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IMPROVING PLANNING TARGET VOLUME COVERAGE BY BOLUS: A LESS COMMONLY USED ENTITY

Radio-Oncology

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ABSTRACT

Introduction: In external beam radiotherapy, megavoltage photon beams exhibit a skin-sparing effect. Therefore, a bolus can facilitate dose build-up, delivering ample doses to superficial lesions. **Aim Of The Study:** The aim of this study was to analyse the impact of a bolus on skin dose and PTV coverage in IMRT plans for head and neck malignancies. **Material And Methods:** Patients with various head and neck carcinomas treated with IMRT plans were recruited for this retrospective study. Eclipse version 13.6 TPS was utilized for planning. All 20 patients underwent IMRT treatment without a bolus. The skin was contoured with a 5mm margin from the body outline. Subsequently, another plan was created, integrating a 5mm virtual bolus across all fields, followed by optimization for inverse planning. Objectives pertaining to PTV and OARs were maintained consistently across both plans. Statistical analyses comparing both plans were conducted using the Student T-test. **Results:** Revealed a significant increase in skin dose with the bolus compared to the non-bolus plans ($P<0.00001$). However, for patients with PTV closer to the skin, bolus-utilizing plans demonstrated superior coverage (V95% – $P=0.02$). The dose received by the OARs did not exhibit statistical significance. **Conclusion:** The utilization of a bolus emerges as an effective method for improving target coverage, especially when the PTV is in proximity to the skin. Nevertheless, it's crucial to precisely fabricate and position the bolus on the patient to mitigate the risk of skin toxicities, given its potential to increase the mean skin dose.

KEYWORDS

Intensity Modulated Radiation Therapy, Skin dose, superficial tumor, Virtual bolus

INTRODUCTION

Cancer is among the most frequent causes of death worldwide, accounting for nearly one in six deaths. It is a disease wherein some of the body's cells grow uncontrollably and spread to other parts of the body [1]. Risk factors for cancer and other non-communicable diseases include tobacco use, alcohol consumption, unhealthy diet, physical inactivity, and air pollution [2].

Various types of cancer treatments are available. In radiotherapy, high-energy radiation such as gamma rays, x-rays, and other sub-atomic particles are utilized to eradicate or manage cancerous cells or tumors. These radiation beams can be generated by a telecobalt machine, producing gamma radiation, or a linear accelerator (LINAC), generating high-energy x-ray beams. External Beam Radiation Therapy (EBRT) encompasses many types, depending on beam energy, size, and shape.

These include conventional external beam radiotherapy, Three-Dimensional Conformal Radiation Therapy (3D-CRT), Intensity Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), Proton Beam Therapy, Image Guided Radiation Therapy (IGRT), stereotactic radiation therapy, particle therapy, and neutron beam therapy [3].

Head and neck cancers are prevalent in several regions worldwide. During EBRT for patients with head and neck malignancies, superficial gross disease is encompassed in the target volume [4]. IMRT has seen increasing use for such cancers. Compared to traditional 3D-CRT, IMRT improves Planning Target Volume (PTV) coverage and effectively reduces the higher dose delivered to Organs at Risk (OARs). High-energy photon beams used in radiation therapy demonstrate skin-sparing properties [5].

This skin sparing effect near the surface inside a patient is caused by the dose build-up effect of megavoltage photon beams. The absorbed dose increases to a certain depth beyond the surface until it reaches a maximum before the megavoltage photon beam reaches electron equilibrium [6]. While the ability to spare the skin is beneficial for many different types of cancer, there are challenges in treating superficial lesions near the skin surface [7]. Hence, a build-up material, known as a bolus, is placed in direct contact with the patient's skin surface to increase the superficial dose and improve dose uniformity by compensating for missing tissue [8].

A bolus is a material that exhibits properties equivalent to tissue when irradiated. Bolus material can effectively modify the radiation dose to the skin and mucosal surfaces [9]. Several types of commercially available bolus materials are often used in RT units [10]. In clinical practice, it is important that the bolus material is sufficiently elastic and deformable to conform to the surface, unaffected by high dose levels, durable, non-toxic, and cost-effective [11]. Bolus materials should be nearly tissue-equivalent and allow a sufficient surface dose boost. Additionally, the use of bolus leads to an increase in skin dose, which may heighten the risk of skin toxicities such as radiodermatitis, potentially impacting the overall quality of life for patients [12].

AIM OF THE STUDY

This study aimed to evaluate the skin dose and PTV coverage in IMRT plans, both with and without the bolus, for head and neck malignancies. It sought to analyse the effect of the bolus on dosimetric indices and other treatment parameters, such as monitor units and treatment time.

