A Retrospective Analysis of the Impact of Head and Neck Immobilization Devices on Target Volumes and Organs at Risk with Various Treatment Planning System Algorithms

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ABSTRACT

Immobilization devices are essential in radiation therapy aiding in setup reproducibility and limiting patient movement. One treatment site that is highly dependent on the use of immobilization for radiotherapy includes head and neck (HN) cancers. There is limited literature on the effects on immobilization in dose calculations for volumetric modulated arc therapy (VMAT) planning. A retrospective study was performed to determine the dosimetric impact of HN immobilization devices on the planning target volume (PTV), in addition to organs at risk (OAR) using the Eclipse treatment planning system (TPS) with Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB), along with Pinnacle TPS using Collapsed Cone Convolution (CCC). This study retrospectively collected data from the treatment plans of 21 head and neck patients. Comparison plans were created from the original treatment plan to either include or exclude immobilization into the dose calculations depending on the treatment planning system. For Pinnacle systems, a contour was created of the head and neck immobilization and assigned a density equivalence of air to be excluded from dose calculations. For Eclipse planning, immobilization devices were contoured and expanded into the body contour to be included in dose calculations. All other planning parameters remained the same and beams were re-calculated to reflect the effects of immobilization. Evaluations of the treatment plans showed that PTV coverage decreased when immobilization was factored into dose calculations. This change was significant when assessing the percentage of the PTV that received 100% of the prescription dose ($V_{100}$), with a mean change in coverage from 91.4% to 74%. In addition, a reduction of dose to OAR structures tested significant ($p<0.05$) between plans for the cord, brainstem, mandible, and left parotid. The skin was also assessed at the dose at 1 cc of volume ($D_{1.0\text{cc}}$) and the dose at 3 cc of volume ($D_{0.03\text{cc}}$), with a mean percent increase of 5.62% and 3.15% respectively. The plans for all 3 treatment planning algorithms displayed consistent trends of decreased dose to PTV and OAR, and increased dose to skin with the inclusion of immobilization devices in dose calculations. This study supports previous research of immobilization impacting PTV coverage and causing increased skin dose due to bolus effect. The results were displayed using 3 different treatment planning algorithms suggesting that additional care should be taken in planning to consider appropriate calculations to immobilization devices.

Keywords:

Immobilization Devices, Radiotherapy, Attenuation, Head and Neck, VMAT
Introduction

Photon beam attenuation occurs any time a material with density enters the path of the beam. When delivering radiation therapy treatments to target volumes, objects that impede the effects of the radiation could alter dose distributions and decrease target coverage. There is no standard practice currently established accounting for these devices in contouring or in dose calculations. Many institutions have implemented couch models to incorporate photon beam attenuation when treating with posterior beam angles; however, immobilization devices often remain unaccounted for in dose calculations.

Immobilization devices are essential in radiation therapy aiding in setup reproducibility and limiting intrafractional patient movement. One treatment site that is highly dependent on the use of immobilization for radiotherapy includes head and neck (HN) cancers. Common devices used for treatment in this anatomic region include head holders, thermoplastic masks, and table top extensions/overlays. Previous studies have shown that immobilization devices attenuate a portion of the beam and decrease skin sparing.

While most current literature compares the effect of immobilization devices on intensity modulated radiation therapy (IMRT) and three-dimensional (3D) based planning, Olson et al showed a statistically significant impact on planning target volume (PTV) coverage due to HN immobilization devices using volumetric modulated arc therapy (VMAT) alone. However, limitations of the study included using a single calculation algorithm in the treatment planning system (TPS) without evaluation of dose to organs at risk (OAR). Thus, the goal of this retrospective study was to determine the dosimetric impact of HN immobilization devices on the PTV, in addition to OAR using the Eclipse TPS with Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB), along with Pinnacle TPS using Collapsed Cone Convolution (CCC).

