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Dose-to-medium vs. dose-to-water: Dosimetric evaluation of head and neck VMAT cases using Monaco treatment planning system

Saravana Kumar Gopal[1,2], Purendra Chandra Dash[2]

[1]CIMS Radiation Centre, CIMS Hospitals. Pvt. Ltd, Ahmedabad, India
[2]Department of Physics, Siksha 'O' Anusandhan University, Bhubaneswar, India

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Original Article

Abstract

Purpose: In this paper, we evaluate the dosimetric differences between absorbed dose to water and absorbed dose to medium in Monte Carlo (MC)-based calculations used for radiation therapy treatment plans. **Methods:** Thirty-four treated Head and Neck simultaneously integrated boost cases were analyzed retrospectively. All of them were planned by Monaco treatment planning system (TPS), calculated and reviewed on absorbed dose to medium (D_m) calculations and treated in Elekta Versa HD LINAC. Absorbed dose to medium D_m was converted to absorbed dose to water D_w in Monaco treatment planning system using the procedure based on stopping power ratios and the Bragg-Gray cavity theory. Dosimetric parameters were then compared and analyzed with respect to absorbed dose to medium (D_m) calculations for multiple planning target volumes (PTVs) and critical organs such as brainstem, spinal cord, left and right lens, left and right parotids, larynx, left and right middle ear and lips. **Results:** It was found that mean and minimum D_w (i.e. $D_{w\,mean}$ and $D_{w\,min}$) of organs at risk did not differ much (hardly differing by 0.8-2%) with respect to those of the absorbed dose to medium. However maximum D_w (i.e. $D_{w\,max}$) in case of lips, left and right middle ear were found to differ more than 4% with respect to $D_{m\,max}$. For serial organs brainstem and spinal cord, maximum dose $D_{w\,max}$ were found to vary around 1% and 2%, respectively, with respect to absorbed dose to medium dose calculation. In case of PTVs, the mean percentages variation of $D_{w\,min}$ and $D_{w\,mean}$ were found to be less than 1 %, although the variation of maximum D_w was found to be high around 5-7% with respect to that of D_m. **Conclusion:** The comparative analysis of dosimetric parameters in the present study shows that the selection of either D_m or D_w in Monaco planning system is less likely to produce any significant clinical effect in tumor control and to the damage of organs at risk.

Keywords: Monte Carlo based calculation, Dose-to-water, Dose-to-medium, Radiotherapy, Treatment planning system

1. Introduction

Monte Carlo (MC)- based calculations algorithms are considered most accurate over the conventional and even more recent model- based algorithms used in the radiation therapy treatment plans[1-7]. Despite its proven accuracy, MC-based-planning has been clinically possible only recently due to the improvement in both computer hardware capabilities and improved MC codes. American association of Physicists in Medicine (AAPM) Task Group-105 (TG-105) has discussed critically the issues associated with clinical implementation of Monte- Carlo-based photon and electron external beam treatment planning[1]. One of the issues which remains debatable is whether one should use absorbed dose-to-water D_w or absorbed dose-to-medium D_m for dose calculations, prescription and evaluation when using MC based treatment planning system (TPS).

Conventional dose calculations for photon beam radiation therapy typically report the absorbed dose-to-water D_w[1,6,8]. This is due to the fact that historically clinical experiences are derived based on D_w. Furthermore, the doses reported in clinical trials and hence the therapeutic and normal tissue tolerance doses

Corresponding author: Saravana Kumar Gopal; CIMS Radiation Centre, CIMS Hospitals. Pvt. Ltd, Ahmedabad, India.

