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Dosimetric impact of immobilization devices in head and neck IMRT: A retrospective analysis

Laleh Rafat-Motavalli[a,*], Elie Hoseinian-Azghadi[a], Niloofar Rafat-Motavalli[b], Mahdieh Dayyani[b,c], Hashem Miri-Hakimabad[a,b], Leila Sobhkhiz-Sabet[d], Zahra Shahamat[d]

[a] *Department of Physics, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran*
[b] *Research and Education Department, Reza Radiotherapy and Oncology Center, Mashhad, Iran*
[c] *Radiation Oncology Department, Reza Radiotherapy and Oncology Center, Mashhad, Iran*
[d] *Medical Physics Department, Reza Radiotherapy and Oncology Center, Mashhad, Iran*

HIGHLIGHTS

- The study provides an analysis of the dosimetric effects of immobilization devices and the treatment couch in IMRT.
- Neglecting immobilization devices in TPS calculations lead to underestimation of target and altered OAR doses.
- Solutions such as integrating immobilization devices and the carbon fiber couch into TPS calculations is proposed.

ABSTRACT

Immobilization devices are critical for ensuring precise and reproducible patient positioning during radiotherapy. These devices, along with the treatment couch, can alter dose distribution by increasing skin dose, reducing target coverage, and introducing attenuation and scattering. Guidelines like TG-176 emphasize incorporating the dosimetric impact of devices into treatment planning system (TPS) calculations, but current practices often neglect or only partially consider these effects, usually modeling the treatment couch as low-density material. This study evaluated the impact of immobilization devices on dosimetric parameters for target volumes and organs at risk (OARs) in 20 head and neck IMRT plans. Five scenarios were compared, from no devices to full immobilization and a double-layer couch in TPS calculations. Two-tailed paired t-tests assessed significance, with p-values reported. The most significant effect was for parameter GTV D100, showing a maximum difference of 5.5% and an average of 2% ($p < 0.0001$). OAR doses had smaller differences, ranging from 1% to 3% ($p < 0.0001$). Pearson correlation analysis indicated a relatively strong correlation between the posterior beam contribution and dose parameters of the target region ($r = 0.93$ to 0.95). To enhance accuracy, include all immobilization devices and the carbon fiber treatment couch in external contour and TPS calculations. If CT simulation equipment differs from treatment setups, apply appropriate CT number overrides. Additionally, use the same immobilization devices as in the treatment room for CT imaging, ensuring the field of view (FOV) is large enough to capture all devices and integrate a complete couch model into the images.

KEYWORDS
Immobilization devices
IMRT
Dose coverage
OARs (Organs at risk)

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1 Introduction

Technological advancements in patient immobilization techniques facilitate the provision of increasingly accurate radiotherapy treatments. This is particularly significant for patients undergoing treatment in the upper body region, especially the head and neck, as the target tissue is often adjacent to numerous healthy and vital structures. Even the slightest patient movement can significantly affect dose coverage (Ahn et al., 2009; Contesini et al., 2017; Howlin et al., 2015; Senkui et al., 2015). With technological advancements in immobilization, radiotherapy can now be delivered with greater precision (Howlin et al., 2015; Pehlivan et al., 2009; Radiotherapy, 2008). These advancements have led to improved treatment reproducibility, thereby enhancing treatment outcomes. In other words, achieving optimal results in radiotherapy requires meticulous attention to patient immobilization and

*Corresponding author: rafat@um.ac.ir

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accurate patient positioning, which help reduce systematic and random errors (Howlin et al., 2015; Radiotherapy, 2008). As a result, it is now possible to employ smaller margins for the planning target volume (PTV) in advanced treatment techniques (Pehlivan et al., 2009).

To successfully reduce systematic and statistical errors, it is crucial to consider all essential components of uncertainty (Radiotherapy, 2008). One such critical component is the dosimetric effect of devices external to the patient, including couch tops and immobilization devices, which must be incorporated into the treatment planning system (TPS) dose calculations. Neglecting these factors can render maximum efforts to reduce systematic and statistical errors futile, particularly in intensity-modulated radiation therapy (IMRT), where precise treatment is crucial in the presence of steep dose gradients. Ensuring the effectiveness of these efforts requires careful consideration of the dosimetric effects of the treatment couch and immobilization devices (Lancellotta et al., 2018; Olson et al., 2018).

This area of research focuses on two main aspects. One line of research is dedicated to developing immobilization devices using materials that minimize beam attenuation and dosimetric effects on dose distribution (Asfia et al., 2022; Dickie et al., 2009; Gerig et al., 2010; Robar et al., 2022; Smith et al., 2010; Snider et al., 2021). Another line of research emphasizes the need for TPS dose calculations to account for the presence of these devices. The dosimetric impact of external immobilization devices is a complex combination of increased skin dose, reduced tumor dose, and altered dose distribution (Chen et al., 2018; De Puysseleyr et al., 2016; Ferrer et al., 2018; Lau, 2020; Lau et al., 2021; Lee et al., 2009; Munjal et al., 2006; Park et al., 2015; van Prooijen et al., 2023; Wang et al., 2024). The magnitude of this effect depends on factors such as beam energy, geometric positioning of the beam relative to the devices, the fraction of dose delivered through these devices, and their material composition. Immobilization devices are generally categorized into two groups: (1) those positioned farther from the patient, which primarily cause attenuation and scattering, and (2) those closer to the patient, such as thermoplastic masks, which act like bolus, increasing skin dose and shifting the depth dose curve toward the patient's surface. The overall effect can often be clinically significant, as will be discussed in this report.

Given that maximizing radiotherapy outcomes typically requires dose delivery accuracy of less than 3% to 5%, based on radiobiological considerations (Bentzen, 2004; Brahme, 1984; Mijnheer et al., 1987), modern calculation methods have significantly improved the accuracy of TPS dose calculations. Many centers routinely apply small corrections (typically 2% to 4%) for Block Trays in monitor unit (MU) calculations. Temperature and pressure corrections for ionization chamber readings and adjustments in TG-51 calibration methods are other common efforts to apply corrections of 1% to 2% (Almond et al., 1999). While addressing these minor corrections is routine, the potentially more significant dosimetric effects of devices such as immobilization systems are often overlooked. This oversight, though unintentional, likely stems from historical practices, as precise or practical methods for incorporating these devices into dose calculations have been scarce, and vendor-provided data on their dosimetric impact has generally been insufficient (Olch et al., 2014).

