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Original Article

In vitro quality assurance of three-dimensional conformal radiotherapy mono-isocentric plan for simultaneous treatment of two targets

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ABSTRACT

Objective: The purpose of this study was to check the *in vitro* efficacy of a radiotherapy plan generated for the treatment of two femoral targets simultaneously in the pelvis.

Methods: The target positions for conformal radiotherapy were simulated by joining two identical water phantoms (approximating the patient dimensions), and a treatment plan to treat the two targets simultaneously with a common isocenter was planned. Calculations were made with a dose prescription of 300cGy to each lesion. The plan was executed on a medical linear accelerator and verified for point doses for individual targets with two ion chambers. Two-dimensional dose verification for fluence was also performed using an array detector of ion chambers (I'mRTMatriXX) to further validate the technique.

Results: The minimum, mean and maximum dose in centiGray(cGy) covered by both Ionization Chamber-1 (IC-1) and Ionization Chamber-2 (IC-2) was 295, 303 and 307 as per dose statistics from the treatment plan. The global dose max obtained from the plan was 307 cGy. Measured point doses to both the targets were within ±2%. Dose Difference and Distance to agreement (3%, 3 mm criteria) criteria also passed for 2Dfluence verification.

Conclusions: Radiotherapy of two or multiple targets using monoisocentric technique can appreciably reduce the scatter dose to the normal surrounding tissue around the target/s and also the required setup and treatment time is reduced significantly. Therefore, the technique can be efficiently used to save time without compromising the radio therapeutic ratio and quality treatment, for both palliative and curative intent.

Keywords: *In vitro* dose verification, monoisocenter, three-dimensional conformal therapy, treatment planning system

Introduction

Solid tumors often present with multiple bone metastases necessitate the simultaneous radiotherapeutic treatment of the targets. Such treatments are executed using modern radiotherapy techniques (e.g., Intensity-modulated Radiotherapy, stereotactic body radiation therapy, Rapid Arc, Cyberknife® & Tomotherapy) where the treatment planning is carried out with treatment planning systems having Inverse planning algorithms. In convention, multiple targets can be treated with beam sets having their isocenters. This results in more scatter dose to the surrounding normal tissue and prolongation of treatment time (starting from quality assurance, patient positioning, setup corrections, and treatment delivery). A simpler method is to have a common isocenter, around which the gantry rotates and delivers the radiation to the multiple target sites. This method can considerably reduce the scatter dose to the surrounding normal tissues and reduce the time of pre-treatment plan quality assurance and execution of that plan significantly. Many investigators have verified the dosimetric quality of a common isocentric plan to treat multiple tumors, especially in brain metastatic lesions. Abdel-Hakim *et al*. have reviewed the merits, limitations, and recent approaches to optimize match line dose in monoisocentric technique in conventional and intensity-modulated radiotherapy for head and neck cancers.[1] Potter *et al*., have investigated the treatment of multiple brain tumors with 4 bank micro multileaf collimators and have found that the single isocentric was as good as the multiple isocentric plan dosimetrically, which can reduce a considerable amount of time in quality assurance and treatment.[2] Wadasadawala *et al*. reported that the monoisocentric technique resulted in better dose homogeneity at the field junctions and reduced mean heart dose as compared to the dual isocentric technique in the clinical practice for breast cancer treatment.[3] Luxton *et al.*, in their study have treated non-spherical targets

