Original Article

To Study the Impact of Different Optimization Methods on Intensity-Modulated Radiotherapy and Volumetric-Modulated Arc Therapy Plans for Hip Prosthesis Patients

Pawan Kumar Singh[1,2], Deepak Tripathi[1], Sukhvir Singh[3], Manindra Bhushan[1,2], Lalit Kumar[2], Kothanda Raman[2], Soumitra Barik[2], Gourav Kumar[2], Sushil Kumar Shukla[2], Munish Gairola[2]

[1]Amity Institute of Applied Sciences, Amity University, Noida, Uttar Pradesh, [2]Department of Radiation Oncology, Division of Medical Physics, Rajiv Gandhi Cancer Institute and Research Centre, New Delhi, [3]Radiological Physics and Internal Dosimetry Group, Institute of Nuclear Medicine and Allied Sciences, Defence Research and Development Organisation, Delhi, India

Abstract

Purpose: To study the impact of different optimization methods in dealing with metallic hip implant using intensity-modulated radiotherapy (IMRT) and volumetric-modulated arc therapy (VMAT) techniques. **Materials and Methods:** A cohort of 16 patients having metallic implants was selected for the study. Three sets of IMRT and VMAT plans were generated. Set 1 IMRT (IM_Base), VMAT (VM_Base) without any restrictions on beam entry and exit, set 2 (IM_ENT and VM_ENT) optimizer restricts the beam entry and set 3 (IM_EXT+ENT), neither entry nor exit doses were allowed toward the metallic implant. **Results:** There was no significant difference in target ($D_{95\%}$) and organ-at-risk doses between IM_Base and IM_ENT. There were significant ($P = 0.002$) improvements in planning target volume (PTV) $V_{95\%}$ and homogeneity from IM_EXT+ENT to IM_ENT. There was no significant difference in plan quality between VM_Base and VM_ENT. There were significant ($P = 0.005$) improvements in PTV, $V_{95\%,}$ homogeneity from VM_EXT+ENT to VM_ENT. V_{40Gy}, V_{30Gy} for bladder, rectum, bowel, and bowel maximum dose decreases significantly ($P < 0.005$) in IM_ENT compared to IM_EXT+ENT, but not significant for VMAT plans. Similarly, there was a significant decrease in dose spill outside target ($P < 0.05$) comparing 40%, 50%, 60%, and 70% dose spills for IM_ENT compared to IM_EXT+ENT, but variations among VMAT plans are insignificant. VMAT plans were always superior to IMRT plans for the same optimization methods. **Conclusion:** The best approach is to plan hip prosthesis cases with blocked entry of radiation beam for IMRT and VMAT. The VMAT plans had more volumetric coverage, fewer hotspots, and lesser heterogeneity.

Keywords: Artifacts, intensity-modulated radiotherapy, metallic implants, optimization, volumetric-modulated arc therapy

Received on: 17-02-2022 **Review completed on: 12-05-2022** **Accepted on: 26-05-2022** **Published on: 08-11-2022**

Introduction

According to GLOBOCAN-GCO data, 20 million new cancer cases were reported in year 2020 and 20% of cases were from the pelvic region.[1] The prostate, colorectal, and cervix malignancies were the common sites in this region, and bone loss is common for both men and women of older age. Osteoporosis increases for older persons of both genders. Patients who undergo hormonal therapy face a significantly higher rate of bone loss; it may go up to 4%–5% for male prostate patients put on androgen deprivation therapy.[2,3] These patients may suffer a bone fracture because of these reasons and to stabilize their bone metallic inserts were implanted in the desired region. Therefore, the number of patients having metallic implants is also increasing.

Patients with metal implants pose a challenge in the treatment planning process for radiation oncologists and physicists. The radiotherapy (RT) starts with the simulation of a patient and computed tomography (CT) images are standard

Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_14_22

Address for correspondence: Mr. Pawan Kumar Singh, Amity Institute of Applied Sciences, Amity University, Noida, Uttar Pradesh, India. Department of Radiation Oncology, Division of Medical Physics, Rajiv Gandhi Cancer Institute and Research Centre, New Delhi, India. E-mail: pawansingh786125@gmail.com

How to cite this article: Singh PK, Tripathi D, Singh S, Bhushan M, Kumar L, Raman K, *et al*. To study the impact of different optimization methods on intensity-modulated radiotherapy and volumetric-modulated arc therapy plans for hip prosthesis patients. J Med Phys 2022;47:262-9.

3-dimensional (3D) imaging procedure for RT patients. The presence of metal in the treatment region changes the attenuation profiles of photon beams passing through it[4] because of these profiles and scattered photons different artifacts are produced in the CT images.[5-7] A few artifacts seen during CT procedures are streaking, shading, rings, and distortions. The actual electron density (ED) and observed ED varies in the surroundings of high Z metallic implants.[7] The perturbations cause error in organ and target delineations.[8] This further leads to underdosing of the target and overdosing of organs at risk (OAR).[9,10]

According to AAPM TG-63, the treatment beams should be avoided from the implanted region.[11] The photons passing through the implant reduce the intensity and increase the dose at the exit interface due to an increase in secondary electron generation, leading to a complete change in the depth dose profile of the photon beam. If the exit doses are allowed in the implanted region, the backscatter of photon and electron causes a higher dose disposition at the interface.[12] Gullane did measurements using a wall-less ionization chamber (IC) at the interfaces of implant and tissue for stainless steel and titanium. They measured for both single and parallel-opposed beams and reported that interface doses increase by as much as 50% at the proximal surface of the metallic inhomogeneity.[13]

