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Advantages of 3D-CT Based Conformal Radiotherapy Treatment Planning Over 2D Conventional Tera Six Planning for Cervical Cancer Treatment at Ocean Road Cancer Institute

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Abstract

Although External Beam Radiation Therapy (EBRT) is essential tool for the radiation therapy of cervical cancer; only one cancer institute in Tanzania performs 3-Dimensional Conformal Radiation Therapy (3DCRT) Computed Tomography (CT)-based planning. To identify benefits and advantages of 3D-CRT over 2D- conventional radiation therapy (2D-CRT), dosimetric parameters for tumor targets and organs at risk (OARs) were compared between these modalities for 23 cervical cancer patients. 11 cervical cancer patients were CT scanned after proper positioning and immobilization and transferred to Eclipse Treatment Planning System (TPS) for dose planning. The remaining 12 curative intent patients were planned using 2D-CRT system and treatment times were calculated for each patient. From the CT based planning, the minimum dose (D min), maximum dose (D max) and mean dose (D mean) to Planning Target Volume (PTV) and organs at risk (OAR), were compared for each plan. On average, the optimized maximum doses for bladder, rectum, femoral heads, PTV and Gross Tumor Volume (GTV) were 46.56 Gy, 42.65 Gy, 28.76 Gy, 48.56 Gy and 48.53 Gy. For 2D-concentional planning, the dose rate was 75.75 cGy/min and the average treatment time was 1.6075 minutes. This study confirms that 3D CT-based planning is a good choice in the treatment protocol for carcinoma cervix as it delivered a highly homogeneous and conformal plan with superior dose coverage to PTV and better OARs sparing.

Keyword: 3D-Conformal radiation planning, cervical cancer, organ at risk, conventional simulator, planned target

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ABSTRACT

Although External Beam Radiation Therapy (EBRT) is essential tool for the radiation therapy of cervical cancer; only one cancer institute in Tanzania performs 3-Dimensional Conformal Radiation Therapy (3DCRT) Computed Tomography (CT)-based planning. To identify benefits and advantages of 3D-CRT over 2D- conventional radiation therapy (2D-CRT), dosimetric parameters for tumor targets and organs at risk (OARs) were compared between these modalities for 23 cervical cancer patients. 11 cervical cancer patients were CT scanned after proper positioning and immobilization and transferred to Eclipse Treatment Planning System (TPS) for dose planning. The remaining 12 curative intent patients were planned using 2D-CRT system and treatment times were calculated for each patient. From the CT based planning, the minimum dose (D_{min}), maximum dose (D_{max}) and mean dose (D_{mean}) to Planning Target Volume (PTV) and organs at risk (OAR), were compared for each plan. On average, the optimized maximum doses for bladder, rectum, femoral heads, PTV and Gross Tumor Volume (GTV) were 46.56 Gy, 42.65 Gy, 28.76 Gy, 48.56 Gy and 48.53 Gy. For 2D-concentional planning, the dose rate was 75.75 *cGy/min and the average treatment time was 1.6075 minutes. This study confirms that 3D CT-based planning is a good choice in the treatment protocol for carcinoma cervix as it delivered a highly homogeneous and conformal plan with superior dose coverage to PTV and better OARs sparing.*

Keywords: 3D-Conformal radiation planning, cervical cancer, organ at risk, conventional simulator, planned target volume, ocean road

1. Introduction

The aim of radiotherapy is to eradicate cancerous cells while sparing normal tissues using ionizing radiation to a dose that is likely to cause complete destruction of the tumor. Eradication of tumour volume requires errors in the treatment protocol ranging from dose planning to dose delivery to be minimized[1] . This requirement is important because these errors lowers accuracy of the dose delivered to the tumour volume, which is intimately related to eradicate of tumour cells. They also undermine the ability of the treatment protocol to offer the desired protect of organ at risk (OARs) [2,3] . ICRU [4] Reports No. 50 and 62 define and describe procedures that can be used in dose planning to minimize errors in dose delivery to achieve the recommended limits of dose uniformity of +7% and –5%.

