Volumetric Arc Therapy Treatment Plan Dosimetry Correction Method to Account Patient Weight Loss during a Course of Radiation Therapy

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Abstract

Aim: This study aims to validate volumetric arc therapy (VMAT) plan correction method for a patient’s lost weight during the course of radiotherapy. Materials and Methods: VMAT plans of prostate and head and neck cancers were considered to evaluate dosimetric effects due to external surface changes caused by patient’s weight loss during treatment. Accepted VMAT treatment plan was recalculated on the planning computed tomography (CT) with a newly created external contour from cone-beam CT and was compared with the original plan. Monitor unit (MU) correction was applied based on a simple formalism, and doses were recalculated. Dose statistics were compared with the original plan. Ten patients with significant weight loss were considered to validate proposed MU correction method by comparing the dose statistics before and after MU corrections. Results: We observed 3.7%–5.2% change in the plan maximum dose for one cm change in path length to isocenter with increased planning target volume dose, D95 by 4%. The organs at risk (OAR) doses increased as high as 6.8%. Using MU correction method, target volume and OARs dose changes were reduced to <1% when compared with the original plan. The correction method brought down the maximum plan dose and volume of 95% isodose (V95) cloud below an acceptable range of 1%–2% in 10 patients treatment plans. Conclusion: Image-guided radiation therapy process detects the weight loss, which affects the treatment plan’s dose distribution and should be corrected. Applying the correction method described here keeps the patient dosimetry within 1% of the original plan, which is clinically acceptable. The process of plan dosimetry correction to address weight loss can be completed within 30 min without repeating imaging and planning process.

Keywords: Dosimetry, intensity-modulated radiation therapy, quality assurance, radiotherapy, treatment planning, validate volumetric arc therapy, weight loss

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INTRODUCTION

Cancer centers around the world use volumetric arc therapy (VMAT) with adaptive imaging to treat a range of cancers, for example, head and neck, prostate, and other tumors. VMAT plans are generated based on patient anatomy from a planning computed tomography (CT) scan to produce uniform dose to planning target volumes (PTVs) and to minimize dose to organs at risks (OARs) by modulating photon fluence by a treatment planning system (TPS). These plans have several control points for multileaf collimator (MLC) leaf movement speed and position, dose rate, and gantry speed.

Patients are prone to lose (or gain) weight during the long course of radiotherapy treatment that may run into several weeks, which may alter the patient’s size and geometry. These changes are associated with several treatment factors, such as diet and by the disease itself.1-4 The patient doses can vary between 2% and 3% when the effective path length to isocenter changes by a centimeter, and depending on the treatment technique, these changes will vary.5,6 The current image guidance (image-guided radiation therapy) modalities,
such as cone-beam CT (CBCT), allow a comparison to be made with reference CT images which can help in identifying patient weight changes.\[7,8\] This is further confirmed by deviations in the weekly recorded source to skin distances. Since the CBCT is matched with the planning-CT based on anatomy and/or target volumes, the external contours will not match on both data sets due to changes in the external contour affected by weight loss. Dosimetric studies by Chow and Jiang on patients and phantoms showed that the magnitude of change in PTV and OAR dose could be estimated by changes in the patient’s surface which can guide the treatment team in deciding on adaptive treatment planning.\[5,6\] VMAT plans have several control points and segment monitor units (MUs), which are difficult to correct to account for such weight changes. In a busy department, an accurate correction method, devoid of time-consuming re-planning process, is highly desirable to correct for the dose changes occurring due to weight loss. The effects of patient surface changes on both target volume and OAR doses are demonstrated for prostate and head and neck cancer patients. A method to correct patient doses without repeating the entire process of simulation, treatment planning, recalculating doses, quality assurance (QA), and plan checking has been developed. The technique is validated in a cohort of VMAT plans for 10 patients.