Previous researchers have studied the different planning strategies in patients having metallic implants in the femur. To evaluate the dosimetric impact on the planning target volume (PTV), the OARs, they used skip arcs in volumetric-modulated arc therapy (VMAT), block field in intensity modulated radiation therapy (IMRT) and used hard constraints during the optimization in their studies.[14] Prabhakar *et al*. used VMAT techniques with hard constraints for an avoidance structure created around prosthesis to restrict doses in the surrounding of the prosthesis.[15] They found this method simple and effective for prostate patients having prosthesis. Kung *et al*. compared 5-field and 6-field 3D conformal radiation therapy plans with 9-field IMRT plans. They have recommended 9-field IMRT plans for prostate patients having metallic prosthetic implants.[16]

This study planned to evaluate two standard treatment planning techniques, i.e., IMRT and VMAT, with different optimization methods.[17,18] In the first method, there was not any restriction on entry or exit of the radiation beam. The method was a standard method used for plan optimization of pelvis patient. The second method restricts the entry of radiation beams through the implanted material shown in Figure 1a, and in the third method both entry and exit of the radiation beam was blocked toward implanted material shown in Figure 1b. This study uses fixed field IMRT and VMAT template-based treatment planning approaches, which will help researchers use knowledge-based planning in these patients. The methods were implemented to study the implication on plan quality and their feasibility to use in the clinic. The plans were created and exposed on a similar geometry pelvis phantom to validate the methods.[19]

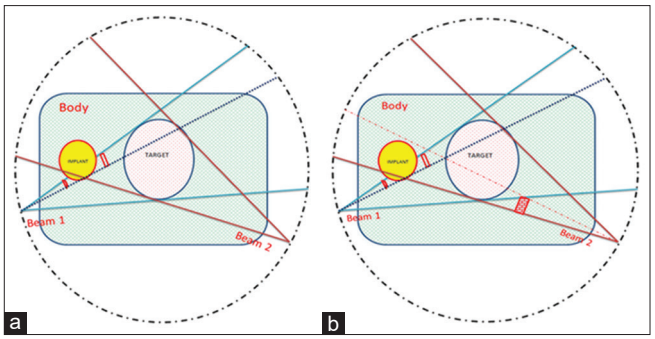

Figure 1: (a) Describes the optimization geometry for a treatment field; Beam 1 was directly facing the implant and the entry of beam is blocked through it, but there was no restriction on Beam2 path and in (b). Both entry and exit of the Beam was blocked

Materials and Methods

Simulation and contouring

Patients having metallic implants in the femur were simulated on a Somatom Sensation Open CT simulator (Siemens Healthineer, Germany) (maximum HU = 3000) using 5 mm slice thickness in head first supine position. All 16 patients (right hip implant = 9, left hip implant = 5, and bilateral hip implant = 2) suffering from carcinoma of cervix. The material used for was "titanium"(composition: titanium 88.5%–91.0%; aluminum 5.6%–6.5%, vanadium 3.5%–4.5%, iron 0.25%, oxygen 0.13% and carbon 0.08%, average ED 3.74 relative to water; diameter of femoral heads of prosthesis ranging from 40 to 54 mm.[20] The thermoplastic cast was made for every patient. The acquired images were transferred to Varian Soma vision contouring stations. The contouring was done using EMBRACE II Guideline.[21] The PTV, clinical target volume, bladder, rectum, and bowel structures were drawn. Implanted material was also contoured to mark the avoidance zones.

Treatment planning

For each patient, both IMRT and VMAT plans were created. Seven field IMRT plans with gantry angles 60°, 100°, 135°, 180°, 230°, 265°, 300° were created. Similarly, VMAT plans were created with two complete arcs (181°–179°) Clockwise and (179°–181°) counterclockwise. All beams were co-planar. Plans were created on Varian Clinac iX 2300CD linear accelerator using the beam energy of 6 MV, machine had Millennium 120 multiple leaf collimator which offers 0.5 cm leaf resolution at isocenter for the central 20 cm of the 40 cm × 40 cm field. Plans were optimized for 45 Gy in 25 fractions keeping the OAR constraints as per the departmental protocol. IM stands for IMRT plans; VM stands for VMAT plans. Three sets of plans were optimized. In set one, there were no restrictions on beam path and the plans were named as IM_ Base and VM_ Base; in set two the entry of the beam through the implanted material was blocked and denoted as IM_ENT

and VM_ENT; in third set both entry and exit were blocked through implanted material named as IM_EXT+ENT and VM_EXT+ENT. All plans were optimized using photon optimizer in Eclipse 15.1 treatment planning systems (TPS) (Maximum, HU = 6000, Relative ED = 3.920) (Varian Medical System, Palo Alto, CA) and calculated with anisotropic analytical algorithm, using 2.5 mm calculation grid spacing.

Plan evaluation and data analysis

All the plans were re-normalized to receive 95% of the PTV to the prescription isodose of 45 Gy. To compare the plans we used $V_{95\%}$ (volume of 95% isodose), $D_{95\%}$ (dose to the 95% isodose), $D_{98\%}$, $D_{2\%}$, D_{mean}, dose homogeneity index (DHI), $V_{107\%}$ and conformity parameters for PTV. For bowel, bladder and rectum V_{40Gy}, V_{30Gy} were used. Bowel D_{max} was also monitored to check the variation in OAR doses. For dose spillage outside the target we extracted the volumes of dose receiving 30%, 40%, 50%, 60% and 70% for structure Body-PTV. All the parameters were extracted using dose-volume histogram Metric Package of R Software (R version 3.6.1) [R Foundation for Statistical Computing, Austria].[22]

We performed statistical analysis using Microsoft office and Python Software (Spyder IDE version 5.1.5) [Python. Scotts Valley, CA: CreateSpace][23] Paired *t*-test with $P \leq 0.05$ was considered significant. DHI was calculated according to ICRU 83.[24] Conformity index was calculated using the RTOG formula.[25]

$$DHI = \frac{D2\% - D98\%}{D50\%}$$

$$\text{Conformity Index (CI)} = \frac{TV_{RI}}{TV}$$

TV_{RI} volume covered by 95% Isodose, TV is total volume of PTV.

