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Optimizing bolus application in postmastectomy radiotherapy: A dosimetric study on the impact of frequency and reoptimization

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► ***Original article***

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ABSTRACT

Background: This study assessed the dosimetric implications of a reduced-frequency bolus regimen combined with treatment plan reoptimization in post-mastectomy radiotherapy (PMRT), with the goal of optimizing target coverage and organ-at-risk (OAR) dose sparing. ***Materials and Methods:*** Eighteen post-mastectomy patients scheduled for radiotherapy were enrolled. CT simulation was performed without bolus. A baseline plan (Plan(all)) was created using a virtual bolus to meet clinical objectives. Two derivative plans were generated from Plan(all): Plan (nobolus)- direct bolus removal without re-optimization and Plan(nobolus-new)- re-optimized after bolus removal to enhance target coverage. Three hybrid 25-fraction plans were generated by combining fractions of Plan(all) and Plan (nobolus): Plan(20bolus) (20 fractions Plan(all)+5 fractions Plan(nobolus)), Plan(18bolus)(18+7), and Plan(13bolus) (13+12). Similarly, three additional hybrid plans were constructed by combining Plan (all) with Plan(nobolus-new): Plan(20bolus-new), Plan(18bolus-new) and Plan(13bolus-new). Dosimetric parameters were compared across all plans. ***Results:*** Compared with Plan(nobolus), Plan(nobolus-new) offered improved target coverage, reduced high-dose volumes within the target, and enhanced dose homogeneity, albeit at the expense of elevated doses to the lungs, heart, and skin. Notably, Plan(13bolus-new) achieved comparable skin dose (body2mm/D10cc: 50.19±1.33 Gy vs 50.19±0.46 Gy, P>0.05) and high-dose target volume (PTV/D2%: 52.95±0.25 Gy vs 52.99±0.20 Gy, P>0.05) relative to the Plan(20bolus), while yielding statistically superior target coverage (PTV/V95%p: 96.59±1.86% vs 97.36 ±1.53%, P<0.05). ***Conclusion:*** A reduction in bolus application frequency compromises target coverage yet attenuates skin dose. A strategy combining reduced bolus frequency with plan reoptimization represents a feasible approach to minimize bolus use while preserving both target coverage and skin dose parameters.

INTRODUCTION

Post-Mastectomy Radiation Therapy (PMRT) represents a well-established intervention associated with improved local control and overall survival in high-risk breast cancer patients [1, 2]. The use of bolus is an essential aspect of PMRT, employed to ensure adequate superficial target dose coverage-including the skin, subcutaneous tissue, and chest wall fascia-by offsetting the build-up effect inherent to megavoltage photon beams [3-5]. However, conventional bolus application has been correlated with a significant increase in the incidence of acute radiation dermatitis and other skin-related toxicities, frequently resulting in patient discomfort, unplanned treatment interruptions, and reduced quality of life [6, 7]. Achieving an optimal balance between target coverage and skin toxicity reduction remains a considerable challenge in PMRT.

Although previous studies focused on intensity-modulated radiation therapy (IMRT) have explored various bolus strategies -including material composition, thickness, and frequency of application [8, 9]- their findings may not be directly generalizable to more contemporary techniques such as volumetric modulated arc therapy (VMAT).

Owing to its dynamic delivery, VMAT exhibits characteristically distinct superficial dose distributions compared with static-field IMRT [10, 11]. Furthermore, a consensus regarding optimal bolus practices is currently lacking [12], leading to substantial variation in clinical practice and an absence of standardized evidence-based protocols.

To bridge this knowledge gap, this study conducts a systematic dosimetric evaluation of different bolus application frequencies in the context of VMAT-based PMRT, assessing their impact on target coverage and organ-at-risk (OAR) sparing. By elucidating the trade-offs between target dose adequacy and normal tissue toxicity, our results aim to inform more individualized and evidence-based clinical planning.