Minimization of these errors as described above is particularly important for treatment of cancer types with high curability (like cervical cancer) when detected and treated early[5]. Dose planning for this cancer type must therefore be optimized to deliverer accurate dose to the cervix while minimizing dose delivered to bladder and rectum which are sensitive organ in dose proximity to the tumour volume [6]. The ability to implement the ICRU procedures to achieve the recommended dose uniformity is dependent on irradiation modality. In particular, modern systems based on 3D-conformal planning and delivery are able to reduce the irradiated volume of normal tissue, and, therefore, offer the opportunity to deliver higher tumor doses with acceptable complication rates compared with conventional RT[7]. The aim of this work therefore is to use this uniformity index to assess the advantages of 3D-CT based conformal radiotherapy over 2D conventional radiotherapy planning at Ocean Road Cancer Institute (ORCI).

2. Materials and Methods

2.1 Patient selection

A cohort of 23 patients, diagnosed with carcinoma cervix was enrolled in this prospective observational study. Eleven patients were included in 3D CT-based plans with 15 MV, and 12 patients were included in 2D conventional plans using Tera six simulator.

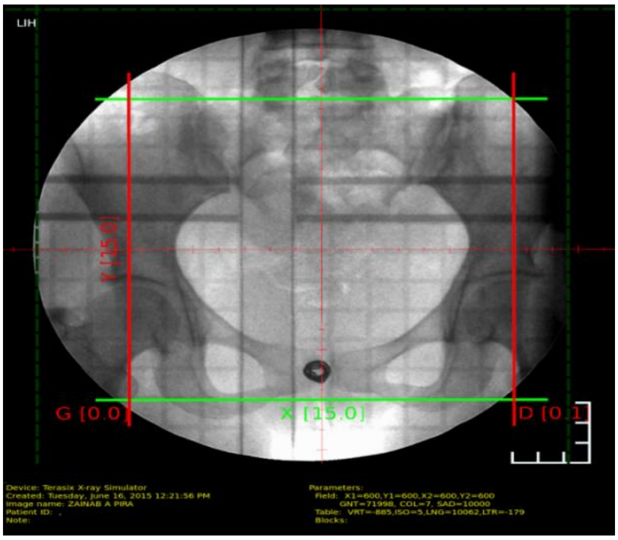
2.2 Radiotherapy Techniques for Treatment Planning

Before treatment planning, a physical examination and medical history reviews were conducted for all patients included in this study. There were two simulators used for acquiring images used in treatment planning systems. These include 2D simulation by Tera six simulator and 3D-CRT simulation using 3D-CT based simulator.

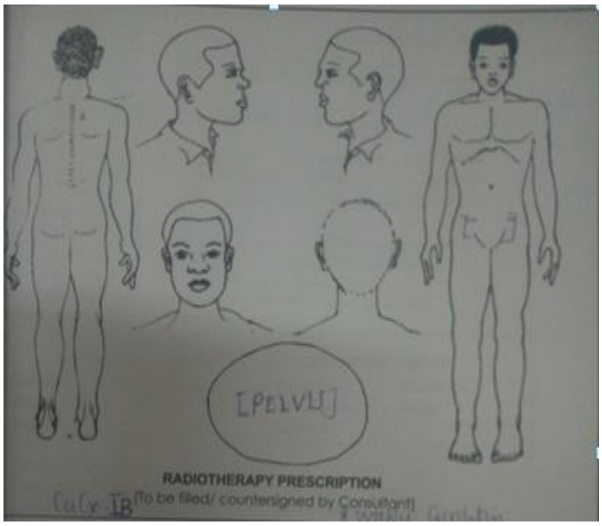
2.3 2D Conventional Treatment Simulation

2.3.1 Acquisition of patient data in 2D Conventional planning

Each cervical cancer patient of the 12 was placed on the treatment couch of Tera six simulator in supine position to determine patient dimensions for dose calculation. The image obtained from this simulator was used to determine the location of the isocenter and reference point. The source to axis distance (SAD) as well as depths of interest was also obtained during this process. The identifiable reference points were then used to determine patient's treatment position and to identify the target volumes and OARs. A landmark using bony markers was used to match positions in the treatment plan with positions on the patient (Figure 1b). After proper determination of the beam geometry, patient contours were taken at a plane of interest to be used for treatment planning. In order to relate the position of the beam geometry to the patient, the wire was placed on the patient cervix on a transverse plane parallel to the isocentre plane (Fig.1a).



