REPORTS OF PRACTICAL ONCOLOGY AND RADIOTHERAPY 18 (2013) 272–278

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Original research article

Comparison of dosimetric variation between prostate IMRT and VMAT due to patient's weight loss: Patient and phantom study

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ARTICLE INFO

Article history:
Received 26 November 2012
Received in revised form
8 March 2013
Accepted 25 May 2013

Keywords:
Prostate IMRT
Prostate VMAT
Patient's weight loss
Treatment planning evaluation and dose–volume points

ABSTRACT

Aim: This study compared the dosimetric impact between prostate IMRT and VMAT due to patient's weight loss.
Background: Dosimetric variation due to change of patient's body contour is difficult to predict in prostate IMRT and VMAT, since a large number of small and irregular segmental fields is used in the delivery.
Materials and methods: Five patients with prostate volumes ranging from 32.0 to 86.5 cm^3 and a heterogeneous pelvis phantom were used for prostate IMRT and VMAT plans using the same set of dose–volume constraints. Doses in IMRT and VMAT plans were recalculated with the patient's and phantom's body contour reduced by 0.5–2 cm to mimic size reduction. Dose coverage/criteria of the PTV and CTV and critical organs (rectum, bladder and femoral heads) were compared between IMRT and VMAT.
Results: In IMRT plans, increases of the D99% for the PTV and CTV were equal to $4.0 \pm 0.1\%$ per cm of reduced depth, which were higher than those in VMAT plans ($2.7 \pm 0.24\%$ per cm). Moreover, increases of the D30% of the rectum and bladder per reduced depth in IMRT plans ($4.0 \pm 0.2\%$ per cm and $3.5 \pm 0.5\%$ per cm) were higher than those of VMAT ($2.2 \pm 0.2\%$ per cm and $2.0 \pm 0.6\%$ per cm). This was also true for the increase of the D5% for the right femoral head in a patient or phantom with size reduction due to weight loss.
Conclusions: VMAT would be preferred to IMRT in prostate radiotherapy, when a patient has potential to suffer from weight loss during the treatment.

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1507-1367/$ – see front matter
http://dx.doi.org/10.1016/j.rpor.2013.05.003

1. Background

In prostate radiotherapy, multi-beam step-and-shoot intensity modulated radiotherapy (IMRT) has in many centers been replaced by volumetric modulated arc therapy (VMAT), which has a shorter delivery time and smaller monitor unit (MU).[1–5] Some studies in patient dosimetry between prostate IMRT and VMAT show that VMAT is a more efficient dose delivery technique than IMRT as it has good target coverage and spares critical organs, such as rectum, bladder and femoral heads.[4,6–13] However, unlike step-and-shoot IMRT in which the gantry is static for each beam angle, VMAT interplays the multi-leaf collimator (MLC) shapes, MLC speed, dose rate and gantry speed in a single or multiple photon arcs for dose delivery.[8,14–18] This complex dose delivery technique results in a difficult MU calculation, almost impossible to be done manually using the basic dose ratio methods.[19–21]

Patient size reduction during radiotherapy was found and studied in head-and-neck cancer.[22–24] However, there is little study related to the dosimetric impact due to the change of body contour. Although the weight loss issue in prostate cancer is less significant than head-and-neck, it sometimes occurs during radiotherapy.[25,26] This is mainly due to the side effects of dehydration and/or loss of appetite during the course of treatment. This size reduction used to reduce the patient's body contour while the bone anatomy remains unchanged. The result of dosimetric change due to reduced size or depth of patient is the increase of delivered dose to the prostate planning and clinical target volume (PTV and CTV). Moreover, a reduction in the patient size increases doses in the rectum, bladder and femoral heads.[27] The dosimetric impacts on the targets and critical organs with regards to reduced depth depend on the dose delivery technique.[28]

It has been proven that prostate VMAT has comparable PTV/CTV coverage and sparing of critical organs as IMRT[12,13]; however, there remains no study on the dosimetric comparison between IMRT and VMAT regarding patient size reduction in prostate radiotherapy.