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MATERIALS AND METHODS

Patient data

This study randomly selected 18 breast cancer patients who underwent radical mastectomy and required adjuvant radiation therapy at our institution. Among them, 7 patients had left-sided breast cancer and 11 had right-sided breast cancer. All patients were immobilized in a carbon fiber breast cradle (R612, Klarity Medical, Guangzhou, China) and positioned supine with head-first orientation. The head was placed on a specific headrest, tilted approximately 10 degrees toward the healthy side, and slightly elevated to avoid neck skin folds. Both arms were raised above the head using armrests to ensure full breast exposure. Patients were immobilized using a dedicated neck-and-chest thermoplastic mold (RLG322, Klarity Medical, Guangzhou, China) featuring a pre-formed opening on the affected side.

Simulation was performed using a large-bore CT simulator (GE Discovery RT, General Electric Company, USA) with a slice thickness of 3.75mm. The scan range extended from the first cervical vertebra to the diaphragm. The simulated CT images were transferred to the Monaco treatment planning system (Version 5.11, Elekta, Sweden) for delineation of the planning target volume (PTV), organs at risk (OARs), and treatment planning. All cases were delineated according to ICRU Report No. 50 [13] for the clinical target volume (CTV), PTV, and OARs. The PTV was created by adding a 0.5 cm margin to the CTV, which was then retracted from the skin surface to achieve a 0 cm margin at the skin. The prescribed dose was 50 Gy in 25 fractions to the PTV.

Plan design

Radiotherapy plans were optimized and computed using the Monte Carlo (MC) algorithm within the Monaco treatment planning system (Version 5.11, Elekta, Sweden). All treatments were delivered using volumetric modulated arc therapy (VMAT) on an Elekta infinity linear accelerator (Elekta, Sweden). During planning, a 5mm-thick bolus was applied over the chest wall. Dose constraints were established in accordance with QUANTEC recommendations [14].

Baseline Plan (Plan(all)): A clinically acceptable plan was generated with the bolus applied throughout the treatment course, meeting the PTV criteria of V50Gy>90%, V47.5Gy> 95%, and V52.5Gy <15%. For OARs constraints, the Dmean of heart dose was constrained to <8Gy for left-sided tumors (without internal mammary irradiation <6Gy; with internal mammary irradiation <8Gy) and <4Gy for right-sided tumors (without internal mammary irradiation<4Gy; with internal mammary irradiation <5Gy). Constraints for the ipsilateral lung included V20Gy < 30%, and V5Gy < 60%, while the total lung was limited to V5Gy < 40%. The mean dose to the contralateral breast was constrained to <7Gy.

Plan without Bolus (Plan(nobolus)): Using identical optimization parameters, segment shapes, and monitor units from Plan(all), a new plan was calculated without the bolus.

Recalculated Plan without Bolus (Plan(nobolus-new)): Starting from the Plan(all) configuration, the bolus was removed and the plan was re-optimized and recalculated. The PTV evaluation criteria were relaxed to V50Gy>80%, V47.5Gy>90%, and V52.5Gy <25%. Adjusted OARs constraints included a mean heart dose of <7 Gy for left-sided plans (<7Gy without internal mammary irradiation; <9Gy with internal mammary irradiation) and <5 Gy for right-sided plans (<5Gy without internal mammary irradiation; <6 Gy with internal mammary irradiation). The ipsilateral lung was constrained to V20Gy <35%, and V5Gy <69%, and the total lung to V5Gy <50%. The mean dose to the contralateral breast was limited to <7.5 Gy.

To evaluate the effects of varying bolus application frequencies, hybrid plans were generated by combining fractions from the bolused and non-bolused plans. Specifically, Plan(20bolus), Plan (18bolus), and Plan(13bolus) were created by combining 20, 18, and 13 fractions of Plan(all) with 5, 7, and 12 fractions of Plan(nobolus), respectively. Similarly, Plan(20bolus-new), Plan(18bolus-new), and Plan(13bolus-new) were constructed by combining the same number of fractions from Plan (all) with corresponding fractions from Plan(nobolus -new). These hybrid plans allow for a systematic analysis of the dosimetric consequences of progressively reducing the number of bolus-applied fractions during the treatment course.