1 (a)



1 (b)

Fig 1(a): Typical simulator radiograph of cervical cancer patient obtained from 2D conventional Tera six simulator with field size 15 cm by 15 cm. **Fig 1 (b):** Radiotherapy prescription paper used in in 2D conventional dose planning for tumour allocation.

2.3.2 Treatment Time Calculation for Conventional Cobalt-60 Units

Treatment time calculations for this unit were carried out with the machine output (dose rate) of 75.59 cGy min^{-1} and the treatment timer setting in minutes replaced the monitor setting in MUs as used in 3DCRT planning. The irradiation time (T) to deliver prescribed dose for each patient was calculated using equation:

$$T = \frac{D_p}{Dr \times S_f \times pdd} \qquad (1)$$

where D_p and D_r represent prescribed dose and dose rate respectively, while S_f is total scatter factor and *pdd* is the percentage depth dose obtained from BJR supplement 25.The depth of a patient which is used to obtain *pdd* were calculated by taking patients' separation (*d*) divided by two, i.e. $d = \frac{s}{2}$. (2)

2.3.3 3D Conformal Treatment Simulation

In this treatment planning, 11 cervical cancer patients underwent a computed tomography (CT) simulation on a (SIEMENS, Healthineer SOMATOME, USA) in a supine position with arms on the chest, using a 5 mm slice thickness. Prior to being scanned, the patients were marked with a reference isocentre, typically, a position near the centre of the proposed scan volume was then chosen. Markers were placed on the anterior and lateral aspects of the patient with the help of the room lasers to ensure proper alignment and the patient was tattooed to record the position of the markers to help with the subsequent patient set-up on the treatment machine. This reference isocentre position will be used as the origin for a reference coordinate system from which the actual treatment isocentre position can be determined through translational motions of the table. The treatment isocentre was identified on the patient through table motions and the use of a movable sagittal laser. Once the relevant treatment parameters have been obtained, the treatment beam geometry, the CT data including contours and the electron density information were transferred to the TPS for the calculation of the dose distribution. The images were sent to a Treatment Planning System (TPS) (Eclipse treatment planning system, Varian, Palo Alto CA, USA). All necessary beam data were entered into the Eclipse system, and medical physicists used this information to design the 3D-CRT beams used for treatment under specification from the radiation oncologist. The beam angles used were as follows: counterclockwise from 0° to 90°, 90° to 180° , 180° to 270° and from 270° to 360° with a collimator angle of 0° and a couch angle of 0°**.** The accelerator used for the cone-based Linac was 15- MV Varian Vital Beam photons. Fig. 2 show a CT imported image for treatment planning in Eclipse system.

Figure 2: An axial slice from planning CT of pelvis imported from Siemens CT simulator to Eclipse TPS

2.3.4 Target volume and organs at risk definition

Target volume (TV) and OAR's were delineated in axial CT slices by radiation oncologists as per the recommendations of International Commission on Radiation Units and Measurements Reports (ICRU) 50 and 62. The gross tumor volume (GTV) includes the cervix with visible tumor extension and the corpus uteri. Clinical target volume (CTV) was created by adding 5 mm margin to the GTV, and, included the external, internal and lymph nodes. The CTV was expanded uniformly with a safe margin of 5mm in all directions to produce a planning target volume (PTV).

2.3.5 Planning Objective and Target Volume in 3DCRT

Prescribed dose to PTV was 50 Gy in 25 fractions at 2 Gy per fraction. It was stipulated that not less than 95% volume of PTV should receive a dose less than the prescribed dose and that not exceeding 105% to minimize the doses incident on the cervix. In order to ensure that the prescribed dose is actually absorbed in the CTV, the PTV was designed to select appropriate beam arrangements, taking into consideration the net effect of all possible geometrical variations. The PTVs were linked to the reference frame of the treatment machine and often described as the CTV plus a fixed or variable margin. Figure 3 shows the four-field treatment plan beams for a cervical cancer tumor as planed in Eclipse TPS at ORCI.