2. Aim

In the prostate treatment plan, dose–volume constraints for the target and critical organs are used in the plan optimization based on objective function.[29,30] Dose distributions on the target and critical organs are different for prostate plans generated by IMRT and VMAT technique using the same set of dose–volume constraints, because IMRT and VMAT use different parameters of gantry angle, dose rate and MLC shapes in the plan optimization. It is therefore, worthwhile to compare the dose coverage due to patient size reduction between IMRT and VMAT. In this study, IMRT and VMAT prostate plans were generated for patients and a heterogeneous pelvis phantom using the same prescription dose and same set of dose–volume constraints for target and critical organs. Changes to Dose–Volume Histograms (DVHs) and dose criteria for the PTV, CTV, rectum, bladder and femoral heads with respect to the patient size reduction were compared between IMRT and VMAT. To our knowledge, this is the first investigation on the dosimetric comparisons between prostate IMRT and VMAT due to patient's weight loss.

3. Materials and methods

3.1. *Patient and phantom*

In this study, IMRT and VMAT prostate plans were created for five patients in a group of 30, covering a range of prostate target volumes from 32.0 cm^3 to 86.5 cm^3 at the Grand River Hospital. The five patients represented the maximum, medium, minimum, halfway between maximum and medium and halfway between medium and minimum prostate volumes in the patient group. On the other hand, a heterogeneous virtual human male pelvis phantom (CIRS 801-P-F) was used for the IMRT and VMAT plans. The phantom was scanned as if it were a patient using the same CT-SIM scanner and protocol. The PTV, rectum, bladder, right and left femoral head volume of the phantom are 72.4, 37.4, 59.5, 131.8 and 124.1 cm^3, respectively. The PTV, CTV, rectum, bladder and femoral heads of the prostate patients and phantom were contoured by the same person using their computed tomography (CT) image sets. The CTV was equal to the prostate volume. The PTV was created by expanding the CTV with a 1 cm margin, except in the posterior direction where a 0.7 cm was used. Patient immobilization used a parallel-leg immobilizer and the patient was ensured to have a comfortably full bladder and empty rectum in the treatment. All patients were scanned by the Siemens SOMATOM Sensation Open CT-simulator with the same protocol. Dosimetric verifications of VMAT for patients and the phantom were done using the ArcCHECK 4D cylindrical detector array.[31]

3.2. *IMRT and VMAT treatment planning*

All prostate plans were created for patients and phantom in the supine position, using a 6 MV photon beam from a Varian 21 EX linear accelerator (Varian Medical System, Palo Alto, CA). A 120-leaf Millennium MLC system was used to generate field segments for the beam intensity modulation. Treatment plans were created using the Eclipse treatment planning system (version 8.5, Varian Medical System, Palo Alto, CA). The prescribed dose was 78 Gy in 39 fractions (2 Gy per fraction). The dose was prescribed to the median dose ($D_{50\%}$) of the PTV as normalization, and the anisotropic analytical algorithm was used in dose calculations with dose grid resolution set to 0.25 cm. For IMRT prostate plan, a seven-beam technique was used with beam angles equal to 40, 80, 110, 250, 280, 310 and 355 degrees.[32] The dose–volume constraints for the target volumes and critical organs for the inverse planning are shown in Table 1. These constraints were parameters in the optimization cost function. The specific fraction of volume based on the function is allowed to exceed the prescribed dose limit in the case of a critical organ or target, to be less than the prescribed value.[32,33] The same set of constraints (Table 1) and prescription dose were used for the VMAT prostate plans, in the optimization. The dose delivery of VMAT was carried out using a single 360 degree photon arc with inverse plan optimized by the Eclipse RapidArc algorithm (Varian Medical System, Palo Alto, CA).

Table 1 – Dose–volume constraints of the CTV, PTV, rectum, bladder, left and right femoral head used in the 7-beam IMRT and VMAT prostate plan.