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are based on D_w. The accelerator and ionization chamber calibration protocols are also based on D_w[9]. The absolute dose measurements, input data used for TPS commissioning are generally dose profiles and output factors measured in water phantoms and specified in terms of absorbed dose to water D_w. However, MC based algorithms perform calculations for absorbed dose to medium instead of absorbed dose to water. Since the particle transport simulations occur in materials representation of patient media, the absorbed dose is specified to the patient medium D_m[10-16]. For comparison of results and their clinical significance in radiation therapy treatment plans, D_m is converted to D_w by the procedure developed by Siebers *et al.*[8] using stopping power ratios, based upon the Bragg-Gray cavity theory for MC-based calculations. For megavolt-age photon beams, the difference between D_w and D_m for tissues with densities near 1.0 g/cm^3 is small (1–2%). However, for higher density materials, such as cortical bone, the difference can be as large as 15% since the stopping powers of water and that of higher-density materials differ more significantly[1,8]. Therefore, there is a systematic difference between the dose computed using conventional analytical algorithms and MC simulation. Any significant differences between D_w and D_m might lead to the change of dose prescriptions in order to maintain consistent radio therapy outcomes[8,17]. A clinical decision has to be made during radiotherapy treatment planning as to whether one should prescribe the dose using D_m or the converted D_w[18]. Several studies have reported dosimetric difference between D_w and D_m based plans for different clinical cases in various planning systems[19,20]. Dogan *et al.*[21]demonstrated that converting D_m to D_w in MC- calculated IMRT plans introduces a systematic error of up to 5.8% for head and neck tumors and 8.0% for prostate cases. However, similar studies for head and neck VMAT cases based on MC-calculated treatment plans using Monaco TPS have not yet been reported. In the present study, we evaluate the dosimetric difference between absorbed dose-to-water and absorbed dose-to-medium in the MC-based dose calculation method in the radiation therapy treatment planning for head & neck VMAT cases and analyze its clinical significance.

2. Methods and Materials

2.1. Patient Selection

A total of 34 head and neck cases with multiple PTVs of different prescriptions were taken for analysis. Out of 34 cases, 28 cases had 3 PTVs and remaining 6 cases had 2 PTVs. Patient total prescription details are given in the Table 1. All patients were treated using Elekta Versa HD Linear Accelerator (Elekta Ltd, Crawley, UK) which is equipped with Agility Beam limiting Device. Mosaiq version (IMPAC Medical systems Inc, Sunnyvale, USA) was used as record and verifying system.

Table 1: Prescription details of patient cases

No of Patients	34
Case	Head & Neck VMAT
3 PTVs cases	28
2 PTVs cases	6
PTV I	6930 cGy – 34 cases
PTV II(Total - 34Cases)	6600 cGy- 12 cases;5940 cGy- 4cases 6300 cGy- 13cases; 6434 cGy- 5 cases
PTV III(Total - 28Cases)	5940 cGy- 5 cases; 5610 cGy-16 cases 5775 cGy- 4cases; 5710 cGy- 3 cases

2.2. Treatment Planning

3D CT scans of slice thickness of 3 mm were acquired using Philips Brilliance CT scanner with patient in supine position. Thermoplastic moulds are used for immobilization of patients. Monaco treatment planning system (Elekta, Crawley, UK) version 5.0 was used for VMAT planning using 6MV photon beams.

Monaco treatment planning system uses the Monte Carlo dose calculation algorithm for VMAT dose calculations. The system provides options either to use absorbed dose to water D_w or absorbed dose to medium D_m mode for treatment dose calculation, prescription and evaluation. Here we used the Monaco TPS in which we perform MC-based calculation for absorbed dose to medium D_m. Then we evaluated the absorbed dose to water D_w in Monaco TPS from the MC calculated D_m using stopping power ratio based on Bragg Gray Cavity theory[8,22]. Thus the clinically approved and treated cases were all specified in terms of absorbed dose to medium, which were then converted to dose to water specification and compared with the treated plan. Minimum segment width assigned was taken to be 0.5 cm. Grid size and calculation accuracy were set to 0.3 cm and 3% percent per control point, respectively.

