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Dosimetric comparison of 3D conformal planning for carcinoma cervix: Telecobalt bhabhatron vs 6 MV Linac beams

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ABSTRACT

Background: Telecobalt units are playing an important role in providing radiotherapy to cancer patients. Addition of advanced features like asymmetric jaws, motorized wedge, multileaf collimation (MLC) etc have made conformal planning possible with telecobalt units.

Methods: In this study we selected thirty known cases of carcinoma cervix. These patients were immobilized and simulated. Target & OAR delineation was done as per RTOG guidelines. Two plans were prepared for each patient, one with 6 MV Linac based setup (MLCs) and another for Telecobalt unit Bhabhatron-II TAW (asymmetrical collimation in Y jaw). Dose to target structures (PTV, CTV) and organs at risk (OARs) (anorectum, urinary bladder (UB), bowel bag and femur head) were evaluated for both setups.

Results: For PTV the average maximum dose for Linac and Cobalt planning had significant difference (p value < 0·001), while, difference in average mean dose was insignificant (p value = 0·9089). Homogeneity index for PTV for Linac and cobalt also had significant difference (p value < 0·001) and more homogenous dose distribution was obtained with Linac. CTV dose statistics for Linac and Cobalt for average maximum dose had significant difference (p value <0.001) and for average mean dose difference was insignificant (p value= 0·5835). For OARs, the difference of average mean dose for Linac and Cobalt for rectum (p value = 0·2198) was insignificant and that for UB, bowel bag and femur head (p value ≤ 0.01) was significant. The treated volumewas 21% and irradiated volume was 15·48% more for cobalt as compared to Linac (p value <0·001).

Conclusions: The 3D plans for linac were superior and homogenous when compared to 3D cobalt based plans for evaluated ca cervix patients. Enhancement of telecobalt units with advanced features may not provide efficient treatment delivery in all treatment sites and hence the decision making for cobalt based 3DCRT shall be selective.

KEYWORDS 3D- CRT, Linac, Telecobalt, Ca Cervix.

Introduction:

Cobalt 60 (Co 60) teletherapy has been playing a tremendous role in management of cancer patients for a long time. It was established as a high energy treatment modality in 1950s. Extensive research work and innovations in the field of radiotherapy have introduced many newer technologies such as 3 dimensional conformal radiation therapy (3DCRT), intensity modulated radiation therapy (IMRT), image guided radiation therapy (IGRT) etc. In this era of advances, Cobalt 60 teletherapy is still playing a significant role in providing radiotherapy in developing as well as industrialized countries. Cobalt teletherapy units are also becoming modernized and well equipped by the addition of advanced features like asymmetrical jaws, motorized wedge, multileaf collimators (MLCs), ergonomic couch etc· With addition of such features, cobalt units may also be used to provide conformal treatment (3DCRT, IMRT etc)·

The modern techniques in radiotherapy are mainly applied with linear accelerator· A few numbers of studies are also available regarding application of these techniques with Cobalt units·[3–8] The limitations faced with cobalt teletherapy units are lower radiation output, lower photon energy, relatively larger penumbra etc.[1,2] These limitations can be overcome and a better dose distribution may be achieved using the modernized machines and advanced beam modifying devices being attached with them·[3–8] Joshi *et al*. (2009) have obtained a comparative data for Co-60 and 6 MV linac based tomotherapy plans for cases of head and neck (H&N) and prostate cancer showing achievement of plan objectives for both machines.[11] Joshi *et al*.(2001,2008) also performed studies to overcome the low dose rate of Co-60 units for fan beam application by redesigning the unit to include multiple sources, different source shape and packing density, and by decreasing source to axis distance (SAD).[9,10] LJ Schreiner *et a*. (2009) have shown in his experiment that conformal dose delivery is possible with Co-60 units.[12] Thus, we can understand from above studies that modernized Co-60 units can play an increased role in this era of advanced radiotherapy.