Verification

Pelvis phantom (solid water, RW3 whitepolystyrene material by ScanditronixWellhofer) was used to verify the methods used. The scan was done on CT Simulator with CC 13 (ScanditronixWellhofer) and CC 0.01 IC. These chamber inserts were created to represent the target (CC 13) and implanted region (CC 0.01). The slice thickness was kept 1 mm to avoid delineation errors for chamber volume. The dummy target PTV, bladder, rectum, dummy implant, and femoral heads were created.[26] The chamber volumes were assigned HU value 0. Figure 2 shows the phantom, dummy target, OARs, and dose distribution.

Results

Table 1 shows all the dosimetric parameters for IMRT plans, IM_Base, IM_ENT and IM_ENT+EXT planning techniques. All plans were normalized to receive the prescription dose. Results were reported as mean ± standard deviation.

Comparing the $V_{95\%}$, $D_{98\%}$ and conformity parameters of PTV, there was no significant variation for IM_Base and IM_ENT plans. However, there were significant increase in D mean (P = 0.028), $D_{2\%}$ (P = 0.009), $V107_{\%}$ (P = 0.050) and also increase in homogeneity of IM_ENT plans DHI (P = 0.010). When we compared the IM_Base plans with IM_ENT+EXT, there was significant variation $V_{95\%}$ (P = 0.001), $D_{98\%}$ (P = 0.005), D mean (P = 0.002), $D_{2\%}$ (P = 0.002), DHI (P = 0.002) and $V_{107\%}$ (P = 0.005) except the conformity of plans. The IM_Base plans were better compared to IM_ENT+EXT. Again comparing the IM_ENT plans with IM_ENT+EXT, there was significant variation $V_{95\%}$, $D_{98\%}$, D mean (P = 0.006), $D_{2\%}$, DHI and $V_{107\%}$ (P = 0.005) except the conformity of the plans. The IM_ENT plans have increased $V_{95\%}$, $D_{98\%}$, DHI and decreased values of D_{mean}, $V_{107\%}$, $D_{2\%}$ than the IM_ENT+EXT plans.

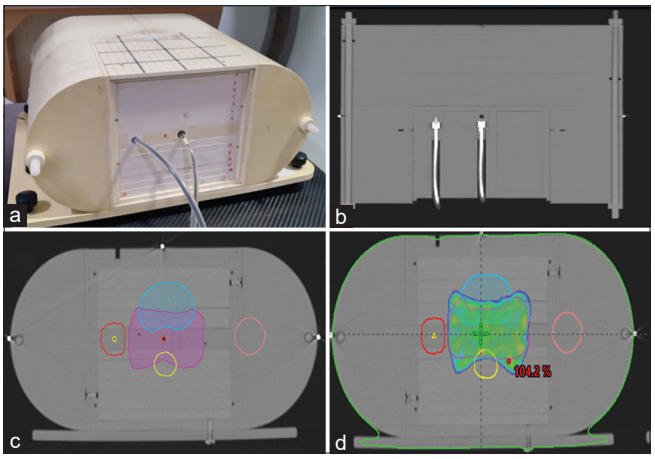

Figure 2: (a) The phantom and chamber inserts. (b) the topographic view of chambers placed, (c) the contours drawn on the phantom and (d) the dose distribution of 95% isodose

For OAR, comparing V_{30Gy} and V_{40Gy} for rectum and bowel, also bowel D_{max}, there was no significant variation between the IM_BASE and IM_ENT plans. There was a significant increase (P = 0.003) in V_{30Gy} from the IM_Base to IM_ENT plans for the bladder. There was no significant difference in 30%, 40%, 50%, 60%, and 70% spill outside target volume between both the plans.

Comparing IM_BASE plans with IM_ENT+EXT for V_{30Gy}, V_{40Gy}, all values increase significantly ($P < 0.05$) for bladder and rectum. Although there was significant variation in bowel V_{30Gy} (P = 0.037) and D_{max} having (P = 0.002), there was no significant variation in bowel V_{40Gy} parameter. There was no significant difference in 30% spill outside target volume, but there was significant increase in 40% (P = 0.004), 50% (P = 0.001), 60% (P = 0.004), and 70%, spill outside target volume between both the plans.

There was no significant variation for V_{30Gy}, V_{40Gy} for rectum and bowel between the IM_ENT and IM_ENT+EXT plans. There was no significant variation in bowel Dmax. There was a significant increase in V_{30Gy} (P = 0.003) and V_{40Gy} (P = 0.049) from the IM_ENT to IM_ENT+EXT plans for the bladder. There was no significant difference in 30%, 40%, and 50%

