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Dosimetric Impact of Contrast Medium on Different Photon Energies Using Conformal & IMRT Techniques in the Treatment of Carcinoma Cervix and Its Validation with Indigenous Phantom

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ABSTRACT

Introduction: Considering the unwanted exposure to organs in the path of the beam, 4-field (4F) and subsequently, Intensity-modulated-radiation-therapy (IMRT), is known as the standard mode of treatment of carcinoma cervix. It is routine practice to inject intravenous contrast during simulation scan which elopes after that from the patient body. Therefore, the impact of contrast media should be investigated for radiation dose calculations.

Material and Methods: An indigenously made phantom, named as 'original contrast (OC)', was used with dimensions 15 x 15 x 30 cm^3. A sleeve was given to place the ionization chamber at the isocentre of the planning target volume (PTV) inside the cylindrical vial of iodinized contrast. Similarly, a virtual phantom was created with similar dimensions in the presence and absence of contrast media, called as 'virtual contrast (VC)' and 'virtual without contrast (VWC)' phantom. Plans were generated with photon energies (6MV/10MV/15MV/6FFF/10FFF) using 4F and IMRT technique. Plans were evaluated for PTV ($D_{99\%}$, $D_{10\%}$, D_{mean}) and Bladder & Rectum (V_{30Gy}, V_{10Gy}). Normal-tissue-integral-dose (NTID) and total-monitor-units (TMU) were also evaluated.

Results: $D_{99\%}$ of the PTV was comparable in VC and VWC phantoms but was decreased for OC phantom. Similarly, $D_{10\%}$ was reportedly higher as 54.03 Gy (4F, 6 MV), 54.71 Gy (4F, 15 MV), 55.78 Gy (4F, 6 FFF) and 57.64 Gy (4F, 10 FFF) for OC phantom. $D_{30\%}$ of the bladder and also the NTID was lesser for IMRT cases in all the selected phantoms. Additionally, 4F has shown lesser spillage with 6MV/15 MV photon beam energies in OC phantom. The 'total monitor units (TMU)' required for IMRT plans were significantly higher.

Conclusion: The contrast material under-estimates the planned dose yet has an insignificant influence on the dose calculation. Therefore, unnecessary exposure of dual scans should be avoided the use of 6MV and IMRT technique should be continued in the clinics.

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Introduction

Carcinoma cervix is one of the most common cancers worldwide. As per data of GLOBOCAN 2020, it was reported as head & neck (66.6%), cervix uteri (60.0%), breast (57.0%), and stomach (50.8%) cancers among the top of the list [1]. The occurrence of cervical malignancies is more in rural areas due to poor hygiene and less awareness about early symptoms. The chances of occurrence increases after post-pregnancy or post-menopausal age. As per available of data, 5% females are suffering from carcinoma cervix worldwide. Radiotherapy of such tumours is a set standard of treatment. The traditional approach for treating such cancers is either antero-posterior/ postero-anterior technique or the inclusion of lateral fields in addition to the above fields which is called as 'box-technique'. Considering the unwanted exposure to organs in the path of the beam, box-technique is known as the standard mode of treatment.

Advancement of technology has evolved the beam-fluence modulation as a newer technique which facilitates the planner to change the photon fluence of different beamlets as per desired outcome. This technique is called 'Intensity-modulated radiation therapy (IMRT)' [2]. IMRT can be delivered either by step-and-shoot method or dynamic method using different static fields. The motion of multi-leaf-

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collimator (MLC) differentiates between the above two methods. In the 'step-and-shoot' method, MLC stops at pre-defined position and irradiate the target while in 'dynamic' delivery; radiation never stops during movement of MLCs. Dedicated treatment planning systems are essential requirements to deliver intensity-modulated plans as these systems help to achieve 'optimum' deliverable outcomes and conformal dose distribution.

As per the definition of three-dimensional conformal radiation therapy, computed-tomography (CT) scans are necessary input on which the radiation oncologist draws the contours of tumour target and other critical structures [3]. It is routine practice to inject intravenous contrast for highlighting the anatomical and physiological landmarks. Contrast-enhanced CT scans used for treatment planning could adversely affect the dose distribution where heterogeneities are accounted, as the contrast media remain present in planning tomographic scans but elope after that from the patient body [4]. This scenario creates a discussion among radiation therapy practitioners in most of the debates and that's why few radiation centres avoid using contrast-enhanced CT for treatment planning.

The use of intravenous contrast definitely improves the recognition and delineation of tumours from CT images, it is necessarily required to conduct a study prevailing the effects of contrast the media on distribution of dose in radiotherapy planning [5]. Ramm et al. and Robar et al. published their research and found the variation of dose distribution with concentration of contrast media and energy of photon beams [6, 7].

When contrast media is introduced into the body prior the examination, the body tissues appear differently as compared to the 'no-contrast' situation. Contrast media helps to distinguish the selected area from the surrounding tissues. By improved visibility of specific organs, contrast media helps the radiation oncologist/ radiologist to diagnose the medical condition. There are three ways of administration of contrast medium: (i) swallow by mouth, (ii) enema by rectum, and (iii) injection into the vein/ artery. After the examination, the contrast media is either absorbed by the body tissues or is removed as urine or excreta.