Volume of interest	Dose–volume control point (Gy)
CTV	D99% ≥ 78
PTV	D99% ≥ 74.1
PTV	Maximum dose to 1 cm^3 ≤ 81.9
Rectum	D50% ≤ 60; D35% ≤ 65; D25% ≤ 70 Gy; D15% ≤ 75
Bladder	D50% ≤ 65; D35% ≤ 70; D25% ≤ 75 Gy; D15% ≤ 80
Left and right femoral head	D5% ≤ 54.3

3.3. *Patient and phantom size reduction*

The contraction of body contours due to size reduction was mimicked by decreasing the body contour with reduced depths (0.5–2 cm) in the anterior, and both lateral directions of the patient and phantom based on our clinical experience. The original normal tissue outside the contracted body contour was replaced by air. Fig. 1(a)–(c) shows the heterogeneous phantom's anatomy in the axial, coronal and sagittal view, after the body contour was contracted by a reduced depth of 1 cm, respectively. Reduced depths of 0.5, 1, 1.5 and 2 cm were used in the patient and phantom size reduction for comparison. Intensity modulated radiotherapy and VMAT prostate plans of zero reduced depth were transferred to the modified patient's and phantom's anatomy with reduced depth for the dose recalculation. Dose–Volume Histogram and dose criteria for the target and critical organs were determined with different reduced depths for each plan.

4. Results

Dose–Volume Histograms of the PTV, rectum, bladder and right femoral head for the patient with the medium prostate volume (48.4 cm^3) are shown in Fig. 2(a–d), respectively. The reduced depths in Fig. 2 are equal to 0, 1 and 2 cm using IMRT and VMAT technique. All dose criteria in IMRT and VMAT plan with zero reduced depth satisfied the dose–volume constraints in Table 1. Fig. 3(a) and (b) shows increases in the D99% of the PTV and CTV with increased reduced depth for the IMRT and VMAT plans for patients and the phantom. All D99% in Fig. 3 calculations were based on the reduced depth and were normalized to those calculated using the zero reduced depth for comparison. For critical organs, increases in the D30% of the rectum and bladder based on the patient and phantom size reductions are shown in Fig. 4(a) and (b), respectively. Increases in the D5% of the right femoral head with an increase in reduced depth are shown in Fig. 4(c). Due to the symmetry of the right and left femoral head in patient and phantom anatomy, only dose criteria of the right femoral head are shown in this study. All D30% and D5% in Fig. 4 were normalized to those calculated based on a zero reduced depth for comparison. Slopes representing changes of dose–volume criteria per reduced depth in Figs. 3 and 4 were determined for patients and the phantom using linear regression fitting with coefficient of determination value R equal to 0.99. It should be noted that all results of dose criteria in this study were