2.3. Plan Analysis

The dose-volume histograms (DVHs) of both the plans calculated for D_m and D_w were generated in the Monaco TPS. Treatment plans were evaluated for various dosimetric parameters. The parameters analyzed were Maximum dose D_{max}, Minimum dose D_{min}, Mean Dose D_{mean} for organs at risk and those analyzed for PTVs are D_{max}, D_{min}, D_{mean} and percentage volume covered by 95% prescribed dose $D_{95\%}$. Cumulative dose volume histogram of one of the patients representing both D_m and D_w calculation is shown in figure 1. Ratios of absorbed dose to water to absorbed dose to medium D_w/D_m were computed for D_{max}, D_{min}, D_{mean} and for percentage volume covered by 95% prescribed dose $D_{95\%}$ (PTVs). The ratios D_w/D_m were plotted for critical organs at risks and for PTVs.

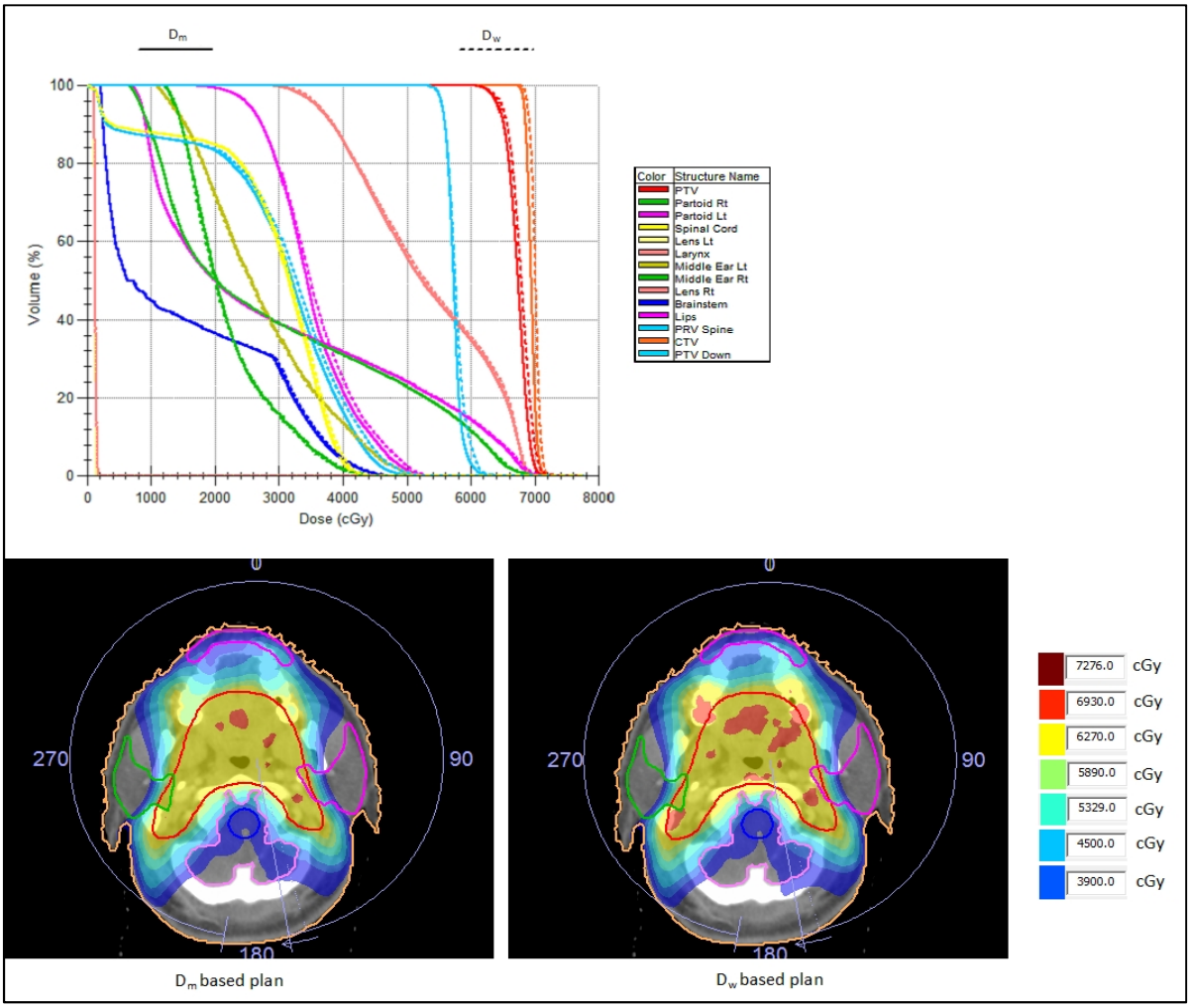

Figure 1: DVHs and isodose distributions of D_w and D_m based plans of one of the cases under study.