Methods and Materials

Patient Selection

All patients selected for this study were diagnosed with cancer of the HN region. The patients were prescribed definitive radiation doses between 60-70 Gy to the primary tumor. The patients were selected from 3 different clinical institutions consisting of 8 patients with tonsillar cancer, 5 patients with base of tongue (BOT) cancer, 3 patients with oropharyngeal cancer, 1 patient with laryngeal cancer, 1 patient with cutaneous squamous cell metastasis, 1 patient with floor of mouth cancer, 1 patient with right parotid cancer, and 1 patient with an unknown
primary of squamous cell cancer. Each clinical site contributed 7 patients to this study, allowing for an equal distribution of patients planned with each treatment planning algorithm. All patients were planned with 6 MV photon VMAT plans using either full or partial gantry arcs.

During the patient selection process, plans generated using a non-VMAT treatment technique were excluded. In addition, assessments of the primary gross tumor volume (GTV) were made, where patients with involvement of the skin surface were excluded. Therefore, treatments requiring the need for bolus were omitted from this study.

All patients in this study underwent a simulation procedure in which a computed tomography (CT) scan was obtained for treatment planning. The patients were simulated in the supine head-first treatment position with the scanning field of view (FOV) to include the entirety of the immobilization devices in the target area. The patients simulated at clinical site 1 included the use of the following immobilization devices during simulation: CIVCO Type-S standard perforated thermoplastic mask, CIVCO Type-S tabletop overlay board, QFix head holder, and CIVCO AccuForm cushion. The patients simulated at clinical site 2 utilized the QFix Curve Board, S-Frame perforated thermoplastic mask, and for some patients a CIVCO AccuForm cushion (Figure 1). Finally, the patients simulated at clinical site 3 were immobilized using CIVCO Type-S head-only perforated thermoplastic mask, CIVCO Type-S tabletop overlay board, QFix Silverman head holder, and for some patient's a CIVCO AccuForm cushion.

Contouring

The CT scan obtained from simulation was used for the contouring of normal structures and target volume delineation. Treatment volumes such as the GTV, clinical target volume (CTV), and PTV were delineated in the TPS by the physician. For the purpose of this study, the PTV was specific to the volume encompassing the primary tumor bed.

The normal tissue structures that were evaluated in this study included the cord, brainstem, mandible, skin, and right and left parotid glands. The skin was defined as a 3 mm rind that was created from the external surface contour using an inner ring structure. All normal tissue contours were delineated by the medical dosimetrist and approved by the radiation oncologist. Any OAR structures that were missing from the original data set were contoured for the completeness of data analysis; with the exception of primary tumor invasions of OAR, in which case, the dose reported to that structure was excluded.
To assess the effect of immobilization devices in the planning process, specific contours were created depending on the TPS utilized. In Eclipse, the body contour was extended to include all immobilization devices including the HN overlay boards, the head holders, and appropriate AccuForm cushions (Figure 2). This allowed the TPS to calculate dose to all densities within the body contour. In the Pinnacle TPS, densities beyond a specific tissue-air threshold were automatically assessed and used in calculation. For this reason, a contour separate from the patient was created to encompass all immobilization devices within the treatment area (Figure 3). This contour was overridden to the density equivalence of air.

**Treatment Planning**

All patients in this study were treated with a curative intent, using treatment doses ranging from 60-70 Gy. There were 12 patients treated to a definitive dose of 70 Gy, 3 treated to a dose of 69.96 Gy, 2 treated to a dose of 68 Gy, 2 treated to a dose of 66 Gy, and 3 treated to a dose of 60 Gy. The patients were treated using a standard fractionation schedule with daily treatments for 5 days per week.

The TPS used to carry out the dosimetric calculations included Varian Eclipse and Philips Pinnacle. The treatment plans were generated using a VMAT technique consisting of 2-3 arcs with the smallest arc spanning 197° and the largest arc consisting of 358°. All plans created used a photon energy of 6 MV, with delivery carried out on the Elekta Agility at clinical site 1, Varian Novalis or Varian TrueBeam at clinical site 2, and Varian Edge at clinical site 3.