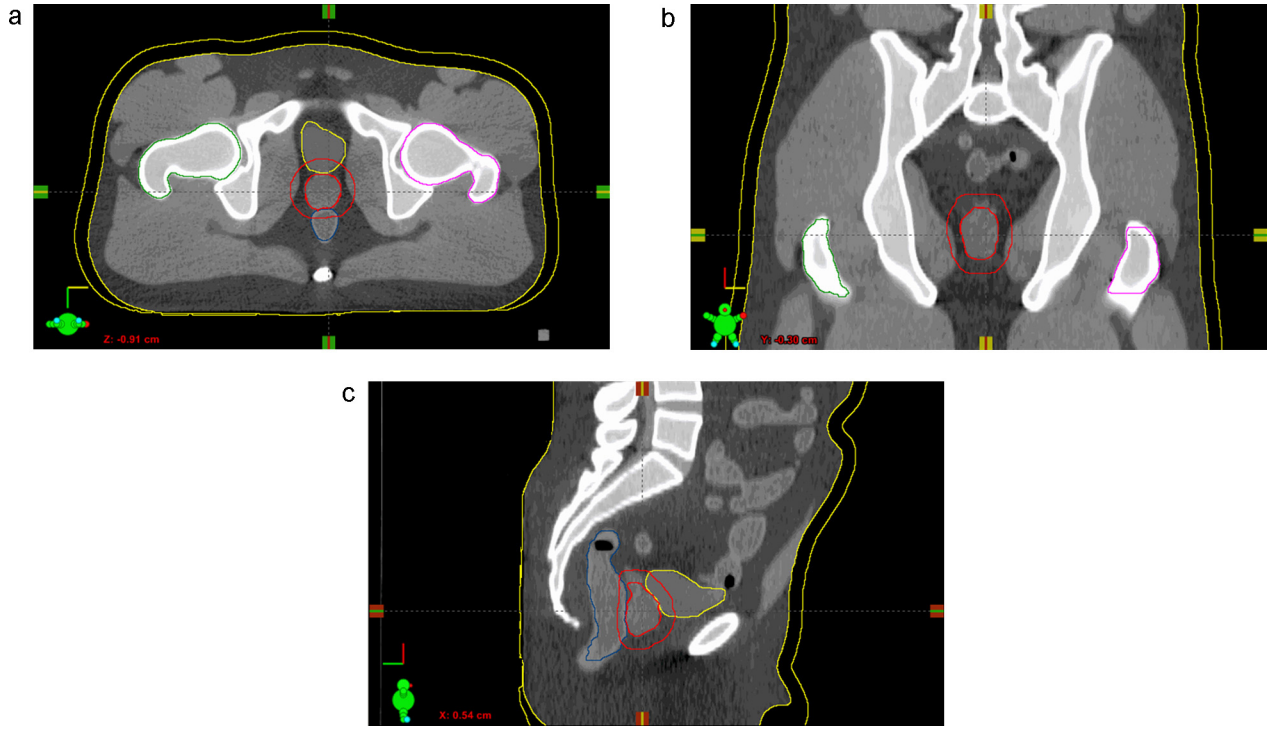

Fig. 1 – CT images of the (a) axial, (b) coronal and (c) sagittal views for the heterogeneous pelvis phantom, with contours of the PTV, CTV (prostate), bladder, rectum and femoral heads. The body contour was reduced by 1 cm depth (anterior, left and right direction) with the excluded patient body (normal tissue) replaced by air.