**Materials and Methods**

To demonstrate the effects of weight loss on the dose to targets and OARs, a prostate case with involved seminal vesicle and a head neck case (carcinoma of oropharynx) were considered. Both patients were scanned as per the protocol for patient preparation and setup with a knee rest for the prostate patient and mask fixation for head and neck patient. Spiral CT (Siemens Somatom Definition AS64) scans were acquired and reconstructed slice images were transferred to a Monaco (Elekta Oncology Systems) TPS. The external volume, OAR, and target volumes were delineated as per the departmental treatment guidelines and protocols. Acceptable VMAT plans were generated by an inverse planning algorithm using a Monaco V5.11 (Elekta AB, Stockholm, Sweden) TPS, which uses Monte Carlo algorithm for dose calculation. These plans were reviewed for the target dose coverage, OAR dose constraints and were approved by the treating radiation oncologist if they were satisfactory in meeting the dose requirements. Two QA plans were generated for patient treatment plan, one using the IMRT Verification Matrix Phantom (PTW-Freiburg, Germany) for the verification of dose at multiple points through ion chamber measurements and the other using an Octavius-four-dimensional (4D) phantom (PTW-Freiburg, Germany) with 1500 ion chambers in a 2D matrix with Verisoft software (PTW-Freiburg, Germany) for planar dose measurement and verification. The patient plan was transferred to MOSAIQ record and verify system and treated using Elekta Versa HD linear accelerator with 160 leaf Agility MLC. Any significant weight loss that occurs during the treatment will lead to change in external surface volume, and this will reflect as an external surface mismatch in the image guidance performed on the patient at the time of treatment delivery. The dose distribution in the plan also will change because of the decrease in patient’s volume and effective beam path length to the isocenter. The volume changes were mimicked by the following method.

The CBCT images wherein significant weight loss observed were imported into the TPS, and external contour was delineated on it. After fusing CBCT images with the planning CT, the external surface from the CBCT was transferred to the planning CT and noted as external contour in the planning CT data set. The original VMAT plan was then imported on to the CT dataset having this new external contour, and the plan was recalculated with the same isocenter and same calculation settings. The dose-volume histogram (DVH) statistics of the new plan were compared with those of the original plan.

Weight loss leads to change in the external surface. Therefore, in case of head and neck patient a mask used for immobilization becomes loose. Reshaping and refitting of the same mask is necessary to provide good immobilization. The weight loss or gain would change the volumes of high-risk PTV (neck nodes) and low-risk PTVs (lower neck nodes) marginally, and PTV created from the GTV had minimum or no change. The OARs, such as parotids, shrink in size whereas the spinal cord and brainstem remain the same. The process of importing CBCT images, fusing and transferring the external contour was the same as in the prostate case. The high-risk and low-risk PTVs were modified to fit inside the external contour which was imported from the CBCT by a distance equal to the changes in dimensions.

Method of dosimetric correction: To calculate the dosimetric correction for a patient with weight change, we used the new external patient surface contour resulting from CBCT. The isocenter path lengths were measured with equal sector increments for both scans. For example, if the arc length was 300 degrees for the VMAT plan with a gantry increment of 20°, then 15 isocenter path lengths were measured. The average sector depth was calculated for the original planning CT surface contour and as well as the CBCT surface contour. The equivalent VMAT field size was noted from the original plan report of the treatment plan. The tissue phantom ratio (TPR) was obtained for the energy E, average segment field size F and isocenter depth for planning CT and weight lost CBCT scan. The ratio TPR (E,d₁,F)/TPR (E,d₂,F) was calculated, where d₁ and d₂ are the average path length to the isocenter or calculation weight point from the external surface of planning CT and CBCT respectively. Multiplying this factor with the original treatment plan’s MUs produced MUs for the corrected plan. When the original MUs of the treatment fields were replaced with the calculated MUs, either in TPS or MOSAIQ, the MUs of all segments of the fields will be altered automatically by the same proportional ratio. This method can be applied routinely in the clinic without going through the entire repeat treatment planning process. For patients with increased weight too, the
same process would work with the only difference of MU
correction factor being >1. The dosimetry of such corrected
plans was compared with the original plans.

A cohort of 10 patients was considered to validate the
proposed correction method. In these 10 patients, the weight
loss occurred during their treatment courses ranged from 3
to 8 kg and patients’ external surface changed over 1 cm.
External contour from the CBCT was used to replace the
original external contour, and the plan was recalculated and
compared with the accepted original plan. The maximum
dose, dose to 95% volume of PTV (D95) and volume of
95% isodose cloud were compared. The average path length
of isocenter was noted in both study sets as explained above
and correction factor thus obtained. The plan MUs were
corrected using this factor and the plan evaluation data has
been noted from the TPS and compared with respect to the
original plan data.