in the brain with a single isocenter and achieved good dose conformity.[4] Clark *et al*., have verified the feasibility of a single isocenter in Volume modulated arc therapy radiosurgery, for the treatment of multiple brain metastasis and concluded it as a better method.[5] Huang *et al*., have compared the quality of target coverage and dose conformity with single isocentric volume modulated arc therapy- stereotactic radiosurgery plans to dynamic conformal arc therapy and concluded that the latter may result in larger low dose regions.[6] VanderSpek *et al*.; Ebert *et al*.; Shtraus *et al*.; have extensively studied the validity of single isocentric plans and concluded it to be a better option in saving pre-treatment quality assurance time as well as treatment delivery time with less systematic errors.[7-9] Marks *et al*., have confirmed through their investigation that three-dimensional conformal radiotherapy can be a possible alternative to radiosurgery with fixed shaped coplanar or non-coplanar wedged radiation fields having individually shaped beams conformed to irregularly shaped intracranial lesions, as the goal of both the techniques is to achieve better dose conformity.[10-12] A similar kind of logic can be used to treat multiple lesions simultaneously with different/single beam sets confirmed using three-dimensional radiation therapy to different lesion sites elsewhere extracrainally which can yield less low dose bath to normal tissue, save pre-treatment quality assurance time and treatment time appreciably. Planning these techniques with a three-dimensional radiation therapy treatment planning system requires a highly logistic approach using different beam sets conformed to multiple lesions sharing a common isocenter, having different weight points, the feasibility/flexibility to use different wedge angles, to obtain a better conformal dose coverage.[13]

Aims and objectives

The objective of this study is to validate a single isocentric plan in terms of dose conformity and dose coverage, generated under the three-dimensional radiation therapy technique for the treatment of two femoral head and shaft metastatic lesions (simulated in water phantom) by composite point dosimetry and two-dimensional fluence verification with an array detector of ionization chambers vizI'mRTMatriXX™.

Materials and Methods

A primary known case of carcinoma right lung with bone metastasis at two different locations (two femoral heads and shafts) was planned using a common isocenter. Planning of this kind is based on the three-dimensional radiation therapy technique possible with a linear accelerator, having a dose rate of greater than 400 MU/min, with 40 pair tungsten multileaf collimator leaves in two banks and motorized wedge, with superposition algorithm.

Treatment planning with common isocenter

To create a plan with good conformity and 95% isodose cloud at two distant target levels a combined clinical treatment volume (CTV) structure with a 5 mm margin was created. Beams with common isocenter were then conformed to the two different targets, two pairs of beams were directed anterio-posteriorly, covering the right femur as clinical target volume 1 (CTV1) and left femur as clinical target volume 2 (CTV2), and another pair bilaterally directed to cover both the targets simultaneously, completely sparing the organs in between the two targets. Additional sub-beams with weight points at different desired locations, within the target were created to get dose uniformity inside the target. The isodose curves and dose-volume histograms were analyzed to check the extent of dose overlapping of the two targets, as both the targets were aimed to get 300cGy per fraction. Figure 1 shows the isodose distribution for the treatment planning with the monoisocenteric technique.

Composite dosimetric verification

For the point dose verification (Composite dosimetry) of this plan same patient geometry was simulated by a phantom comprising of two identical tissue phantoms placed side by side, having surface fiducials, with two ionization chambers simulating the targets, and a planning computed tomography scan of slice thickness 3 mm was acquired as shown in Figure 2. The serially scanned images were transferred to the contouring station, and the external contouring was performed, the two chambers simulating the two targets were contoured with a margin of 2 mm around them and named ionization chamber 1 and ionization chamber 2. The contoured Dicom data set was then transferred to the planning system. For treatment planning, ionization chamber 1 and ionization chamber 2 were combined to generate ionization chamber 3 with a 5 mm margin. The reference point was assigned as a common isocenter and the same beam template as planned for the actual patient was imported on this phantom simulating the actual patient.

