Assessing Dose Variance from Immobilization Devices in VMAT Head and Neck Treatment Planning: A Retrospective Case Study Analysis

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Abstract:

Introduction: Radiation therapy immobilization devices help to minimize daily set-up error. If left unaccounted for, however, they can significantly impact the dose distribution and decrease dose to the target. Volumetric modulated arc therapy (VMAT) is an innovative treatment technique capable of delivering highly conformal dose to a designated target volume. A retrospective case study was performed to evaluate beam attenuation from head and neck (HN) immobilization devices in VMAT radiotherapy using the Eclipse treatment planning system (TPS) and the Anisotropic Analytical Algorithm (AAA).

Case Description: Together, 3 radiation oncology facilities evaluated 15 patients which presented with various HN carcinomas. The patients were simulated with similar HN immobilization devices and a test plan was created from an existing VMAT plan in Eclipse to account for these immobilization devices in the dose calculation. Plan comparisons were performed using dose-volume histograms (DVH), which assessed the percentage of the planning target volume (PTV) that received 95% of the prescription ($V_{95}$), dose covering 100% of the PTV ($D_{100}$), and maximum dose. The test plan normalization values were adjusted, matching the original PTV coverage, and overall plan outcome changes were evaluated.

Conclusion: Attenuation from immobilization devices, when unaccounted for, can cause a misrepresentation of the dose delivered to the PTV. It is not a standardized practice among institutions to include immobilization devices within the body contour for dose calculations. However, with the increasing use of VMAT for treatment of the HN region, precision is of the utmost importance and inclusion of immobilization devices should be standardized.

Key Words: Volumetric modulated arc therapy, immobilization devices, beam attenuation, dose distribution
Introduction

Immobilization devices serve several purposes in radiation oncology including improved positional reproducibility and decreased patient movement during treatment delivery. However, studies dating back to the early 1980s have proven immobilization devices attenuate the radiation beam.\(^1\) If beam attenuation is not accounted for in the treatment planning process, PTV coverage can be compromised.\(^1,2\) To help decrease attenuation, carbon fiber material has become widely used in the field of radiation oncology, for both immobilization and treatment couch material, due to its strong rigidity, low density, and low attenuation properties. Carbon fiber, along with the use of innovative immobilization materials, have become especially important with the increased use of image-guided radiation therapy (IGRT) and arc therapy treatment techniques due to increased gantry angles and radiation beam through the couch.

Volumetric modulated arc therapy, a specialized branch of intensity modulated radiation therapy (IMRT), is an innovative treatment technique capable of delivering highly conformal dose to targets in an arc fashion.\(^1\) Arc therapy, in particular, has an increased propensity to deliver a higher percentage of the prescribed dose through the posterior aspect of the patient when compared to static three dimensional (3D) conformal techniques. To accommodate the increased beam attenuation from the patient couch system, many manufacturers have developed standard couch contours to account for the appropriate attenuative properties. On the contrary, radiation immobilization device attenuation can often times get overlooked, ultimately compromising the dose distribution to the desired target.

Currently, there is no standard of practice among institutions to include immobilization devices within the body contour structure.\(^1\) This can be attributed to the variances in the TPS capabilities in addition to user preferences.\(^1,3\) The ultimate goal of radiation therapy is driven by the therapeutic ratio; the ability to deliver therapeutic doses to a designated target volume while avoiding critical structure toxicities. Current recommendations for dose delivery accuracy should be within 3%-5%. This range can be jeopardized when immobilization devices are used to create daily reproducible positions.\(^1\) Immobilization devices included in a treatment field can cause contraindications including dose attenuation and increased skin dose.

Beam attenuation is dependent upon energy, field size, beam geometry, and immobilization device composition.\(^1\) Much of the current device attenuation data pertains solely
to 3D conformal or static IMRT techniques. Intensity modulated radiation therapy, specifically the VMAT technique, has gradually replaced conventional treatment techniques as the preferred treatment planning method for cancers of the HN. With the increasing use of VMAT, new research data on immobilization device attenuation must be defined. Therefore, the goal of this retrospective case study was to determine the dosimetric impact of HN immobilization on PTV coverage using the Eclipse TPS and AAA.

**Case Description**

*Patient Selection and Set-up*

This retrospective case study included a random selection of 15 different patients who were collectively treated at 3 different treatment institutions—5 patients from each center. All patients selected for this study had been diagnosed and treated for some form of cancer of the HN, including the supraglottis, base of tongue, oropharynx, floor of mouth, and an unspecified primary malignant neoplasm. Additionally, each patient was planned on the Eclipse TPS using the AAA and VMAT technique. Two or three arcs, partial or full rotation, were utilized with an energy of 6 MV.

All 5 patients treated at clinic 1 were simulated in the head-first, supine position using a Civco Type-S Overlay Board. Each patient’s head was supported with a Qfix Silverman head support cup and a custom mask. A 3.2 mm thick IMRT reinforced head and shoulder mask with neck relief was used. Shoulder assistance straps were placed around the individuals’ wrists to help pull the shoulder region out of the treatment area (Figure 1). The simulation was completed using a General Electric Lightspeed CT scanner.