There are mainly two types of contrast materials i.e. iodine-based contrast and barium-sulphate based contrast. Iodine is a naturally occurring element which can be injected into the vein or arteries. Similarly, barium-sulpahte is mostly used for oral and rectal administration.

It must be noted that intravascular concentration of the contrast media depends on the concentration of injected contrast, rate of blood flow, and rate of delivery of contrast media, but the concentration of injected contrast is not so high for clinical applications [8].

On the other hands, Holloway et al. and Choi et al. have found that the impact of iodinized contrast on dose distribution in radiotherapy planning of various anatomical cites was negligible where the concentration of contrast media was relatively low [9, 10]. Shi et al. highlighted that intravenous contrast cause changes in the calculated doses in carcinoma lung patients, yet the dose deviation between the plans in the presence and absence of contrast-enhanced images are small and clinically tolerable [11].

It is clear that contrast-enhanced CT is comparable with MR images for delineation of normal structures and recommended for staging esophagus cancers, to identify lung metastases and the region from the liver to rectum. Therefore, the impact of contrast media should be taken into account for radiation dose calculations [12]. Hence, it was required to find out the changes in the dose calculations due to the presence of non-ionic contrast media and the dose delivered to the patients in different treatment techniques like 3DCRT and IMRT.

The aim of the present study is to investigate the effect of intravenous contrast on dose calculation of three-dimensional conformal radiation therapy (3DCRT) and IMRT techniques and to examine the impact of photon beam energies in pelvic malignancies in presence of contrast media.

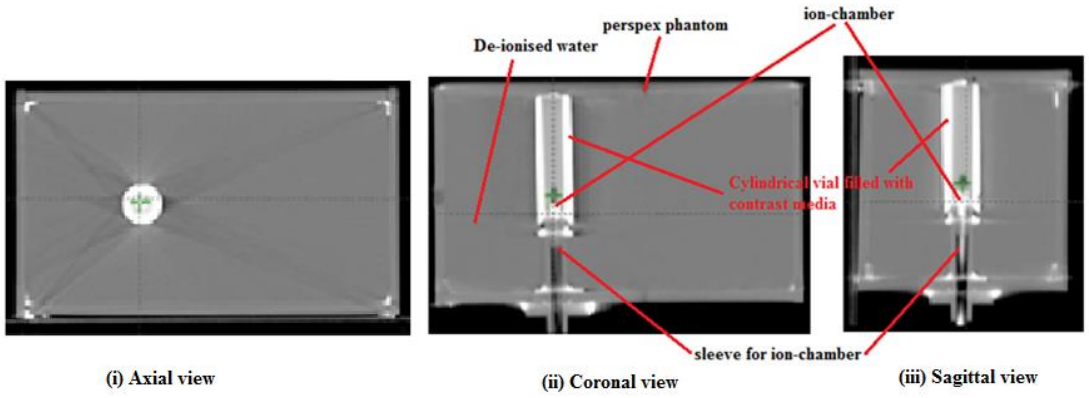
Materials and Methods

Phantom preparation and target delineation

An indigenously made phantom was used for the study with dimensions 15 cm x 15 cm x 30 cm. Phantom was made using Perspex sheets which is a tissue-equivalent material and water was filled inside to mimic the body tissues. Centre of fields was kept at the geometrical centre of the circular target with equivalent sphere diameter 5.4 cm drawn off-centre and other critical structures like bladder and rectum were imported from recommendations of reports of task group TG-119 of American Association of Physicist in Medicine (AAPM) which is available on web site www.aapm.org. A sleeve was given to place the ionization chamber at the isocentre of the planning target volume (PTV) and the sleeve was placed inside the cylindrical vial of iodinized contrast. This phantom was considered as the 'original contrast (OC)' phantom in the study, as shown in Figure 1(a). Iohexol (Omnipaque ™) non-ionic (aqueous, 350mg I/ml) contrast medium was used for the study. Iohexol is a non-ionic, monomeric, tri-iodinated and water-soluble x-ray contrast medium.

OC phantom was scanned using institutional computed-tomography (CT) unit (Siemens Somatom Sensation Open) with slice thickness 0.1 cm. The planning CT scan was transferred to the contouring station (SOMAVISION, Varian Medical Systems) in Dicom (digital imaging and communication in medicine) format where the critical structures were drawn/imported by a qualified radiation oncologist.

Similarly, a virtual phantom was created with the same dimensions as OC phantom, using the Eclipse software (Varian Medical Systems; version 11.0).



(a) Assigned Hounsfield Units (HU) to Virtual phantoms

Original-contrast (OC) Virtual-contrast (VC) Virtual-without-contrast (VWC)

Figure1. Preparation of Original-Contrast (OC) phantom and other virtual phantoms
Original contrast (OC) phantom

The Hounsfield Unit (HU) numbers were identified from the OC phantom and similar was assigned to Perspex wall, filled water, contrast ring, and chamber sleeve to maintain the authenticity of the data. This phantom was considered as a 'virtual contrast (VC)' phantom. Again, the assigned HU number of the contrast ring was changed to water HU to ignore the effect of contrast media. This phantom was considered as a 'virtual without contrast (VWC)' phantom, as shown in Figure 1(b).