The relative percentage difference Δ between the dosimetric parameters D_w and D_m based plans for each case was calculated using the relation

$$\Delta = \left[\frac{(D_{wx} - D_{mx})}{D_{mx}} \right] \times 100\ \%\ ,$$

where x is the corresponding dosimetric parameter (mean dose, maximum dose, etc.). The mean and the standard deviation of the percentage variations of corresponding dosimetric parameters corresponding to all patient cases were calculated.

3. Results

The percentage variation of D_w with respect to D_m and the respective standard deviation for all critical organs were obtained as shown in the Table 2. The variations of ratio D_w/D_m for Maximum dose D_{max}, Minimum dose D_{min}, Mean Dose D_{mean} for critical organs at risk are shown in the Figure 2. The mean percentage variation of $D_{w\ min}$ with respect to $D_{m\ min}$ for brainstem, spinal cord, left and right lens, left and right parotids, larynx, left & right middle ear and lips were found to be 0.80, 1.13, 0.80, 0.85, -0.43, -0.61, 0.84, 2.23, 2.16, and -0.49, respectively. The corresponding values of $D_{w\ mean}$ with respect to $D_{m\ mean}$ for brainstem, spinal cord, left and right lens, left & right parotids, larynx, left and right middle ear and lips were obtained as 0.95, 1.10, 0.77, 0.77, 0.30, 0.30, 0.45, 1.80, 1.86, 1.91 and 0.77, respectively. However, the mean percentage variation of $D_{w\ max}$ with respect to $D_{m\ max}$ for brainstem, spinal cord, left and right lens, left and right parotids, larynx, left & right middle ear and lips were found to be 1.06, 1.95, 0.60, 0.61, 0.62, 0.52, 1.24, 4.70, 4.02 and 4.35, respectively. The plots showing the variation of ratio D_w/D_m for D_{max}, D_{min} and D_{mean} of critical organs at risk are shown in Figure 2.

Table 2: Percentage variation ± standard deviation of D_w with respect to D_m for critical organs at risk

Organs at risk	$\left[\frac{(D_{wmin}-D_{mmin})}{D_{mmin}}\right]\times 100\ \%$	$\left[\frac{(D_{wmax}-D_{mmax})}{D_{mmax}}\right]\times 100\ \%$	$\left[\frac{(D_{wmean}-D_{mmean})}{D_{mmean}}\right]\times 100\ \%$
Brain stem	0.80±0.23	1.06±0.51	0.95±0.07
Spinal cord	1.13±1.16	1.95±1.15	1.10±0.13
LT lens	0.80±0.26	0.60±0.32	0.77±0.29
RT lens	0.85±0.31	0.61±0.35	0.77±0.29
Parotid LT	-0.43±0.64	0.62±0.99	0.30±0.38
Parotid RT	-0.61±0.60	0.52±0.70	0.30±0.39
Larynx	0.84±0.83	1.24±0.82	0.45±0.28
Middle ear LT	2.23±3.47	4.70±2.76	1.80±1.38
Middle ear RT	2.16±3.64	4.02±2.48	1.86±1.43
Lips	-0.49±0.73	4.35±3.32	1.91±1.25