RESULTS

The accepted and approved initial treatment plan with its dose
distributions and DVHs are shown in Figure 1a and d (solid
lines) for a prostate treatment plan. Treatment plans
recalculated on the CT data on which the external contour
was extracted from weight loss based on CBCT with the axial
dose distribution are shown in Figure 1b and c (2 scenarios)
and DVH in dotted lines are shown in Figure 1d. The plan
maximum dose, DVH data for PTVs and OAR, volume of
95% isodose cloud (V95%) with plan MUs are presented in
Table 1 with values being percentage difference of doses
compared with those in the original plan. The maximum
dose increased by 2.9% for 0.7 (0–1.2) cm (95.6%) change
and 4.8% for 1.3 (0–2.3) cm (91.9%) change in the isocenter
along the radial direction of a CT slice when the planned
MUs remained same as that of original plan. Figure 1d also
shows increased dose to targets and OARs (dotted lines) for
the prostate case. The dose to PTVs and OARs is increased by
1.4% and 2.9%, 3.8% and 5.2% for 0.7 cm and 1.3 cm average
effective path length change respectively for 10 MV X-ray
treatment plans [Table 1]. The volume of 95% isodose cloud
increased significantly by 13.2 and 25.7% for the same path
length changes. After adjusting the MUs by TPR method for
the effective path length to isocenter, the comparison of the
plans showing axial dose distribution and DVH are presented

| Plan evaluation parameters | Test case 1 | Test case 2 |
|---------------------------|------------|------------|
|                           | Uncorrected plan | Corrected plan | Uncorrected plan | Corrected plan |
| MUs                       | 100.0       | 97.8       | 100.0           | 95.6           |
| Mean isocenter depth      | 100.0       | 95.6       | 100.0           | 91.9           |
| Correction factor         | 100.0       | 97.8       | 100.0           | 95.6           |
| Max dose                  | 2.9         | 0.7        | 4.8             | 0.6            |
| D95 to PTV60              | 2.3         | 0.2        | 4.8             | 0.2            |
| D95 to PTV57.6            | 2.2         | -0.1       | 4.8             | 0.2            |
| D95 to PTV48              | 1.8         | -0.4       | 4.7             | 0.0            |
| Volume of 95% isodose cloud | 13.2       | 1.2        | 24.7            | 2.4            |
| D5 to bladder             | 2.9         | 0.7        | 5.2             | 0.6            |
| D25 to bladder            | 2.8         | 0.5        | 5.0             | 0.4            |
| D50 to bladder            | 2.5         | 0.3        | 4.3             | -0.2           |
| D3 to rectum              | 2.0         | -0.3       | 4.5             | -0.1           |
| D15 to rectum             | 2.0         | -0.3       | 4.5             | -0.1           |
| D30 to rectum             | 1.9         | -0.3       | 4.1             | -0.4           |
| D50 to rectum             | 1.8         | -0.4       | 4.0             | -0.5           |
| D60 to rectum             | 1.8         | -0.4       | 4.0             | -0.6           |
| D50 to RtFemH             | 2.1         | -0.2       | 4.2             | -0.3           |
| D50 to LtFemH             | 1.4         | -0.9       | 3.8             | -0.8           |

MU: Monitor unit

Figure 1: Axial images showing dose distribution for a prostate plan:
(a) Original accepted plan, (b) Weight loss plan with the average depth
to isocenter changed by 0.7 cm, (c) Weight loss plan with the average
depth to isocenter changed by 1.3 cm, (d) Dose-volume histogram of
planning target volumes and organs at risks for all 3 plans.

Table 1: Percentage of plan evaluation parameters in comparison with the original treatment plan for the uncorrected and corrected prostate plans
in Figure 2. The DVH lines are closely overlapping with the original DVH [Figure 2d] with good agreement within 1%. The PTV dose differences are <0.5% with the maximum dose difference below 1%. Dose to OARs is also within 1% for both test cases of prostate, as shown in Table 1. The volume of 95% isodose line has also dropped below 3% when compared with the initial plan, which is within an acceptable range of variation.

Figure 3 shows the effect of changes on the dose distributions due to changes in external contour in a VMAT treatment plan using 6 MV-X-rays for cancer of the oropharynx. Figure 3a-c shows the dose color wash in sagittal and axial planes for the original plan, for the plan with CBCT external contour, and for the plan with corrected MUs, respectively. The DVH of target and OARs is shown in Figure 3d before correction and Figure 3e after applying correction. The comparison of the treatment plan maximum, PTVs, OARs doses and 95% isodose volume are presented in Table 2 for head and neck case.