Characteristics of contrast media

Contrast medium is a chemical substance of very high or very low atomic number or weight, therefore it increases or decreases the density of the organ under examination. The contrast media should have the following properties:

1. Easy to administer,
2. No toxicity,
3. Stable and will not dissociate into toxic ions,
4. Rapid elimination,
5. No carcinogenicity,
6. Appropriate viscosity,
7. Minimal distress to the patients, and
8. Cost-effective.

Validation of HU and Assessment of Isocentric dose

The ring of contrast was delineated and HU number was noted at different locations to validate the homogeneity of contrast medium throughout the structure. For assessment of isocentric dose, an anterior beam (Field size 10.0 cm x 10.0 cm) was placed at 'active volume', marked as structure 'IC', of the ionization chamber. 6MV photon beam was used initially to assess the isocentric dose and planned for 200 cGy. A similar experiment was followed with other selected photon energies in all the three phantoms, keeping monitor units i.e. 248 MU (as received with 6MV plan), same.

Treatment Planning

Plans were generated for TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, USA) using Eclipse (version 11.0) treatment planning system (TPS). TrueBeam linear accelerator (linac) is equipped with 03 flattened photon energies i.e. 6MV, 10MV, 15MV and 02 unflattened (flattening filter free i.e. FFF) photon energies i.e. 6FFF and 10FFF, available for patient treatment. Linac is also equipped with high-definition multileaf collimator (HDMLC) (characterized by a spatial resolution of 0.25 cm at isocentre for the central 32 leaves and 0.5 cm in the outer 28 leaves) which facilitates the planner to generate conformal treatment plans. The maximum dose rate available for a flattened beam is 600 MU per minute. But after removing the flattening filter, the available dose rate for 6FFF and 10FFF photon beam is 1400MU/min and 2400MU/min respectively.

30 isocentric plans were made using the 4-field 'box-technique' and IMRT technique. For 'box-

technique'; antero-posterior, postero-anterior, left-lateral and right-lateral fields were placed using gantry angle 0 degree, 180 degree, 90 degree and 270 degree respectively with collimator and couch angle 0 degree. Photon beam energy used for calculation was 6MV. The goal of the treatment plan was to cover at least 99% of prescription dose to 95% of target volume. The plans were re-calculated for rest of the available photon energies. The isocentre of each plan was kept at geometrical isocentre of PTV which is also the centre of active volume of ionization chamber.

IMRT plans were generated using the gantry angle 0 degree, 51 degree, 102 degree, 153 degree, 204 degree; 255 degree and 306 degree with collimator and couch angle 0 degree. Plans were optimized to achieve desired planning objectives and dose spillage was restricted using 'Normal-tissue-objective (NTO)'. Plans were recalculated on different available phantoms and photon energies. Inter-comparison analysis was performed to conclude the significance of data and results were tabulated for interpretation.

Evaluation parameters

Plan parameters evaluated were:

PTV: $D_{99\%}$, $D_{10\%}$, D_{mean};

Bladder: V_{30Gy}, V_{10Gy};

Rectum: V_{30Gy}, V_{10Gy}.

For measurement of quality of plan, conformity index (CI) and homogeneity index (HI) were evaluated using following formulae:

CI_{98} = Volume of 98% isodose coverage (in cm^3)/ Total volume of PTV (in cm^3) [13]

$HI_{98} = D_{2\%}/D_{98\%}$ [14]

For assessment of dose to nearby healthy tissues, a separate structure 'body-PTV' was created and normal tissue integral dose (NTID) was calculated using the following formula:

NTID $_{body\text{-}PTV}$ = Product of 'mean dose (in cGy) and 'volume (in cm^3)' of structure 'body- PTV'. [15]