Taking into account the feasibility of Telecobalt units in providing conformal treatment, we have performed this study to compare the 3D-CRT plans generated for our telecobalt unit and 6 MV linac based setup. In this study we compared the 3DCRT plans generated for 30 Ca cervix patients for both telecobalt unit and 6MV Linac. A comparison was made in terms of dose coverage to target volumes (PTV, CTV) and avoidance of the organs at risk (OARs) namely ano-rectum, urinary bladder(UB), bowel bag, femur head. Along with the dose coverage we also compared the dose volume histogram (DVH) of above structures for these two units. A comparative data of treated and irradiated volumes and homogeneity index were also obtained.

MATERIALS AND METHODS:

a) Patient selection:

In this study we selected thirty histologically proven cases of squamous cell carcinoma cervix (FIGO stage II, III and post operative cases). For each of these thirty patients 3DCRT planning was done for both, 6 MV Linac based setup and Telecobalt unit· The plans for these two machines were then compared for above mentioned parameters.

b) Configuration of Treatment Planning System for Bhabhatron-II TAW:

Configuring the treatment unit in the T.P.S was the most essential preliminary step for implementing 3D treatment planning in the teletherapy unit. The treatment unit, Bhabhatron-II TAW (Fig.1) was configured in the administration workspace of the Eclipse TPS.[15] Beam configuration was done by collecting the basic beam data (Profiles, Central axis depth dose curves & dose rate table) for pencil beam convolution algorithm. The required beam data were collected by using the Radiation field analyzer from Scanditronix Wellhofer, IBA Dosimetry systems (Fig.2). Central axis depth dose curves, profiles & dose rate tables were the basic measurement required by the PBC algorithm for dose calculation.

c) 3D-Treatment planning:

Treatment planning for the selected thirty patients for both Linac and Cobalt was performed in the same Eclipse treatment planning system, (Make: Varian Medical System, version: 8·9·15). All the selected thirty patients were immobilized using thermoplastic moulds and then simulated. The simulation CT scans for these patients were obtained from Wipro G.E.C.T scan machine. These scans were then imported and contouring of treatment volumes and organs at risk was done as per RTOG guidelines.(13) For each of these patients two separate plans were prepared, one for 6 MV Linac based setup (6 MV X-rays with MLCs) and another plan for our configured Telecobalt unit Bhabhatron-II TAW (asymmetrical collimation in Y jaw). These patients were planned by Isocentric method with the isocentre placed at the centre of PTV. In case of Linac based plans MLCs were used for shielding of normal structures, while, asymmetrical jaws and blocks were used for the same purpose in Cobalt based plans. Beams were planned for 0o, 90o, 180o and 270o angles used routinely for 3DCRT planning of carcinoma cervix patients.[14] Dose calculation was done using Pencil Beam Convolution algorithm. The treatment plans were performed to obtain the optimal conformity i.e. 95% of the prescribed dose to the planning target volume & not more than 107% of the same.

d) Treatment plan evaluation :

Treatment plans performed for Linear accelerator & telecobalt unit were evaluated by comparing the Dose Volume Histograms (DVH), Dose Statistics & Dose colour wash features available in the eclipse TPS. The maximum, mean & minimum point doses received by the PTV, CTV, bladder, anorectum, bowel bag & femoral head were obtained from the dose statistics feature for both types of plans. The data for treated volume and irradiated volume were also obtained for both machines by converting isodose levels to structures and comparison was made. The values of D5 & D95 for the PTV were noted from the DVH. The Homogeneity index (H·I) for the PTV was calculated with the formulae $H \cdot I = \frac{D5\% - D95\%}{Dd}$

Where

$D_{5\%}$ - Dose received (cGy) by the 5% of the PTV volume

$D_{95\%}$ - Dose received (cGy) by 95% of the PTV volume

D_d - Prescribed dose (cGy)

Results and discussions:

1.1) PTV Dose Statistics analysis: Table 1·1

It was observed that the average maximum dose of Linac and Cobalt based plans are 53·69 ± 1·60 Gy and 58·38 ± 3·30 Gy respectively with a highly significant difference between the two machines, p value <0·001. It was evident that the average maximum dose for the cobalt based plans were higher, which may be explained by lesser percentage depth dose of cobalt source as compared to Linac. However, the average mean dose for PTV for the two machines was comparable, that is 49·94 ± 1·41Gy for Linac and 49·88 ± 2·39 Gy for cobalt. The difference between the plans for both machines was insignificant for average mean dose, p value = 0·9089.