Table 1: Dosimetric parameters for all intensity-modulated radiotherapy plans

	Over all IM_Base (mean±SD)	IM_Base versus IM_ENT (*P*)	Over all IM_ENT (mean±SD)	IM_ENT versus IM_ENT+EXT (*P*)	Over all IM_ENT+EXT (mean±SD)	IM_Base versus IM_ENT+EXT (*P*)
PTV						
$V_{95\%}$ (%)	99.65±0.22	0.320	99.61±0.24	0.000	98.59±0.97	0.000
D_{mean} (Gy)	46.02±0.28	0.028	46.13±0.29	0.006	47.09±0.86	0.000
$D_{2\%}$ (near maximum Gy)	46.95±0.58	0.009	47.30±0.62	0.000	49.03±1.50	0.000
$D_{98\%}$ (near minimum Gy)	44.34±0.17	0.063	44.27±0.18	0.001	43.10±1.22	0.005
DHI	0.06±0.02	0.010	0.07±0.02	0.000	0.12±0.05	0.002
$V_{107\%}$ (cc)	0.15±0.29	0.050	0.48±0.68	0.005	25.19±31.01	0.005
Conformity index	0.996±0.002	0.870	0.988±0.190	0.989	0.987±0.094	0.720
Bladder						
V_{30Gy} (%)	73.31±3.75	0.003	75.40±4.17	0.003	80.56±6.55	0.006
V_{40Gy} (%)	54.34±5.14	0.079	55.55±4.44	0.049	57.63±4.54	0.005
Rectum						
V_{30Gy} (%)	66.56±27.23	0.348	68.49±28.09	0.174	72.75±30.18	0.002
V_{40Gy} (%)	43.48±18.32	0.672	44.15±18.52	0.032	48.22±20.78	0.005
Bowel						
V_{30Gy} (cc)	249.37±135.91	0.841	132.99±85.93	0.390	133.79±96.64	0.037
V_{40Gy} (cc)	2.16±3.70	0.661	2.19±3.67	0.570	1.83±2.67	0.605
D_{max} (Gy)	46.17±2.05	0.730	46.34±2.11	0.270	47.05±2.50	0.002
Body-PTV						
$V_{70\%}$ (l)	1.848±0.540	0.908	1.859±0.523	0.040	2.179±0.689	0.000
$V_{60\%}$ (l)	3.090±0.914	0.788	3.043±0.824	0.023	3.512±1.058	0.004
$V_{50\%}$ (l)	5.119±1.451	0.815	5.049±1.295	0.101	5.640±1.576	0.001
$V_{40\%}$ (l)	7.971±2.464	0.658	7.742±2.073	0.157	8.568±2.527	0.004
$V_{30\%}$ (l)	11.542±3.438	0.428	10.941±2.850	0.454	11.696±3.277	0.719

$V_{x\%}$: Volume receiving x% of prescription dose, Dmax: Maximum dose to a volume, Dmean: Mean dose, V_{xGy}: Volume receiving x Gy of radiation, $D_{x\%}$: Dose receiving x% of volume, PTV: Planning target volume, DHI: Dose homogeneity index, EXT: Exit, ENT: Entry, IM: Intensity-modulated, SD: Standard deviation

spill outside target volume, but there was significant increase in 60% ($P = 0.004$), and 70% ($P = 0.002$), spill outside target volume between IM_ENT to IM_ENT+EXT plans.

Table 2 shows all the dosimetric parameters for VMAT plans, VM_Base, VM_ENT, and VM_ENT+EXT planning techniques. Comparing the $V_{95\%}$, D_{mean}, $D_{2\%}$, DHI, $V_{107\%}$, $D_{98\%}$ and conformity parameters of PTV, there was no significant variation for VM_Base and VM_ENT plans. When we compared the VM_Base plans with VM_ENT+EXT, there was significant variation $V_{95\%}$, $D_{98\%}$, D_{mean}, $D_{2\%}$, DHI and $V_{107\%}$ ($P = 0.001$) except the conformity of plans. Again comparing the VM_ENT plans with VM_ENT+EXT, there was significant variation $V_{95\%}$, $D_{98\%}$, ($P = 0.001$), Dmean ($P = 0.006$), $D_{2\%}$ ($P = 0.002$), DHI ($P = 0.001$) and $V_{107\%}$ ($P = 0.004$) except the conformity of plans. The VM_ENT plans have higher values of $V_{95\%}$, $D_{98\%}$, DHI and lower values of D_{mean}, $V_{107\%}$, $D_{2\%}$ than the VM_ENT+EXT plans.

Comparing V_{30Gy}, V_{40Gy} for the rectum, bladder, and bowel, there was no significant variation between the VM_BASE and VM_ENT plans. There was no significant variation in Bowel D_{max}. There was no significant difference in 30%, 40%, 50%, 60%, and 70% spill outside the target volume between both the plans. Comparing VM_BASE plans with VM_ENT+EXT for V_{30Gy}, V_{40Gy} all values increase significantly ($P < 0.05$) for bladder and rectum. There was no significant variation in bowel V_{30Gy} and $V_{40\ Gy}$ but Dmax increased significantly. There was no significant difference in 30% spill outside target volume, but there was significant increase in 40% ($P = 0.001$), 50%, 60% and 70% ($P = 0.002$), spill outside target volume between both the plans.

There was no significant variation for V_{30Gy}, V_{40Gy} for rectum and bowel between the VM_ENT and VM_ENT+EXT plans. Bladder V_{40Gy} was not changing significantly, but bladder V_{30Gy} ($P = 0.021$) and bowel D_{max} ($P = 0.010$) increased significantly from the VM_ENT to VM_ENT+EXT plans. There was no significant difference in 30%, 40%, 50%, 60%, and 70% spill outside target volume between VM_ENT to VM_ENT+EXT plans.

Table 3 shows all the dosimetric parameters for IMRT versus VMAT plans. When we compared the base plans for both the techniques IMRT and VMAT, VMAT plans were better than in terms of volumetric coverage ($P = 0.025$), $D_{2\%}$ ($P = 0.090$) and conformity ($P = 0.030$). There were no significant differences in D_{mean}, $D_{98\%}$, DHI, and $V_{107\%}$ between IM_Base and VM_Base. There was no significant variation for V_{30Gy}, V_{40Gy} for bladder, bowel, and bowel Dmax. However, the variations are