For beams perpendicular to a uniform slab phantom, attenuation factors can be measured and manually applied to MU calculations. However, for beams passing obliquely through non-uniform parts of the devices, precise manual MU calculations become challenging. The ability of TPS dose calculation algorithms to account for these devices is often underutilized. As with other scenarios where dosimetric corrections are deemed necessary, the dosimetric effects of external immobilization devices must be included in dose calculations.

Another critical point is the use of identical immobilization devices during imaging and treatment. This systematically enhances accuracy, allowing for precise replication of imaging setups during all treatment sessions. However, in some cases, higher-density and more rigid immobilization devices have been used during CT simulation. These devices, due to their rigid structure, do not degrade over time and can be used for a longer period in clinical settings. Since these devices are geometrically similar and do not play a role in treatment, their use during imaging is considered acceptable. However, using identical immobilization devices for both imaging and treatment can resolve this issue, allowing all devices, including the treatment couch, to be included in TPS dosimetric calculations.

Nevertheless, not all clinics follow this practice, either due to a lack of identical equipment or the failure to implement the process of including these devices in dose calculations. Various researchers have studied the impact of including or excluding immobilization devices in dosimetric calculations (Chen et al., 2018; De Puysseleyr et al., 2016; Ferrer et al., 2018; Lau, 2020; Lau et al., 2021; Lee et al., 2009; Munjal et al., 2006; Park et al., 2015; van Prooijen et al., 2023; Wang et al., 2024). When high-density immobilization devices are used during CT simulation, the resulting images cannot be used to assess the attenuation effects of the devices used during treatment. Additionally, using these images requires a lengthy process of contouring the immobilization devices and adjusting the Hounsfield units (HU) to match the materials used in treatment, which is often overlooked in high-workload, low-staff settings. At best, a simplified treatment couch model filled with air-equivalent polymer foam without a carbon fiber layer is considered in dose calculations, making it the most feasible suggestion at this time. Headrests and other immobilization devices are also not included.

This issue was addressed by AAPM TG 176 in 2014 (Olch et al., 2014), which examined the effects of a wide range of treatment couches and immobilization devices on surface dose and dose attenuation. However, estimates for a significant number of clinically used immobilization devices are still lacking (Wang et al., 2024). Furthermore, a comprehensive assessment of their impact on real treatment plans is needed. Given that volumetric dose parameters are currently used to evaluate the acceptability of treatment plans, the dosimetric effects of immobilization devices should also be presented in terms of volumetric dose parameters. This would clarify the impact of includ-

ing or excluding each component of these devices. In 2020, a study investigated this for breast treatment setups in the prone position (Lau, 2020; Lau et al., 2021). Previous research has shown that the use of immobilization devices in radiotherapy may lead to reduced tumor dose, increased skin dose, and altered dose distribution (De Puysseleyr et al., 2016; Lee et al., 2009; Munjal et al., 2006; Wang et al., 2024).

Therefore, this study was conducted as a preliminary investigation to highlight the potential dosimetric impact of patient immobilization devices and treatment couch structures in external beam radiotherapy planning. Rather than aiming to quantify exact dose discrepancies across treatment sites, our primary objective was to demonstrate that the omission of these structures from dose calculations may result in clinically relevant inaccuracies. With the widespread availability of advanced treatment planning systems capable of accurate heterogeneity modeling, we argue that these components should be routinely incorporated into planning workflows. This work serves as a call to reevaluate traditional simplifications and advocate for greater consistency between simulation and treatment environments- both geometrically and in material composition.

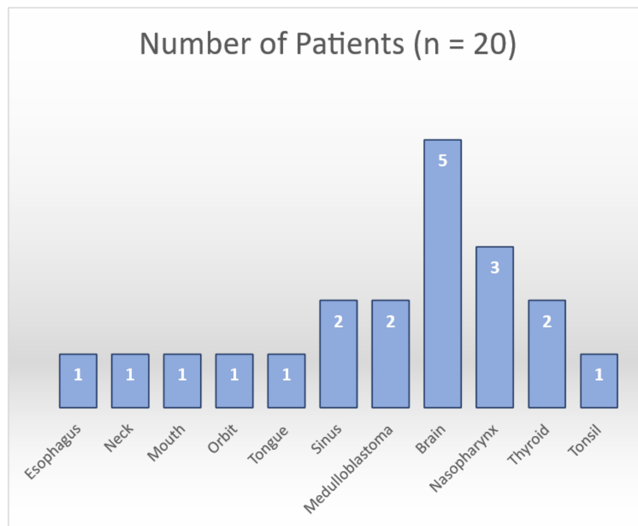

Figure 1: Distribution of selected patients by disease site.

2 Materials and Methods

2.1 Patient Selection Criteria

All patients selected for this study were diagnosed with upper body cancers, including head and neck malignancies. The prescribed dose for these patients ranged between 54 and 70 Gy for primary treatment. The patient cohort included two thyroid cancer patients, one tongue cancer patient, four nasopharyngeal cancer patients, one tonsil cancer patient, one oral squamous cell carcinoma (SCC) patient, four brain tumor patients, one patient with metastatic cervical lymph nodes of unknown origin, two sinus cancer patients, one eye cancer patient, two medulloblastoma patients, and one esophageal cancer patient. Figure 1 presents a bar chart showing the distribution of patients by disease type. This study is retrospective, and the inclusion criteria were treatment with intensity-modulated radiation therapy (IMRT) and the presence of head and neck immobilization devices.

All patients underwent the same simulation and imaging process, and these images were used in the treatment planning system (TPS). Imaging was performed in the supine position, with the patient's head entering the CT scanner first. The field of view (FOV) included the entire immobilization setup for the target region. The immobilization devices used during the simulation included a standard thermoplastic mask, base plate, headrest, wedge, and block.

