
	D _{10%} [Gy]	0.88	0.88	0.87	0.89	0.88	0.86	0.87	0.85	0.87	0.87	0.87	0.87	0.87	0.87	0.86	0.86

PTV — planning target volume; HN — head and neck; CS — C-shaped; PR — prostate; MU — monitor unit; VWC — virtual without contrast; OC — original contrast; VC — virtual contrast

Table 10. Variation of plan parameters from standard TG-119 limiting values for volumetric-modulated-arc therapy (VMAT)

Structure	Parameters	VWC phantom					OC phantom					VC phantom				
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF
Mock head and neck target																
HN PTV	D _{95%} [Gy]	1.04	1.04	1.04	1.03	1.05	1.04	1.04	1.05	1.04	1.04	1.04	1.03	1.04	1.04	1.03
	D _{90%} [Gy]	1.02	1.02	1.02	1.01	1.03	1.02	1.02	1.02	1.02	1.02	1.01	1.01	1.02	1.02	1.01
	D _{20%} [Gy]	0.97	0.97	0.97	0.96	0.98	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.97
Cord	D _{max} [Gy]	0.89	0.91	0.90	0.92	0.93	0.82	0.83	0.82	0.83	0.82	0.83	0.88	0.88	0.91	0.91
	D _{50%} [Gy]	0.43	0.44	0.45	0.43	0.47	0.34	0.38	0.40	0.32	0.36	0.42	0.45	0.43	0.45	0.45
Lt. Parotid	D _{50%} [Gy]	0.43	0.46	0.46	0.43	0.47	0.36	0.41	0.41	0.34	0.43	0.46	0.47	0.43	0.43	0.45
Mock multi target																
Centre	D _{95%} [Gy]	0.97	0.96	0.96	0.97	0.96	0.91	0.94	0.94	0.92	0.93	0.96	0.97	0.96	0.97	0.96
	D _{10%} [Gy]	0.99	0.99	0.99	0.99	0.99	1.05	1.01	1.02	1.02	1.03	0.99	1.02	1.01	0.99	0.99
Superior	D _{95%} [Gy]	0.97	0.96	0.96	0.97	0.96	0.93	0.97	0.97	0.89	0.91	0.97	0.98	0.98	0.97	0.97
	D _{10%} [Gy]	0.72	0.72	0.72	0.72	0.72	0.76	0.74	1.03	0.75	0.76	0.72	0.73	0.73	0.72	0.72
Inferior	D _{95%} [Gy]	0.85	0.88	0.88	0.85	0.85	0.81	0.81	0.81	0.81	0.81	0.86	0.87	0.86	0.86	0.83
	D _{10%} [Gy]	0.51	1.01	1.02	1.01	1.01	1.12	1.08	1.09	1.09	1.12	1.02	1.04	1.04	1.02	1.02
Mock C-shaped target																
CS PTV	D _{95%} [Gy]	0.99	0.99	1.01	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.99	0.99
	D _{10%} [Gy]	0.98	0.97	0.98	0.98	0.98	0.96	0.97	0.97	0.97	0.96	0.98	0.96	0.97	0.96	0.96
Core	D _{3%} [Gy]	0.91	0.94	0.94	0.93	0.92	0.98	0.89	0.88	0.89	0.88	0.89	0.88	0.88	0.89	0.87
Mock prostate target																
PR PTV	D _{95%} [Gy]	1.01	1.00	1.00	1.01	1.01	0.98	0.98	0.98	0.98	0.98	1.01	0.99	0.99	1.01	1.00
	D _{5%} [Gy]	0.96	0.96	0.96	0.96	0.96	0.93	0.93	0.93	0.93	0.94	0.96	0.96	0.96	0.95	0.95
Bladder	D _{30%} [Gy]	0.23	0.24	0.24	0.23	0.24	0.22	0.23	0.23	0.24	0.22	0.21	0.21	0.22	0.19	0.21
	D _{10%} [Gy]	0.43	0.42	0.42	0.41	0.42	0.39	0.41	0.43	0.42	0.43	0.41	0.39	0.42	0.39	0.39
Rectum	D _{30%} [Gy]	0.68	0.66	0.67	0.68	0.68	0.67	0.66	0.67	0.67	0.66	0.66	0.67	0.67	0.66	0.65
	D _{10%} [Gy]	0.84	0.85	0.85	0.85	0.85	0.81	0.83	0.84	0.81	0.83	0.83	0.84	0.84	0.82	0.84

