Original Article

Dosimetric Impact of Prescription Point Placement in Heterogeneous Medium for Conformal Radiotherapy Dose Calculation with Various Algorithms

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Abstract

Objective: The aim of the study is to compare the accuracy of dose calculation for different dose calculation algorithms with different prescription points (air, tissue, air–tissue interface in carcinoma lung patients and bone, tissue, and bone–tissue interface in carcinoma buccal Mucosa tumors). **Materials and Methods:** Forty-one patients with carcinoma lung and buccal mucosa were retrospectively selected for this study. A three-dimensional conformal radiotherapy reference plan was created using the prescription point in the tissue with Monte Carlo (MC) algorithms for both the groups of patients. The reference plan was modified by changing the prescription point and algorithms in the tissue, air, air–tissue interface for lung patients and tissue, bone, and bone–tissue interface for buccal mucosa patients. The dose received by the target volume and other organs at risk (OAR) structures was compared. To find out the statistical difference between different prescription points and algorithms, the statistical tests were performed with repeated measures ANOVA. **Results:** The target volume receiving 95% dose coverage in lung patients decreased to −3.08%, −5.75%, and −1.87% in the dose prescription point at the air–tissue interface with the dose calculation algorithms like MC, collapsed cone (CC), and pencil beam (PB), respectively, compared to that of the MC tissue. Spinal cord dose was increased in the CC and PB algorithms in all prescription points in patients with lung and buccal mucosa. OAR dose calculated by PB in all prescription points showed a significant deviation compared to MC tissue prescription point. **Conclusion:** This study will help demonstrate the accuracy of dose calculation for the different dose prescription points with the different treatment algorithms in radiotherapy treatment planning.

Keywords: Air–tissue interface, bone–tissue interface, dose calculation algorithms, dose prescription point, weight point

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Introduction

The goal of radiotherapy is to deliver an accurate dose to the tumor according to the dose prescription and to irradiate the surrounding normal structures with a low dose.[1] In the last 30 years, various advanced modalities have been introduced to treat cancer patients using radiotherapy.[2] Treatment planning system (TPS) plays an important role in planning radiotherapy in these advanced techniques.[3] The accuracy of dose calculation in the radiotherapy TPS is based on the algorithms used for dose calculation.[4] Therefore, it is important to understand the principles and limitations of these different dose calculation algorithms.[5] The human body is composed of various heterogeneous materials such as soft tissue, bone, fat, lung, and oral cavity.[6] Due to the heterogeneity of human anatomy, the radiation interaction is different for each of these organs. To more accurately calculate dose in a heterogeneous medium, more accurate dose calculation algorithms are needed.[3]

Currently, there are many dose calculation algorithms for radiotherapy treatment planning. The beam modeling and dose

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calculation characteristics are different for each algorithm, so the accuracy of dose calculation is different for each algorithm.[7] Several studies have shown the accuracy of dose calculation with different TPSs in a heterogeneous medium.[8-12] They have shown that the accuracy of dose calculation with Monte Carlo (MC) algorithms is more precise and that the Acuros XB (AXB) algorithm will be comparable to MC algorithms in heterogeneous dose calculation. The different phantom studies performed have shown the different accuracy of dose calculation.[13-16]

In the treatment areas, which are more heterogeneous, the dose calculation strongly depends on the algorithms.[8] Lung cancer is the most common cancer in the world in both women and men.[17] Density differences are greater in lung tissue/tumor due to the presence of air and tissue.[18] Air has a lower Hounsfield unit (HU) than tissue and tumors. Similarly, in carcinomas of the buccal mucosa, the density of the treated tumor/soft tissue varies due to the underlying bone in the treatment field. The bone has a high density compared to the HU value of the tissue. In this scenario, the different dose calculation algorithms have differences in their characteristics. The calculated dose differs more in the heterogenous medium due to the density variation in the prescription point and in turn varies with the different dose calculation algorithms.[2,7,10,19] The dose prescription point also plays an important role in calculating the dose to tumors, treatment monitor units (MUs), and dose distribution. All of these affect the hot spot and cold spot within the treatment area.[20] This study will help to show the changes in dose distribution for the different dose prescription points with the different treatment algorithms in radiotherapy treatment planning.

Materials and Methods

Selection of patients

This clinical study was performed in accordance with the law and the provisions of a study protocol. Data collection and analysis were approved by the hospital's institutional review board (IRB), and the IRB waived informed consent for participants. Forty-one patients treated with the three-dimensional conformal radiotherapy (3DCRT) technique at our center from January 2014 to March 2023 were retrospectively selected for this study. The first group consisted of twenty patients with primary lung cancer who were treated with 66 Gy in 33 fractions using the 3DCRT technique. This group includes 16 male patients and 4 female patients. The planning target volume (PTV) for this group of patients was 385.82 ± 188.45 cm^3. The second group consisted of 21 patients with carcinoma of the buccal mucosa treated with 60 Gy in 30 fractions using the 3DCRT technique. This group includes 14 male patients and 7 female patients. The PTV for this group of patients was 413.85 ± 136.26 cm^3.