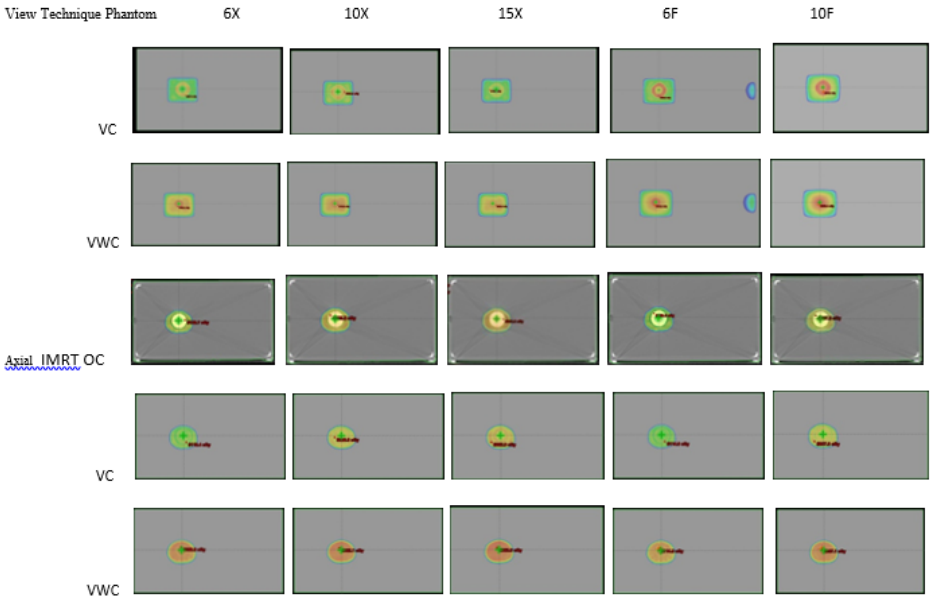
Results

Planning target volume (PTV)

$D_{99\%}$ of the PTV was reported and tabulated in Table 1 and Table 2, as 49.76 Gy and 49.62 Gy for 4F and IMRT techniques respectively in VWC phantom for 6 MV photon beam energy which was comparable (49.43 Gy and 49.14 Gy) for VC phantom but was decreased for OC phantom (46.86 Gy (4F, 6 MV); 46.45 Gy (IMRT, 10 MV); 46.02 Gy (4F, 15 MV); 46.80 Gy (4F, 6 FFF); 44.78 Gy (4F, 10 FFF)). Similarly, $D_{10\%}$ was reportedly higher as 54.03 Gy (4F, 6 MV), 54.71 Gy (4F, 15 MV), 55.78 Gy (4F, 6 FFF) and 57.64 Gy (4F, 10 FFF) for OC phantom. CI_{98} evaluated was significantly lower for the 4F technique in OC phantom but HI_{98} was comparable for all the energies among all the phantoms as tabulated in Table 3. Dose coverage of 95% of maximum prescribed dose was shown in Figure 2.

Bladder & rectum

$D_{30\%}$ of the bladder was reported lesser (26.99 Gy (VWC, 10 MV); 27.01 Gy (VWC, 6 FFF); 26.86 Gy (VWC, 10 FFF); 26.72 Gy (OC, 6 FFF); 27.03 Gy (OC, 10 FFF); 26.37 Gy (VC, 6 MV); 26.47 Gy (VC, 10 MV); 26.73 Gy (VC, 15 MV); 26.12 Gy (VC, 6 FFF) and 26.33 Gy (VC, 10 FFF) with IMRT technique. However, $D_{10\%}$ was lesser with 4F technique in OC phantom except 10 MV photon beams which was comparable with other results. The results for the structure 'rectum' were comparable with all the photon beam energies but $D_{30\%}$ was reported lesser with 4F technique in OC phantom, except for 10 MV photon energy, as shown in Table 1.