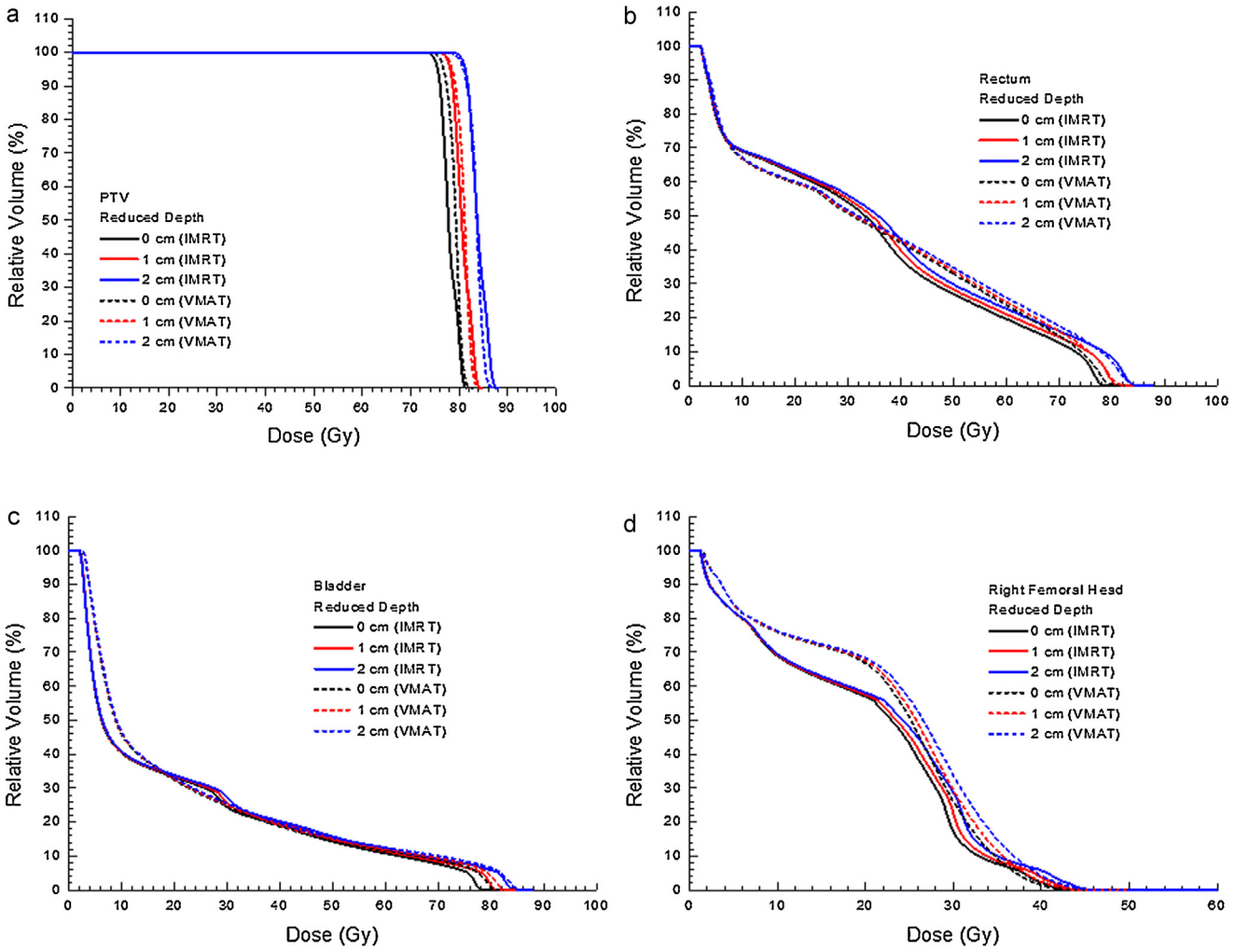

Fig. 2 – DVHs of the (a) PTV, (b) rectum, (c) bladder and (d) right femoral head in prostate IMRT (solid lines) and VMAT (broken lines) plans for the patient with medium prostate volume (48.4 cm^3). Depths of the body contours were reduced by 0, 1 and 2 cm.

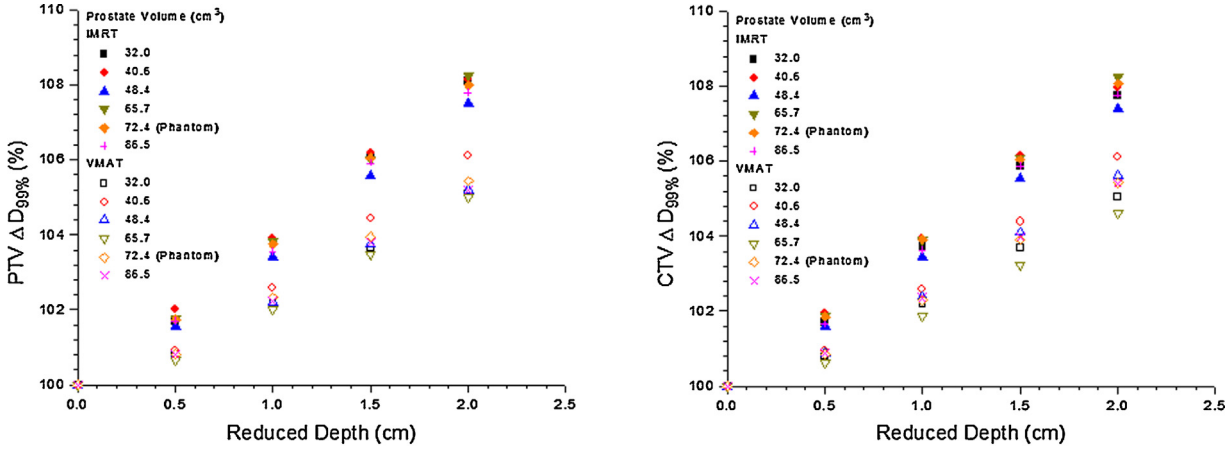

Fig. 3 – Relationships between changes of the D99% and size reduction of patients and the phantom in term of the reduced depth for the (a) PTV, and (b) CTV of patients in IMRT and VMAT.