Table 2: Dosimetric parameters for all volumetric modulated arc therapy plans

	Over all VM_Base (mean±SD)	VM_Base versus VM_ENT (*P*)	Over all VM_ENT (mean±SD)	VM_ENT versus VM_ENT+EXT (*P*)	Over all VM_ENT+EXT (mean±SD)	VM_Base versus VM_ENT+EXT (*P*)
PTV						
$V_{95\%}$ (%)	99.76±0.23	0.883	99.75±0.18	0.005	99.00±0.70	0.0001
D_{mean} (Gy)	46.20±0.58	0.16	46.43±0.51	0.006	47.19±1.05	0.0002
$D_{2\%}$ (near maximum Gy)	47.28±0.91	0.123	47.68±0.84	0.002	49.17±1.75	0.0008
$D_{98\%}$ (near minimum Gy)	44.36±0.21	0.81	44.34±0.19	0.001	43.75±0.62	0.0001
DHI	0.06±0.02	0.165	0.07±0.02	0.001	0.11±0.05	0.0007
$V_{107\%}$ (cc)	4.90±14.21	0.952	4.65±13.90	0.004	24.08±28.64	0.001
Conformity index	0.997±0.0022	0.877	0.990±0.191	0.969	0.992±0.097	0.827
Bladder						
V_{30Gy} (%)	73.55±6.05	0.37	74.77±6.67	0.021	80.01±8.65	0.0001
V_{40Gy} (%)	52.44±7.44	0.97	52.40±7.75	0.091	58.58±15.06	0.030
Rectum						
V_{30Gy} (%)	69.31±29.25	0.695	70.57±29.35	0.480	72.85±30.45	0.018
V_{40Gy} (%)	46.71±20.76	0.812	47.26±21.10	0.067	53.91±25.54	0.001
Bowel						
V_{30Gy} (cc)	293.35±248.60	0.266	331.48±358.23	0.882	344.24±336.7	0.49
V_{40Gy} (cc)	2.65±3.86	0.71	2.52±3.89	0.59	3.03±4.23	0.646
D_{max} (Gy)	46.20±2.38	0.74	46.40±2.71	0.011	48.61±3.16	0.0002
Body-PTV						
$V_{70\%}$ (l)	1.749±0.974	0.734	1.687±0.814	0.059	2.260±1.497	0.002
$V_{60\%}$ (l)	2.832±1.440	0.792	2.757±1.222	0.075	3.481±1.988	0.0007
$V_{50\%}$ (l)	4.619±2.153	0.75	4.485±1.821	0.124	5.321±2.616	0.003
$V_{40\%}$ (l)	7.306±3.252	0.661	7.015±2.686	0.230	7.898±3.434	0.001
$V_{30\%}$ (l)	10.879±4.424	0.548	10.313±3.605	0.494	11.128±4.294	0.308

$V_{x\%}$: Volume receiving x% of prescription dose, Dmax: Maximum dose to a volume, Dmean: Mean dose, V_{xGy}: Volume receiving x Gy of radiation, $D_{x\%}$: Dose receiving x% of volume, PTV: Planning target volume, DHI: Dose homogeneity index, EXT: Exit, ENT: Entry, VM: Volumetric-modulated, SD: Standard deviation

significant in V_{30Gy} ($P = 0.060$) V_{40Gy} ($P = 0.009$) for rectum between both plans. There was no significant difference in 30%, 60%, and 70% spill outside target volume, but there was significant increase in 40% ($P = 0.040$), and 50% ($P = 0.010$) spill outside target volume between IM_Base to VM_Base plans.

VMAT plans were found better in terms of volumetric coverage ($P = 0.005$), D_{mean} ($P = 0.040$), $V_{107\%}$ ($P = 0.024$) and conformity ($P = 0.006$). The variations were also significant in V_{40Gy} ($P = 0.001$) for bladder and V_{40Gy} ($P = 0.018$) for rectum between IM_ENT and VM_ENT plans. However, there were no significant differences in $D_{98\%}$, $D_{2\%}$, DHI for PTV, V_{30Gy} for bladder and bowel, bowel D_{max}, 30%, 70% spill outside target volume but there was significant increase in 40% ($P = 0.003$), and 50% ($P = 0.010$), 60% ($P = 0.037$) spill outside target volume between IM_ENT to VM_ENT plans.

The comparison of IM_ENT+EXT and VM_ENT+EXT plans shows that VMAT plans were better in volumetric coverage ($P = 0.009$), $D_{98\%}$ ($P = 0.003$) and conformity ($P = 0.001$) as compared to the IMRT plans. There were no significant differences in $D_{98\%}$, $D_{2\%}$, $V_{107\%}$, and DHI between IM_ENT+EXT and VM_ENT+EXT. There was no significant variation for V_{30Gy}, V_{40Gy} for bladder and bowel. However, the variations are significant in V_{40Gy} ($P = 0.018$) for rectum and bowel D_{max} ($P = 0.030$) for both plans. There was no significant difference in 30%, 50%, 60%, and 70% spill outside target volume but there was significant decrease in 40% ($P = 0.030$) spill outside target volume between IM_ENT+EXT to VM_ENT+EXT plans. Figure 3 shows the dose distribution given by different optimization methods and techniques.

To validate the optimization methods, we performed phantom measurements for all techniques used in this study. The point doses were well within ± 3% for target, and the variations in avoidance were <±10%.[27,28] Table 4 shows all the phantom measurements and doses from TPS.

Discussion

We compared the plan qualities for IM_Base and IM_ENT. We found that the plans were clinically acceptable with no change in target coverage, minimum dose, and conformity. Although with restrictions of beam entry from particular angles, the plans had increased D_{mean}, maximum dose, and heterogeneity for the target without affecting the OARs and spillage outside the target. When we compared IM_Base with IM_ENT+EXT, the plan's quality deteriorates in all the aspects

Table 3: Comparision of intensity-modulated radiotherapy versus volumetric-modulated arc therapy dosimetric parameters