Similarly, the 5 patients treated at clinic 2 were simulated in the head-first, supine position using the Civco Type-S Overlay Board. A Qfix Silverman head support cup, paired with a Civco AccuForm cushion, was custom fitted to each patient’s head for comfort. A sponge was placed under the knees for added back support. An IZI Klarity Thermoplastic Mask was custom molded over the face and shoulders, and a CT scan was completed using a General Electric Optima CT580 CT scanner (Figure 2).

The remaining 5 patients treated at clinic 3 were simulated in the head-first, supine position using a carbon fiber laminate AIO base plate. The patient’s head rested on an Orfit head
support pillow and a custom Orfit thermoplastic mask was created. A knee sponge was placed under the knees for added comfort and a CT scan was performed using a General Electric Lightspeed CT scanner (Figure 3).

Target Delineation

In the contouring application, the original CT data set and existing contours—including the PTV—were copied into each test plan. The immobilization devices in each test plan were then manually added into the body contour, completely encompassing the immobilization system (Figure 4). This action allowed AAA calculation algorithm to account for such immobilization devices when calculating dose. Organs at risk (OR) that were contoured, but not evaluated in this specific study, included the oral cavity, cord, brainstem, parotid glands, submandibular glands, esophagus, and mandible.

Treatment Planning

The PTV of 5 patients was treated to a total dose of 70 Gy, 6 treated to a total of 60 Gy, 1 treated to a total of 66 Gy, 2 treated to a total of 66.96 Gy, and 1 treated to a total of 30 Gy. These prescriptions were delivered using 6MV energy on Varian linear accelerators; a Varian IX linear accelerator was utilized to treat all patients at the first two clinics and a Varian TrueBeam linear accelerator was utilized to treat patients at clinic 3. For consistency purposes, data entry into each patient’s dose prescription tab was kept the same to mirror the original treatment course. Such parameters included the designated target volume, the number of fractions, the total dose planned, and the dose per fraction. The plan normalization value was kept at the defaulted value of 100. Finally, each field from the pre-existing plan was copied into the test plan.

To reflect the most accurate comparison of the achieved prescription dose coverage to the PTV, the test plan dose was calculated using the same number of monitor units (MU) as the initial HN plan. Using the newly acquired dose calculations, the 2 plans were analyzed and compared for PTV dose coverage variances.

Plan comparisons were performed using a DVH. Planning target volume coverage was assessed in the HN plan and the test plan by comparing the differences of the $V_{95}$ and the $D_{100}$ as
shown in Table 1. The $V_{95}$ was chosen as a consistent point of measurement because it was a common standard of care at each of the 3 clinics. Additionally, the percent difference between the maximum dose prior to normalization was recorded. The test plan normalization was then adjusted to replicate the PTV coverage as utilized in each HN plan; both of these normalization values were recorded and compared. Upon adjusting the test plan normalization, the new maximum dose was recorded and evaluated against the initial HN plan outcome.

**Plan Analysis and Evaluation**

It is not a standardized practice among institutions to include immobilization devices within the body contour for dose calculation; however, with the increasing use of VMAT for treatment of the HN region, more dose is often delivered through underlying immobilization structures. Based on the data presented in Table 1, notable variances were observed between the HN and test plan with regard to the maximum dose, $V_{95}$, $D_{100}$, and adjusted normalization.

In 13 of the 15 patients studied, the test plan maximum dose decreased when compared to the initial HN plan. The maximum dose difference calculated, prior to normalization adjustment, ranged from 0.3% to 4.1%, with an average difference of 1.29%. After adjusting the normalization value of the test plan to match PTV coverage of the HN plan, the difference between the new maximum dose of the test plan and the initial HN plan ranged from 0.2% to 2.1%, with an average value of 0.99%. According to Olch et al, slight variations, such as the aforementioned, are the result of increased photon attenuation within the immobilization devices. Likewise, increased attenuation compromises target coverage. These variances, although not statistically significant, can only be accounted for if immobilization equipment is included within the TPS calculation.

Similarly, the $V_{95}$ and $D_{100}$ were also assessed. Often times, the $V_{95}$ of the PTV is a commonly observed prescription request when designing a treatment plan. This value is frequently the driving force behind the success of the plan, directly impacting maximum dose and normalization. The absolute difference in $V_{95}$ coverage between the HN and test plans ranged from 0.4% to 2.3%, amounting to an average variation of 1.39% (Figure 5). This represents a decrease in $V_{95}$ coverage when beam attenuation from immobilization devices is accounted for. The difference in the $D_{100}$ was more statistically significant between the 2 plans,
reporting a range of 1.2% to 71.4%, and an average difference of 23% (Figure 6). This again displays a decrease in the PTV coverage receiving 100% of the prescription dose when devices are included in the body contour. While it is hard to completely encompass a PTV within the prescription dose without causing considerable maximum dose increases, it is still important to assess what dose 100% of the PTV is receiving. The average $D_{100}$ of the HN plan was 92.5% while the test plan $D_{100}$ average decreased to a mere 69.5%.