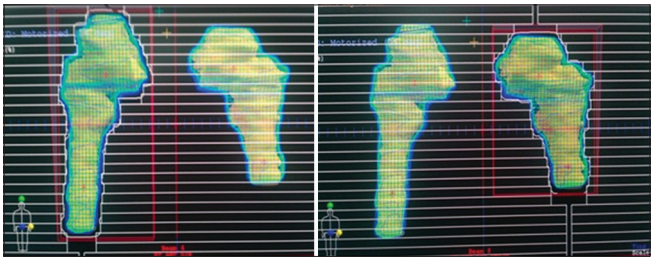

Figure 1: Treatment planning with common isocenter using 3DCRT technique

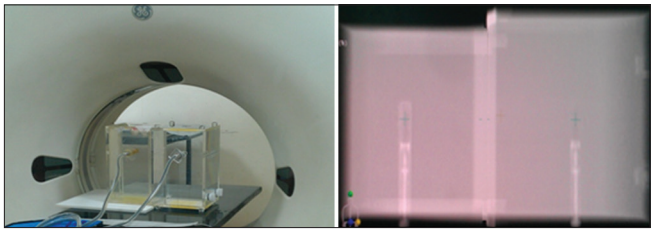

Figure 2: Computed tomography simulation of the phantom with ionization chambers and its DRR view

The beams were conformed to the ionization chamber 1 and ionization chamber 2 with a margin of 2 cm around the targets as shown in Figure 3. The isodose curves and dose statistics were analyzed to check the dose uniformity and the extent of dose overlapping of the two targets, for 300cGy/#. The plan was scheduled and executed with the dosimeters simulating the targets. An online record of cumulative charge from both the ionization chambers was recorded which was later converted to absorbed dose to the targets using International Atomic Energy Agency-Technical Report Series 398.

2D fluence verification

The same plan template used in the phantom study was executed on a 2D ion chamber array detector (I'mRTMatriXX) for 2D fluence verification using solid phantom-34 30 cm × 30 cm × 30 cm with gantry different angles, as shown in Figure 4.

Results

The electrometer average meter reading (M) in nanocoloumbs(nC) obtained from composite dosimetry with two 0.6 cc Farmer type Ionization Chambers (ionization chamber 1 and ionization chamber 2) are shown in Table 1. The final dose measurements were obtained using N_{DW} based formalism using International Atomic Energy Agency-Technical Report Series 398.[14,15] Table 2 displays the percent deviation between the measured (point dosimetry) and treatment planning system calculated dose. The minimum, maximum, and mean dose in centiGray (cGy) covered by the ionization chamber 1 and ionization chamber 2 volumes were 295, 307 and 303 as per the dose statistics from the generated treatment plan. The global dose max obtained from the plan was 307.4 cGy. Measured point doses to both lesions were within ±2%. Figure 5, shows the validity of the gamma index

Table 1: Cumulative charge collected (*nC) Dose Measurements for IC-1 and IC-2 using point dosimetry

Beam	IC-1		IC-2	
	Trial-1	Trial-2	Trial-1	Trial-2
RT LAT DIR WEDGE	6.930	6.919	18.36	18.20
RT ANT DIR WEDGE	7.021	7.010	36.76	36.55
RT ANT DIR SUB	7.035	7.023	40.67	40.38
LT ANT DIR WEDGE	10.18	10.16	40.69	40.36
LT ANT DIR SUB 1	14.74	14.71	40.70	40.34
LT ANT DIR SUB 2	30.48	30.43	40.80	40.31
LT LAT DIR WEDGE	46.47	46.27	46.98	46.27
LT LAT SUB	46.56	46.36	57.34	46.27
LT POST DIR WEDGE	46.59	46.39	61.10	60.24
LT POST DIR SUB	59.91	59.67	61.24	60.24
RT POST DIR	61.87	61.62	61.25	60.24
Mean meter reading (M in nC)	61.745		60.245	