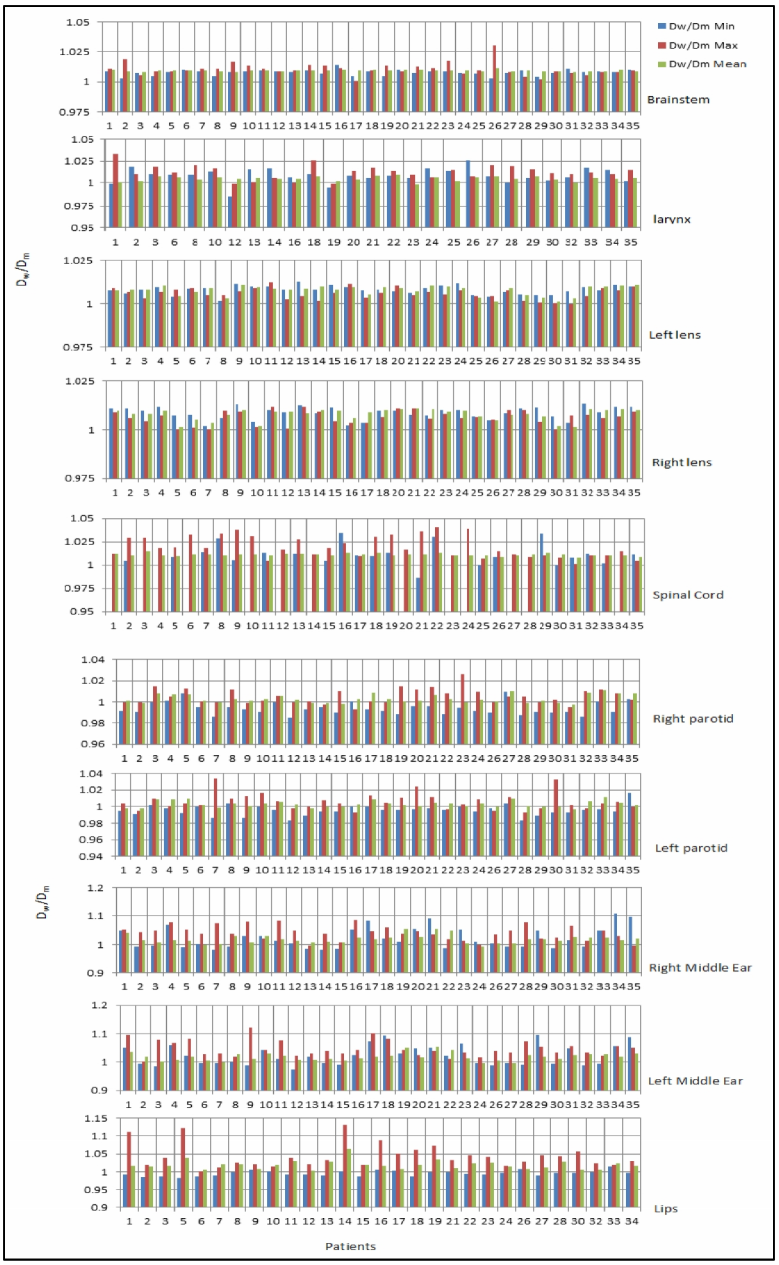

Figure 2: Variations of ratio D_w/D_m for D_{max}, D_{min}, D_{mean} for critical organs at risk.

Table 3: Percentage variation ± standard deviation of D_w with respect to D_m for multiple planning target volumes.

PTVs	$\left[\frac{(D_{wmin}-D_{mmin})}{D_{mmin}}\right]\times 100\%$	$\left[\frac{(D_{wmax}-D_{mmax})}{D_{mmax}}\right]\times 100\%$	$\left[\frac{(D_{wmean}-D_{mmean})}{D_{mmean}}\right]\times 100\%$	$\left[\frac{(V_{95\%Dw}-V_{95\%Dm})}{V_{95\%Dm}}\right]\times 100\%$
PTV I	0.97 ±2.01	4.95 ±5.29	0.76 ±0.37	0.07 ±0.20
PTV II	0.61 ±1.81	6.37 ±4.75	0.88 ±0.27	0.48 ±0.30
PTVIII	-0.35 ±1.42	6.38 ±4.86	0.49 ±0.37	-0.04 ±0.20