PTV — planning target volume; HN — head and neck; CS — C-shaped; PR — prostate; MU — monitor unit; VWC — virtual without contrast; OC — original contrast; VC — virtual contrast

Table 11. Variation of plan parameters in comparison with 6MV photon beam in VWC phantom for intensity-modulated-radiation-therapy (IMRT) cases

Structure	Parameters	VWC phantom						OC phantom						VC phantom					
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF			
Mock head and neck target																			
HN PTV	D _{99%} [Gy]	1.00	1.07	1.06	1.06	1.06	1.05	1.06	1.05	1.04	1.05	1.06	1.07	1.06	1.06	1.06	1.06		
	D _{98%} [Gy]	1.00	1.00	0.99	0.99	1.00	0.98	0.99	0.99	0.98	0.99	0.98	0.99	0.98	0.98	0.99	0.99		
	D _{90%} [Gy]	1.00	0.94	0.93	0.93	0.94	0.92	0.93	0.92	0.91	0.92	0.92	0.94	0.92	0.92	0.93	0.93		
	D _{50%} [Gy]	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99		
	D _{20%} [Gy]	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99		
	D _{2%} [Gy]	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99		
Cord	D _{max} [Gy]	1.00	1.01	1.01	1.01	1.00	0.98	1.01	0.99	0.98	1.01	1.02	1.01	1.01	0.98	1.00			
Rt. Parotid	D _{50%} [Gy]	1.00	1.07	1.06	0.95	1.05	1.01	1.10	1.11	0.96	1.07	1.06	1.06	1.07	0.96	1.01			
Lt. Parotid	D _{50%} [Gy]	1.00	1.09	1.09	0.93	1.07	1.02	1.11	1.12	0.95	1.06	1.06	1.09	1.00	0.96	1.02			
MU		1.00	0.88	0.78	1.04	1.12	1.01	0.81	0.83	1.13	1.04	0.86	0.77	1.07	0.97				
Mock multi target																			
Centre	D _{99%} [Gy]	1.00	1.01	1.01	1.02	1.02	1.03	1.01	1.01	1.01	1.01	1.02	1.02	1.01	1.01	1.02			
	D _{10%} [Gy]	1.00	1.00	0.99	1.00	1.00	1.04	1.04	1.04	1.04	1.05	1.05	1.01	1.01	1.00	0.99			
Superior	D _{99%} [Gy]	1.00	0.99	0.96	0.99	0.98	1.06	1.01	0.99	1.02	1.01	1.03	1.01	1.01	1.01	0.99			
	D _{10%} [Gy]	1.00	1.01	1.01	0.99	0.99	0.99	1.09	1.08	1.03	1.05	1.01	1.01	1.01	0.99	0.98			
Inferior	D _{99%} [Gy]	1.00	0.99	1.01	0.99	1.05	1.14	1.18	1.03	1.07	1.15	1.03	1.05	1.02	1.04	1.05			
	D _{10%} [Gy]	1.00	1.01	1.02	0.98	1.00	1.10	1.16	1.14	1.03	1.12	1.03	1.03	1.03	1.00	1.00			
MU		1.00	0.80	0.79	1.00	0.93	1.87	1.59	1.17	1.34	1.35	0.96	0.83	1.52	0.97				



Table 11. Variation of plan parameters in comparison with 6MV photon beam in VWC phantom for intensity-modulated-radiation-therapy (IMRT) cases