*nC = nanoCoulombs, IC =Ionization chamber

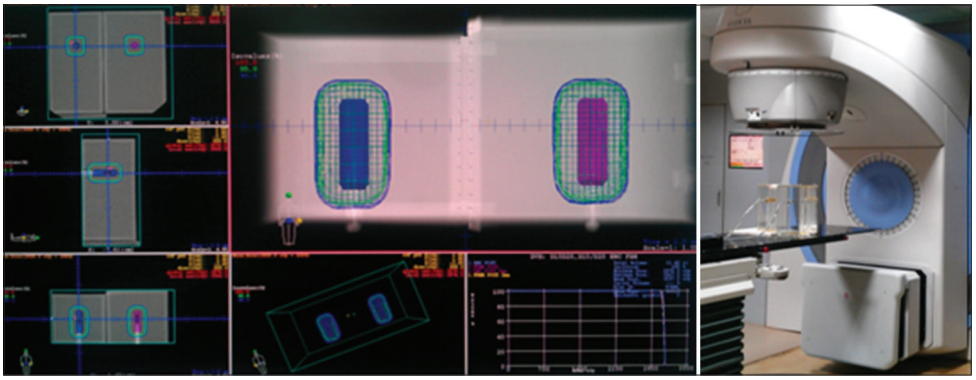

Figure 3: Phantom treatment planning and its execution at the linear accelerator

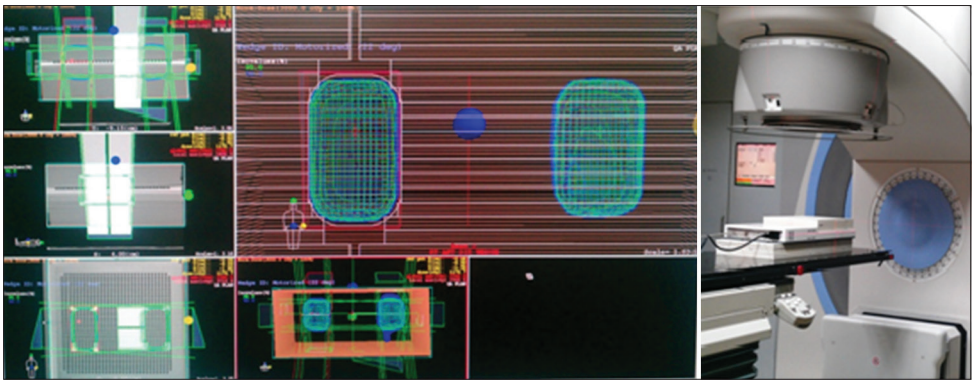

Figure 4: Application of the treatment plan on IMatriXX and its execution

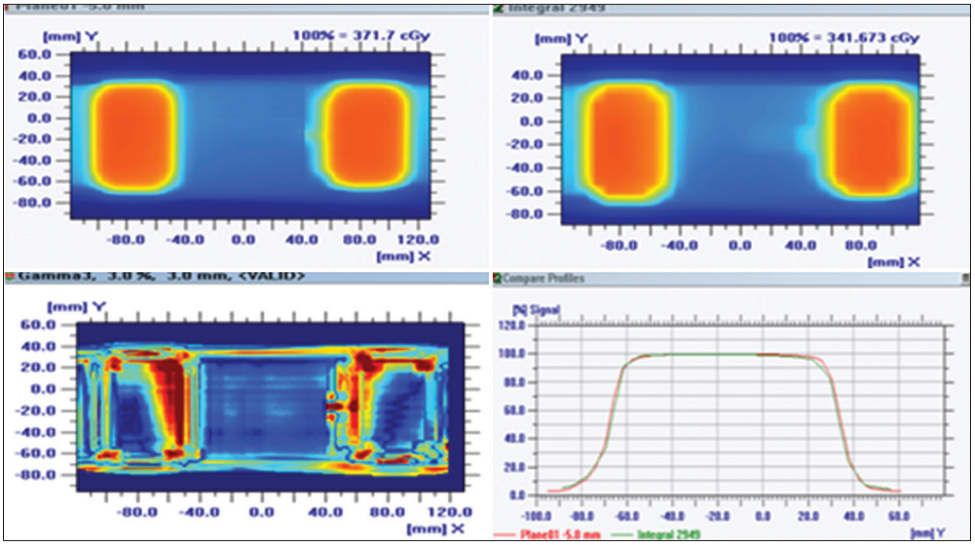

Figure 5: 3% Dose difference, 3 mm distance to agreement, validity by two dimensional fluence verifications