Throughout the initial planning process, plans were optimized to achieve target coverage goals while considering normal tissue constraint recommendations as proposed by published sources such as Quantitative Analyses of Normal Tissue Effects in the Clinic (QUANTEC) and Radiation Therapy Oncology Group (RTOG) protocols.\(^8\) The immobilization devices were then introduced into the dosimetric calculation process to reflect either the addition or subtraction of immobilization devices for the corresponding TPS. For Eclipse, the immobilization devices were added into dose calculations through the use of an expanded body contour to include immobilization devices. For Pinnacle, immobilization devices were removed from dose calculations by performing a density override to the immobilization device contour. Throughout this process, plan normalizations were kept consistent and beams were re-computed to assess any changes in target coverage and dose to OAR.

**Plan Comparisons**
The process of plan evaluation was dependent on the TPS used for each patient. With Eclipse TPS, the planning target coverage and dose to OAR were evaluated first from the initial treatment plan without the inclusion of immobilization devices. The plan was then copied, and the body contour was extended to include all HN treatment devices. The beams were then recomputed and dose to targets and OAR were analyzed in the comparison plan.

In the Pinnacle TPS, the initial plan represented the inclusion of the immobilization devices because of the planning system’s ability to detect all densities within the scan. The treatment devices were then contoured, and the CT density of this contour was assigned to 0 g/cm³ (air equivalence) to simulate the exclusion of the device. The beams were then recomputed maintaining the same normalization and monitor units to achieve the comparison plan.

During the plan evaluations, the assessed OAR structures included the cord, brainstem, mandible, skin, and right and left parotid glands. For the skin, the dose at 1 cc of volume (D₁cc) and the dose at 0.03 cc of volume (D₀.₀₃cc) were reported with and without inclusion of immobilization devices. The remaining OAR listed were evaluated by assessing the mean dose (Dₘₑᵃⁿ) and the D₀.₀₃cc for each plan.

To assess target coverage, specific volume metrics were analyzed. These metrics included the percentage of the PTV that received 95% of the prescription dose (V₉₅), and the percentage of the PTV that received 100% of the prescription dose (V₁₀₀). These parameters were used clinically for assessing target coverage of the PTV and were applied in both scenarios for dosimetric calculations with and without the inclusion of immobilization devices.

**Results**

**Target Coverage**

The data obtained from this study showed a decrease in target coverage when immobilization devices were accounted for in dose calculations. The target coverage was assessed by measuring the V₉₅ and V₁₀₀ with and without the inclusion of HN immobilization. The mean values were then calculated for these metrics and compared in both plans. When evaluating the PTV (V₉₅), the mean value decreased from 99.3% to 98.2% after the plans were recomputed to account for the attenuation of the immobilization devices. When analyzing the mean value of the PTV (V₁₀₀), the effects of immobilization were even more apparent with a change in coverage from 91.4% to 74.0% (Figure 4). Furthermore, the mean percent difference was calculated for the PTV (V₁₀₀), which showed a significant change of 45.0% between plans.
Organs at Risk

Data was also collected for specific organs at risk in the HN area and doses were reported as the mean dose to the structure and the $D_{0.03 \text{ cc}}$. The structures included the cord, brainstem, mandible, and right and left parotid glands. When evaluating these structures in both plans, the data collected showed a decrease in dose when immobilization was included in planning. The mean percent difference ranged from 0.28% to 2.50% between plans (Figure 5). To ensure that the results were not due to random error, a repeated measures T-Test was performed. This test found that all OAR presented a significant change between plans ($p < .05$), except for the right parotid gland ($p = .09$).