In this case, the treatment plan maximum dose increased by 3.1% for 0.6 (0–0.9) cm (91.4%) change in effective path length to isocenter from the external surface. The dose to PTV increased by 3.1% while the dose to OARs increased by as high as 6.8% as shown in Table 2. The 95% isodose cloud volume also changed by 24%. Figure 3d and 3e shows the DVH of the target volumes and OARs before correction and after applying the correction method which are seen to be in good agreement. The dose difference is <0.6% and 1.1% for the target volumes and OARs, respectively. The plan maximum dose difference is 0.5% and volume of 95% isodose cloud is 2% when compared with accepted original plan. As shown in Figure 4a, when the mean depth to isocenter changed from 97.4% to 91.4% (13.5–12.7 cm) in 10 patients, the plan maximum dose varied by 1%–8% (mean 4%) and the volume of 95% isodose cloud varied from 2% to 25% (mean 14%). Figure 4b shows similar data after correcting plans using the proposed method. The changes in maximum dose and volume of 95% isodose line are now below ±2% which is within the acceptable range.

**Discussion**

Loss of the patient body weight by more than 5% from the start of treatment until week 8 is considered to be critical, and it may vary up to 57% in head and neck patients.\(^{[1,2,9]}\) This would lead to a reduction in the dimension of the patient’s external surface and would affect the overall dose distribution resulting in overdose to PTVs and altered dose to OARs. We observed a change in the plan maximum dose by 3.7%–4.1% in prostate plans and 5.2% in head and neck cancers for 1 cm change in average axial path length to the isocenter. For the prostate, VMAT plans using 10 MV X-rays the maximum dose increased by 2.9% for an average path length change of 0.7 cm and 4.8% for an average path length change of 1.3 cm. In the head and neck case, 6 MV VMAT plan showed an increased maximum dose of 3.1% for an average path length change of 0.6 cm. These changes are not negligible and should be brought within acceptable limits to deliver the plan as intended. An estimation of the dose distribution changes due to variation in patient surface contours in prostate treatment by VMAT was undertaken by Chow and Jiang\(^{[5,6]}\) and they observed a
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2.8% increase of D99 of PTV and 2.2% increase of D30 to rectum and bladder per cm change in effective path length to the treatment plan isocenter. In this study, the results of dose changes to PTVs and OARs obtained were similar. These results are helpful in understanding the magnitude of dose changes to PTVs and OARs due to surface contour changes in patients with weight loss and as to making a timely decision for adaptive planning. However, adaptive planning requires extra time up to 3 working days for imaging, replanning and QA which causes patient treatment delay and use of additional resources. The method demonstrated in this work uses planning CT and CBCT images to correct the treatment plan dosimetry for the external surface change due to weight loss and the entire task can be completed within 30 minutes time slot. It is accurate and the dose difference is ≤1% which is clinically acceptable. The results for ten patients who lost weight significantly during radiotherapy treatment showed that the magnitude of dose changes due to weight loss can be kept within clinically acceptable limits using the proposed MU correction method.

CONCLUSION

Patients are prone to lose or sometimes gain weight during a course of radiotherapy treatment due to the side effects of the chemotherapy, surgery, diet or from the disease by itself. VMAT plans are complex in nature and are calculated by the TPS, which have several control points for MLC position, dose rate and gantry speed, and are delivered based on the treatment plan. These plans are difficult to correct to account for external volume changes as a result of weight loss or gain. Without a correction or replanning, PTV doses are altered by 3.7%–4.1% per cm of change in the average path length to the isocenter for prostate patients. Likewise, the dose changes are about 5% in a head and neck case. OAR dose is also altered as much as 6.4%. The volume of 95% isodose line increased as high as 25% with the mean being 14% in 10 patients. However, after using the correction method, maximum dose, PTV, and OAR volume dose change is ≤1% when compared with the original accepted treatment plan. The patient can then complete the treatment within the intended duration without any gap in the treatment course. This method is accurate up to 1% and the VMAT plans can be corrected within 30 min. Thus, the proposed method can avoid lengthy replanning process resulting in saving of time and the need for complex radiobiological corrections and resources.

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Conflicts of interest
There are no conflicts of interest.

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