Structure	Parameters	VWC phantom					OC phantom					VC phantom				
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF
Mock C-shaped target																
CS PTV	D _{98%} [Gy]	1.00	1.00	1.00	0.99	1.00	0.99	1.02	1.04	0.98	1.01	1.00	1.01	1.01	1.01	1.01
	D _{95%} [Gy]	1.00	1.00	1.00	0.99	1.00	0.99	1.02	1.03	0.98	1.01	1.00	1.00	1.01	1.00	1.00
	D _{50%} [Gy]	1.00	1.00	0.99	0.99	1.00	0.99	1.02	1.03	0.98	1.01	0.99	0.99	0.99	0.99	0.99
	D _{10%} [Gy]	1.00	0.99	0.99	0.99	1.00	0.99	1.02	1.03	0.99	1.01	0.99	0.99	0.99	0.99	0.99
	D _{2%} [Gy]	1.00	0.99	0.99	0.99	1.00	1.00	1.01	1.03	0.99	1.01	0.99	0.99	0.99	0.98	0.99
Core	D _{5%} [Gy]	1.00	1.02	1.03	0.99	1.03	1.01	1.04	1.06	0.98	1.04	0.99	1.02	1.03	0.96	1.03
MU		1.00	0.88	0.82	1.12	1.03	1.02	0.91	0.85	1.15	1.03	1.00	0.87	0.80	1.06	1.01
Mock prostate target																
PR PTV	D _{98%} [Gy]	1.00	0.99	0.99	0.99	0.99	0.97	0.98	0.97	0.96	0.99	0.99	0.99	0.99	0.99	0.99
	D _{95%} [Gy]	1.00	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.99	0.99	1.01	0.99	0.99	0.99	0.99
	D _{50%} [Gy]	1.00	0.99	0.99	0.99	0.99	0.97	0.98	0.97	0.97	0.97	0.99	0.99	1.00	0.99	0.99
	D _{5%} [Gy]	1.00	0.99	0.99	0.99	0.99	0.97	0.98	0.97	0.97	0.97	0.99	0.99	1.01	0.99	0.99
	D _{2%} [Gy]	1.00	0.99	0.99	0.99	0.99	0.97	0.98	0.97	0.97	0.97	0.99	0.99	1.01	0.99	0.99
Bladder	D _{30%} [Gy]	1.00	0.98	1.00	1.06	1.02	0.91	0.96	0.88	1.04	1.07	0.94	0.94	0.89	0.93	0.89
	D _{10%} [Gy]	1.00	0.99	1.02	1.06	1.03	0.96	1.00	0.96	1.02	1.05	0.97	0.96	0.94	0.94	0.92
Rectum	D _{30%} [Gy]	1.00	0.99	0.99	1.02	1.01	0.97	0.98	0.96	0.98	0.99	0.99	0.99	0.98	0.98	0.97
	D _{10%} [Gy]	1.00	0.99	0.99	1.01	0.99	0.97	0.98	0.97	0.99	0.99	0.99	0.99	0.99	0.98	0.97
MU		1.00	0.92	0.85	1.00	0.91	1.08	0.92	0.87	1.06	0.84	0.99	0.89	0.88	1.08	0.93

PTV — planning target volume; HN — head and neck; CS — C-shaped; PR — prostate; MU — monitor unit; VWC — virtual without contrast; OC — original contrast; VC — virtual contrast

Table 12. Variation of plan parameters in comparison with 6MV photon beam in VWC phantom for volumetric-modulated-arc therapy (VMAT) cases