Dosimetric analysis

Dosimetric evaluation was conducted based on dose-volume histograms (DVHs) to compare the radiation doses delivered to the PTV and the OARs across various plans for each patient.

The evaluation indices [15] for the PTV included PTV/D2% (dose covering 2% of the PTV), PTV/ V105%p (volume receiving ≥105% of the prescribed dose), PTV/D95% (dose covering 95% of the PTV), PTV/V100%p (volume receiving ≥100% of the prescribed dose), PTV/D98% (dose covering 98% of the PTV), PTV/V95%p (volume receiving ≥95% of the prescribed dose), PTV/D50% (median dose), and homogeneity index (HI). The evaluation indices for OARs included Ipsilateral Lung/V20Gy (%), Ipsilateral Lung/V5Gy (%), Total-Lung/V5Gy (%), Heart/Dmean (Gy), contralateral-Breast/Dmean (Gy), and Homogeneity Index (HI). Skin evaluation parameters included body2mm/D10cc and body3mm/D10cc, representing the dose to 10cc of skin at depths of 2mm and 3mm, respectively.

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Statistical analysis

SPSS software was used to analyze the dosimetric differences between the directly calculated plans (Plan(25bolus), Plan(20bolus), Plan(18bolus), Plan (13bolus)) and the recalculated plans (Plan(25bolus-new), Plan(20bolus-new), Plan(18bolus-new), Plan (13bolus-new)). Parameters satisfying normal distribution were analyzed using paired t-tests, whereas non-normally distributed data were analyzed using non-parametric tests. A p-value <0.05 was considered statistically significant. Figure 1 visually demonstrates the dosimetric effects of different bolus applications.

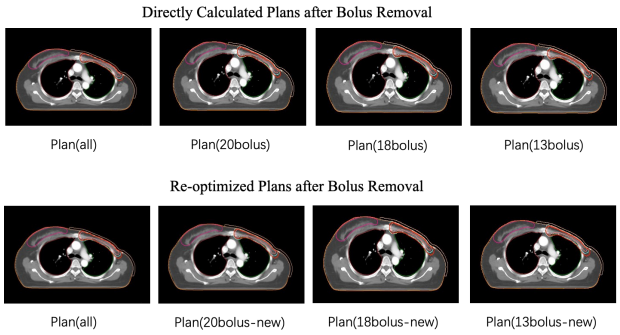

Figure 1. Comparison of plans using varying numbers of compensators.

RESULTS

Dosimetric analysis of directly calculated plans with varied bolus frequency after bolus removal

Dosimetric comparisons among the four plans-Plan(all), Plan(20bolus), Plan(18bolus), and Plan (13bolus)-revealed significant differences in target coverage, dose homogeneity, and doses to OARs as the bolus application frequency decreased.

For the target volumes, the high-dose PTV/D2% and PTV/V105%p increased progressively across the four plans. No statistical difference was observed between Plan(all) and Plan(20bolus) (*P>0.05*), whereas all other pairwise comparisons showed statistically significant differences (*P<0.05*). Target volume coverage indicators, PTV/V100%p, PTV/D98%, and PTV/V95%p, decreased sequentially across the four plans, with statistically significant differences between each pair of plans (*P<0.05*). Similarly, the homogeneity index (HI) increased significantly in all groups (*P<0.05*), indicating a degradation in dose uniformity within the target.

Regarding OARs, a decrease in bolus application frequency was associated with an increase in the ipsilateral lung V20Gy(Lung/V20Gy), but a decrease in both the ipsilateral lung V5Gy(Lung/V5Gy) and the total lung V5Gy(Lungs/V5Gy). All pairwise differences for these lung parameters were statistically significant(*P<0.05*). The mean heart dose (Heart/Dmean) decreased sequentially across the four plans, with statistically significant differences between each pair. Conversely, the mean dose to the contralateral breast (contralateral-Breast/Dmean) increased sequentially across the four plans, with statistically significant differences between each pair (*P<0.05*).