2.2 Contouring

CT simulation images were used to contour healthy structures and define target volumes. Treatment volumes, including the gross tumor volume (GTV), clinical target volume (CTV), and planning target volume (PTV), were delineated by a specialist physician using the TPS. Eighteen organs at risk (OARs) were evaluated, including the spinal canal, brainstem, hippocampus, optic chiasm, cochlea, mandible, esophagus, right and left parotid glands, optic nerves, eyes, lacrimal glands, trachea, temporal lobe, brachial plexus, submandibular glands, oral cavity, larynx, and constrictor muscles.

To assess the impact of immobilization devices on the treatment planning process, contours were drawn to include these devices. Since the TPS ignores all regions outside the external contour and does not include them in dose calculations, the external contour was modified for all treatment plans to encompass the treatment couch and immobilization devices. This ensured that the TPS calculated the dose for all structures within the external contour. Five different scenarios were considered to evaluate the dosimetric effects of these devices (Fig. 2). Scenario (a) represents the simplest case, where only the patients body is included in the external contour, and the treatment couch and immobilization devices are excluded. Scenario (b) includes a simple couch with a Hounsfield unit (HU) value of -900, which is the simplest and most feasible practice. Scenario (c) adds a 1.1 mm layer to the couch model with an HU value of 1240. Scenario (d) includes the base plate in addition to the couch. Finally, scenario (e) is the most comprehensive, incorporating all immobilization devices into the external contour.

To accurately model the immobilization devices and treatment couch in the treatment planning system, CT scans of these components were acquired using the same scanner and imaging protocol applied during patient simulation. HU values for each material were determined by analyzing pixel value histograms from the acquired CT images. Furthermore, to validate our measurements, we referenced published data. In particular, Njeh (2012) reported HU values of 1240 for the carbon fiber layer and -890 for the foam layer of the treatment couch, which closely matched our experimental findings. These HU values were then used to assign material properties within

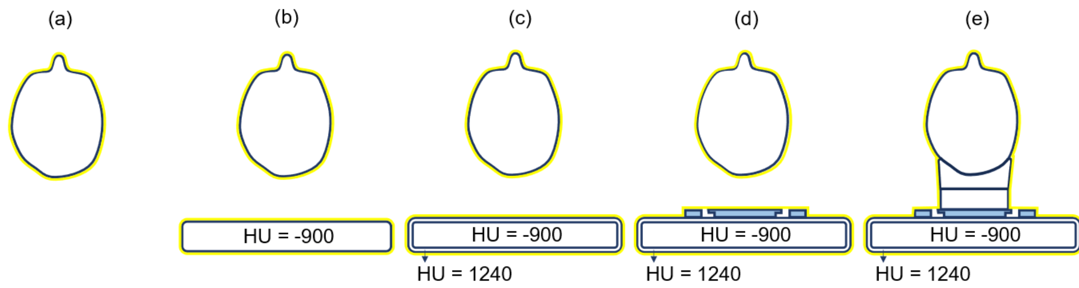

Figure 2: Different scenarios evaluated in the study, ranging from the simplest (a) to the most comprehensive (e). The simplest scenario includes only the patient's body within the external contour. In contrast, the most comprehensive scenario includes the carbon fiber couch, base plate, headrest, wedge, and block within the external contour. The yellow line indicates the external contour defined in the TPS, and the HU values for the couch materials are shown for each case.

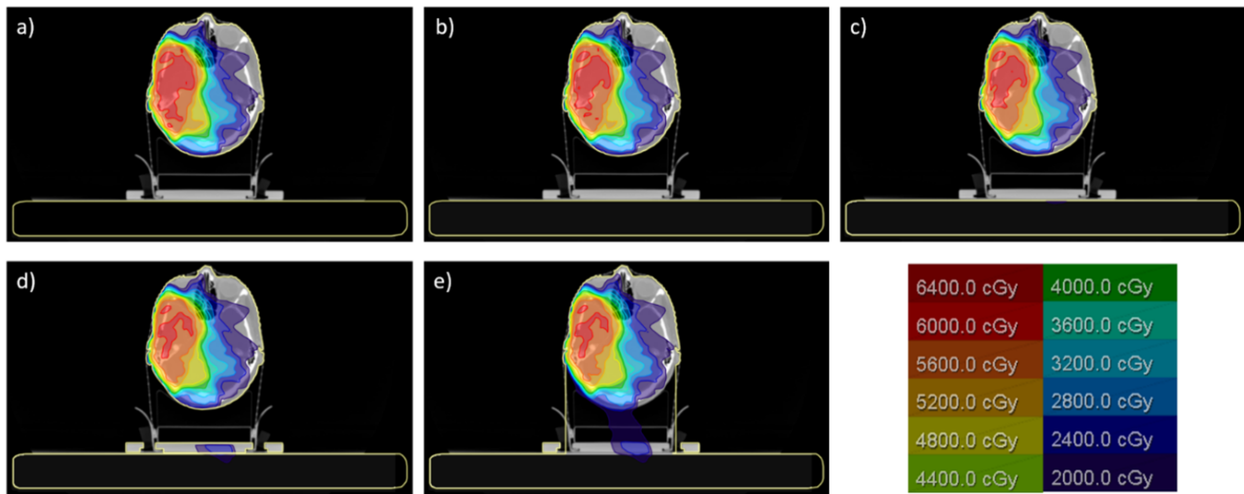

Figure 3: Dose distribution obtained from Prowess calculations for Scenarios (a) to (e).

Table 1: Dose constraints for head and neck treatment plans.