Structure	Parameters	Virtual without contrast (VWC) phantom					Original Contrast (OC) phantom					Virtual Contrast (VC) phantom					
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	
Mock head and neck target																	
HN PTV	D _{99%} [Gy]	1.01	1.01	1.01	0.99	1.02	1.02	1.01	1.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00
	D _{98%} [Gy]	1.00	1.00	1.01	0.99	1.01	1.01	1.01	1.01	1.01	1.01	1.00	0.99	1.00	1.00	1.00	0.99
	D _{90%} [Gy]	0.99	0.99	0.99	0.98	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98
	D _{50%} [Gy]	0.98	0.98	0.98	0.97	0.99	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.97
	D _{20%} [Gy]	0.97	0.97	0.97	0.96	0.98	0.96	0.96	0.96	0.96	0.96	0.97	0.96	0.97	0.97	0.97	0.96
	D _{2%} [Gy]	0.97	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.97	0.98	0.97
Cord	D _{max} [Gy]	1.20	1.23	1.21	1.24	1.25	1.10	1.12	1.11	1.11	1.12	1.19	1.22	1.23	1.22	1.22	
Rt. Parotid	D _{50%} [Gy]	1.02	1.06	1.08	1.05	1.13	0.82	0.92	0.77	0.87	0.87	1.01	1.07	1.04	1.07	1.07	
Lt. Parotid	D _{50%} [Gy]	1.04	1.10	1.09	1.03	1.12	0.87	0.98	0.81	0.89	1.03	1.11	1.12	1.03	1.08	1.08	
MU		0.36	0.33	0.31	0.37	0.41	0.37	0.30	0.41	0.39	0.36	0.31	0.31	0.39	0.39	0.39	
Mock multi target																	
Centre	D _{99%} [Gy]	1.06	1.05	1.04	1.06	1.05	0.99	1.03	1.01	1.01	1.05	1.06	1.05	1.06	1.05	1.05	
	D _{10%} [Gy]	1.00	0.99	1.01	1.00	0.99	1.06	1.02	1.03	1.04	1.01	1.02	1.02	1.01	1.01	1.01	
Superior	D _{99%} [Gy]	0.98	0.96	0.97	0.98	0.97	0.94	0.98	0.90	0.92	0.97	0.98	0.99	0.98	0.98	0.98	
	D _{10%} [Gy]	0.98	0.97	0.97	0.97	0.97	1.02	0.99	1.01	1.02	0.97	0.99	0.99	0.98	0.98	0.98	
Inferior	D _{99%} [Gy]	0.88	0.91	0.91	0.97	0.88	0.84	0.84	0.84	0.82	0.89	0.89	0.88	0.89	0.88	0.86	
	D _{10%} [Gy]	0.94	0.93	0.94	0.94	0.94	1.03	1.00	1.01	1.03	0.94	0.96	0.96	0.94	0.95	0.95	
MU		0.65	0.56	0.51	0.66	0.62	0.85	0.62	0.88	0.89	0.62	0.55	0.55	0.71	0.61	0.61	



Table 12. Variation of plan parameters in comparison with 6MV photon beam in VWC phantom for volumetric-modulated-arc therapy (VMAT) cases

Structure	Parameters	Virtual without contrast (VWC) phantom					Original Contrast (OC) phantom					Virtual Contrast (VC) phantom				
		6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF	6X	10X	15X	6FFF	10FFF
Mock C-shaped target																
CS PTV	D _{98%} [Gy]	1.00	1.00	1.01	1.00	1.00	0.99	0.99	0.99	1.00	0.99	0.99	1.01	1.00	0.99	1.00
	D _{95%} [Gy]	0.99	0.99	1.01	0.99	0.99	0.99	0.99	0.99	1.00	0.99	0.99	1.00	0.99	0.99	0.99
	D _{50%} [Gy]	1.00	1.00	1.01	1.00	1.00	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.99	0.99	0.99
	D _{10%} [Gy]	0.99	0.99	1.00	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.98	0.98	0.98
	D _{2%} [Gy]	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.98	0.98	0.98
Core	D _{3%} [Gy]	0.87	0.90	0.90	0.89	0.88	0.94	0.85	0.86	0.85	0.84	0.85	0.85	0.84	0.85	0.83
MU		0.49	0.46	0.46	0.57	0.54	0.49	0.47	0.53	0.56	0.44	0.50	0.46	0.56	0.57	
Mock prostate target																
PR PTV	D _{98%} [Gy]	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.97	0.97	0.97	0.99	0.99	0.99	0.99	0.99
	D _{95%} [Gy]	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.97	0.97	0.97	0.99	0.99	0.99	0.99	0.99
	D _{50%} [Gy]	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.97	0.97	0.97	0.99	0.99	0.99	0.99	0.99
	D _{5%} [Gy]	1.01	1.01	1.01	1.01	1.01	0.98	0.98	0.98	0.98	0.98	1.01	1.01	1.01	1.01	1.01
	D _{2%} [Gy]	1.01	1.01	1.01	1.01	1.01	0.98	0.99	0.99	0.99	0.99	1.01	1.01	1.01	1.01	1.01
Bladder	D _{30%} [Gy]	1.33	1.44	1.43	1.33	1.41	1.29	1.36	1.42	1.33	1.21	1.21	1.26	1.31	1.16	1.27
	D _{10%} [Gy]	1.15	1.13	1.14	1.08	1.12	1.06	1.10	1.13	1.14	1.09	1.07	1.07	1.12	1.07	1.07
Rectum	D _{30%} [Gy]	1.00	0.98	0.99	1.01	1.01	0.99	0.98	0.99	0.98	0.98	0.99	0.99	0.99	0.97	0.97
	D _{10%} [Gy]	0.95	0.96	0.97	0.96	0.97	0.92	0.94	0.92	0.94	0.94	0.95	0.95	0.96	0.93	0.95
MU		0.88	0.77	0.72	0.98	0.83	0.82	0.69	0.86	0.76	0.85	0.79	0.71	0.95	0.83	