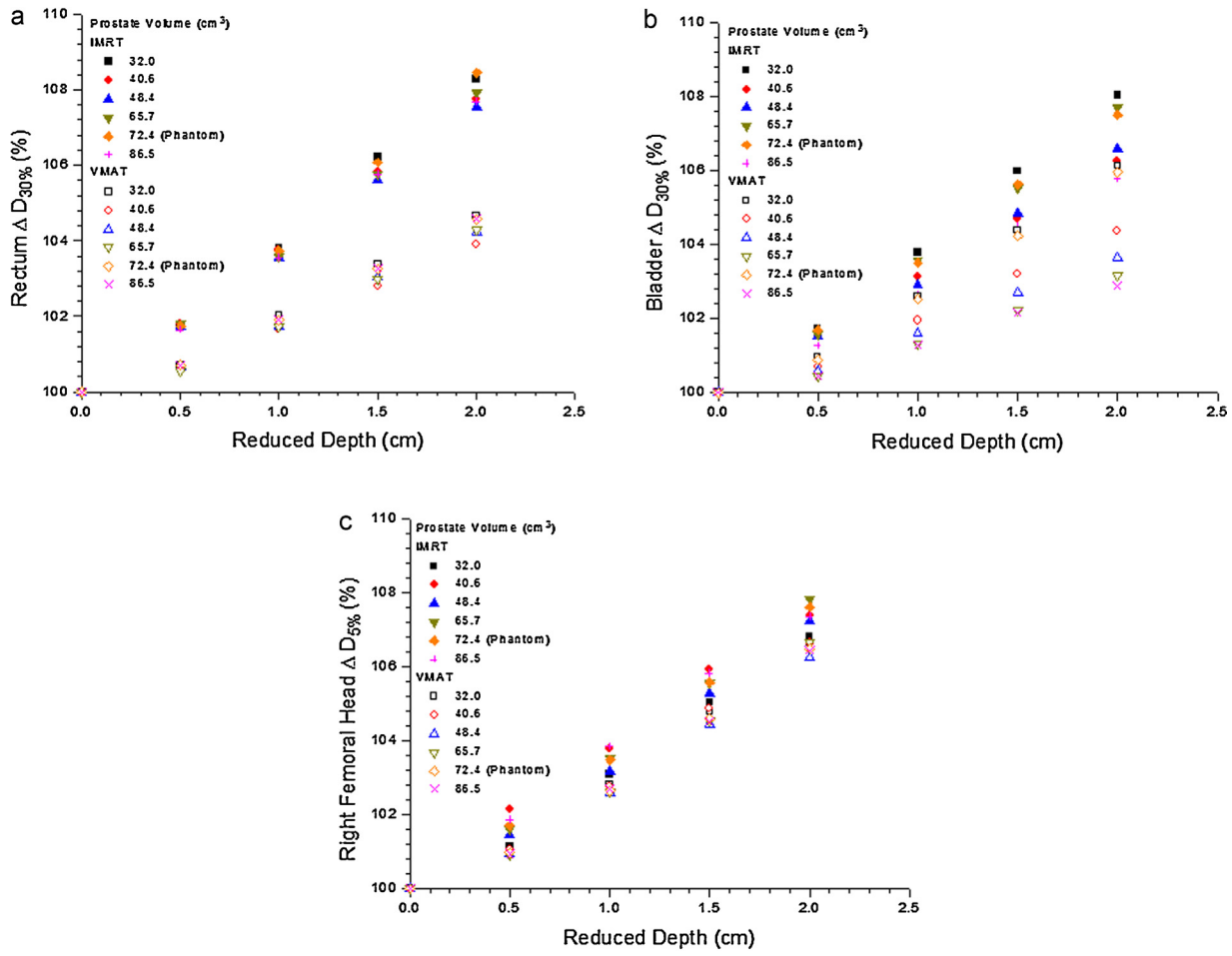

Fig. 4 – Relationships between changes of the D30% and size reduction of patients and the phantom in term of the reduced depth for the (a) rectum, and (b) bladder in IMRT and VMAT. (c) shows changes of the D5% of the right femoral head varying with the reduced depth for patients and the phantom.

based on the treatment dose evaluation criteria in our previous work.[32]

5. Discussion

Fig. 2(a) shows DVHs of the PTV for the patient with medium prostate volume (48.4 cm^3) planned by IMRT and VMAT technique, using reduced depths of 0, 1 and 2 cm. In Fig. 2(a), maximum doses of dose–volume curves (IMRT and VMAT) move toward the positive x-axis with an increase in the reduced depth. The maximum dose increases because the reduced depth results in an increase of dose at the PTV. Such dose enhancements due to a decrease in beam attenuation can also be observed in critical organs, such as rectum, bladder and femoral head, as shown in Fig. 2(b–d), respectively. Similar dosimetric results can be found in IMRT and VMAT plans for the phantom. These variations in DVHs for the target and critical organs may lead to changed dose criteria higher than the planned values, which may not be acceptable in the treatment plan evaluation. Therefore, more detailed examinations concerning variations in dose criteria with the reduced depths in IMRT and VMAT were carried out.