Skin dosimetry analysis revealed that the high doses at 2mm (body2mm/D10cc) and 3mm (body3mm/D10cc) below the surface decreased sequentially as the number of bolus applications decreased, with statistically significant differences between each pair (*P<0.05*).

Overall, the results demonstrate that reducing the frequency of bolus applications in the hybrid plans led to a reduction in target volume coverage and plan homogeneity, while increasing high-dose regions within the target. The trade-offs included increased lung dose at higher thresholds, decreased heart dose, reduced total lung dose, increased contralateral breast dose, and reduced skin dose (table 1).

Table 1. Directly calculated dosimetric data for four planning groups.

	Plan (25bolus)	Plan (20bolus)	Plan (18bolus)	Plan (13bolus)
PTV/D2%(Gy)	52.98±0.18^{c}	52.99±0.20^{c}	53.04±0.21^{ab}	53.23±0.23^{abc}
PTV/V105%p(%)	8.61±3.49^{c}	9.37±3.94^{c}	10.46±4.38^{ab}	14.75±5.88^{abc}
PTV/V100%p(%)	92.64±2.14^{bc}	88.26±3.01^{ac}	86.69±3.33^{ab}	83.96±3.88^{abc}
PTV/D98%(Gy)	48.06±1.54^{bc}	47.01±1.36^{ac}	46.36±1.39^{ab}	44.46±1.75^{abc}
PTV/V95%p(%)	98.54±1.24^{bc}	97.36±1.53^{ac}	96.22±1.94^{ab}	93.20±2.86 ^{abc}
PTV/D50%(Gy)	51.52±0.16^{bc}	51.53±0.18^{ac}	51.55±0.19^{ab}	51.61±0.21^{abc}
Lung/V20Gy(%)	26.18±2.42^{bc}	26.22±2.42^{ac}	26.24±2.42^{ab}	26.28±2.41^{abc}
Lung/V5Gy(%)	56.47±2.53^{bc}	56.36±2.53^{ac}	56.31±2.53^{ab}	56.19±2.53^{abc}
Total-Lung/ V5Gy(%)	38.44±4.16^{bc}	38.41±4.17^{ac}	38.40±4.18^{ab}	38.35±4.19^{abc}
Heart/ Dmean(Gy)	4.63±1.56^{bc}	4.62±1.57^{ac}	4.62±1.57^{ab}	4.61±1.57^{abc}
con-Breast/ Dmean(Gy)	5.45±1.14^{bc}	5.49±1.16^{ac}	5.51±1.16^{ab}	5.55±1.18^{abc}
body2mm/ D10cc(Gy)	51.84±0.34^{bc}	50.19±0.46^{ac}	49.59±0.51^{ab}	48.18±0.65^{abc}
body3mm/ D10cc(Gy)	52.18±0.30^{bc}	50.98±0.38^{ac}	50.52±0.48^{ab}	49.68±0.58^{abc}
HI	0.087 (0.1,0.1)^{bc}	0.114 (0.1,0.1)^{ac}	0.131 (0.1,0.1)^{ab}	0.181(0.1,0.2) ^{abc}

Note: a: There is a statistical difference compared to Plan (25 bolus) (P<0.05); b: There is a statistical difference compared to Plan (20 bolus) (P<0.05);c: There is a statistical difference compared to Plan (18 bolus) (P<0.05). con-Breast: contralateral-Breast. HI: homogeneity index.

Dosimetric analysis of re-optimized plans with varied bolus frequency after bolus removal

Dosimetric differences in the PTV and OARs were analyzed across four re-optimized composite plans: Plan(25bolus-new), Plan(20bolus-new), Plan (18bolus-new) and Plan(13bolus-new).

For the PTV, both PTV/D2% and PTV/V105%p exhibited a sequential decrease across the four plans. Statistically significant differences were observed between Plan(25bolus-new) and Plan(20bolus-new), as well as between Plan(18bolus-new) and Plan (13bolus-new) (*P<0.05*), but not between other pairs of plan(*P>0.05*). Coverage metrics, including PTV/V100%p, PTV/D98%, and PTV/V95%p, also decreased sequentially across the four plans, with all pairwise comparisons reaching statistical significance

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(*P <0.05*). Conversely, the HI increased progressively across plans, also with significant differences between all pairs.