Computed tomography simulation and contouring

The first group of patients with lung carcinoma was placed in the supine position with a wing board for immobilization. The second group of patients with carcinoma of the buccal mucosa was positioned supine with a head-neck base plate and immobilized with a 5-pointer thermoplastic mask. All patients were imaged using general electric computed tomography (CT) scanner with a slice thickness of 5 mm. The kilo voltage potential for CT simulation was 125 KVp for patients with carcinoma lung and 100 KVp for patients with carcinoma buccal mucosa. The origins were placed on the sternum notch for carcinoma lung patients and near the mandible for buccal mucosa patients, respectively. A certified radiation oncologist contoured the critical structure and target volume in accordance with the International Commission on Radiation Units (ICRU 62) and measurements protocol for both patient groups.[21]

Treatment planning

Three prescription points were created for all lung cancer patients. The first prescription point was placed in the center axis of the beam on the tissue. The second prescription point was placed at the center axis of the beam on the air. The third prescription point was placed at the center axis of the beam on the air–tissue interface. Figure 1 shows the three prescription points created on the tissue, air, and air–tissue interface at the center axis of the beam for carcinoma lung patients.

For the first group of lung cancer patients, the reference 3DCRT treatment plan was created using Monaco™ V5.51 TPS with the MC dose calculation algorithm and the beam prescription points were placed on the central axis of the beam in the tissue. The beam isocenter were placed at the center of the PTV and the beam energy used for this study was 6 MV. The beam arrangement for this group of patients consisted of two opposite beams, with each beam carrying 50% of the weightage. The prescribed dose for this group was 66 Gy in 33 fractions. A grid size of 3 mm was used for the dose calculation. The reference treatment plan was modified (without changing the beam angle, beam shape, number of beams, and prescription point), changing only the dose prescription point at the air and air–tissue interface using the MC algorithms. The reference treatment plan was modified by changing the dose calculation algorithms to collapsed cone (CC) and pencil beam (PB) algorithms for all three prescription points. A total of 180 treatment plans were generated for carcinoma lung patients with different dose calculation algorithms and different prescription points.

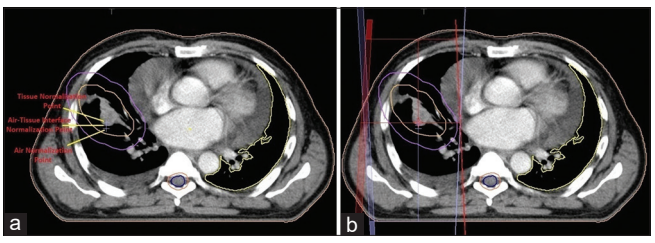

Figure 1: (a) Three prescription points were created on the tissue, air, and air-tissue interface for carcinoma lung patients, (b) Shows all three prescription points placed on the central axis of the beam for carcinoma lung patient

Three prescription points were created in the carcinoma buccal mucosa patients, with the first prescription point placed on the center axis of the beam on the tissue. The second prescription point was placed at the center axis of the beam on the bone. The third prescription point was maintained at the center axis of the beam on the bone–tissue interface.

Figure 2 shows the three prescription points created on the tissue, bone, and bone–tissue interface in the central axis of the beam for the patient with carcinoma of the buccal mucosa. For the second group of patients, the reference 3DCRT treatment plan was created using Monaco™ V5.51 TPS with MC dose calculation algorithm and the beam prescription points were placed on the central axis of the beam in the tissue. The beam isocenter were placed at the center of the PTV and the beam energy used for this study was 6 MV. The beam arrangement for this group of patients consisted of two opposite beams, with each beam carrying 50% of the weightage. The prescribed dose for this group was 60 Gy in 30 fractions. A grid size of 3 mm was used for the dose calculation. The reference treatment plan was modified by changing only the dose prescription at the bone and bone–tissue interface using the MC algorithm. The reference treatment plan was modified by changing the dose calculation algorithms to CC algorithms and PB algorithms for all three prescription points. A total of 189 treatment plans were generated for patients with carcinoma of the buccal mucosa using different dose calculation algorithms and different normalization points. For both groups of patients, the coverage of the PTV achieved at least 95% of the prescribed dose to 95% of the PTV volume, and V107% of the prescribed dose remained below 1% of the PTV volume for the reference treatment plan. Dose to critical organs was kept as low as possible to avoid exceeding the tolerance level.

Plan evaluation index

According to the ICRU report, dose coverage to target was analyzed for both groups of patients with carcinoma of the lung and buccal mucosa.[22]

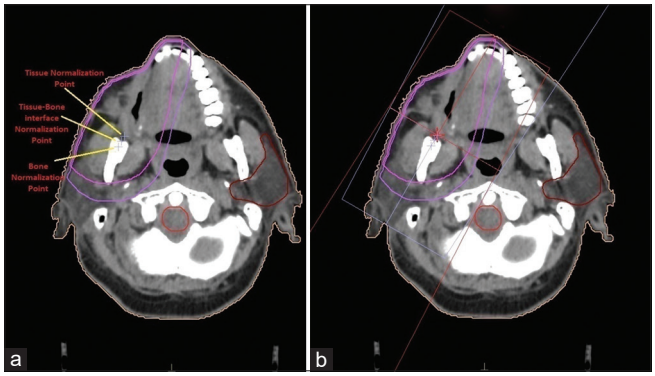

Figure 2: (a) Three prescription points created on the tissue, bone, and bone–tissue for the patient with carcinoma of the buccal mucosa, (b) Shows all three prescription points placed on the central axis of the beam for the patient with carcinoma of the buccal mucosa

For this study, the conformity index (CI) and homogeneity index (HI) were calculated as follows.[23]

CI = VR/VT ……(1)

where,

VR is the volume of the reference dose (95% of the prescribed dose)

VT is the total volume of the target.