CTV	**PTV**
100% of CTV Receiving 100% of the Prescribed Dose (PD)	90% of PTV Receiving 100% of the Prescribed Dose (PD)
Sharp dose fall off is expected for all targets to minimum the hot dose areas	
Dose Constraint Goals for Non-involved Normal Structure	
Spinal Channel: Max Dose (0.1 cc) < 50 Gy Spinal Channel (3mm PRV): Max Dose < 54 Gy	Eyes: Mean Dose < 35 Gy, Max Dose < 50 Gy
Optic Chiasma: Max Dose < 50 Gy Optic Chiasma (3 mm PRV): Max Dose < 54 Gy	Lens: Max Dose < 7-10 Gy
Brainstem (3 mm PRV): Max Dose (0.1 cc) 54 Gy 2 cc < 60 Gy (Intersection with PTV)	Temporal Lobes: Max Dose < 60 Gy
Optic Nerves: Max Dose < 50-54 Gy	Oral Cavity: Mean Dose < 30-40 Gy, V40 < 50%
Brachial Plexus: Max Dose < 60-66 Gy	Mandible & TMJ: Max Dose 70 Gy
Sub Mandible Glands: Mean Dose < 30-36 Gy	Parotid Glands: Mean Dose < 20-24 Gy, V30 ¡45-50%, Max Dose < 60 Gy
Glottic Larynx: Mean Dose ¡36-45 Gy, V40 < 50%	Trachea: Mean Dose < 36-45 Gy
Esophagus: Mean Dose < 34-45 Gy, Max Dose 60 Gy	Superior & Middle Pharyngeal Constrictor muscles (PCM): Mean Dose 50 Gy
Cochlea: Mean Dose < 36 Gy, V55 < 5% (Max Dose < 40 Gy if Possible)	Lacrimal Glands: Max Dose < 40 Gy V30 < 50%
Hippocampus: Mean Dose < 16-25 Gy	Cerebellum: Max Dose < 60 Gy

the treatment planning process.

2.3 Treatment Planning

All selected patients were treated with prescribed doses ranging from 54 to 70 Gy. Eight patients received 70 Gy, two patients received 66 Gy, two patients received 60 Gy,

one patient received 59.4 Gy, one patient received 55.8 Gy, and six patients received 54 Gy. Patients were treated using standard fractionation, with sessions scheduled 5 days per week.

The TPS used for dose calculations was Prowess Panther 5.50, which utilizes the Collapsed Cone Convolution (CCC) algorithm for dose calculations. Treatment plans were generated using the IMRT technique, consisting of 9 equally spaced beams with four segments. All plans used 6 MV photon beams, and the prescribed dose was delivered using accelerator number 1 (Siemens Artiste). The initial treatment planning process aimed to achieve optimal target dose coverage while adhering to healthy tissue dose constraints, as outlined in the QUANTEC guidelines. Subsequently, immobilization devices were incorporated into the dose calculation process to assess their individual dosimetric effects. The same treatment plan was used, and dose calculations were repeated to evaluate any changes in target coverage and OAR doses. Table 1 lists the dose constraints for head and neck IMRT plans at the Reza Radiotherapy and Oncology Center. Table 2 presents the quality assurance criteria for major and minor deviations from the protocol, as reported in a 2021 study (Corry et al., 2021).

3 Results

This study evaluated five scenarios to account for patient immobilization devices in dose calculations for 20 patients with upper body cancers. The results are presented using dose-volume histogram (DVH) parameters for both target volumes and organs at risk (OARs). Box plots were used to display the statistical characteristics of dose parameters for the evaluated patients, categorized by target volumes and OARs. Figure 3 shows the dose distribution extracted from the TPS for a representative patient across all scenarios. The isodose curves in this figure demonstrate that as the immobilization devices are more fully incorporated into the calculations (Scenario e), the area covered by the red isodose curve (6400 cGy for this patient) decreases.

3.1 Target Volume Coverage

Figure 4 presents box plots comparing dose parameters for the gross tumor volume (GTV), clinical target volume (CTV), and planning target volume (PTV) across the 20 patients. The differences in dose parameters between Scenarios (a-d) and Scenario (e) are shown. Scenario (e) represents the most comprehensive inclusion of immobilization devices in dose calculations, comparing other scenarios to it highlights the differences between simple and more comprehensive calculation methods.

Table 2: Quality assurance criteria for major and minor deviations from the protocol, as reported in reference (Corry et al., 2021).

Parameters	D 0.03 cc	D 1cc
Brainstem	$\leq$ 54 Gy	-
Spinal Canal	$\leq$ 45 Gy	-
Optic chiasm	$\leq$ 54 Gy	-
Optic nerves	$\leq$ 54 Gy	-
Temporal lobe	$\leq$ 72 Gy	< 65 Gy