	Over all IM_Base (mean±SD)	Over all VM_Base (mean±SD)	IM_Base versus VM_Base (*P*)	Over all IM_ENT (mean±SD)	Over all VM_ENT (mean±SD)	IM_ENT versus VM_ENT (*P*)	Over all IM_ENT+EXT (mean±SD)	Over all VM_ENT+EXT (mean±SD)	IM_ENT+EXT versus VM_ENT+EXT (*P*)
PTV									
$V_{95\%}$ (%)	99.65±0.22	99.76±0.23	0.025	99.61±0.24	99.75±0.18	0.005	98.59±0.97	99.00±0.70	0.009
D_{mean} (Gy)	46.02±0.28	46.20±0.58	0.19	46.13±0.29	46.43±0.51	0.04	47.09±0.86	47.19±1.05	0.71
$D_{2\%}$ (near maximum Gy)	46.95±0.58	47.28±0.91	0.09	47.30±0.62	47.68±0.84	0.077	49.03±1.50	49.17±1.75	0.74
$D_{98\%}$ (near minimum Gy)	44.34±0.17	44.36±0.21	0.739	44.27.±0.18	44.34±0.19	0.165	43.10±1.22	43.75±0.62	0.003
DHI	0.06±0.02	0.06±0.02	0.19	0.07±0.02	0.07±0.02	0.23	0.12±0.05	0.11±0.05	0.28
$V_{107\%}$ (cc)	0.15±0.29	4.90±14.21	0.19	0.48±0.68	4.65±13.90	0.024	25.19±31.01	24.08±28.64	0.90
Conformity index	0.996±0.002	0.997±0.002	0.03	0.988±0.190	0.990±0.191	0.006	0.987±0.094	0.992±0.097	0.001
Bladder									
V_{30Gy} (%)	73.31±3.75	73.55±6.05	0.87	75.40±4.17	74.77±6.67	0.680	80.56±6.55	80.01±8.65	0.72
V_{40Gy} (%)	54.34±5.14	52.44±7.44	0.107	55.55±4.44	52.40±7.75	0.001	57.63±4.54	58.58±15.06	0.77
Rectum									
V_{30Gy} (%)	66.56±27.23	69.31±29.25	0.06	68.49±28.09	70.57±29.35	0.057	72.75±30.18	72.85±30.45	0.92
V_{40Gy} (%)	43.48±18.32	46.71±20.76	0.009	44.15±18.52	47.26±21.10	0.018	48.22±20.78	53.91±25.54	0.018
Bowel									
V_{30Gy} (cc)	249.37±135.91	293.35±248.60	0.34	132.99±85.93	331.48±358.23	0.25	133.79±96.64	344.24±336.7	0.44
V_{40Gy} (cc)	2.16±3.70	2.65±3.86	0.40	2.19±3.67	2.52±3.89	0.51	1.83±2.67	3.03±4.23	0.22
D_{max} (Gy)	46.17±2.05	46.20±2.38	0.95	46.34±2.11	46.40±2.71	0.914	47.05±2.50	48.61±3.16	0.03
Body-PTV									
$V_{70\%}$ (l)	1.848±0.540	1.749±0.974	0.46	1.859±0.523	1.687±0.814	0.078	2.179±0.689	2.260±1.497	0.73
$V_{60\%}$ (l)	3.090±0.914	2.832±1.440	0.11	3.043±0.824	2.757±1.222	0.037	3.512±1.058	3.481±1.988	0.91
$V_{50\%}$ (l)	5.119±1.451	4.619±2.153	0.04	5.049±1.295	4.485±1.821	0.007	5.640±1.576	5.321±2.616	0.34
$V_{40\%}$ (l)	7.971±2.464	7.306±3.252	0.01	7.742±2.073	7.015±2.686	0.003	8.568±2.527	7.898±3.434	0.03
$V_{30\%}$ (l)	11.542±3.438	10.879±4.424	0.194	10.941±2.850	10.313±3.605	0.11	11.696±3.277	11.128±4.294	0.25

$V_{x\%}$: Volume receiving x% of prescription dose, Dmax: Maximum dose to a volume, Dmean: Mean dose, V_{xGy}: Volume receiving x Gy of radiation, $D_{x\%}$: Dose receiving x% of volume, PTV: Planning target volume, DHI: Dose homogeneity index, EXT: Exit, ENT: Entry, IM: Intensity-modulated, VM: Volumetric-modulated, SD: Standard deviation

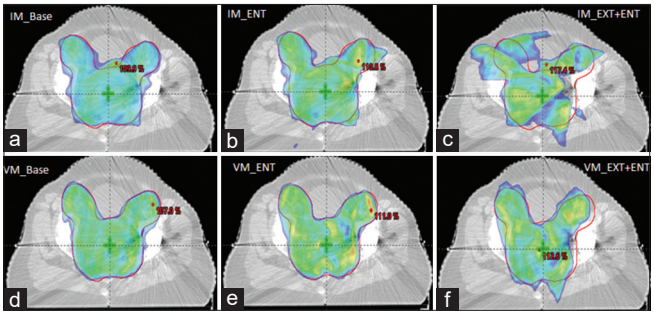

Figure 3: (a-c). The dose distribution of intensity-modulated radiotherapy plans with different optimization methods and (d-f). Were the dose colorwash for volumetric-modulated arc therapy plans

of the target's coverage, homogeneity, and other parameters. The drastic change in the plan quality was because of the decreased degree of freedom for optimization for the IM_ENT+EXT plans. Comparing the constrained plans IM_ENT and IM_ENT+EXT, the IM_ENT plans were found superior in target dose parameters, but there was little change in OAR doses and spill doses.[29]

Evaluation of the VMAT plans also showed similar observations VM_Base and VM_ENT plans were similar in all aspects. VM_Base plans had better plan quality and OAR sparing than VM_ENT+EXT. In VM_ENT, the target volume parameters were comparatively better than VM_ENT+EXT, without appreciable change in OAR and spillage dose.

While comparing the two techniques, IMRT and VMAT keeping the optimization method the same, we found the VMAT plans were better in target coverage and OAR sparing. However, there was not much variation in spillage outside target volume. The dominance of VMAT plans was due to a higher degree of freedom in optimization for VMAT plans than IMRT.