MATERIALS AND METHODS

Patient selection:

For this retrospective study, twenty patient plans were randomly selected from the pool of patients who had undergone IMRT for head and neck cancer. The patient plans were developed using Varian Medical Systems Treatment Planning Systems (TPS), specifically Eclipse version 13.6.

All patients were immobilized with Klarity's five-push pin head and neck thermoplastic cast within the Head and Neck base frame. They were positioned in a supine position, with their arms alongside their bodies. Contrast-enhanced Computed Tomography (CT) scans were utilized to differentiate the tumour volume from surrounding tissues.

The CT datasets were acquired using a Siemens Somatom Scope CT 32 Slice scanner at a slice thickness of 3 mm. These scans spanned from the supraorbital region to the trachea bifurcation. Subsequently, the data were transferred to the Treatment Planning System (TPS) in DICOM format.

Delineation of structures:

Targets and OARs were delineated in the 3mm CT slices by a Radiation Oncologist. To analyse the dose received by the skin, it was contoured with a 5mm margin from the body outline. This thickness was selected to encompass three layers of the skin (epidermis, dermis, and hypodermis) as per Timmerman's guidelines [13].

Treatment planning:

All plans were developed using Eclipse version 13.6 TPS. The IMRT plan involved 7 or 9 beams (6 MV) around the PTV to achieve an optimal dose distribution. Figure 1 provides a visual representation of the beam orientation used for planning.

A new IMRT plan was created using the same beam orientations and energy. During treatment planning, a 5mm virtual bolus, tailored to overlay only superficial regions of the PTV to spare dose build-up to normal skin, was designed and linked with all fields. This was followed by Progressive Resolution Optimization (PRO) for inverse planning. The virtual bolus needed to be fabricated and positioned before patient treatment. Figure 2 displays the transverse view of a CT slice depicting the bolus, skin contour, and the PTV.

The objectives of PTV and OARs were kept consistent in plans both with and without a bolus. The 3D dose was calculated using the Anisotropic Analytical Algorithm (AAA) with a 2.5mm dose calculation grid size. Monitor Units (MUs) were obtained for each field after dose calculation.

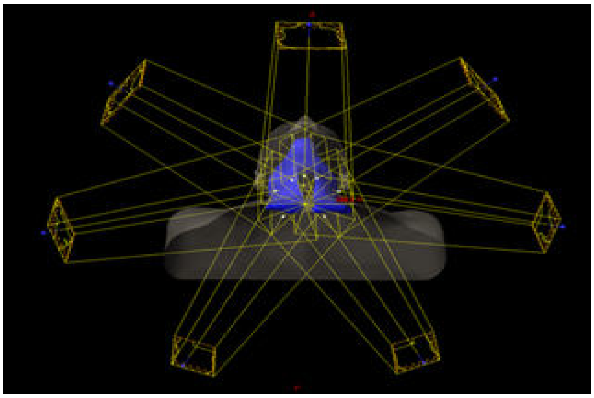

Figure 1– Beam orientations used for the IMRT planning

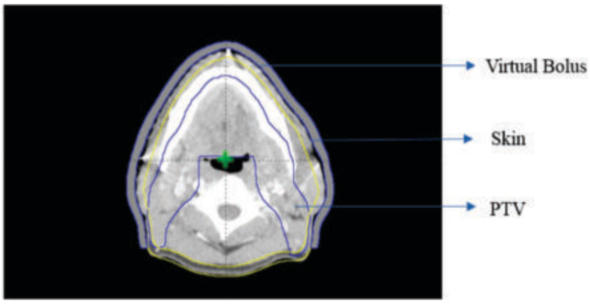

Figure 2 – Transverse view of CT slice with virtual bolus, skin contour and PTV

The study measured the coverage of the PTV by comparing the maximum, median, and mean doses received by it. Assessment of the plans was conducted using dose statistics and Dose Volume Histogram (DVH) analysis [14]. OAR parameters derived from the DVH included the maximum dose (Dmax) for Planning Organ at Risk Volume (PRV) Brainstem, PRV Spine, and Mandible, as well as the mean dose (Dmean) received by the parotid, cochlea, and lips. The mean skin dose was evaluated from the dose statistics for both sets of plans.

Additionally, monitor units and treatment time were calculated for the entire patient cohort in both plan sets. Statistical analyses for PTV, skin, and OARs were performed using a Student's T test.