1.2) Homogeneity index for PTV: Table 1·2

A very important requirement of radiation treatment is to provide maximum dose to the treatment area and at the same time minimize dose to nearby normal structures. Along with the above requirement, the dose should also be distributed uniformly over the treatment area for better outcome (in case of 3D conformal and conventional planning). This uniformity of dose distribution over the PTV was evaluated by the help of Homogeneity Index (HI).(16) In our study the formula of modified Homogeneity Index (mHI) was used to calculate the HI. A significant difference (p value < 0·001) between the homogeneity of dose distribution over PTV was observed between the plans generated for two machines i.e. Linac and Cobalt. For Linac based plans the mean HI was 0·0734 ± 0·014, while, for Cobalt based plans it was 0·1874 ± 0·025. The value of Homogeneity Index equal to or less than Zero indicates better homogeneity. Dose homogeneity for linac based plans was higher as compared to Cobalt based plans.

2) CTV dose statistics analysis: Table 2.

As seen for PTV the dose statistics was observed to follow the same pattern for CTV. There was highly significant difference (p value <0·001) between the average maximum dose for Linac (53·18 ± 1·71 Gy) and Cobalt (56·74 ± 3·11 Gy). The difference between the average mean dose for Linac (50·31 ± 2·30 Gy) and Cobalt (49·96 ± 2·40 Gy) was insignificant (p value = 0·5835). The dose statistics for CTV for two machines is as shown in Table 2.

3) Dose statistics for Organs at Risk (OARs): Table 3.

For a good treatment plan the maximum dose should be delivered to the treatment area while the dose to nearby normal structures should be minimal. There are some normal structures located in or very close to the treatment fields, whose radio sensitivity influences the treatment planning. These normal structures are known as "Organs at Risk".[17] The dose statistics for these OARs must always be checked and efforts must be made to keep the dose under acceptable limits. Crossing the dose limits may have deleterious effects on proper functioning of these OARs or may also lead to function loss.

Since we selected the cases of carcinoma cervix in our study, therefore, we analyzed the dose statistics for OARs for pelvic fields. The OARs selected for our study were namely Anorectum, Urinary Bladder (UB), Bowel Bag and Femur Head. The dose statistics for each of this structure is shown in the tables given below (Table 3). We can see from the data shown below, there is insignificant difference (p value 0·2198) between the average mean dose of anorectum for the Linac (45·42 ± 3·77 Gy) and Cobalt (44·73 ± 4·72 Gy) based plans. The difference between the average mean dose for UB (p value = 0·01), for bowel bag (p value <0·001) and for femur head (p value < 0·001) for Linac and Cobalt base plans is significant. The dose values for each of these parameters can be seen in table 3.

4.) Treated Volume Statistics analysis: Table 4.

The International commission on radiation units and measurements (ICRU) report 50 & 62 has recommended the volumes of Treated volume & irradiated volume.[18,19] The volume enclosed by the isodose surface representing the minimal target dose (i.e. 95% of prescribed dose), is called the Treated volume (TV); The volume that receives a dose considered significant in relation to normal tissue tolerance (i.e. 50 % of prescribed dose) is called Irradiated volume (IV)·

In our study we observed the mean TV for linac based plan was 2536 ± 528·61cc whereas the cobalt based plans resulted in the mean TV of 3133·55 ± 765·85cc· The percentage of difference between treated volumes for Linac and Cobalt based plans was estimated to be 21%· This percentage difference was calculated by the formula

$$percentage\ difference = \frac{\textbf{TV Linac} - \textbf{TV cobalt}}{\textbf{avergae TV of linac \&}\ cobalt} \text{ x } 100$$

The applied paired "t" test resulted in p value <0·001(highly significant). 21 % of the volume was treated more in cobalt based plans as compares to Linac based plans·

The mean irradiated volumes for linac & cobalt based plans are 7785·6 ± 1421·97cc & 9092·1 ± 1687cc, p value <0·001(highly significant) with percentage difference of 15·48%· The percentage difference was again calculated by a similar formula as given above with respect to irradiated volume· There was 15·48 % more irradiation in cobalt based plans as compared to Linac based plans.