Regarding OARs, doses to the ipsilateral lung (Lung/V20Gy, Lung/V5Gy), total lung (Lungs/V5Gy), heart (Heart / Dmean), and contralateral breast (contralateral-Breast / Dmean) increased progressively with reduced bolus frequency, with all pairwise comparisons being statistically significant (*P<0.05*). Conversely, skin doses at 2mm (body2mm/D10cc) and 3mm (body3mm/D10cc) decreased significantly across all plan pairs (*P < 0.05*).

Overall, the results indicate that as the frequency of bolus application decreases in the composite plans, PTV coverage and high-dose regions within the target are reduced, accompanied by a decline in plan homogeneity. Meanwhile, doses to the lungs, heart, and contralateral breast increase, while skin doses are reduced. These findings underscore the trade-offs associated with reducing bolus frequency (table 2).

Table 2. Recalculated dosimetric data for four planning groups.

	Plan(25bolus)-New	Plan(20bolus)-New	Plan(18bolus)-New	Plan(13bolus)-New
PTV/D2% (Gy)	52.98±0.18[b]	52.90±0.23[a]	52.89±0.22	52.95±0.25[c]
PTV/V105%p(%)	7.72(6.6,10.6)[b]	7.26(4.8,8.1)[a]	6.76(4.5,7.9)	6.44(5.1,9.9)[c]
PTV/V100%p(%)	92.64±2.14[bc]	91.22±2.34[ac]	90.63±2.44[ab]	89.46±2.53[abc]
PTV/D98% (Gy)	48.06±1.54[bc]	47.18±2.44[ac]	47.33+1.29[ab]	46.40+1.55[abc]
PTV/V95%p (%)	98.54±1.24[bc]	98.13±1.20[ac]	97.74±1.32[ab]	96.59±1.86[abc]
PTV/D50% (Gy)	51.52±0.16[bc]	51.54.±0.15[ac]	51.54±0.13[ab]	51.60±0.22[abc]
Lung/V20Gy(%)	26.18±2.42[bc]	26.94±2.52[ac]	27.24±2.57[ab]	28.00±2.76[abc]
Lung/V5Gy (%)	56.47±2.53[bc]	57.66±2.54[ac]	58.11±2.61[ab]	59.17±2.91[abc]
Total-Lung/V5Gy(%)	38.44±4.16[bc]	39.35±4.30[ac]	39.70±4.38[ab]	40.55±4.65[abc]
Heart/Dmean(Gy)	4.63±1.56[bc]	4.73±1.55[ac]	4.78±1.55[ab]	4.88±1.54[abc]
con-Breast/Dmean(Gy)	5.46±1.14[bc]	5.60±1.08[ac]	5.66±1.06[ab]	5.81±1.06[abc]
body2mm/D10cc(Gy)	51.84±0.35[bc]	51.04±0.73[ac]	50.77±0.90[ab]	50.19±0.133[abc]
body3mm/D10cc(Gy)	52.18±0.30[bc]	51.71±0.59[ac]	51.58±0.72[ab]	51.34±0.11[abc]
HI	0.087 (0.1,0.1)[bc]	0.100 (0.1,0.1)[ac]	0.107(0.1,0.1)[ab]	0.131(0.1,0.1)[abc]

Note: a: There is a statistical difference compared to Plan (25 bolus-new) (P<0.05); b: There is a statistical difference compared to Plan (20 bolus-new) (P<0.05); c: There is a statistical difference compared to Plan (18 bolus-new) (P<0.05). con-Breast: contralateral-Breast. HI: homogeneity index.

Comparison of dosimetric differences among two calculation methods

Dosimetric comparisons were performed between the following plan pairs: Plan(20bolus) versus Plan(20bolus-new), Plan(18bolus) versus Plan(18bolus-new), and Plan(13bolus) versus Plan (13bolus-new).