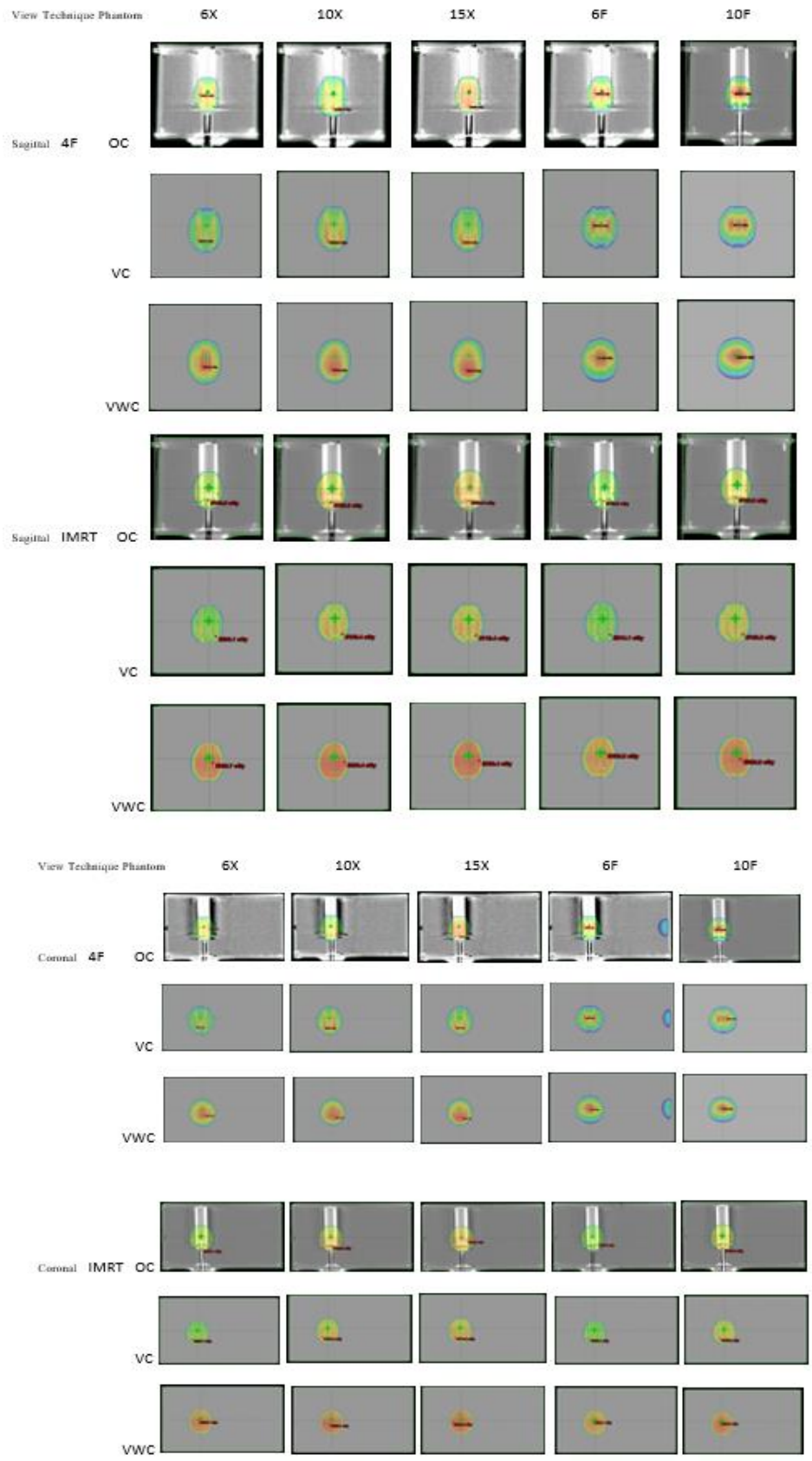


Figure 2. Dose coverage of 95% of maximum prescribed dose

Table 1. Parameters evaluated for flattened photon beam energies in different contrast phantoms

Structure	Phantom	Virtual without contrast (VWC)						Original Contrast (OC)						Virtual Contrast (VC)					
	Energy	6 MV		10 MV		15 MV		6 MV		10 MV		15 MV		6 MV		10 MV		15 MV	
	Parameter	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT
PTV	D99% (Gy)	49.76	49.62	49.19	49.47	49.02	49.41	46.86	49.46	49.33	46.45	46.02	49.49	49.43	49.14	49.84	49.17	49.34	49.14
	D10% (Gy)	51.43	50.78	51.08	50.78	51.19	50.76	54.03	51.02	51.11	50.88	54.71	50.81	52.06	50.94	51.68	50.87	51.23	50.84
	Dmean (Gy)	51.98	50.58	50.63	50.57	50.65	50.56	55.09	50.65	50.52	51.38	52.97	53.00	50.55	50.53	51.03	50.54	50.56	50.56
	CI98	1.75	1.26	1.28	1.22	1.25	1.41	0.64	1.22	1.31	1.22	0.52	1.23	1.88	1.18	1.46	1.38	1.43	1.39
	HI98	1.04	1.02	1.04	1.02	1.04	1.02	1.12	1.03	1.04	1.03	1.14	1.02	1.05	1.03	1.04	1.03	1.04	1.03
Bladder	D30% (Gy)	28.61	27.10	28.51	26.99	28.44	27.22	27.84	27.17	28.57	27.22	27.67	27.47	28.51	26.37	28.58	26.47	28.33	26.73
	D10% (Gy)	47.19	41.62	46.04	41.66	45.61	41.88	31.12	41.86	46.53	42.06	32.49	42.21	47.03	40.79	46.30	41.04	45.55	41.25
Rectum	D30% (Gy)	49.81	49.39	48.81	49.24	48.72	49.24	38.47	48.95	48.89	49.03	39.81	49.09	49.67	49.05	49.18	49.08	48.58	49.18
	D10% (Gy)	50.89	50.62	50.31	50.63	50.29	50.62	51.56	50.66	50.19	50.59	51.57	50.59	50.66	50.61	50.61	50.62	50.08	50.62
NTID (Gy*cm3) *103		54.17	45.43	50.51	43.35	49.76	42.69	36.72	44.67	48.93	42.91	34.47	42.42	53.75	44.61	50.76	42.69	49.51	42.19
TMU		303	482	259	450	243	436	326	529	259	453	269	439	305	531	263	464	244	449

Table 2. Parameters evaluated for un-flattened photon beam energies in different contrast phantoms