The ideal value for CI is "1"

HI = ([D2%]/[D98%])……(2)

where,

D2% represents the dose close to the maximum dose.

D98% represents the dose close to the minimum dose.

The ideal value for HI is "1."

Treatment plan analysis

For both groups of patients, the isodose distributions of 95% and 107% of the prescribed dose for all treatment plans with different dose calculation algorithms and different prescription point treatment plans were compared with the reference MC tissue prescription point treatment plan. The dose–volume histogram (DVH) was used to analyze each treatment plan for lung cancer patients. The PTV dose distribution, the mean dose to the PTV, the treatment MU, V95%, V107%, the CI, the HI, the spinal cord, the planning organ at risk volume (PRV) spinal cord, the mean dose of the heart, the 50% volume dose of the heart, the mean dose of the ipsilateral lung– PTV, the cumulative mean lung dose, and the cumulative 20% lung dose were compared with the MC-tissue reference plan for all treatment plans.

Similarly, DVH were used to analyze each treatment plan for patients with carcinoma of the buccal mucosa. PTV dose distribution, mean dose to PTV, treatment MU, V95%, V107%, CI, HI, spinal cord, PRV spinal cord, brainstem, mean parotid gland dose, and 50% volume parotid gland dose were compared for all treatment plans with the MC-tissue reference plan. The mean difference and percentage deviation were calculated from MC tissue with different treatment plans for patients with lung and buccal mucosa.[4]

Statistical analysis

To find out the statistical difference between the MC tissue with other prescription points and algorithms, the statistical tests ANOVA with repeated measures and Bonferroni pairwise comparisons were performed for both carcinoma lung and buccal mucosa patients.[4] For carcinoma lung patients, the statistical analysis was performed for MC-tissue with MC-air, MC air–tissue interface, CC-tissue, CC-air, CC air–tissue interface, PB-tissue, PB-air, and PB air–tissue interface to the target volumes and OAR's. Similarly, for the carcinoma buccal mucosa patients, the statistical analysis was performed to MC-tissue with MC-bone, MC

bone–tissue interface, CC-tissue, CC-bone, CC bone–tissue interface, PB-tissue, PB-bone, and PB bone–tissue interface to the target volumes and OAR's. P <0.05 was considered statistically significant.

Results

Carcinoma lung patients

The average mean difference was calculated from the reference MC-tissue dose prescription point treatment plan with other prescription point treatment plans and dose calculation algorithms. The percentage of deviation was calculated for all parameters between the reference plan of MC-tissue dose prescription point and the other different prescription point using MC, CC, and PB. Table 1 shows the percentage deviation and mean difference for different dose calculation algorithms and different dose prescription points compared to the reference MC-tissue dose calculation algorithms for lung cancer patients. The percentage difference in V95% dose is −3.08%, −5.75%, and −1.87% for the dose prescription points MC air–tissue interface, CC air–tissue interface, and PB air–tissue interface, respectively, compared to MC-tissue dose prescription point. The mean dose difference for the spinal cord was 4.73 Gy, 4.99 Gy, 4.65 Gy, 1.56 Gy, 1.64 Gy, and 1.62 Gy for CC-tissue, CC-air, CC air–tissue interface, PB-tissue, PB-air, and PB air–tissue interface, respectively. MC algorithm with different dose prescription points, the percentage of deviation was <3.5% compared with the MC tissue prescription point for both the target and OARs. CC algorithms with different prescription points showed that the percentage deviation was <5.0% compared with the MC-tissue dose prescription point for target and OARs, except for spine, PRV spine, and 50% volume of heart. The PB algorithm with the different dose prescription points showed that the deviation was <3.0% for the target volume compared with the MC-tissue normalization treatment plan. The PB algorithm with all dose normalization points of the treatment plan showed more than 5.0% deviation when compared with the MC-tissue treatment plan for PRV spinal cord (1cc), mean cardiac dose, cumulative mean lung dose, and cumulative volume receiving 5 Gy of lung dose.

Figure 3 shows the percentage of deviation for different dose calculation algorithms and different dose prescription points compared to the reference MC-tissue dose calculation algorithms for the target volumes of lung cancer patients. Figure 4 shows that the percentage deviation for different dose calculation algorithms and different dose prescription points compared with the reference MC-tissue dose calculation algorithms for the carcinoma lung cancer patient's OAR volumes. Table 2 shows the results of the statistical analysis ANOVA for different dose calculation algorithms and different dose prescription points compared with the reference MC-tissue dose calculation algorithms for lung cancer patients.

Carcinoma buccal mucosa

The 107% dose distribution in all treatment plans for bone prescription point (MC-bone, CC-bone, and PB-bone) showed that there was more spillage in the axial slices compared to MC-tissue dose prescription point treatment plan. Table 3 shows the percentage of deviation and the mean difference for different dose calculation algorithms and different dose prescription points compared with the reference MC-tissue dose calculation algorithms for patients with carcinoma of the buccal mucosa. MC dose calculation algorithms with different prescription points results showed that <2% of deviation was present when compared with the MC tissue prescription point treatment plan for treatment MU, mean dose, CI, HI, spine max dose, PRV spine (1cc), ipsilateral parotid mean dose, 50% volume dose of the ipsilateral parotid and Brain Stem max dose.