The results showed that the re-optimized plans consistently demonstrated lower high-dose regions, improved target coverage, and enhanced dose homogeneity within the target volume compared to the plans generated by the direct calculation method.

In terms of OARs, the re-optimized plans resulted in significantly higher doses to the lungs, heart, and skin (P<0.05 for all evaluated parameters of these OARs). In contrast, no statistically significant difference was observed in the mean dose to the contralateral breast for any of the plan pairs (*P>0.05*) (table 3).

Table 3. Comparison of dosimetric differences among 25 plans obtained by two calculation methods.

	Plan (20bolus)	Plan (20bolus)-New	Plan (18bolus)	Plan (18bolus)-New	Plan (13bolus)	Plan (13bolus)-New
PTV/D2% (Gy)	52.99± 0.20*	52.90± 0.23*	53.04± 0.21*	52.89± 0.22*	53.23± 0.23*	52.95± 0.25*
PTV/V105%p(%)	9.37± 3.94*	7.26 (4.8,8.1)*	10.46±4.38*	6.76 (4.5,7.9)*	14.75±5.88*	6.44 (5.1,9.9)*
PTV/V100%p(%)	88.26± 3.01*	91.22± 2.34*	86.69± 3.33*	90.63± 2.44*	83.96± 3.88*	89.46± 2.53*
PTV/D98% (Gy)	47.01± 1.36*	47.18± 2.44*	46.36± 1.39*	47.33± 1.28*	44.46± 1.75*	46.40± 1.55*
PTV/V95%p (%)	97.36± 1.53*	98.13± 1.20*	96.22± 1.94*	97.74± 1.32*	93.20± 2.86*	96.59± 1.86*
PTV/D50% Gy)	51.53± 0.18*	51.54± 0.15*	51.55± 0.19*	51.54± 0.14*	51.61± 0.21*	51.60± 0.23*
Lung/V20Gy(%)	26.22± 2.42*	26.94± 2.52*	26.24± 2.42*	27.24± 2.57*	26.28± 2.41*	28.00± 2.76*
Lung/V5Gy (%)	56.36± 2.53*	57.66± 2.54*	56.31± 2.53*	58.11± 2.61*	56.19± 2.53*	59.17± 2.91*
Total-Lung/V5Gy(%)	38.41± 4.17*	39.35± 4.30*	38.40± 4.18*	39.70± 4.38*	38.35± 4.19*	40.55± 4.65*
Heart/Dmean(Gy)	4.62± 1.57*	4.73± 1.55*	4.62± 1.57*	4.78± 1.55*	4.61± 1.57*	4.88± 1.54*
con-Breast/Dmean(Gy)	5.49± 1.16	5.60± 1.08	5.51± 1.16	5.66± 1.06	5.55± 1.18	5.81± 1.06
body2mm/D10cc(Gy)	50.19± 0.46*	51.04± 0.73*	49.59± 0.51*	50.77± 0.90*	48.18± 0.65*	50.19± 1.33*
body3mm/D10cc(GY)	50.98± 0.38*	51.71± 0.59*	50.52± 0.48*	51.58± 0.72*	49.68± 0.58*	51.34± 1.05*
HI	0.114 (0.1,0.1)*	0.100 (0.1,0.1)*	0.131 (0.1,0.1)*	0.107 (0.1,0.1)*	0.181 (0.1,0.2)*	0.131 (0.1,0.1)*

Note: *: Statistically significant difference compared to the corresponding data group (P<0.05). con-Breast: contralateral-Breast. HI: homogeneity index.

Dosimetric comparison between Plan(20bolus) and Plan(13bolus-new)

The comparison between Plan(20bolus) and Plan (13bolus-new) revealed no statistically significant difference (*P>0.05*) in skin dose (body2mm/D10cc, body3mm/D10cc), maximum target dose (PTV/D2%), or high-dose target volume (PTV/V105%p). However, for target region coverage parameters, including PTV/V100%p, PTV/D98%, and PTV/V95% p, Plan(13bolus-new) demonstrated significantly higher values than Plan(20bolus) (*P<0.05*). Additionally, the doses to OARs-including the lungs, heart, and contralateral breast-were significantly higher in Plan(13bolus-new) than in Plan(20bolus) (*P<0.05*).