In our study, all comparisons suggested that the optimization method, where only the beam's entry was blocked, was the best approach to dealing with the patients having prosthetic implants. This approach helped the optimizer avoid the perturbed photon dose profile along the beam path. It provided adequate degrees of freedom to the optimizer to give the feasible solutions.[19,30] The optimization method three, which

Table 4: Phantom measurements

Plans\parameters	Techniques	Structure	TPS (CGY)	Measured (CGY)	Percentage difference
Entry dose avoided to implant	IMRT	Target	183.8	182.17	0.89
		Avoidance	81.52	80.28	1.52
	VMAT	Target	180.94	180.3	0.35
		Avoidance	74.5	80.69	−8.31
Dose avoided to implant	IMRT	Target	190.17	188.02	1.13
		Avoidance	35.18	32.07	8.84
	VMAT	Target	185.18	189.49	−2.33
		Avoidance	29.63	27.13	8.44
No shielding of implant	IMRT	Target	179.92	184.06	−2.30
		Avoidance	116.748	115.17	1.35
	VMAT	Target	181.8	181.1	0.39
		Avoidance	109.12	103.84	4.84

IMRT: Intensity-modulated radiotherapy, VMAT: Volumetric-modulated arc therapy, TPS: Treatment planning systems

completely avoids the implants, results in heterogeneous dose distribution because the optimizer had a minimal scope of beam modulation to provide the optimal solution for the target and OARs. Method two avoided the backscatter, but the study shows less significant spillage outside the target than method three. Method one did not consider any constraints on the entry and exit of the beam. This method included photon profiles for dose calculations, perturbed and unperturbed (without being impacted by the implant), which may lead to higher variation in dose delivery parameters. Therefore, we must avoid using this method for metallic implant patients.

The IM_ENT plans had provided similar dose distribution described in the study conducted by Kung *et al*. where they used nine equally spaced fields avoiding the implant to plan the prostate cases.[16] R. Prabhakar *et al*. conclude in their study that the two arcs VMAT plans with avoidance structure are the best approach for hip prosthesis patients.[15] Our results also show consistency with them. The study of Koutsouvelis *et al*. investigated the need for the avoidance sector in hip prosthesis patients, and they concluded that the avoidance sector was not necessary for VMAT planning in these patients.[31] We also observed the same when we evaluated the parameters for VM_Base and VM_ENT. We only blocked the implant in method two without creating any extra structure around it therefore, method two was the midway approach between the studies conducted by Prabhakar *et al*. and Koutsouvelis *et al*. We can quickly implement this method for planning prosthesis cases.

There were many publications on the planning of hip implant patients.[4,16,32,33] For the hip prosthesis patients, the optimization strategies used in our study were less explored. We used seven fields for IMRT plans and two arcs for the VMAT plans. The two options used in this study are part of modern TPS. The options help the planner create templates and write scripts to automate the planning of the patients having metallic implants. The planners can efficiently utilize the characteristics of metallic implant the ED or HU number to discriminate from the human body. Different researchers used metal artifact reduction algorithm, maximum transmission algorithm, and other simulation studies to reduce artifacts in hip prosthesis patients.[34,35] The absence of actual metallic implant in phantom, artifact reduction software and the effect of positional variation in implant are a few limitations of our study. As future prospects the other sites and effects of Monte Carlo simulation studies should be carried out to validate these methods.

Conclusion

The best approach is to plan hip prosthesis cases with blocked entry of radiation beam for IMRT and VMAT. However, VMAT omits these requirements. Template-based IMRT and VMAT plans can be utilized to plan the patients having prosthesis in the femur and physical characteristics of implants may help implement automated methods.

Acknowledgments

The authors thank the management of Rajiv Gandhi Cancer Institute and Research Centre in New Delhi, India, for their continued support and encouragement to complete this research work.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Global Cancer Observatory. Available from: https://gco.iarc.fr/. [Last accessed on 2022 Jan 20].
2. Guise TA. Bone loss and fracture risk associated with cancer therapy. Oncologist 2006;11:1121-31.
3. Maillefert JF, Sibilia J, Michel F, Saussine C, Javier RM, Tavernier C. Bone mineral density in men treated with synthetic gonadotropin-releasing hormone agonists for prostatic carcinoma. J Urol 1999;161:1219-22.
4. Bhushan M, Tripathi D, Yadav G, Kumar L, Dewan A, Kumar G. Effect of hip prosthesis on photon beam characteristics in radiological physics. Asian Pac J Cancer Prev 2020;21:1731-8.
5. Roth TD, Maertz NA, Parr JA, Buckwalter KA, Choplin RH. CT of the