Unlike the other organs at risk, the skin showed an increase in dose when including immobilization devices into the dose calculation and was thus analyzed further (Figure 6). The $D_{1.0 \text{ cc}}$ and $D_{0.03 \text{ cc}}$ parameters were observed between treatment plans and the mean dose differences were calculated for all patients. The mean percent difference for the $D_{1.0 \text{ cc}}$ was a 5.62% increase in dose and the $D_{0.03 \text{ cc}}$ showed a 3.15% increase in dose between plans.

Planning Algorithms

This study gathered data using 3 different planning algorithms including Pinnacle’s CCC, Eclipse’s AAA and AXB. The results showed a consistent trend across all planning algorithms with an increase in skin dose when including immobilization devices in the dose calculations. For example, the percent difference of $D_{1.0 \text{ cc}}$ of the skin showed increases in plans ranging from 0.88% to 8.28% using CCC, 7.97% to 12.71% using AAA, and 2.72% to 7.56% using AXB. In addition, all planning algorithms showed a trend of decreased PTV coverage and dose to OAR when evaluating the mean percent difference between plans with and without immobilization (Figure 6).

Discussion

The results of this study were consistent with the findings of Olson et al$^7$ suggesting that the attenuating effects of immobilization have an impact on PTV target coverage. In addition, these findings were confirmed using a larger sample size and were consistent when tested across 3 different treatment planning algorithms. This suggests that there is a deficit in treatment planning practices across multiple systems in accounting for immobilization devices in dose calculations.
Furthermore, this study also considered skin dose which is a topic of interest with regards to VMAT treatment techniques. Previous studies suggest up to an 8% higher skin dose with a marginally higher significance of Grade ≥ 2 acute skin toxicities when using a VMAT treatment technique vs. IMRT in HN patients. Other studies report a bolus effect from thermoplastic masks in HN cancer with an increase in the average skin dose by 18%. Although the previous studies differ by reporting measurements of skin dose using thermoluminescent dosimeters, the results are aligned with the findings of this study indicating an increase in skin dose due to HN immobilization in VMAT planning. Therefore, it is suggested that care be taken in VMAT planning with considerations of limiting skin toxicity.

**Conclusion**

In conclusion, the presence of immobilization devices in dose calculations influences PTV coverage, OAR, and skin dose. The decrease in PTV coverage and dose to OAR can be attributed to the increased attenuation of the photon beam when considering immobilization. For PTV coverage, the greatest effects were seen when assessing the V100, which may be attributed to differences of dose homogeneity within the PTV at prescription dose. For OAR, although the mean percent difference did not suggest a large change, all changes tested statistically significant with the exception of the right parotid.

This study also supports the reported increase in skin dose due to the inclusion of immobilization devices in dose calculations. Multiple studies have shown the potential for bolus effect with the use of immobilization devices related to 3D conformal and IMRT planning. This study continues to support the literature and, in addition, confirms the need for considerations of skin toxicity in VMAT planning.

Finally, this study observed the effects of immobilization across 3 different treatment planning algorithms which has not been addressed in current literature. All planning algorithms used in this study supported previous conclusions recommending the standardization of accounting for immobilization devices in treatment planning. Although the findings of this study were consistent across multiple planning algorithms, each patient data set was not collectively observed across all treatment algorithms. Further research may be completed to evaluate the changes in dose calculations using one data set across multiple algorithms with and without immobilization devices.
References


Figures

**Figure 1.** Patient positioning using a QFix Curve Board, thermoplastic mask and AccuForm headrest.

**Figure 2.** Contour representation of body (green) including HN immobilization devices in Eclipse TPS.
Figure 3. Contour (purple) used for immobilization devices separate from body contour in Pinnacle TPS.

Figure 4. The mean PTV coverage for plans without immobilization devices (pre) vs. plans with immobilization devices (post).
Figure 5. The mean percent difference and significance value between plans with and without immobilization devices for organs at risk.
Figure 6. Increase in skin dose for patients using the treatment planning algorithms Collapsed Cone Convolution (CCC), Anisotropic Analytical Algorithm (AAA), and Acuros XB (AXB).