These findings indicate that, while skin dose and high-dose target metrics remained comparable between the two plans, Plan(13bolus-new) provided superior target coverage at the cost of increased dose to OARs.

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DISCUSSION

This study systematically evaluated the impact of varying bolus application frequency on dosimetric outcomes in postmastectomy radiotherapy using VMAT. The primary finding is that reducing the number of bolus applications presents a complex trade-off between PTV coverage, dose sparing to OARs, and skin toxicity, offering a potential strategy to modulate skin dose without compromising target coverage excessively.

Our results align with and extend the previous work by Andic *et al*. [16], who investigated bolus use in 3D conformal radiotherapy. They reported that increasing bolus applications elevated skin dose and recommended a specific frequency to optimize coverage. The current study confirms that a similar trade-off exists in the context of modern VMAT techniques, which are known for superior dose conformity [17]. However, our findings further demonstrate that even with reduced bolus frequency, acceptable target coverage (e.g. PTV/V95%p> 90%) can be maintained in a VMAT framework, a detail not extensively explored in earlier studies. This suggests that advanced treatment modalities like VMAT may offer greater flexibility in managing skin dose through bolus modulation compared to older techniques.

A key insight from our analysis is the differential impact of simply removing the bolus versus re-optimizing the plan without it. Direct bolus removal primarily reduced skin and superficial target dose due to the loss of build-up, often leading to unacceptable target coverage [18]. In contrast, re-optimizing the plan after virtual bolus removal (Plan (nobolus-new)) allowed the algorithm to compensate for the lack of bolus by modulating beam intensities, which successfully restored target coverage metrics to clinically acceptable levels. This improvement, however, was achieved at the cost of increased doses to deep OARs, such as the lungs and heart [19]. This distinction underscores the critical importance of the method of bolus omission and the necessity of re-optimization to achieve a viable plan, albeit with altered OARs dose profiles.

The clinical implication of our findings is that a one-size-fits-all approach to bolus application may not be optimal. For patients at high risk of severe skin reactions, a reduced bolus frequency protocol, coupled with plan re-optimization, could be a feasible strategy to minimize toxicity while preserving adequate target coverage. This approach requires careful dosimetric validation, as our study showed it could lead to higher doses to critical structures like the heart and lungs. The choice of strategy should therefore be personalized, based on individual patient anatomy and risk factors for both skin toxicity and OARs complications.

Despite these insights, our study has several limitations. First, it is a dosimetric planning study based on a limited sample size from a single institution. The clinical correlation between the observed dose differences and patient outcomes (e.g., actual skin toxicity rates or long-term cardiac and pulmonary function) was not assessed [20]. Second, all plans were generated using a single treatment planning system (Monaco) with a specific algorithm (Monte Carlo). The generalizability of our findings to other planning systems or algorithms (e.g., Collapsed Cone) should be verified. Future research should involve larger, multi-center patient cohorts, incorporate different TPS and algorithms, and ideally, include clinical outcome data to validate the proposed strategies.

CONCLUSION

This study demonstrates that modifying bolus application strategies significantly influences radiotherapy plan quality. Reducing bolus frequency compromised target coverage and homogeneity while lowering skin doses at the expense of increased organ doses. However, re-optimization improved target coverage—particularly in the 13-bolus plan (Plan(13bolus-new)), which achieved coverage comparable to the standard 20-bolus plan (Plan (20bolus)) while maintaining similar skin and high-dose metrics. These findings highlight the potential for individualized bolus strategies to balance target accuracy and normal tissue protection, suggesting re-optimization can enhance efficacy while reducing treatment applications.

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Authors contribution: Z.S., was responsible for the conception of the study and writing the initial manuscript. F,Z,, provided critical guidance and supervision throughout the research and manuscript preparation. All authors made great contributions to manuscript preparation.

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