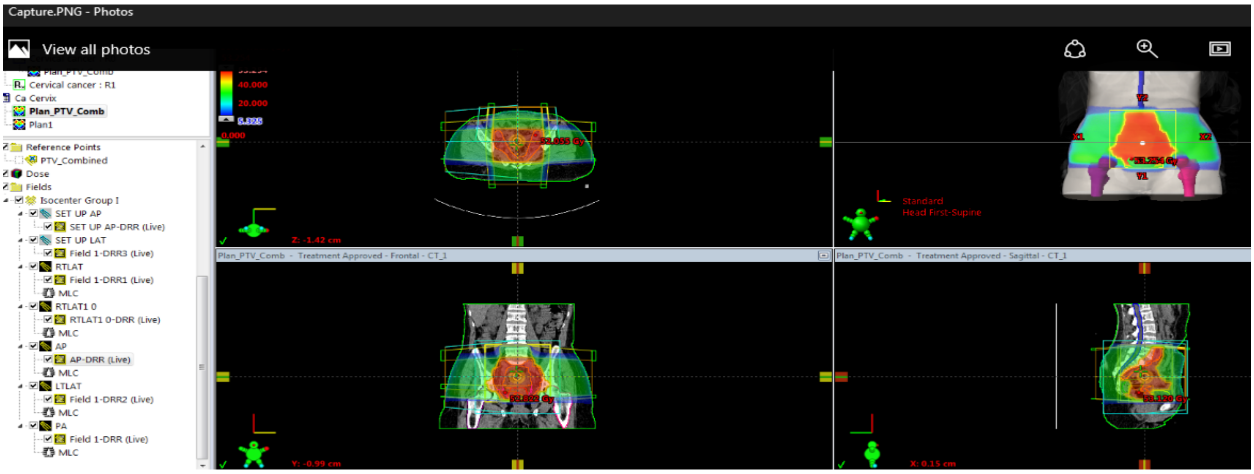


Figure 3: A combination of anterior-posterior and tangential fields using four-field box technique produce isodose lines for isocenter selection of a cervical cancer allows beams from any gantry angle to be centered on the tumor.

3. Results

3.1 Treatment Time in 2D Conventional Planning

The treatment times obtained after calculation using equation (1) are presented in table 1.The patient with greater depth (12 cm) had a relatively higher treatment time while that of smaller depth (7 cm) had a lower treatment time among all patients.

Table 1: Treatment time for cervical cancer patient underwent 2D conventional planning

Field size (cm^2)	Patient depth (cm)	Scatter factor (S_f)	Dose rate (cGy/min)	Tissue air ratio (TAR)	Treatment time (min)
15×18	7	1.033	75.95	0.892	1.43
15×15	7.5	1.028	75.95	0.86	1.48
15×17	8.5	1.031	75.95	0.836	1.53
15×18	9	1.033	75.95	0.821	1.55
15×15	9	1.028	75.95	0.813	1.58
15×17	9	1.031	75.95	0.818	1.56
15×16	9.5	1.03	75.95	0.799	1.60
15×16	9.5	1.03	75.95	0.782	1.63
15×17	10	1.031	75.95	0.785	1.63
15×16	10.5	1.03	75.95	0.763	1.68
15×18	11.5	1.031	75.95	0.735	1.73
15×18	12	1.033	75.95	0.675	1.89

3.2 Dose statistics in 3D-CRT planning

In contrast to the other tools, the plan evaluation tool described here do not show the spatial distribution of dose superimposed on CT slices or on anatomy that has been outlined based on CT slices, instead, they provide quantitative information on the volume of the target or critical structure and on the dose received by that volume. From the matrix of doses to each volume element within an organ, key statistics were obtained included mean volume, minimum dose to the volume, maximum dose, and mean dose (Table 2).

Table 2: Dose-volume Statistics for 3DCRT (4-field) treatment technique

Structure	Volume (cc)	Min Dose (cGy)	Max Dose (cGy)	Mean dose (cGy)
PTV	494.5	20.949	48.586	45
CTV	365	33.702	48.529	45.5
Rectum	61.7	9.412	46.65	34.36
Bladder	205.8	25.988	46.65	34.37
L. femoral head	172.3	0.378	28.763	5.44
R. femoral head	183.5	0.384	31.03	4.578

3.3 Dose Volume Histogram in 3DCRT planning

To create a direct DVH, the computer sums the number of voxels with an average dose within a given range and plots the resulting volume as a function of dose. An example of a direct DVH for a target obtained in this study is shown in Figure 4. The ideal DVH for a target volume would be a single volume indicating that 100% of the volume receives the prescribed dose. For a critical structure, the DVH may contain several peaks, indicating that different parts of the organ receive different doses. In Fig. 4, a typical DVH for a PTV, CTV, bladder, rectum, left and right femoral heads and spinal cord are well displayed.