RESULTS

PTV Coverage and Dose Distribution:

For all IMRT plans, adherence to the International Commission on Radiation Units and Measurements (ICRU) dose prescription protocol was maintained. This protocol included a minimum coverage dose of 95% and a maximum hot spot dose of 107% of the prescribed dose to the PTV. Additionally, the dose reporting followed the guidelines outlined in ICRU level 2 reporting.

Table. 1 – PTV Coverage

Parameters	Without Bolus (Gy)	With Bolus (Gy)	P Value
Dmean	60.10 ± 0.31	60.33 ± 0.42	0.0181
D50%	60.23 ± 0.32	60.41 ± 0.41	0.0408
D98%	57.75 ± 0.71	58.06 ± 0.52	0.0188
D95%	58.52 ± 0.47	58.89 ± 0.41	0.0019
D2%	61.56 ± 0.39	61.68 ± 0.53	0.1769

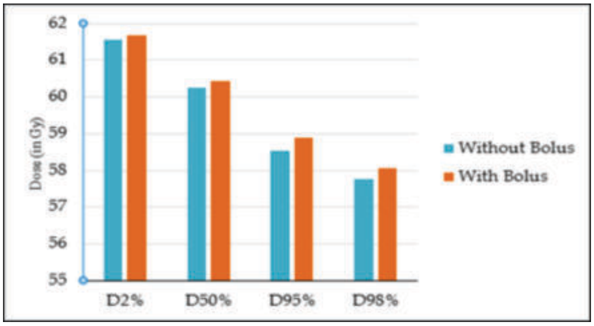

Figure 3 – Comparison of D$_{2\%}$, D$_{50\%}$, D95$_{\%}$ and D$_{98\%}$ in the plans with and without the bolus

The data presented in the table and graph illustrate that the plans incorporating a bolus deliver a notably higher dose to the PTV compared to the plans without a bolus. Notably, the Dmean, D50%, D98%, and D95% values exhibit high significance, highlighting the advantageous impact of utilizing a bolus, particularly for treating superficial lesions

OAR Doses:

The doses to the OARs didn't show significant differences among all the patients. Both plans successfully met the constraints for all the OARs.

Table. 2– Dose to OAR

OAR'S	Without bolus (Gy)	With Bolus (Gy)	P value
PRV Brainstem (Dmax)	33.323 ± 8.00	33.321 ± 8.05	0.4966
PRV Spine (Dmax)	39.183 ± 5.93	39.355 ± 6.10	0.1803
Mandible (Dmax)	61.523 ± 4.54	62.269 ± 2.61	0.2491
Parotid-Right (Dmean)	33.823 ± 10.89	33.857 ± 11.06	0.3885
Parotid-Left (Dmean)	34.527 ± 13.02	34.584 ± 13.01	0.3047
Cochlea-Right (Dmean)	20.263 ± 10.17	20.026 ± 10.05	0.0316
Cochlea-Left (Dmean)	18.365 ± 11.36	18.302 ± 11.62	0.4067
Lips (Dmean)	27.356 ± 8.26	28.226 ± 8.45	0.0033

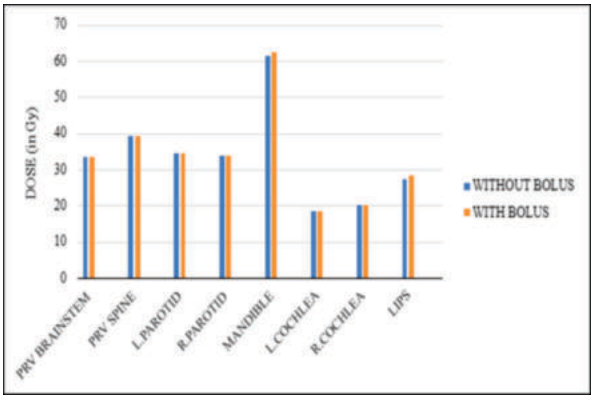

Figure 4: Comparison of OAR doses for plans with and without a bolus

Skin Dose:

The mean dose received by the skin was significantly higher in the plans that utilized a bolus. This is clearly depicted in the following figure.

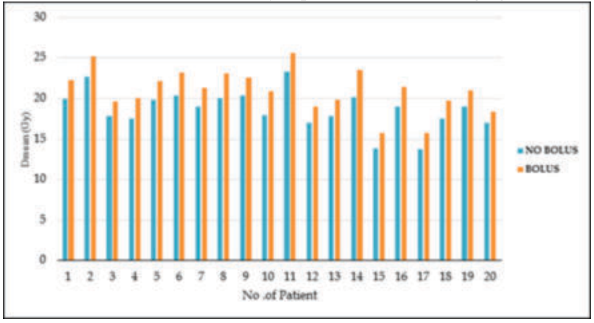

Figure 5 – Comparison of skin dose in plans with and without the bolus

Monitor Units and Treatment Time:

Based on the results, the MUs and treatment time were considerably higher in the plans without a bolus compared to those with a bolus. The mean MUs and treatment times for all patients are provided in Table 3.