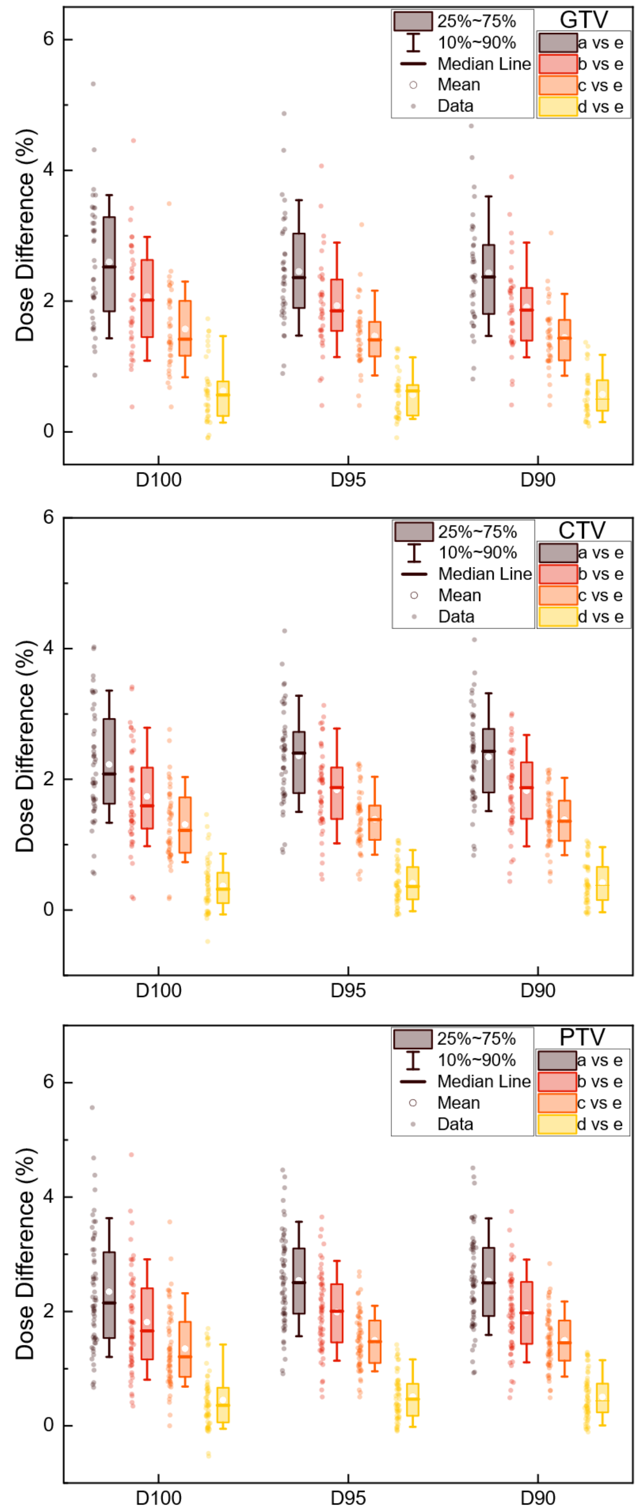

Figure 4: Box plots ($n = 20$) comparing differences in D90, D95, and D100 for the GTV, CTV, and PTV between Scenarios (a-d) and Scenario (e).

In Fig. 4 (top), which focuses on the GTV, the maximum difference in the D100 parameter was up to 5.5%, observed when comparing Scenario (a) with Scenario (e). For the comparison between Scenario (b) and Scenario (e), the maximum difference in D100 was close to 4.5%. The differences in D100, D95, and D90 for the GTV were approximately 5.5%, 5%, and 4.5%, respectively. When con-

sidering Scenario (b), these values were reduced by about 0.5%. The median differences ranged from 2% to 2.5%.

In Fig. 4 (middle), which focuses on the CTV, the maximum difference in the D100 parameter was approximately 4%, observed when comparing Scenario (a) with Scenario (e). For Scenario (b) compared to Scenario (e), the maximum difference in D100 was also around 4%. The differences in D100, D95, and D90 for the CTV were approximately 4%, with median differences ranging from 1.5% to 2%. In Fig. 4 (bottom), which focuses on the PTV, the maximum difference in the D100 parameter was close to 5.5% when comparing Scenario (a) with Scenario (e). For Scenario (b) compared to Scenario (e), the maximum difference in D100 was close to 4.5%. The median differences for D100, D95, and D90 for the PTV ranged from 2% to 2.5%.

These results indicate that target volume coverage (GTV, CTV, and PTV) decreased when immobilization devices were fully included in dose calculations. Overall, the maximum difference in dose parameters for target volumes was approximately 5.5%. When considering Scenario (b), the maximum difference was 4.5%, with a median difference of 2%.

3.2 Organs at Risk (OARs)

Similar box plots were generated for OARs, considering four dose parameters: Dmax, D1cc, D2cc, and Dmean (Figs. 5 to 7). Additional box plots of other OARs evaluated in this study are provided in the supplementary file accompanying this article. The downward trend in the box plots, as seen in the previous section, was observed when comparing Scenarios (a vs e) to Scenarios (d vs e). For some OARs, such as the brainstem, spinal canal, optic chiasm, optic nerves, and temporal lobes, the maximum dose (Dmax) was critical. For others, such as the larynx, trachea, and cochlea, the mean dose (Dmean) was the primary determining factor for plan approval. Changes in all these parameters were reported for the OARs.

In Fig. 5, the maximum difference in Dmax for the spinal canal was approximately 7% when comparing Scenarios (a-d) with Scenario (e). When comparing the current practice (Scenario b) with Scenario (e), this difference was around 6%. The median difference for the 20 patients ranged from 2% to 3%. For the brainstem, the maximum difference in Dmax was up to 6%, which reduced to 5% when considering Scenario (b). Across all OARs, the differences in dose parameters between Scenarios (a-d) and Scenario (e) did not exceed 6.5%. When focusing on the current practice (Scenario b), the differences were slightly smaller. Overall, the median differences for the four evaluated parameters ranged from 1% to 2.5% across the 20 patients (Figs. 5 to 7). These results indicate that OAR doses also decreased when immobilization devices were fully included in dose calculations.

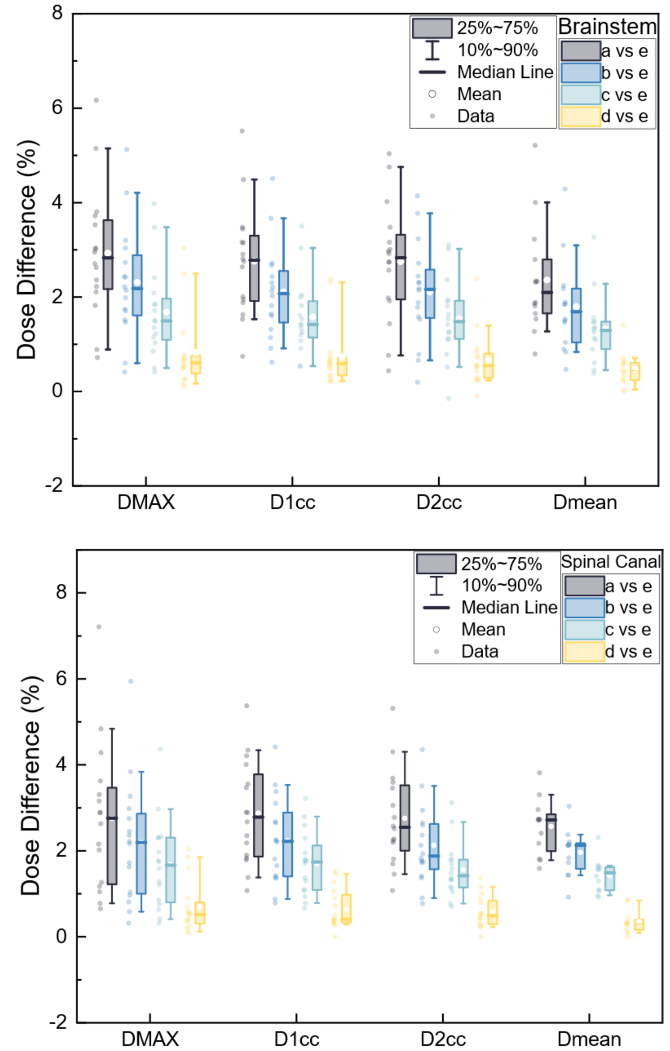

Figure 5: Box plots ($n = 20$) comparing differences in Dmax, D1cc, D2cc, and Dmean for the Brainstem and Spinal Canal between Scenarios (a-d) and Scenario (e).