Figure 5 shows that the percentage deviation for the different dose calculation algorithms and the different dose prescription point compared with the reference MC-tissue dose calculation algorithms for the target volumes of the patient with carcinoma of the buccal mucosa. The results

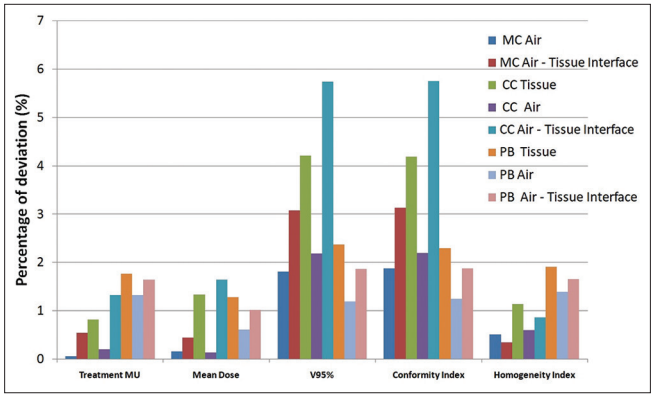

Figure 3: Percentage of deviation for different dose calculation algorithms and different dose prescription points compared to the reference Monte Carlo tissue dose calculation algorithms for the target volumes of lung cancer patients. MC: Monte Carlo, CC: Collapsed cone, PB: Pencil beam

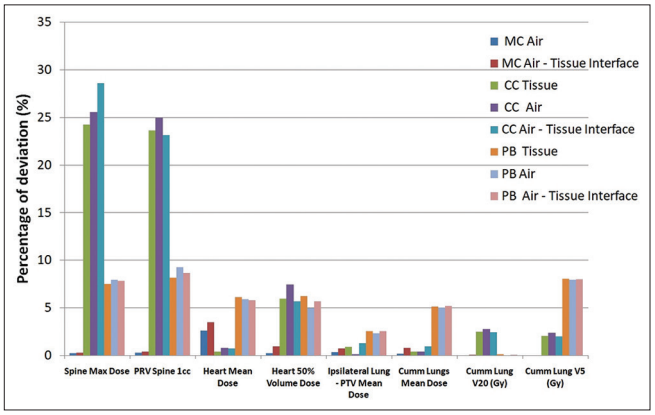

Figure 4: Percentage deviation for different dose calculation algorithms and different dose prescription points compared with the reference Monte Carlo tissue dose calculation algorithms for the carcinoma lung cancer patient's organ at risk volumes. MC: Monte Carlo, CC: Collapsed cone, PB: Pencil beam

Table 1: The percentage of deviation and mean difference for different dose calculation algorithms and different dose prescription point compared with the reference Monte Carlo tissue dose calculation algorithms for carcinoma lung patients

Parameters	MC tissue versus MC air		MC tissue versus MC air - tissue interface		MC tissue versus CC tissue		MC tissue versus CC air	
	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation
Treatment MU	−0.178	−0.07	−1.415	−0.55	−2.100	−0.82	0.544	0.21
Mean dose (Gy)	0.111	0.17	−0.294	−0.45	−0.886	−1.34	−0.086	−0.14
V95%	−1.739	−1.82	−2.941	−3.08	−4.027	−4.22	−2.088	−2.19
CI	−0.018	−1.88	−0.030	−3.14	−0.040	−4.19	−0.021	−2.20
HI	0.006	0.52	0.004	0.35	−0.013	−1.14	−0.007	−0.61
Spine max dose (Gy)	0.047	0.27	−0.065	−0.32	4.731	24.25	4.996	25.59
PRV spine 1cc (Gy)	0.062	0.32	−0.077	−0.42	4.506	23.65	4.754	24.96
Heart mean dose (Gy)	−0.476	−2.65	−0.630	−3.48	−0.075	−0.44	0.152	0.83
Heart 50% volume dose (Gy)	0.027	0.26	−0.111	−0.94	0.697	6.00	0.869	7.46
Ipsilateral lung - PTV mean dose (Gy)	−0.115	−0.38	−0.240	−0.77	−0.293	−0.96	0.065	0.19
Cumm lungs mean dose (Gy)	−0.024	−0.19	−0.116	−0.78	−0.074	−0.45	0.066	0.45
Cumm lung V20 (Gy)	0.009	0.04	−0.022	−0.08	0.604	2.54	0.666	2.79
Cumm lung V5 (Gy)	0.022	0.06	0.003	0.03	0.651	2.11	0.747	2.44
Parameters	**MC tissue versus CC air - tissue interface**		**MC tissue versus PB tissue**		**MC tissue versus PB air**		**MC tissue versus PB air - tissue interface**	
	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation
Treatment MU	−3.125	−1.33	−4.619	−1.77	−3.421	−1.33	−4.235	−1.65
Mean dose (Gy)	−1.097	−1.65	−0.852	−1.29	−0.409	−0.62	−0.672	−1.02
V95%	−5.491	−5.75	−2.272	−2.38	−1.148	−1.20	−1.793	−1.87
CI	−0.055	−5.76	−0.022	−2.30	−0.012	−1.26	−0.018	−1.88
HI	−0.010	−0.87	−0.022	−1.92	−0.016	−1.40	−0.019	−1.66
Spine max dose (Gy)	4.654	28.63	1.564	7.53	1.644	7.96	1.621	7.85
PRV spine 1cc (Gy)	4.414	23.17	1.562	8.20	1.774	9.30	1.660	8.72
Heart mean dose (Gy)	−0.137	−0.77	−1.105	−6.14	−1.064	−5.91	−1.057	−5.86
Heart 50% volume dose (Gy)	0.666	5.75	−0.732	−6.26	−0.581	−4.97	−0.671	−5.75
Ipsilateral lung - PTV mean dose (Gy)	−0.417	−1.34	−0.800	−2.56	−0.737	−2.37	−0.795	−2.56
Cumm lungs mean dose (Gy)	−0.150	−0.97	−0.795	−5.18	−0.778	−5.05	−0.813	−5.25
Cumm lung V20 (Gy)	0.593	2.49	−0.044	−0.17	−0.009	−0.04	−0.029	−0.13
Cumm lung V5 (Gy)	0.624	2.05	−2.492	−8.09	−2.460	−7.99	−2.480	−8.06