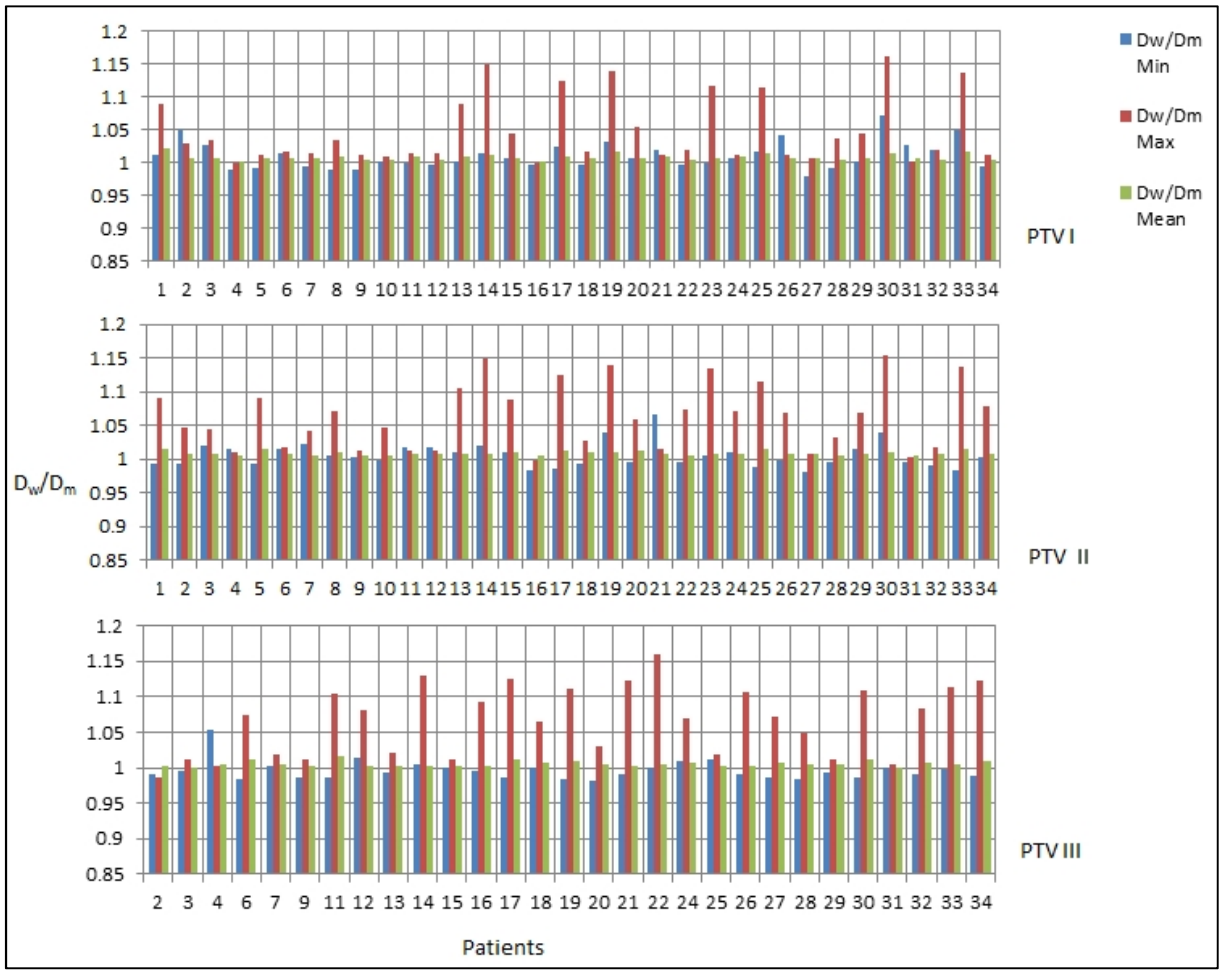

Figure 3: Variations of ratio D_w/D_m for Maximum dose D_{max}, Minimum dose D_{min}, Mean Dose D_{mean} for multiple PTVs.