Fig. 3(a) and (b) shows changes in the D99% of the PTV and CTV with the reduced depth for patients and the phantom planned per IMRT and VMAT. Fig. 3(a) and (b) indicates that the D99% of the PTV and CTV increase with the reduced depth from 0 to 2 cm, which agrees with the relationship between the DVH and reduced depth as shown in Fig. 2(a). For the PTV and CTV, variations in the D99% with the reduced depth were found to be independent to the patient's prostate volume in IMRT and VMAT plans (Fig. 3(a) and (b)). From the patient results, increases in the D99% for the PTV and CTV in IMRT were both equal to $4.0 \pm 0.1\%$ per cm of the reduced depth. These increases in the D99% are higher than those of $2.7 \pm 0.2\%$ per cm in VMAT. It is found that the increases in the D99% for the PTV and CTV for the phantom were 4.06 and 2.79% per cm, which are within the range of patient results. It should be noted that changes in the D99% are similar for the PTV and CTV, because of the small margin difference of 0.5–1 cm, and have the same isocenter. Fig. 3 indicates that increase in the D99% was more significant in prostate IMRT than VMAT under a patient or phantom size reduction.

For the critical organs, Fig. 4(a) indicates increases in the D30% of the rectum with an increase in the reduced depth in IMRT and VMAT. Again, the D30% increases more for IMRT

(4.0 ± 0.2% per cm for patient and 4.20% per cm for phantom) than VMAT (2.2 ± 0.2% per cm for patient and 2.34% per cm for phantom). For the bladder, increases in the D30% due to the reduced depth are slightly less than the rectum. The changes of D30% are 3.5 ± 0.5% per cm for IMRT and 2.0 ± 0.6% per cm for VMAT for patients, and 3.79% per cm for the IMRT and 2.55% per cm for the phantom (within the range of patient results) according to Fig. 4(b). This smaller change of the D30% of the bladder compared with the rectum is based on the position of bladder further away from the isocenter compared with the rectum. Fig. 4(c) shows increases in the D5% of the right femoral head with the reduced depth for patients and phantom. From the patient results, increases in the D5% are 3.7 ± 0.1% per cm for IMRT and 3.3 ± 0.1% per cm for VMAT. These agree to the phantom results of D5% increased 3.71% per cm for IMRT and 3.32% per cm for VMAT. The difference in the D5% between IMRT and VMAT was smaller than those of the D30% for the rectum and bladder. This may be due to the depth of the femoral head from the body contour being smaller than those of the rectum and bladder. Similar to the PTV and CTV, dose criteria of critical organs increased more significantly in IMRT than VMAT, when patient or phantom size reduction occurs during the treatment. To estimate dosimetric changes of the target and critical organs in greater detail, there is a need to construct a more delicate deformation model in future. This will be carried out based on the cone-beam CT image set obtained from patients who lost weight during their radiotherapy courses.

6. Conclusions

It was concluded that for prostate patient having high potential of weight loss during radiotherapy, VMAT would be preferred to IMRT regarding the dosimetric changes in the target and critical organs under a patient size reduction. The dosimetry estimation presented in this study using both patient and phantom present important data for the radiation oncology staff to justify whether a CT rescan is necessary when a patient experiences weight loss during treatment. In addition, it is important to know if the patient's weight loss is tolerable (i.e. the changed dose accepted by the treatment dose evaluation criteria), how the doses and dose criteria would change as per change of the patient's size in prostate IMRT and VMAT.

Conflict of interest

None declared.

Financial disclosure

None declared.

Acknowledgement

All patient and treatment planning data were provided by the Grand River Regional Cancer Center in the Grand River Hospital, Kitchener, Canada.

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