MC: Monte Carlo, CC: Collapsed cone, MU: Monitor unit, PB: Pencil beam, PRV: Planning organ at risk volume, PTV: Planning target volume, CI: Conformity index, HI: Homogeneity index

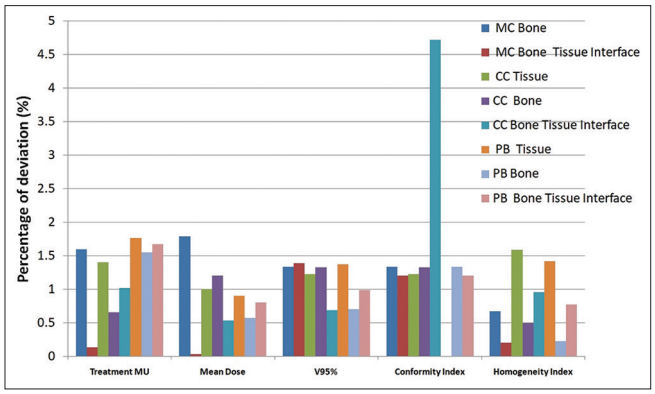

Figure 5: Percentage deviation for the different dose calculation algorithms and the different dose prescription point compared with the reference Monte Carlo tissue dose calculation algorithms for the target volumes of the patient with carcinoma of the buccal mucosa. MC: Monte Carlo, CC: Collapsed cone, PB: Pencil beam

of the CC and PB algorithms with different prescription points for the treatment plans show that the deviations in the target volume parameters are <2.0%, except for the CC bone–tissue interface treatment plans compared with the MC-tissue prescription treatment plans. CC dose calculation algorithm with different dose prescription points showed that the percentage deviations were more than 5.0% for all OAR volumes compared to the MC-tissue dose prescription plans. The results of the PB algorithms with the different dose normalization plans also showed that the deviation compared with the MC-tissue dose prescription plan was more than 5.0% for all OARs except the maximum brainstem. Figure 6 shows the percentage deviation for the different dose calculation algorithms and the different dose prescription points compared with the reference MC-tissue dose calculation algorithms for the carcinoma buccal mucosa patients OAR volumes. Table 4 shows that ANOVA statistical

Table 2: The ANOVA statistical analysis *P* value for different dose calculation algorithms and different dose prescription point compared with the reference Monte Carlo tissue dose calculation algorithms for carcinoma lung patients

Parameters	*P* (ANOVA)	MC tissue versus MC air		MC tissue versus MC air - tissue interface		MC tissue versus CC tissue		MC tissue versus CC air	
		Mean difference	*P*	Mean difference	*P*	Mean difference	*P*	Mean difference	*P*
Treatment MU	<0.001*	−0.178	1.000	−1.415	1.000	−2.100	0.727	0.544	1.000
Mean dose (Gy)	<0.001*	0.111	1.000	−0.294	1.000	−0.886	0.162	−0.086	1.000
V95%	0.140	−1.739	1.000	−2.941	1.000	−4.027	1.000	−2.088	1.000
V107%	0.001*	2.597	1.000	0.362	1.000	−2.227	0.064	−0.136	1.000
CI	0.141	−0.018	1.000	−0.030	1.000	−0.040	1.000	−0.021	1.000
HI	<0.001*	0.006	0.005*	0.004	0.008*	−0.013	0.098	−0.007	1.000
Spine max dose (Gy)	<0.001*	0.047	1.000	−0.065	1.000	4.731	0.002*	4.996	0.002*
PRV spine 1cc (Gy)	<0.001*	0.062	1.000	−0.077	1.000	4.506	0.001*	4.754	0.001*
Heart mean dose (Gy)	0.013*	−0.476	1.000	−0.630	1.000	−0.075	1.000	0.152	1.000
Heart 50% volume dose (Gy)	0.001*	0.027	1.000	−0.111	1.000	0.697	1.000	0.869	0.971
Ipsilateral lung - PTV mean dose (Gy)	<0.001*	−0.115	1.000	−0.240	1.000	−0.293	1.000	0.065	1.000
Cumm lungs mean dose (Gy)	<0.001*	−0.024	1.000	−0.116	1.000	−0.074	1.000	0.066	1.000
Cumm lung V20 (Gy)	<0.001*	0.009	1.000	−0.022	1.000	0.604	<0.001*	0.666	<0.001*
Cumm lung V5 (Gy)	<0.001*	0.022	1.000	0.003	1.000	0.651	<0.001*	0.747	<0.001*