The percentage variations of D_w with respect to D_m for PTVs are shown in Table 3. The mean percentage variation of $D_{w\,min}$ with respect to $D_{m\,min}$ for PTV I, PTV II and PTV III were obtained as 0.97, 0.61 and -0.35, respectively; The mean percentage variation of $D_{w\,mean}$ with respect to $D_{m\,mean}$ were found to be 0.76, 0.88 and 0.49 respectively. However, the mean percentage variation of $D_{w\,max}$ with respect to $D_{m\,max}$ were found to be 4.95, 6.37, and 6.38 respectively. Plots showing the variations of ratio D_w/D_m for Maximum dose D_{max}, Minimum dose D_{min}, Mean Dose D_{mean} of PTV I, PTV II and PTV III are shown in Figure 3.

4. Discussion

In clinical evaluation and dose calculation methods adopted for radiation therapy treatment plans, it still remains unsettled whether one should consider dose-to-medium D_m in place of dose-to-water D_w. There are strong arguments in favor of both. In dosimetry, when using ionization chamber, one measures the charge produced in air then converts the measured charge to dose to water. So, it will be more sensible to convert dosimeter readings and results from dose calculation algorithms to D_m for comparison with Monte Carlo results. Also, converting D_m to D_w might bring additional uncertainty and complexity. However, since dosimetry calibration protocols are based on D_w

standard (AAPM TG-51 1999)[23], conversion of all dose calculation results to this standard seems reasonable. Furthermore, the biological indices (NTCP, TCP etc.) are given in terms of D_w. Ma *et al.*[24] suggested in favor of D_m-based approach for radiation therapy dose prescription, treatment plan evaluation and plan outcome consistent with previous radiation therapy experience. On the other hand, Walter *et al.*[25] suggested that the selection of D_w in place of D_m in MC treatment plans is more reasonable, since D_w provides better estimate of dose to sensitive skeletal tissues. The AAPM TG 105 report recommends that in TPS one can avail both the options (D_m and D_w) for dose reporting[1]. Such an approach helps to have a comparative dosimetric analysis leading to appropriate dose prescription in TPS and thus revealing the clinical significance of the method used.

In the present study, it was observed that $D_{w\,min}$, $D_{w\,mean}$ and volume of $D_{w\,95\%}$ for PTVs did not vary much (0.5-2%), whereas $D_{w\,max}$ varied significantly around 5-7% which may have some biological effect like necrosis in tumor. Since maximum dose escalation may be acceptable in most PTV cases, its variation may not be clinically that significant and may not affect the tumor control. For critical organs at risk, the variation of $D_{w\,mean}$ for parallel organs like left and right parotids, larynx, left & right middle ear and lips were found to be small (1-2%). But, maximum doses for lips, left and right middle ear in D_w based calculation were found to differ more than 4%. Since only mean dose is clinically significant for parallel organs, present analysis shows that the choice of D_w or D_m based calculation, does not have any significant clinical effect. In case of serial organs like spinal cord and brainstem, the mean percentage variation of $D_{w\,max}$ with respect to $D_{m\,max}$ was found less around 1-2%. For Lenses, it was varying only about 0.6%. Hence, it looks like that in plan evaluation and implementation whether one uses D_w or D_m based calculations, the clinical endpoint almost remains unaffected. Further studies encompassing larger sample size of patients and more sites may reveal more about the clinical significance of using D_w or D_m in such MC based radiation therapy treatment planning systems.

5. Conclusion

The present study evaluates the dosimetric differences between D_m or D_w based calculations for head & neck VMAT cases in the radiation therapy treatment planning system (Monaco TPS) using the Monte Carlo-based dose calculation algorithms. The analysis of dosimetric parameters indicates that the selection of either D_m or D_w based calculations in the Monaco planning system is less likely to produce any significant clinical effect in tumor control and damage to organs at risk. However, there is appreciable increase in the maximum doses calculated based on D_w compared to $D_{m\,max}$ in target which may be clinically desirable in PTVs.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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