Structure	Phantom	Virtual without contrast (VWC)				Original Contrast (OC)				Virtual Contrast (VC)			
	Energy	6 FFF		10 FFF		6 FFF		10 FFF		6 FFF		10 FFF	
	Parameter	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT	4F	IMRT
PTV	D99% (Gy)	48.99	49.61	47.67	49.54	46.80	49.37	44.78	49.53	48.75	49.11	48.44	49.21
	D10% (Gy)	53.41	50.76	55.44	50.72	55.78	50.97	57.64	50.88	53.26	50.92	56.06	50.87
	Dmean (Gy)	54.43	50.54	53.32	50.55	53.51	50.53	54.43	50.58	54.08	50.50	53.69	51.58
	CI98	1.22	1.44	0.32	1.23	0.31	1.16	0.17	1.22	0.84	1.32	0.36	1.18
	HI98	1.09	1.02	1.16	1.02	1.16	1.03	1.23	1.02	1.09	1.03	1.15	1.03
Bladder	D30% (Gy)	29.61	27.01	30.62	26.86	28.34	26.72	28.25	27.03	28.74	26.12	30.58	26.33
	D10% (Gy)	48.59	41.57	49.17	41.64	31.97	41.07	34.33	41.91	47.45	40.18	49.21	40.92
Rectum	D30% (Gy)	50.78	49.29	51.05	49.19	40.56	48.46	44.19	49.03	50.03	48.62	51.34	49.07
	D10% (Gy)	52.39	50.59	53.51	50.58	52.93	50.52	53.74	50.59	51.41	50.54	53.72	50.57
NTID (Gy*cm3) *103		56.08	46.02	53.42	43.11	38.48	44.59	37.12	42.66	54.67	44.68	53.42	42.52
TMU		339	518	299	454	360	560	316	460	335	566	303	470

Table 3. Inter-comparison of plan evaluation parameters

Structure	Phantom	VWC										OC										VC									
	Energy	6 MV		10 MV		15 MV		6 FFF		10 FFF		6 MV		10 MV		15 MV		6 FFF		10 FFF		6 MV		10 MV		15 MV		6 FFF		10 FFF	
	Parameter	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM	4F	IM
PTV	D99%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	0.9	0.9	1.0	0.9	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	D10%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.1	1.0	1.0	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0
	CI98	1.0	0.7	0.7	0.7	0.7	0.8	0.7	0.8	0.2	0.7	0.4	0.7	0.8	0.7	0.3	0.7	0.2	0.7	0.1	0.7	1.1	0.7	0.8	0.8	0.8	0.8	0.5	0.8	0.2	0.7
	HI98	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.0	1.1	1.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.1	1.0
Bladder	D30%	1.0	1.0	1.0	0.9	1.0	1.0	1.0	0.9	1.1	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.1	0.9
	D10%	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	0.7	0.9	1.0	0.9	0.7	0.9	0.7	0.9	0.7	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9
Rectum	D30%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	0.8	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	D10%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0
Skin-box	Mean dose	1.0	0.8	0.9	0.8	0.9	0.8	1.0	0.9	1.0	0.8	0.7	0.9	0.9	0.8	0.7	0.8	0.7	0.9	0.7	0.8	1.0	0.8	0.9	0.8	0.9	0.8	1.0	0.8	1.0	0.8
NTID		1.0	0.8	0.9	0.8	0.9	0.8	1.0	0.9	1.0	0.8	0.7	0.9	0.9	0.8	0.7	0.8	0.7	0.8	0.7	0.8	1.0	0.8	0.9	0.8	0.9	0.8	1.0	0.8	1.0	0.8
TMU		1.0	1.6	0.9	1.5	0.8	1.4	1.1	1.7	1.0	1.5	1.1	1.8	0.9	1.5	0.9	1.5	1.2	1.9	1.0	1.5	1.0	1.8	0.9	1.5	0.8	1.5	1.1	1.9	1.0	1.6

NTID and TMU

Dose to normal healthy tissues, other than tumour target, was evaluated and noted by assessing the mean dose to structure 'Skin-PTV'. It was reported lesser for IMRT cases in all the selected phantoms. Spillage of 50% of prescription dose in different treatment techniques is shown in Figure 3. Additionally, 4F has shown lesser spillage with 6 MV and 15 MV photon beam energies in OC phantom. The 'total monitor units (TMU)' required for IMRT plans were significantly higher. A comparative analysis of above mentioned parameters related to PTV and OARs were detailed in Table 3.

Validation of HU and Assessment of Isocentric dose

The values of HU number at predefined locations and isocentric dose for fixed MUs were noted and tabulated in Table 4 and Table 5 respectively. It was shown that the minimum percentage variation of dose for 6MV photon beam, keeping 'water' as reference (in VWC phantom). Other chosen energies have deviated approximately 3.0% in isocentric dose and under-estimated the same due to the effect of contrast media as shown in Figure 4.