3.3 Data Fitting

To investigate the correlation between target volume dose parameters and the fraction of monitor units (MU) passing through immobilization devices and the treatment couch, the MU for posterior beams (gantry angles 160° and 200°) was extracted from all treatment plans. This MU was divided by the total MU for each plan. The difference in D100 between Scenarios (a) and (e) for the GTV and CTV was plotted against the fraction of MU for posterior beams, and linear fits were applied to the data (Fig. 8). The Pearson coefficient and R-squared values were relatively high, indicating a strong correlation between these parameters.

4 Discussion

In terms of the clinical relevance of the reported dose differences, it is important to emphasize that maximizing radiotherapy outcomes requires dose delivery accuracy

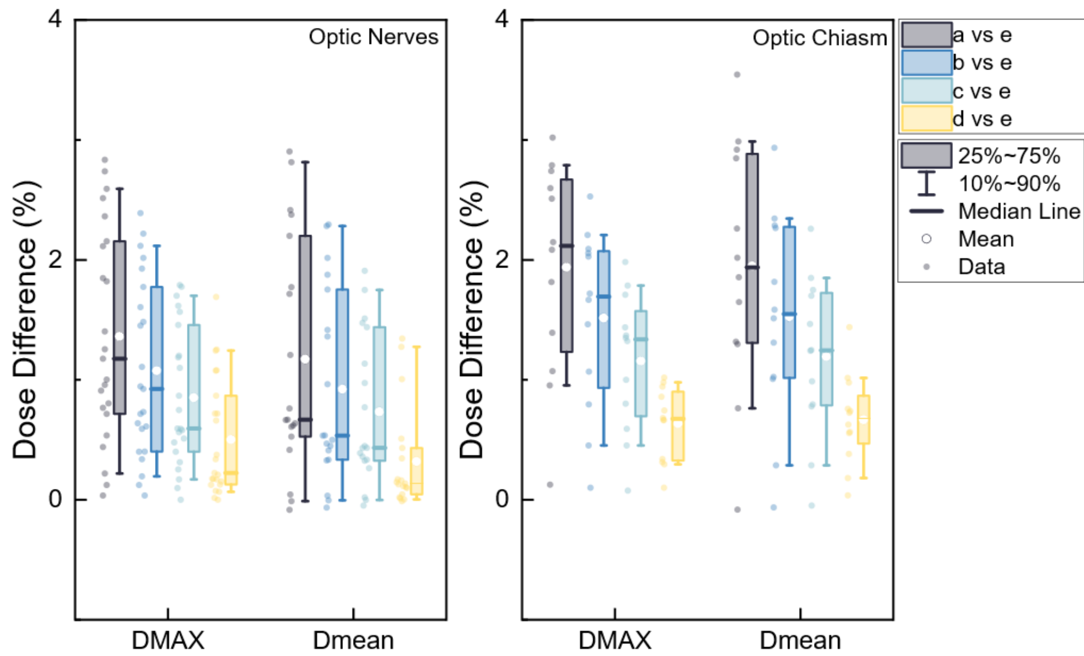

Figure 6: Box plots ($n = 20$) comparing differences in Dmax, D1cc, D2cc, and Dmean for the Optic Nerves and Optic Chiasm between Scenarios (a-d) and Scenario (e).

within 3% to 5%, as established by theoretical radiobiological models (Olch et al., 2014). Modern dosimetry protocols -such as AAPM TG-51- achieve calibration uncertainties typically ranging from 1% to 2%. Many treatment centers routinely apply minor monitor unit (MU) corrections, usually between 2% and 4%, to account for factors such as blocking trays or wedge filters. Additional corrections for temperature and pressure variations in ion chamber measurements, as well as transitions between calibration protocols (e.g., from TG-21 to TG-51), are also commonly performed -often involving efforts to correct for uncertainties in the 1% to 2% range.

Despite this routine attention to relatively small dosimetric corrections, the radiotherapy community frequently underestimates or overlooks the potentially larger dosimetric effects (up to 5.5% in this study) introduced by treatment couch tops and immobilization systems. These components can contribute to dose discrepancies exceeding the levels for which other corrections are meticulously applied, thereby warranting greater consideration in both clinical practice and treatment planning workflows.

Currently, Scenario (b) is considered the most practical approach for evaluating the impact of immobilization devices. In Figs. 5 to 7, the results labeled with the symbol (b vs e) illustrate the comparison between Scenario (b) and Scenario (e). Meanwhile, the comparison labeled (a vs e) refers to the scenario that does not include immobilization devices. The other scenarios were examined to demonstrate the effect of including each component of the immobilization devices in dose calculations and to determine whether it is necessary to account for all components of the immobilization setup in dose calculations. Below, these aspects are analyzed in two sections: target volume coverage and OAR doses, followed by a final summary.