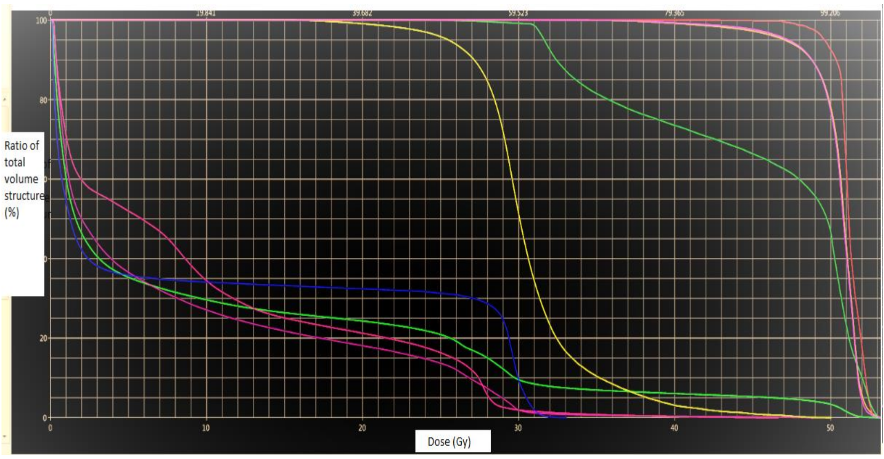


Figure 4: A dose-volume histogram expressed in terms of percentage of the structure volume of PTV, GTV and OARS for 15 MV 3D CT-based planning

3.4 Optimization of the Dose Distribution in 3DCRT plans

The 3DCRT plan creates beams in the Eclipse TPS using the automatically defined beam apertures set at the automatically located isocentre. The system then automatically calculates the dose delivered by each beam using 15 MV photons. (i.e. each beam contributed the same dose to the calculation point). The maximum dose, defined by the hottest points of tissue, was evaluated and the dosimetric metrics used for evaluating target coverage and OARs dose were extracted from the dose-volume histograms (figure 4). In this optimization, bladder, rectum, femoral heads, PTV and GTV received maximum doses of 46.56 Gy, 42.65 Gy, 28.76 Gy, 48.56 Gy and 48.53 Gy.

3.5 Healthy Tissues Sparing and OARs in Eclipse TPS

Conformal radiotherapy is now accepted as best practice for treatment of various cancer types, having the advantages of sparing normal tissue and providing the opportunity for dose escalation. Figure 5 shows head first-supine of cervical cancer patient planning with some of the MLCs closed to block unnecessary doses to OARs.

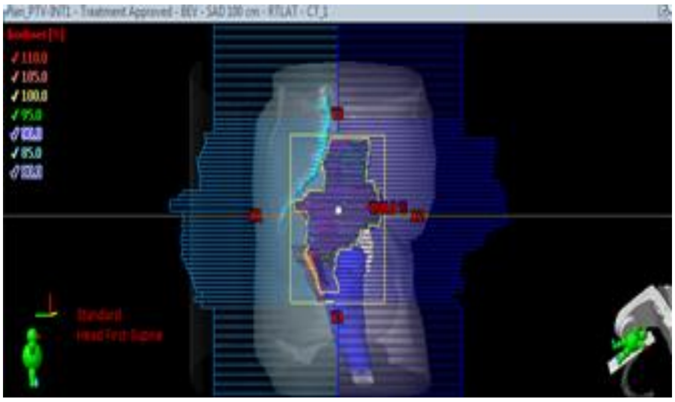


Figure 5: CT scan images showing radiotherapy planning showing MCL closing for sparing OARs and healthy tissues.

This TPS allows to fine tune treatment plans and can explore the possibilities between optimal organs at risk sparing and target coverage easily and efficiently without having to change current process. This 3DCRT planning is essential to visualize the coverage of the target volume and the avoidance of OARs in the highly complex treatment plans.