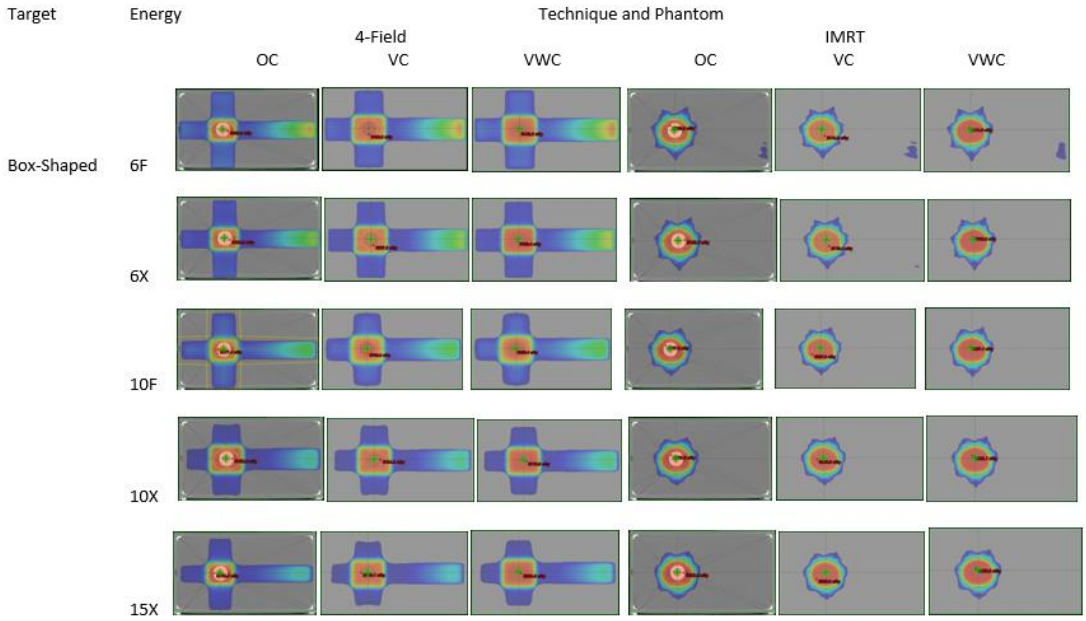


Figure 3. Spillage of 50% of prescription dose in different treatment techniques (Axial view)

Table 4. Validation of HU at different locations of contrast vial

Location	Phantom	Positions			
		Anterior (A)	Posterior (P)	Left (L)	Right (R)
-4.0 cm	OC	3068 HU	3069 HU	3071 HU	3069 HU
	VC	2800 HU	2800 HU	2800 HU	2800 HU
	VWC	0 HU	0 HU	0 HU	0 HU
-2.0 cm	OC	3067 HU	3069 HU	3071 HU	3070 HU
	VC	2800 HU	2800 HU	2800 HU	2800 HU
	VWC	0 HU	0 HU	0 HU	0 HU
+0.0 cm	OC	3065 HU	3069 HU	3071 HU	3070 HU
	VC	2800 HU	2800 HU	2800 HU	2800 HU
	VWC	0 HU	0 HU	0 HU	0 HU
+2.0 cm	OC	3065 HU	3069 HU	3071 HU	3069 HU
	VC	2800 HU	2800 HU	2800 HU	2800 HU
	VWC	0 HU	0 HU	0 HU	0 HU
+4.0 cm	OC	3067 HU	3069 HU	3071 HU	3070 HU
	VC	2800 HU	2800 HU	2800 HU	2800 HU
	VWC	0 HU	0 HU	0 HU	0 HU
+5.0 cm	OC	3071 HU	3071 HU	3071 HU	3070 HU
	VC	2800 HU	2800 HU	2800 HU	2800 HU
	VWC	0 HU	0 HU	0 HU	0 HU

Table 5. Assessment of isocentric dose

Photon Beam Energy	Dose at chamber isocentre (in cGy)			Percentage dose deviation	
	OC Phantom	VC Phantom	VWC Phantom	OC versus VWC	VC versus VWC
6 MV	200.9	200.0	200.0	0.45	0.00
10 MV	223.1	223.6	229.5	-2.79	-2.57
15 MV	233.0	233.7	239.6	-2.75	-2.46
6 FFF	192.9	191.2	196.8	-1.98	-2.85
10 FFF	214.3	214.3	219.5	-2.37	-2.37

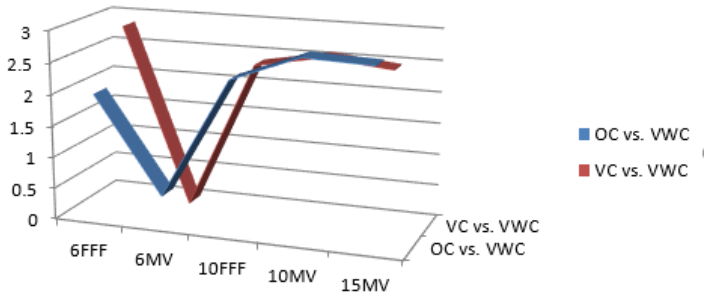


Figure 4. Ribbon plot showing percentage dose variation in OC & VC phantoms

Discussion

Radiotherapy is the standard care of practice for the treatment of carcinoma cervix. Delivering the dose to a patient with accuracy is a challenge with planners. Planning the treatment on contrast-enhanced tomographic images and delivering the same treatment in the absence of intravenous contrast media remain a matter of discussion on many forums. Also, the choice of treatment technique from conformal 4-field to advanced IMRT, and selection of appropriate photon beam energy is an added responsibility of treatment planner.

The dose delivered to the patient in radiotherapy can be accurately assessed by using computed tomographic (CT) images and treatment planning systems (TPS).The use of intravenous contrast seems beneficial for localization and delineation of tumour and critical structures. But it is believed that the contrast agent raises the Hounsfield Unit (HU) number in the CT images.