Table 3– MUs and Treatment time

Parameters	Without Bolus	With Bolus	P Value
MU	1466	1385	0.0030
Treatment time (Min)	3.67	3.46	0.0030

The plan with a bolus requires fewer MUs and less treatment time, which, in turn, contributes to reducing the time patients spend on the treatment couch..

DISCUSSION

Despite advancements in treatment techniques like 2D to 3D-CRT, IMRT, and VMAT, radiotherapy has been a longstanding method used to treat head and neck cancer, with treatment approaches varying based on the cancer stage.

In this study, a virtual bolus notably improved the volume receiving the reference isodose of the prescribed dose to the PTV in most patients by a clinically significant amount (p=0.02). Similarly, a study by Shenoy et al. [15] demonstrated the ability to achieve clinically acceptable coverage for all patients using a bolus, successfully covering 97% of the PTV with the 95% isodose in all cases.

In another study by Andrew Luu et al. [16], the virtual bolus improved the minimum dose to the superficial CTV. The enhanced dose distribution in plans with a bolus is attributed to the bolus acting as a dose build-up, delivering maximum dose to the target, including superficially located positive GTV nodes. However, there was minimal difference in the conformity and homogeneity of the prescribed dose to the target.

Tyran et al. [17] conducted a study on the benefits of using a virtual bolus in breast cancer treatment, demonstrating that VMAT plans utilizing a virtual bolus achieved delivery of 95% of the prescribed dose to 95% of the CTVs.

All OAR constraints were met in both plans due to the TPS performing inverse planning optimization to achieve the specified dose constraints. There were no significant differences in OAR doses among most patients, except for the lips and right cochlea. The increased mean dose to the lips, being a superficial organ, may be attributed to the involvement of the bolus. The significance of cochlear dose may relate to patient selection, where some cases involved ipsilateral targets.

Gina Wong et al. [18] conducted a study titled 'Quantitative Effect of Bolus on Skin Dose in Post-mastectomy Radiation Therapy', revealing that within a 3mm depth, bolus plans had a maximum skin dose 7% ± 2.5% higher than non-bolus plans ($P < .00001$). Mean skin doses within depths of 3 and 5 mm were significantly higher ($P < .00001$) for bolus plans.

Another study by Andic et al. [19] 'Evaluation of skin dose associated with different frequencies of bolus applications in post-mastectomy three-dimensional conformal radiotherapy' demonstrated that mean, minimum, and maximum skin doses significantly increased with increasing days of bolus applications ($p < 0.001$), providing a 20.8% ± 2.8% minimum skin dose increment with bolus use in all fractions.

Consistent with previous studies, this research displayed a similar pattern of skin dose increment in plans with a bolus. The difference in mean skin dose in Gy was highly significant in plans with a bolus ($p<0.0001$). The higher skin dose in plans utilizing a bolus can be attributed to compensating for skin sparing of photons using a tissue-equivalent bolus.

Monitor Units (MUs) measure machine output from a clinical accelerator for radiation therapy, representing treatment time for a patient. Plans without a bolus resulted in a larger number of MUs and higher treatment time in minutes. Since most patient targets were superficial and lay in the dose build-up region of 6 MV photon beams, TPS executed multiple fluence optimizations to achieve prescribed dose distribution over the PTV, leading to increased MUs. Conversely, in plans with a bolus, the build-up was provided by the bolus, enabling delivery of Dmax to the target.

Utilizing a bolus proves advantageous in treatment planning for superficial targets or when adequate target coverage is not achieved. However, the risk of skin toxicities remains a concern. Therefore, precise creation and positioning of the bolus over the required regions of the target are crucial to achieve acceptable clinical results while ensuring normal skin sparing.

CONCLUSION

In this study, The results suggest that the use of bolus is an efficient method to achieve clinically significant improvement in target coverage, particularly when the PTV is closer to the skin. In the plans with bolus, the clinical objectives were achieved, such as obtaining optimal PTV coverage, keeping doses to OARs within their tolerance limits, and ensuring the maximum dose in the overall plan is less than 110%.

However, the use of bolus can increase the mean dose to the skin. Therefore, the precise design and placement of bolus material are necessary to reduce the risk of skin toxicities.

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