Parameters	MC tissue versus CC air - tissue interface		MC tissue versus PB tissue		MC tissue versus PB air		MC tissue versus PB air - tissue interface	
	Mean difference	*P*	Mean difference	*P*	Mean difference	*P*	Mean difference	*P*
Treatment MU	−3.125	0.088	−4.619	0.004*	−3.421	0.164	−4.235	0.011*
Mean dose (Gy)	−1.097	0.036*	−0.852	0.114	−0.409	1.000	−0.672	0.350
V95%	−5.491	1.000	−2.272	1.000	−1.148	1.000	−1.793	1.000
V107%	−2.266	0.057*	−2.099	0.200	−0.715	1.000	−1.822	0.923
CI	−0.055	1.000	−0.022	1.000	−0.012	1.000	−0.018	1.000
HI	−0.010	0.534	−0.022	<0.001*	−0.016	0.096	−0.019	0.007*
Spine max dose (Gy)	4.654	0.003*	1.564	1.000	1.644	1.000	1.621	1.000
PRV spine 1cc (Gy)	4.414	0.001*	1.562	1.000	1.774	0.610	1.660	0.727
Heart mean dose (Gy)	−0.137	1.000	−1.105	1.000	−1.064	1.000	−1.057	1.000
Heart 50% volume dose (Gy)	0.666	1.000	−0.732	<0.001*	−0.581	0.082	−0.671	0.003*
Ipsilateral lung - PTV mean dose (Gy)	−0.417	0.167	−0.800	<0.001*	−0.737	<0.001*	−0.795	<0.001*
Cumm lungs mean dose (Gy)	−0.150	1.000	−0.795	<0.001*	−0.778	<0.001*	−0.813	<0.001*
Cumm lung V20 (Gy)	0.593	<0.001*	−0.044	1.000	−0.009	1.000	−0.029	1.000
Cumm lung V5 (Gy)	0.624	<0.001*	−2.492	<0.001*	−2.460	<0.001*	−2.480	<0.001*

*Statistically significant. MC: Monte Carlo, CC: Collapsed cone, MU: Monitor unit, PB: Pencil beam, PRV: Planning organ at risk volume, PTV: Planning target volume, CI: Conformity index, HI: Homogeneity index

analysis results for the different dose calculation algorithms and the different dose prescription point compared with the reference MC-tissue dose calculation algorithms for patients with carcinoma of the buccal mucosa.

Discussion

The aim of the study is to compare the accuracy of dose calculation for different dose calculation algorithms with different prescription points. Based on the percentage deviation, statistical analysis of the mean deviation, and individual patient dose distributions, it is evident that there are significant differences between the various dose calculation algorithms with different prescription points for both carcinoma lung and buccal mucosa patients.

In lung cancer patients, the results showed that when dose prescription points were placed at the air–tissue interface, the isodose distribution and V95% dose were reduced in all three dose calculation algorithms compared with the MC tissue dose prescription point. The number of electrons generated and absorbed near the interface of low and high media density tissues affects the dose buildup.[2] Again, the dose to the lung is underestimated if the effects of electronic disequilibrium are not considered. Li *et al*. explained the effects of air cavities on dose calculations, emphasizing that the dose decrease near an air cavity is greater for smaller fields, higher energies, larger air cavities, and shallower water depths.[24] The MC algorithms dose calculation accuracy was more superior for both the target and OAR with different dose normalization points in the heterogeneous

Table 3: The percentage of deviation and mean difference for different dose calculation algorithms and different dose prescription point compared with the reference Monte Carlo tissue dose calculation algorithms for carcinoma buccal mucosa patients

Parameters	MC tissue versus MC bone		MC tissue versus MC bone tissue interface		MC tissue versus CC tissue		MC tissue versus CC bone	
	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation
Treatment MU	4.082	1.60	−0.362	−0.14	−3.605	−1.41	1.677	0.66
Mean dose (Gy)	1.078	1.79	−0.025	−0.04	−0.609	−1.01	0.732	1.21
V95%	1.280	1.34	−1.330	−1.39	−1.173	−1.23	1.271	1.33
CI	0.013	1.34	−0.012	−1.21	−0.012	−1.23	0.013	1.33
HI	0.008	0.68	0.002	0.21	−0.018	−1.59	−0.006	−0.50
Spine max dose (Gy)	0.305	1.32	−0.020	−0.08	5.404	23.48	6.058	26.32
PRV spine 1cc (Gy)	0.458	1.73	0.046	0.17	5.716	21.55	6.440	24.28
Ipsilateral parotid mean dose (Gy)	−0.005	−0.44	−0.000	−0.04	0.106	8.88	0.136	11.44
Ipsilateral parotid 50% volume dose (Gy)	0.023	2.04	0.001	0.07	0.103	8.95	0.133	11.53
Brain stem max dose (Gy)	0.280	1.69	0.063	0.38	3.899	23.52	4.343	26.20
Parameters	**MC tissue versus CC bone tissue interface**		**MC tissue versus PB tissue**		**MC tissue versus PB bone**		**MC tissue versus PB bone tissue interface**	
	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation	Mean difference	Percentage of deviation
Treatment MU	−2.596	−1.02	−4.522	−1.77	−3.948	−1.55	−4.283	−1.68
Mean dose (Gy)	−0.327	−0.54	−0.550	−0.91	−0.351	−0.58	−0.491	−0.81
V95%	−0.663	−0.69	−1.320	−1.38	−0.677	−0.71	−0.948	−0.99
CI	−0.045	−4.72	0.000	0.00	0.013	1.34	−0.012	−1.21
HI	−0.011	−0.96	−0.016	−1.42	−0.003	−0.23	−0.009	−0.78
Spine max dose (Gy)	5.550	24.11	2.528	10.98	2.552	11.09	2.520	10.95
PRV spine 1cc (Gy)	5.840	22.01	3.907	14.73	3.935	14.83	3.902	14.71
Ipsilateral parotid mean dose (Gy)	0.111	9.34	−1.040	−87.18	−1.039	−87.10	−1.040	−87.17
Ipsilateral parotid 50% volume dose (Gy)	0.110	9.55	−1.068	−92.67	−1.068	−92.66	−1.064	−92.29
Brain stem max dose (Gy)	3.970	23.95	0.427	2.58	0.482	2.91	0.436	2.63