PTV — planning target volume; HN — head and neck; CS — C-shaped; PR — prostate; MU — monitor unit; VWC — virtual without contrast; OC — original contrast; VC — virtual contrast

Choi et al. [22] also investigated the effect of intravenous contrast in head and neck patients and reported that IMRT dose distribution remained unchanged and insensitive to contrast media. Additionally, Wertz et al. [23] highlighted the effect of intravenous contrast in skull base tumours at the time of CT simulation and found a maximum change of 36 HU in tumour tissue homogeneity. Maximum dose to the 'core' in the C-shaped target case was improved with VMAT and was increased with higher photon energies due to involvement of exit-dose contribution and increased HU numbers.

As per literature, the choice of beam energy depends on depth of a tumour target due to the spectrum of penetration power and the basic teaching is that the planner should choose higher photon beam energy for deep-seated targets over low-energy photons. But there are discussions among practitioners to select higher photon energies for IMRT and VMAT treatment techniques.

Soderstorm et al. [24] reported that there was no significant difference between 6 MV and 18 MV for radiotherapy treatment while Henry et al. [25] mentioned a clear advantage of dual arc VMAT over IMRT. Similarly, Kumar et al. [26] performed a study using 6 and 10 MV FFF beam and reported the FFFB of 6 MV to be superior as compared to 10 MV, for RA planning in case of gynaecological malignancies. Moreover, it offered better HI and CI values, as well as a lower number of MUs (3.33%). In addition, it delivered more NTID (4.42%) for similar target coverage and OARs sparing. However, Pirzkall et al. [27] demonstrated a significant impact of energy selection on dose distribution. The lesser sparing of the cord in the head and neck test case with VMAT planning might be due to additive contribution of lower dose components in the maximum dose of the structure.

The other aspect of high energy photons related to neutron production was discussed by Gurjar et al. [28] and Kry et al. [29]. The similar results were concluded by Zhai et al. [30] and Yadav et al. [31] and, hence, the use of higher photon beam energies was restricted to conformal radiotherapy planning. It was noted in our study that VMAT planning improved the conformity and homogeneity of the plans due to continuous placement of beams around the targets. Even though Hussein

et al. [32] conducted their study and addressed the benefits of IMRT using 15 MV photon beams energy outweighing risk. We found that integral dose to nearby healthy tissues was increased with IMRT plans but higher photon beams delivered less dose to these areas due to their skin-sparing effects. Wonmo et al. [33] also concluded to use 10 MV photons after their known negligible neutron dose equivalent considering their biological and clinical significance. But the present study suggested that the monitor units required for delivering the dose to target with VMAT planning was much lower and further reduced with selection of higher photon energies due to their penetration power in the tissues.

Conclusion

The contrast-enhanced CT images definitely lower the dose to targets when compared with non-contrast CT structures set. The IMRT or VMAT plans, generated on such enhanced CT images will be delivered with higher doses than evaluated. However, the overdose remains non-significant and not very sensitive to contrast media. Higher photon energies also do not make clinically important changes. As the intravenous contrast is helpful in delineation of targets, we conclude that it is useful to include contrast-enhanced CT images for planning and the dose deviation remains insignificant as the output of treatment delivery.

Authors' contribution

D.T. — study design, G.Y. — data interpretation, L.K. — data collection, A.D. — statistical analysis, S.T. — literature search, G.K. — manuscript preparation, I.K.W. — literature search, M.G. — data interpretation

Conflict of interest

No potential conflict of interest related to this article was reported.

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