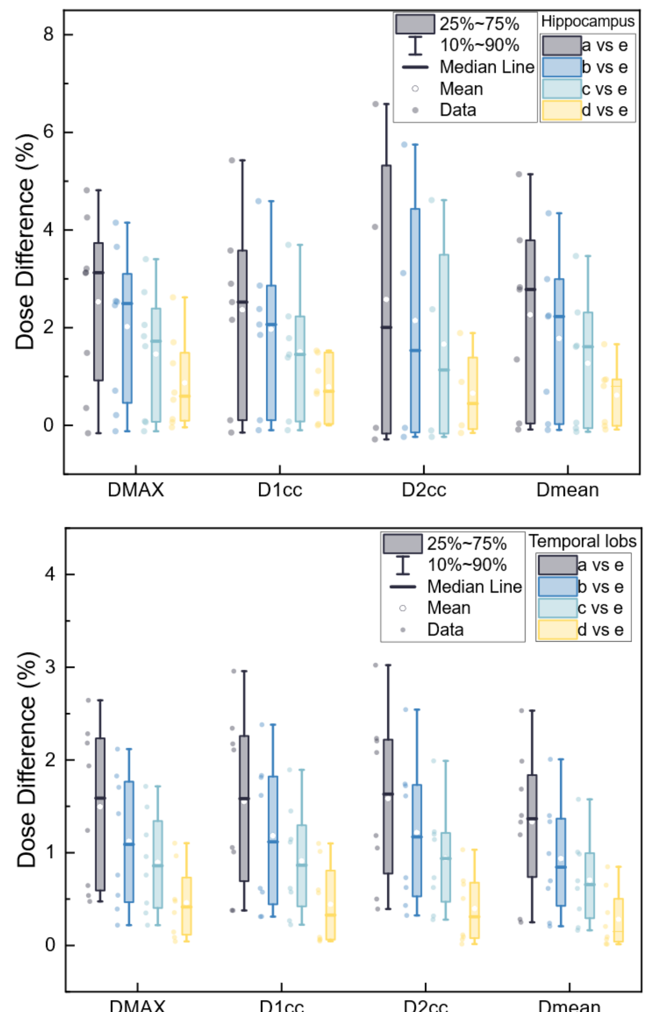

Figure 7: Box plots ($n = 20$) comparing differences in Dmax, D1cc, D2cc, and Dmean for the Hippocampus and Temporal Lobes between Scenarios (a-d) and Scenario (e).

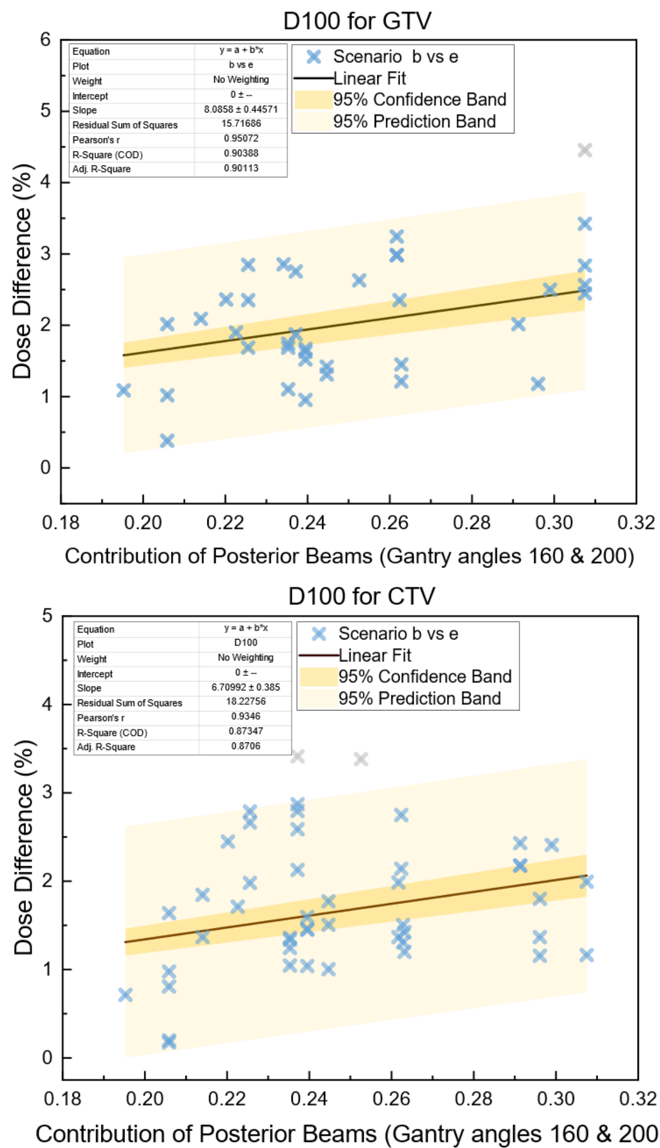

Figure 8: Linear fit of the difference in D100 between Scenarios (b) and (e) for the GTV and CTV as a function of the fraction of MU for posterior beams.

4.1 Target Volume Coverage

The results of this study are consistent with findings from reviewed studies, including the AAPM TG-176 report and other research, indicating that the attenuating effects of immobilization devices significantly impact target volume dose coverage and considerably reduce it (Lau, 2020; Lau et al., 2021; Olch et al., 2014). Additionally, these findings were retrospectively validated using a sample of 20 head and neck cancer patients treated with IMRT at the Reza Radiotherapy and Oncology Center between winter 2021 and winter 2022. The results demonstrate that incorporating immobilization devices into dose calculations in treatment planning systems (TPS) enhances the accuracy of target volume dose coverage. The findings highlight that as scenarios approach the most realistic (i.e., the most comprehensive scenario), the dose differences decrease. However, if fewer details of the immobilization setup are included in dose calculations, the dose discrepancy becomes significant, potentially leading to underdosage of the target volume.

Although the dosimetric differences observed for target volumes (e.g., up to 5.5% for GTV) may seem modest, their potential clinical implications should not be underestimated. While it is not possible to directly predict changes in local control or toxicity outcomes based solely on these differences, the impact could be significant in specific clinical scenarios. For instance, in cases where treatment plans are intentionally designed to prioritize OAR sparing at the expense of target coverage -which is common in complex regions such as the head and neck- failure to account for the attenuation effects of immobilization devices might compromise the therapeutic ratio. Due to the multifactorial nature of treatment outcomes, the exact influence is difficult to quantify; however, this consideration becomes especially important in clinically constrained planning situations.