MC: Monte Carlo, CC: Collapsed cone, MU: Monitor unit, PB: Pencil beam, PRV: Planning organ at risk volume, CI: Conformity index, HI: Homogeneity index

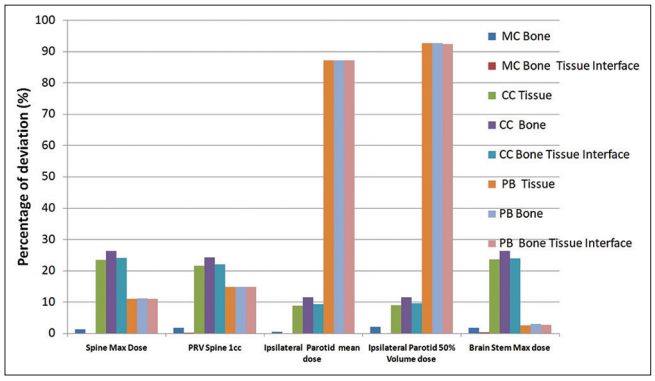

Figure 6: Percentage deviation for the different dose calculation algorithms and the different dose prescription points compared with the reference Monte Carlo tissue dose calculation algorithms for the carcinoma buccal muccosa patients organ at risk volumes. MC: Monte Carlo, CC: Collapsed cone, PB: Pencil beam

medium. The results of the study show that the calculation of serial OAR volume dose in both patients with lung carcinoma and buccal mucosa had significant differences at different prescription points using the CC and PB algorithms.

The accuracy of dose calculation for the parallel organ OAR was within the tolerance limit for the CC algorithm with different dose prescription points for carcinoma lung patients. At different prescription points with PB algorithms, the OAR dose calculation results for serial and parallel organs differed more than for the MC tissue dose calculation algorithms. Dose to the spinal cord was overestimated for all prescription points in PB and CC dose calculation algorithms. But within the target volume, the accuracy of dose calculation using all three dose calculation algorithms with different dose prescription points was good, except for the air–tissue interface in lung cancer patients. The results of the study by Elcim *et al*. showed similar findings to our study results for the dose calculation algorithms MC and PB.[12] The TPS and dose calculation technique also play an important role in calculating the dose for the target volume.

The accuracy of target volume dose calculation in patients with carcinoma of the buccal mucosa was not very different for all three algorithms with different dose prescription points. For both serial and parallel organ OAR, the accuracy of dose calculation, the percentage deviation, was greater for the CC

Table 4: The ANOVA statistical analysis *P* value for different dose calculation algorithms and different dose prescription point compared with the reference Monte Carlo tissue dose calculation algorithms for carcinoma buccal mucosa patients

Parameters	*P* (ANOVA)	MC tissue versus MC bone		MC tissue versus MC bone tissue interface		MC tissue versus CC tissue		MC tissue versus CC bone	
		Mean difference	*P*	Mean difference	*P*	Mean difference	*P*	Mean difference	*P*
Treatment MU	<0.001*	4.082	0.004*	−0.362	1.000	−3.605	0.001*	1.677	1.000
Mean dose (Gy)	<0.001*	1.078	0.001*	−0.025	1.000	−0.609	0.010*	0.732	0.216
V95%	0.013*	1.280	0.351	−1.330	1.000	−1.173	1.000	1.271	0.208
V107%	0.008*	6.500	0.003*	0.795	1.000	−0.432	0.001*	3.623	1.000
CI	0.218	0.013	0.346	−0.012	1.000	−0.012	1.000	0.013	0.204
HI	<0.001*	0.008	<0.001*	0.002	0.212	−0.018	0.232	−0.006	0.598
Spine max dose (Gy)	<0.001*	0.305	0.426	−0.020	1.000	5.404	<0.001*	6.058	<0.001*
PRV spine 1cc (Gy)	<0.001*	0.458	0.018*	0.046	1.000	5.716	<0.001*	6.440	<0.001*
Ipsilateral parotid mean dose (Gy)	<0.001*	−0.005	1.000	−0.000	1.000	0.106	<0.001*	0.136	<0.001*
Ipsilateral parotid 50% volume dose (Gy)	<0.001*	0.023	0.004*	0.001	1.000	0.103	<0.001*	0.133	<0.001*
Brain stem max dose (Gy)	<0.001*	0.280	0.363	0.063	1.000	3.899	<0.001*	4.343	<0.001*