Finally, to achieve the same PTV coverage as observed in the HN plan, an adjustment to the normalization value was needed. There was a consistent decrease in normalization for 13 of the 15 patients, with an adjustment range of 0.1 to 7.7. The average normalization difference was found to be a value of 2.0. Plan normalization is the key factor in achieving adequate PTV coverage. A decrease in plan normalization, however, can negatively impact plan outcomes through unwanted maximum dose points and increased dose to surrounding critical structures. On the contrary, the remaining 2 patient plans demonstrated the need to decrease the normalization; a higher than needed plan normalization can result in an overdose to the PTV, skin, and surrounding internal critical structures. In either case, the risk for permanent or chronic tissue damage is eminent.

Conclusion

At the time of this retrospective case study, the majority of research regarding device attenuation was conducted with a focus on 3D conformal or static IMRT treatment planning techniques; however, IMRT--more specifically, VMAT--is currently the preferred treatment planning method for HN cancers. As previously stated, there is no standard of practice across institutions regarding the inclusion of immobilization devices within the body contour for treatment planning purposes. Thus, this study assessed the dosimetric impact of HN immobilization devices on PTV coverage with the use of the Eclipse TPS, AAA, and VMAT treatment planning techniques. Current recommendations to vendors by Olch et al include the addition of preloaded immobilization equipment into the TPS software for easy manipulation or to provide the ability to include external structures outside the body contour.

Munjal et al determined that beam attenuation through the couch, additional inserts, and immobilization devices was significant when considering the static IMRT treatment planning
technique; however, VMAT was not a considered component of focus with respect to beam attenuation. In this study, plan comparisons of 15 retrospective patients identified a discrepancy in PTV coverage with a specific focus on immobilization device attenuation. All initial HN plans met the standard of care of providing coverage to 95% of the PTV; however, when immobilization devices were taken into account, PTV coverage was lacking and required an adjustment in plan normalization. Although not considered statistically significant, variations in $V_{95}$ and $D_{100}$ to the PTV averaged 1.4% and 23% respectively. When precision is of the utmost importance, a combination of small discrepancies in dose delivery can lead to significant alterations in PTV coverage. A visual containing the minimum, average, and maximum differences in PTV coverage between the test and HN patient population plans can be found in Figure 7. A lack of standardization for the inclusion of the immobilization system within the calculation volume can be problematic. Attenuation from immobilization devices, when unaccounted for, can cause a misrepresentation of the actual dose delivered to the PTV, therefore causing a deviation by more than the recommended 3% to 5% accuracy range. Although the focus of this study was PTV coverage, inaccurate dose representations can also indirectly affect patient skin dose and dose to surrounding critical structures.

In order to provide the most accurate PTV dose representation, it is plausible to suggest the standardization of including immobilization devices for treatment planning using the VMAT technique. Despite the positive findings of this study, it did not come without limitations. Further research is needed to provide more concrete conclusions which include a larger patient population, different TPS or dose algorithms, and a more detailed focus on the dosimetric impact to the surrounding critical OR. Radiation therapy treatment outcomes have been proven successful with advancements made from continued research and technology. As vendors continue to improve treatment planning software and HN immobilization, continued research surrounding HN radiotherapy is imperative. This research will help to define a new standard of care for this patient population and will continue to guarantee the highest level of patient care and accuracy possible.
References


Figure 1. Display of patient positioning from clinic 1 using a Civco type-S overlay board with IMRT reinforced mask system (A) and shoulder-assistance straps (B).
Figure 2. Display of patient positioning from clinic 2 using the IZI Klarity mask system paired with a Civco AccuForm cushion (A) and supporting knee cushion (B).
Figure 3. Display of patient positioning from clinic 3 using a custom Orfit thermoplastic mask system and carbon fiber base plate (A) with knee support and arms resting at sides (B).
Figure 4. Display of the adjusted body contour (green) to include immobilization devices in the axial (A) and sagittal view (B). The couch contour is displayed in pink.
Figure 5. A comparison of the PTV volume receiving 95% of prescription dose between the HN plan (red) and test plan (blue).
Figure 6. A comparison of the dose encompassing 100% of the PTV volume between the HN plan (red) and test plan (blue).
Figure 7. DVH displaying minimum (A), average (B), and maximum (C) PTV coverage outcomes for the HN plan (red) and test plan (blue).
### Tables

**Table 1.** A plan comparison evaluating the percent differences in immobilization device inclusion within the body contour.\(^a\)

<table>
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<tr>
<th>Patient</th>
<th>Maximum Dose Before Normalization</th>
<th>V(_{95})</th>
<th>D(_{100})</th>
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\(^a\)Each category was calculated by subtracting the test plan results from the HN plan results. Adjusted normalization represents the value needed to achieve the same PTV coverage as the original HN plan.