4.2 Organs at Risk (OARs)

The results for OARs also indicate a reduction in OAR doses when immobilization devices are included in dose calculations. This inaccuracy in OAR dose reporting can affect treatment planning in various ways. For example, in head and neck treatment planning, medical physicists aim to maximize PTV coverage while keeping OAR doses within limits defined by established criteria (such as those in QUANTEC guidelines). The reduction in OAR doses when accounting for immobilization devices suggests greater potential for optimizing PTV coverage, as OAR dose constraints often limit the ability to increase target volume doses.

The maximum observed difference in spinal canal Dmax reached up to 7%, primarily in head and neck cases where immobilization devices introduced measurable attenuation in high-dose regions. Notably, this variation consistently manifested as a decrease in the delivered dose to the spinal canal when the devices were included in the calculation. Consequently, the clinical impact in terms of OAR toxicity is expected to be negligible or even beneficial. Unlike target structures, where underdosage could compromise treatment efficacy, reductions in OAR dose do not raise concerns and may enhance the therapeutic ratio by reducing the risk of toxicity.

4.3 Statement of the study

Accurate dose calculation in radiation therapy requires careful consideration of all materials present in the treatment beam path -including the treatment couch and immobilization devices. Although these devices often appear artifact-free in CT and CBCT images, their physical properties can considerably affect dose distribution. These materials may attenuate the beam or act as a bolus, leading to increased surface dose and reduced dose at depth.

The AAPM TG-176 report (2014) (Olch et al., 2014) highlights that a carbon fiber couch alone can attenuate the beam by approximately 2% for perpendicular posterior fields and up to 6% for highly oblique beams. When

thick immobilization devices are also present, this effect can reach 17%. It is important to note that these values were derived for individual beams and do not necessarily reflect cumulative effects in complex, multi-beam treatment plans. This gap in practical clinical understanding formed one of the primary motivations for the current study.

In our work, we analyzed 20 real treatment plans for upper-body malignancies, primarily in the head and neck region, to assess the cumulative dosimetric impact of treatment couches and immobilization devices under clinical conditions. We also focused on volumetric dose parameters used in plan evaluation. For example, we observed a maximum difference of up to 5.5% in the D100 parameter of the GTV -a clinically critical metric for radiation oncologists.

While the TG-176 report also states that surface dose may increase by as much as 100% when these devices are present (Olch et al., 2014), we did not include skin dose evaluation in this preliminary analysis due to the well-known limitations of TPS algorithms in the superficial region.

Although the sample size in this study was limited to 20 patients -which may influence the observed range of variations- the primary aim was neither to determine statistically generalizable dose deviations nor to calculate attenuation coefficients. Rather, the study sought to underscore the clinical importance of incorporating both the treatment couch and immobilization devices in TPS calculations. Our findings reinforce the notion that even seemingly minor structures can cause meaningful deviations if excluded from the dose calculation process. Given the advanced modeling capabilities of current TPS platforms, relying solely on constant attenuation factors is no longer sufficient.

Finally, this study underscores the importance of maintaining consistency -both geometrically and in terms of materials -between CT simulation and actual treatment delivery. Doing so minimizes the need for manual overrides of CT Hounsfield Units (HUs), thereby reducing the risk of additional uncertainties. We advocate for a shift in routine clinical workflows toward more comprehensive and precise modeling practices to enhance treatment accuracy and patient safety.

4.4 Limitations

This study investigates the dosimetric effects of head and neck immobilization devices, including headrests, blocks, wedges, and base plates, combined with the treatment couch in IMRT delivered using a Siemens Artiste accelerator (accelerator number one).

- If custom-made immobilization devices or any other setup with different materials and HU values are used, they should be re-evaluated for accuracy.
- The patients in this study were treated using Linac 1, the first accelerator in the Reza Radiotherapy and Oncology Center, so the couch model for this accelerator was included in our analysis. If a Varian accelerator is used, the corresponding couch model should be re-evaluated.
- Additionally, immobilization setups for other treatment sites, such as supine and prone breast treatments, should be investigated separately in future studies.
- The sample size in this study was limited to 20 patients; therefore, the results should not be used to define the possible range of variations or to derive correction factors that could be generalized to all cases.
- In this study, TPS calculations were not compared with another reference model, such as Monte Carlo simulations, as our aim was not to validate TPS performance. Rather, the objective was to demonstrate that radiotherapy immobilization devices should be incorporated into TPS dose calculations. For information on the agreement between the TPS (Prowess Panther 5.5) used here and Monte Carlo calculations, readers are referred to previous publications (Tuğrul and Eroğul, 2019).

5 Conclusions

Based on previous studies, the presence of immobilization devices has a significant impact on dose calculations for target volume coverage and OAR doses. The American Association of Physicists in Medicine (AAPM) addressed this topic in its 2014 Report No. 176, which extensively reviewed a wide range of immobilization devices used in clinics for treating various sites. This report documented the effects of single beams at specific angles, reporting the percentage increase in skin dose and the amount of beam attenuation. Consequently, the question arises as to whether these effects are significant in a real IMRT treatment plan, which involves a combination of beams from different directions. Furthermore, apart from beam attenuation, the impact on volumetric dose parameters has not been thoroughly investigated, even though these parameters are critical during treatment planning. To address these questions, this study evaluated 20 treatment plans for patients with upper body regions, including the head and neck, treated with IMRT. The reduction in dose coverage for PTV, CTV, GTV, and OARs was assessed both with and without consideration of immobilization equipment. For target volume coverage, the maximum effect was approximately 5.5%, with a median value of around 2.5% when evaluating D100 for GTV. In the current operational scenario, the maximum effect on the target volume was up to 4.5%, with a median value of about 2%. For OARs, the median percentage difference showed variations ranging from 1% to 2.5%. Analysis of the data based on the fraction of total MU delivered from the posterior direction also revealed a relatively strong correlation, although there was a slight difference between treatment plans with the lowest (approximately 20%) and highest (approximately 30%) contribution of posterior beams in the reviewed treatment plans.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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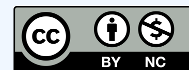

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