Parameters	MC tissue versus CC bone tissue interface		MC tissue versus PB tissue		MC tissue versus PB bone		MC tissue versus PB bone tissue interface	
	Mean difference	*P*	Mean difference	*P*	Mean difference	*P*	Mean difference	*P*
Treatment MU	−2.596	0.090	−4.522	<0.001*	−3.948	0.001*	−4.283	<0.001*
Mean dose (Gy)	−0.327	1.000	−0.550	0.159	−0.351	1.000	−0.491	0.351
V95%	−0.663	1.000	−1.320	1.000	−0.677	1.000	−0.948	1.000
V107%	−0.393	0.005*	−0.260	1.000	0.068	1.000	−0.260	1.000
CI	−0.045	1.000	0.000	–	0.013	0.346	−0.012	1.000
HI	−0.011	0.001*	−0.016	0.525	−0.003	1.000	−0.009	0.648
Spine max dose (Gy)	5.550	<0.001*	2.528	0.033*	2.552	0.043*	2.520	0.037*
PRV spine 1cc (Gy)	5.840	<0.001*	3.907	<0.001*	3.935	<0.001*	3.902	<0.001*
Ipsilateral parotid mean dose (Gy)	0.111	<0.001*	−1.040	<0.001*	−1.039	<0.001*	−1.040	<0.001*
Ipsilateral parotid 50% volume dose (Gy)	0.110	<0.001*	−1.068	<0.001*	−1.068	<0.001*	−1.064	<0.001*
Brain stem max dose (Gy)	3.970	<0.001*	0.427	1.000	0.482	1.000	0.436	1.000

*Statistically significant. MC: Monte Carlo, CC: Collapsed cone, MU: Monitor unit, PB: Pencil beam, PRV: Planning organ at risk volume, CI: Conformity index, HI: Homogeneity index

and PB algorithms with different prescription points. The dose prescription point plays a crucial role in calculating the dose to tumors, treatment MUs, and dose distribution. When the dose prescription point is located within bone tissue, the dose distribution to the target volume increases due to increased in treatment MUs, resulting in more hotspots within the target volume for MC, PB, and CC algorithms. If additional MUs are delivered to the tumor, the dose to surrounding normal structures also increases. For head and neck tumors, high doses to normal structures such as the spinal cord can lead to myelopathy, while high doses to the optic nerve/chiasm may cause optic neuropathy, and high doses to the cochlea can result in sensory neural hearing loss. Long-term side effects may manifest in parotid glands (xerostomia) and the mandible (osteoradionecrosis).[25] The results of the study by Pandu *et al*. showed that the PB algorithms overestimated the calculated dose for both target and OAR volumes in the intensity modulated radiation therapy (IMRT) patient groups.[3] Similar to the above results, many studies have shown that PB algorithms overestimate the dose to the target when calculating the IMRT treatment technique.[8,10,23] The results of this study show that the accuracy of dose calculation with the PB algorithm in 3DCRT treatment planning does not have much difference compared to the MC algorithms for the target volumes with all the prescription points in the heterogeneous medium.

Kim *et al*. investigated the accuracy of the different dose calculation algorithms with different grid sizes in the heterogeneous treatment area.[26] Kim *et al*. concluded that a grid size of 2.0 mm with AXB dose calculation algorithms resulted in better efficiency and accuracy of the treatment plan for volumetric modulated arc therapy (VMAT).[26] The dose calculation for the OAR volume was not significantly different from that of the anisotropic analytical algorithm (AAA).[9] Rana *et al*. showed that the results of the AXB algorithm were more accurate compared with AAA algorithms.[7] The AXB algorithm has a more accurate dose calculation when a heterogeneous medium is involved in the dose calculation than the AAA algorithm. The AXB algorithm will provide

accurate beam modeling for heterogeneous media compared to the AAA algorithm.[27]

Many research studies show that the accuracy of dose calculation using MC algorithm is higher compared to other dose calculation algorithms.[2,3,10,28] In more heterogeneous treatment areas (such as air or bone), more accurate dose calculation algorithms must be used.[29] Accurate dose calculation and precise delivery play crucial role in radiotherapy treatment plan.[30] The study results of the MC and AXB algorithms show that they are more suitable for heterogeneous treatment areas in more complex treatment plans such as IMRT, VMAT, SBRT. In IMRT, VMAT, and SBRT treatment planning, the segment width is smaller, which leads to greater uncertainty in the dose calculation.

Conclusion

The results of this study conclude that the target dose calculation for the algorithms MC, CC, and PB with different prescription points were similar for both patients with carcinoma of lung and buccal mucosa. However, the dose distribution between the different prescription points for the different dose calculation algorithms showed little variation compared with the MC-tissue prescription points. The spinal cord dose was overestimated for both CC and the PB algorithm with all dose prescription points in patients with carcinoma of the lung and buccal mucosa. The results of the PB algorithms show that the dose of all OAR structures does not show good agreement with the MC-tissue prescription point. The results of the CC algorithms show that all OAR structures have good agreement with the MC-tissue prescription point, except for the spinal cord. This study concludes that the results of the MC dose calculation algorithms show good agreement between all dose prescription points in both patients with lung carcinoma and buccal mucosa. The dose prescription point at the air–tissue interface reduces the dose to the target volume for all algorithms, including MC. This study will help to demonstrate the accuracy of dose calculation for the different dose prescription points with the different treatment algorithms when planning radiotherapy.

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Conflicts of interest

There are no conflicts of interest.

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