The present study investigated the above facts and tabulated the results. Target coverage was found comparable in all the phantoms but a little deviation was seen in 4-field (6MV, 15MV, 6FFF, 10FFF) and IMRT (10MV) with original-contrast phantom. The increased HU values of contrast under-estimate the prescribed dose in the case of 4-field technique. Deviation of dose with 10MV photons with IMRT technique may caused by the effect of optimizer. It must be noted here that heterogeneity corrections were also applied during the calculations of treatment plans. In a similar experiment, Ramm et al. irradiated the barium sulphate cylinder (3.0 cm diameter) in the water phantom for evaluating the effect of contrast on tomographic images and found that the effect of contrast by using either 6MV or 25MV was relatively small when the number of beams was increased.

Lees et al. have suggested a corrective approach that implicated alteration in the CT to density table to eliminate the effect of contrast agent on the dose calculation [16]. However, the contrast-enhanced simulated images and planning scans were not consistent in their report. Shibamoto et al. found that contrast media did have an influence on upper-abdominal radiation treatment planning [17]. Additionally, Liu et al. denied the idea of using pre- and post- contrast CT during simulation and showed that treatment planning had an insignificant effect and less than 2.0% difference of dose in head and neck cases [18]. However, slight under-estimation of dose was report contrast-enhanced images. The initial assessment data of isocentric dose of the present study is in agreement with published data. It has also highlighted that changes with 6MV photon beam energy remain insignificant in the vicinity of contrast media, as shown by Haghparast et al. [19].

An increase in $D_{10\%}$ was found with 4F plans in OC phantom with 6MV, 15MV, 6FFF and 10FFF. HUs of intravenous contrast were found approximately 3000 HU in the present study, were nearer to HU of bony structures. The attenuation caused by bone-like structure may alter the dose-volume-histogram (DVH) and increase the dose-tail. Kim et al. have also mentioned that the HU and beam attenuation coefficients have linear relation in the CT data which changes with the electron densities of the materials introduced in the beam path [20]. The relative electron densities identify the heterogeneities in the beam path.

The study revealed higher HUs were required in presence of contrast medium as it constitutes with high-Z material. Ramm et al. also found an average dose difference of approximately 3.0% and a maximum of 10.3% in their phantom study. Rankine et al. also showed the dose difference of approximately 7.0% in another phantom study [21].

Data suggested that conformity index CI_{98} decreases with 4-field technique in most of the selected cases. The increase in the number of beams increased the degree of freedom in IMRT cases and covered the target with a better conformal dose. However, the homogeneity increases significantly with 6FFF photon beam in all the phantoms selected with 4F plans. The mean energy of 6FFF photons is equivalent to 4MV beam and hence the target attains more homogeneous dose with lower photon energy components. Four-field plans further reduced the dose spillage by focused beam portals. As per study by Robar et al., investigations carried out on the phantoms showed that the dose deviated approximately 5.0% and changes the dose calculations when the concentration of contrast medium was relatively high but was actually contradicted with routine clinical applications where the concentration remains low. Jabbari et al. also evaluated the effect of intravenous contrast on dose calculation and found that the influence of contrast on dose calculation decreased with an increase of beams and photon energies [22].

It was noted in the present study that the dose to normal tissues i.e. normal-tissue-integral-dose (NTID) was significantly lower for IMRT cases and was further reduced for original-contrast phantom. The use of multiple beams in IMRT and inversely planned optimized output reduced the dose to normal tissues with the help of normal-tissue-objective (NTO) settings and dose fall-off. Further reduction of dose spillage with OC phantom may cause by higher HU values of those voxels. The variation of the electron densities depends on the degree of absorption of contrast media in the beam path which alters the dose computation. With the contrast, the effective depth increased, resulting in decreased doses. The study by Kim et al. found the maximum variation of 20.3% for the dose to the target and 13.3% for the critical structures in the treatment of carcinoma lung patients when maximum numbers of beams were passing through the lung [20].

The present study also highlighted that total MUs required to deliver the appropriate dose to target were sufficiently higher for IMRT plans and were approximately 1.5-2.0 times higher than four-field plans. As the number of beams increased, their increased path length raised MUs to cover the target with optimum dose prescription. Burridge et al. also demonstrated that a mean increase of the overall MUs occurred approximately 3.3% when the contrast media was used during dose calculation [23]. Chu et al. has also reported that the changes in MU occurred less than 1% for lung cases and approximately 2% for pelvis cases when there were changes of 20 HU for soft tissue and 250 HU for bone, respectively [24].

It was further noted that 10MV photon beam energy remains relatively unchanged with contrast media in both the treatment modalities in terms of target coverage and other parameters. Hence the use of 10MV photon beam energy for the treatment of pelvic malignancies needs to be further investigated, as published by Kumar et al. [25].

Conclusion

The use of contrast-enhanced CT is useful for better delineation of tumour targets and other critical structures. It is evident from the study that although the contrast material underestimates the planned dose yet has insignificant influence on the dose calculation, therefore unnecessary exposure of dual scans should be avoided. IMRT has an edge over conventional techniques for all photon energies, in absence and presence of contrast media, used in clinics.

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