hip prosthesis: Appearance of components, fixation, and complications. Radiographics 2012;32:1089-107.
6. Barrett JF, Keat N. Artifacts in CT: Recognition and avoidance. Radiographics 2004;24:1679-91.
7. De Man B, Nuyts J, Dupont P, Marchal G, Suetens P. Metal streak artifacts in X-ray computed tomography: 4 simulation study. IEEE Transactions on Nuclear Science 1999;3:691-6. DOI:10.1109/23.775600.
8. Acquah GF, Kyeremeh PO, Hasford F, Boadu M, Sosu EK, Inkoom S. Evaluation of metallic implant artifact on photon beam calculation algorithms using a CIRS thorax phantom. New Pub 2019;11:347-9.
9. Çatli S. High-density dental implants and radiotherapy planning: Evaluation of effects on dose distribution using pencil beam convolution algorithm and Monte Carlo method. J Appl Clin Med Phys 2015;16:46-52.
10. Schild SE, Robinow JS, Casale HE, Bellefontaine LP, Buskirk SJ. Radiotherapy treatment planning for prostate cancer in patients with prosthetic hips. Med Dosim 1992;17:83-6.
11. Reft C, Alecu R, Das IJ, Gerbi BJ, Keall P, Lief E, *et al.* Dosimetric considerations for patients with HIP prostheses undergoing pelvic irradiation. Report of the AAPM Radiation Therapy Committee Task Group 63. Med Phys 2003;30:1162-82.
12. Das IJ, Kahn FM. Backscatter dose perturbation at high atomic number interfaces in megavoltage photon beams. Med Phys 1989;16:367-75.
13. Gullane PJ. Primary mandibular reconstruction: Analysis of 64 cases and evaluation of interface radiation dosimetry on bridging plates. Laryngoscope 1991;101:1-24.
14. Parenica HM, Mavroidis P, Jones W, Swanson G, Papanikolaou N, Stathakis S. VMAT optimization and dose calculation in the presence of metallic hip prostheses. Technol Cancer Res Treat 2019;18:1533033819892255.
15. Prabhakar R, Kumar M, Cheruliyil S, Jayakumar S, Balasubramanian S, Cramb J. Volumetric modulated arc therapy for prostate cancer patients with hip prosthesis. Reports Pract Oncol Radiother 2013;18:209-13.
16. Kung JH, Reft H, Jackson W, Abdalla I. Intensity-modulated radiotherapy for a prostate patient with a metal prosthesis. Med Dosim 2001;26:305-8.
17. Ezzell GA, Galvin JM, Low D, Palta JR, Rosen I, Sharpe MB, *et al.* Guidance document on delivery, treatment planning, and clinical implementation of IMRT: Report of the IMRT Subcommittee of the AAPM Radiation Therapy Committee. Med Phys 2003;30:2089-115.
18. Kumar L, Kishore V, Bhushan M, Kumar P, Chaudhary RL. Dosimetric impact of Acuros XB on cervix radiotherapy using RapidArc technique: A dosimetric study. Rep Pract Oncol Radiother 2021;26:582-9.
19. Parenica HM, Ford JR, Mavroidis P, Li Y, Papanikolaou N, Stathakis S. Treatment planning dose accuracy improvement in the presence of dental implants. Med Dosim 2019;44:159-66.
20. Bhushan M, Tripathi D, Yadav G, Kumar L, Chowdhary RL, Pahuja AK, *et al.* Feasibility of Monte-Carlo algorithm in comparison with collapse-cone dose calculation algorithm of a commercial treatment planning system in the presence of high-density metallic implant: A dosimetric study. J Egypt Natl Canc Inst 2021;33:2.
21. Pötter R, Tanderup K, Kirisits C, de Leeuw A, Kirchheiner K, Nout R, *et al.* The EMBRACE II study: The outcome and prospect of two decades of evolution within the GEC-ESTRO GYN working group and the EMBRACE studies. Clin Transl Radiat Oncol 2018;9:48-60.
22. Citing R | An Introduction to R. Available from: https://intro2r.com/citing-r.html. [Last accessed on 2022 Jan 21].
23. Statistics – Mathematical Statistics Functions – Python 3.10.2 Documentation. Available form: https://docs.python.org/3/library/statistics.html. [Last accessed on 2022 Jan 21].
24. Menzel HG. The international commission on radiation units and measurements. J ICRU 2010;10:1-106.
25. Lomax NJ, Scheib SG. Quantifying the degree of conformity in radiosurgery treatment planning. Int J Radiat Oncol Biol Phys 2003;55:1409-19.
26. Kumar L, Yadav G, Kishore V, Bhushan M, Gairola M, Tripathi D. Validation of the RapidArc delivery system using a volumetric phantom as per task group report 119 of the American association of physicists in medicine. J Med Phys 2019;44:126-34.
27. Miften M, Olch A, Mihailidis D, Moran J, Pawlicki T, Molineu A, *et al.* Tolerance limits and methodologies for IMRT measurement-based verification QA: Recommendations of AAPM Task Group No. 218. Med Phys 2018;45:e53-83.
28. Kry SF, Bednarz B, Howell RM, Dauer L, Followill D, Klein E, *et al.* AAPM TG 158: Measurement and calculation of doses outside the treated volume from external-beam radiation therapy. Med Phys 2017;44:e391-429.
29. Kumar G, Bhushan M, Kumar L, Kishore V, Raman SK. Dosimetric evaluation of low-dose spillage volumes for head and neck cancer using intensity-modulated radiation therapy and volumetric modulated arc therapy treatment techniques. Prog Med Phys 2021;32:70-81.
30. Huang JY, Followill DS, Howell RM, Liu X, Mirkovic D, Stingo FC, *et al.* Approaches to reducing photon dose calculation errors near metal implants. Med Phys 2016;43:5117.
31. Koutsouvelis N, Dipasquale G, Rouzaud M, Dubouloz A, Nouet P, Jaccard M, *et al.* Bilateral metallic hip implants: Are avoidance sectors necessary for pelvic VMAT treatments? Z Med Phys 2021;31:420-7.
32. Zhao S, Robertson DD, Wang G, Whiting B, Bae KT. X-ray CT metal artifact reduction using wavelets: An application for imaging total hip prostheses. IEEE Trans Med Imaging 2000;19:1238-47.
33. Ziemann C, Stille M, Cremers F, Buzug TM, Rades D. Improvement of dose calculation in radiation therapy due to metal artifact correction using the augmented likelihood image reconstruction. J Appl Clin Med Phys 2018;19:227-33.
34. Shen ZL, Xia P, Klahr P, Djemil T. Dosimetric impact of orthopedic metal artifact reduction (O-MAR) on Spine SBRT patients. J Appl Clin Med Phys 2015;16:106-16.
35. Lee MJ, Kim S, Lee SA, Song HT, Huh YM, Kim DH, *et al.* Overcoming artifacts from metallic orthopedic implants at high-field-strength MR imaging and multi-detector CT. Radiographics 2007;27:791-803.