Table 2: Percentage deviation from the calculated dose, by composite point dosimetry

Dose measured (Mean) cGy/# (M×@TCF)		TPS calculated dose (Mean) cGy/#		Percent deviation (%)	
IC-1	IC-2	IC-1	IC-2	IC-1	IC-2
297.345	299.049	303	303	–1.87	–1.30

@TCF=Total Correction Factor(N_{DW}×K_{TP}×K_{Pol}×K_{Sat}×K_{QQo}).[14] IC =Ionization chamber

criterion, within 3%, 3 mm (Dose difference and distance to the agreement) on fluence verification.

Discussion

The radiotherapy treatment planning for the treatment of multiple targets usually results in increased scatter dose, that is, increased low dose bath to the surrounding normal tissues if the different targets are planned individually with multiple isocenters for separate targets as described by the international commission on radiation units and measurements- ICRU. It also results in overall increased treatment planning time, patient setuptime as well as plan execution time. In this study, treatment planning of two targets in the pelvic region with a common isocenter was verified dosimetrically and the results obtained were well within the tolerance doses as prescribed by the international commission on radiation units and measurements- ICRU. Earlier a similar kind of attempt has already been made by several investigators for the treatment of multiple lesions/targets especially intracranial using highly sophisticated state of art of radiotherapy with special computerized algorithms based on inverse planning.[16-18] Another group of investigators has tried to achieve the same target using conformal techniques to treat multiple intracranial lesions with coplanar and non-coplanar beams. Keeping the ultimate goal of radiotherapeutic treatment in view, that is, to achieve maximum target dose coverage (95–107% isodose coverage to Target Volume) and conformity with maximum possible normal tissue sparing, the idea of treating two/multiple targets (intra or extracranial) simultaneously having a common isocenter is always appreciable.[19] It usually offers a low dose bath to normal surrounding tissues, with the least possible time consumed in pre-treatment quality assurance. The treatment delivery time also decreases appreciably and therefore the setup errors also are reduced.[20,21] On the contrary, the treatment plans with multiple isocenters are time-consuming, error-prone, and may attribute many uncertainties in setup and positioning ending up with many systematic errors in the treatment delivery.

Conclusions

The results obtained for the composite point dosimetry and the two-dimensional fluence verification during the plan execution, evaluation, and analysis were in agreement with the treatment planning system calculated dose. Thereby validating the technique using monoisocenter to treat multiple targets simultaneously. This technique had resulted in decreasing the scatted dose appreciably. It also helped to save the beam on time as well as the whole radiotherapeutic procedure. Monoisocentric technique has proved dosimetrically as well as radiobiologically better than multiple isocenters. In conclusion, we would recommend the monoisocentric plans to be planned and executed wherever and whenever possible to treat multiple targets within the same patients to save time and achieve better tumor control.

Limitations/future study

The drawback of our study is that the study is limited to two targets only which otherwise could also be applied for multiple targets. Furthermore, ours was not a comparative study, that is, *in vitro* versus *in vivo*, as the femoral targets were not suitable

for the available *in vivo* dosimeters at our center. The future possible research will focus on the comparison of *in vivo* and *in vitro* dosimetric and radiobiological significance of the monoisocentric technique for the treatment of multiple targets simultaneously.

Authors' Declaration Statements

Ethics approval and consent to participate

Ethical approval not required.

Availability of data and material

The data used in this study are available and will be provided by the corresponding author on a reasonable request.

Competing interest

None.

Funding

None.

Authors' Contributions

Misba Hamid Baba: Worked during the experimental process as well as prepared the manuscript; Benoy Kumar Singh: Provided overall guidance in the preparation of manuscript.

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