4 Discussions

Treatment field of whole pelvis for cervical cancer has long been defined by bony pelvic structure in the treatment of cervical cancer. For decades, patients with this cancer type had traditional radiography based treatment plans where a fluoroscopic imaging system may also be included and would be used from a remote console to view the patient's anatomy and to modify beam placement. However, this technique didn't allow the radiation oncologist and medical physicists to know exact dose to OARs or to the PTVs above and below the tolerance. Without using individual patient's CTV, this technique does not provide a customized treatment planning for each patient and may result in nodal-CTV coverage. Several results have been reported by other investigators supporting the used of image guided and 3D treatment planning algorithm for external beam radiation therapy of cervical cancer[8,9] . Pendlebury *et.al.* [10] and Bonin et *al*. [11] respectively, reported inadequate coverage of the external iliac lymph nodes using standard irradiation fields in 45% and 62% of patients. Finlay [12] showed that 34 patients (79.1%) had inadequate coverage and inadequate margin when bony landmarks were used to set the field boundaries. Most of the previous studies have indicated that, for complex target volumes in cervical cancer, 2D conventional planning may be less favorable dosimetrically than a 3DCRT[13]. The proposed beam configurations and split-field technique for treating cervical cancer with 3D-CRT is robust against simulated setup using conventional simulation because significant dosimetric gain was observed, whereby a reduction of dose in the low to intermediate dose region was achieved for the bladder, rectum and femoral heads. This study clearly demonstrated that satisfactory dose distribution in PTVs and OARs is achieved using 3D-CRT technique, and hence, the risk of destruction to healthy tissues is decreased. Review of several papers also suggested that no secondary cancer is developed in patients treated with 15 MV 3D-CRT as a result of treatment with radiation therapy while in 2D conventional technique there is high probability of recurrence of cancer [12-15].

4.1 3D CT- based versus 2D Conventional Simulations

In comparing the two methods of simulation, studies have shown that the target volumes and field sizes are smaller for CT-based than conventional simulation in cervical cancer with the associated reduction in irradiation of normal tissue [16]. One of the perceived advantages of CT-based simulation is the improved coverage of the GTV and the avoidance of OARs as a result of better visualization of soft tissue structures on a CT scan compared with a simulator image, particularly if shielded by bone. The increased soft tissue contrast in combination with the axial anatomical information available from CT scans provides the ability to localize very precisely the target volumes and OARs. The CT simulation segment allows for accurate identification and delineation of these structures directly on to the CT data set. This planning system, allows the user to define treatment fields with respect to the target volume and critical structure location easily. In contrast, 2D conventional simulation requires knowledge of tumor position with respect to the visible landmarks on the diagnostic quality simulator radiographs in which oncologist might over estimates malignant doses and underestimates OARs doses[16]. Since these radiographs provide limited soft tissue contrast, the user is restricted to setting field limits with respect to either the bony landmarks evident on the radiographs or anatomical structures visible with the aid of contrast agents such as barium. Another important factor is that time required for patient to stay in conventional simulator is quite longer until the end of simulation process has taken place. While in CT- based simulation, the patient only stays the minimum time necessary to acquire the CT data set. It is also remains unclear how much dose received to OARs using 2D conventional Tera six simulation treatments planning if you compare with 3DCRT which use CT simulation. CT simulation allows dose statistics which helps in providing qualitative information on the volume of target and OARs on the amount of dose received by each volume. From this matrix of dose to each volume element within an organ key statistics include minimum dose to the volume, maximum dose and mean dose as received by at least 95% of the volume, it hereby is recommended to avoid using 2D conventional simulation in treatment planning.

4.2 The future study

The GTVs is an oncological concept which varies according to the imaging technique used. However, many imaging techniques are now available which give an indication of the functional state of the tissues from cancer patient. This information can potentially be used in addition to CT-based planning at ORCI to improve the treatment of cervical cancer. Hence a prospective study will be conducted to assess EBRT techniques including beam flatness, tumor coverage and conformity indices at ORCI in order to determine the radiation the clinical benefits that will minimize and provides better cancer treatment in this center.

5 Conclusions

From this study, it can be concluded that the application of 3D-CRT planning of pelvic radiation is highly recommended in radiotherapy centers equipped with CT simulators and 3D TPSs to decrease uncertainties in the radiation planning process. The use of Tera six simulator for patients to be treated using Cobalt-60 techniques should be limited or avoided for curative intent patients due to its uncompromised tumor coverage to PTVs.

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