Conclusion:

The 3D plans performed for the telecobalt were compared with the Linear accelerator based plans. Majority of the parameters were observed to show significant difference other than mean dose for treatment volumes. Significant difference was also observed for all the organs at risks other than mean dose of Anorectum. This study evaluated the implementation of 3DCRT in Ca-Cervix for telecobalt machines and observed that the Linac based treatment plans were superior to the telecobalt plans. The high dose volumes observed in telecobalt patients were due to the lesser percentage depth dose characteristics of cobalt source. The tissue lateral effect was highly pronounced for telecobalt plans as the separation for cervix region is higher when compared to other body sites. This study also agree that the telecobalt machines are a good solution for cranial & head & neck tumours where the separation is lesser. The paradigm of implementing multileaf collimator in telecobalt machines to provide appropriate conformal therapy shall provide lesser benefit in treating cervix carcinomas.

Figure1: Telecobalt unit: BHABHATRON – II (TAW)

Figure 2: Configuration of Telecobalt unit in the TPS with Radiation Field Analyzer.

Table1·1: PTV Dose statistics:

Parameter	Linac	Cobalt	P- Value	Significance
Average Maximum Dose (Gy)	53·69 ± 1·60	58·38 ± 3·30	<0·001	Highly Significant
Average Mean Dose (Gy)	49·94 ± 1·41	49·88 ± 2·39	0·9089	Insignificant
Average Minimum Dose (Gy)	32·83 ± 8·94	36·83 ± 5·72	0·3795	Insignificant

Table 1·2: Homogeneity Index comparison:

Teletherapy plan	D5%	D95%	Homogeneity index	P - value
Linac	51·578 ± 1·796	47·91 ± 1·852	0·0734 ± 0·014	<0·001
Cobalt	54·513 ± 2·19	45·15	0·1874 ± 0·025	

Parameter	Linac	Cobalt	P-Value	Significance
Average Maximum Dose (Gy)	53·18 ± 1·71	56·74 ±3·11	<0·001	Highly Significant
Average Mean Dose (Gy)	50·31 ± 2·30	49·96 ± 2·40	0·5835	Insignificant
Average Minimum Dose (Gy)	46·51 ± 4·36	42·67 ± 4·17	<0·001	Highly Significant

Table 3: Dose statistics of OARs:

OARs	Parameters	Linac	Cobalt	p Value	significance
Anorectum	Average Maximum Dose (Gy)	51·29 ±2·06	50·43 ± 2·78	0·1378	Insignificant
	Average Mean Dose (Gy)	45·42 ± 3·77	44·73 ± 4·72	0·2198	Insignificant
	Average Minimum Dose (Gy)	12·36 ± 12·88	15·22 ± 13·11	0·005	Insignificant
Urinary Bladder	Average Maximum Dose (Gy)	51·79 ± 1·53	54·43 ± 2·82	<0·001	Highly significant
	Average Mean Dose (Gy)	48·99 ± 1·64	50·27 ± 2·34	0·01	significant
	Average Minimum Dose (Gy)	34·84 ± 6·88	45·30 ± 3·91	<0·001	Highly significant
Bowel bag	Average Maximum Dose (Gy)	52·71 ± 1·65	52·27 ± 3·28	<0·001	Highly Significant
	Average Mean Dose (Gy)	27·47 ± 9·52	31·62 ± 9·92	<0·001	Highly Significant
	Average Minimum Dose (Gy)	4·34 ± 8·78	4·84 ± 10·15	0·776	Insignificant
Femur head	Average Maximum Dose (Gy)	51·26 ± 1·37	53·35 ± 2·72	0·001	Highly Significant
	Average Mean Dose (Gy)	29·10 ± 4·00	33·21 ± 5·67	<0·001	Highly Significant
	Average Minimum Dose (Gy)	4·32 ± 3·13	5·93 ± 4·34	<0·001	Highly Significant

Table 4: Treated & Irradiated volume statistical analysis

Parameter	Linac	Cobalt	P- Value	Significance
Mean Treated Volume(cc)	2536·5 ± 528·61	3133·6 ± 765·85	<0·001	Highly Significant
Mean Irradiated Volume(cc)	7785·6 ± 1421·97	9092·1 ± 1687	<0·001	Highly Significant

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