3D printed customized bolus for intensity-modulated radiotherapy in a patient with nasal radiotherapy

R. Song and W. Li*

Department of Radiotherapy, Tianmen First People's Hospital, Tianmen 431700, Hubei, China

▶ ***Technical note***

***Corresponding author:**
Li Wei, Ph.D.,
***E-mail:** 609987176@qq.com*

Received: March 2022
Final revised: October 2022
Accepted: October 2022

Int. J. Radiat. Res., January 2023; 21(1): 153-157

DOI: 10.52547/ijrr.21.1.21

***Keywords:** 3D-printed bolus, commercial bolus, IMRT, head phantoms, Dosimetric.*

ABSTRACT

Background: The aim of the study was to compare the dose differences between 3D-printed bolus, commercial bolus (wax), thermoplastic mask bolus and bolus-free head phantoms simulating nose radiotherapy. ***Materials and Methods:*** We used 3D printing technology to make a 3D-printed bolus. To evaluate the clinical feasibility, intensity-modulated radiation therapy (IMRT) plans were created for head phantoms that were 3D-printed bolus, commercial bolus (wax), thermoplastic mask bolus or bolus-free. Dosimetry differences were compared in simulating nose radiotherapy. ***Results:*** For the PTV of all the plans, 3D-printed bolus, commercial bolus (wax) and thermoplastic masks bolus had lower Dmax and D1% than the plan without the bolus; for Dmean and D95%, the results were the opposite. For V90%, V95%, V100% and HI, the plan with the 3D-printed bolus was better than the others, and the plan without the bolus was the worst. ***Conclusions:*** The dosimetric differences of 3D-printed bolus, commercial bolus (wax), thermoplastic mask bolus and bolus-free were compared in head phantoms simulating nose radiotherapy. The 3D-printed bolus was good for fit, had a high level of comfort and repeatability, and also had better dose parameters in IMRT plans.

INTRODUCTION

Megavoltage photon beams are widely used in modern radiotherapy using a linear accelerator (i.e., LINAC system). The build-up of the megavoltage photon beam improves dose effectiveness for the treatment of deep-seated tumors while sparing the skin. However, this skin-sparing effect, which reduces the effective dose delivered to the superficial tissues, can jeopardize target coverage in cases of superficial tumors [1]. The International Commission on Radiation Units and Measurements Report 62 recommends that the target volume be encompassed within the area that receives at least 95% of the prescribed dose when radiotherapy is administered [2]. However, a sufficient dose cannot be delivered to the surface due to the skin sparing effect of high-energy radiation beams. To avoid this limitation, several types of commercially available boluses are often used [3]. These bolus materials should be nearly tissue equivalent and allow a sufficient surface dose enhancement. Despite the advent of commercial boluses (wax) and the modernization of clinical equipment, uncertainties in the preparation and utilization of boluses remain [4]. In practice, most commonly used commercial flat boluses cannot form perfect contact with the irregular surface of the patient's skin, particularly the nose, ear, and scalp, and the resulting air gap affects the second skin sparing effect and reduces both the maximum and surface dose [5–9]. Even more problematic, however, is that the depth of the air gap cannot be anticipated and thus accounted for in the treatment planning step, leading to a discrepancy between the planned and delivered dose. Thus, commercial flat boluses need to be used with great care, especially when the skin has a particularly irregular shape. Recently, there have been significant advances in 3-dimensional (3D) printer technology, and attempts have been made to utilize them in medicine [10,11].

With the arrival and still maturing technology of three-dimensional printing, some studies have already tested and applied the concept of 3D-printed boluses [12, 13] to optimize treatment preparation time and reduce overall costs [12]. Applications of patient-specific 3D-printed boluses have also been investigated for range shifter air gap reduction in intensity-modulated proton therapy [14]. All of the 3D-printed boluses in these studies were created by using computed tomography (CT) data.

The highlight of this paper and its innovation are the comparisons of doses between 3D-printed bolus, commercial bolus (wax), thermoplastic masks bolus and bolus-free in head phantoms simulating nose radiotherapy.

MATERIALS AND METHODS

Head phantom

The head phantom was used to simulate a patient with a tumor under the nasal region. The head phantom was immobilized using a thermal plastic mask for clinical positioning. The bolus region was marked using a marking pen. The sphere calibration model was positioned and stuck onto the head phantom near the orbital region where the bolus was needed. Siemens Sensation Open 24-slice scanner (Siemens, Forchheim, Germany) was used in the scanning head phantom (HN-711 CIRS (Computerized Imaging Reference Systems Inc).

Three-dimensional printing

Eclipse Treatment Planning System version 13.5 (Varian Medical Systems, USA) was used for treatment planning. Based on a simulation model of the PTV reconstructed from CT images. According to the treatment plan, the 5-mm bolus was sufficient to cover the PTV. DICOM images of the bolus structure were converted into a stereolithography file for 3D printing. The bolus was printed by the 3D printer (Objet350 Connex3, Stratasys Ltd., USA)

To evaluate the clinical feasibility, intensity modulated radiation therapy (IMRT) plans were created for head phantoms with the bolus of commercial bolus (wax), thermoplastic masks bolus, 3D-printed bolus (with the matter of FDM TPU 92A) and without bolus, which can be seen from figure 1d and 1a respectively. Dosimetry differences were compared in simulating nose radiotherapy separately.

5mm wax bolus used in the study was presented in figure 1b. Thermoplastic masks bolus was made by thermoplastic masks (Guangzhou Klarity Medical Equipment Co.,Ltd. Guangzhou China) which was used for radiotherapy localization membrane shown in figure 1c.

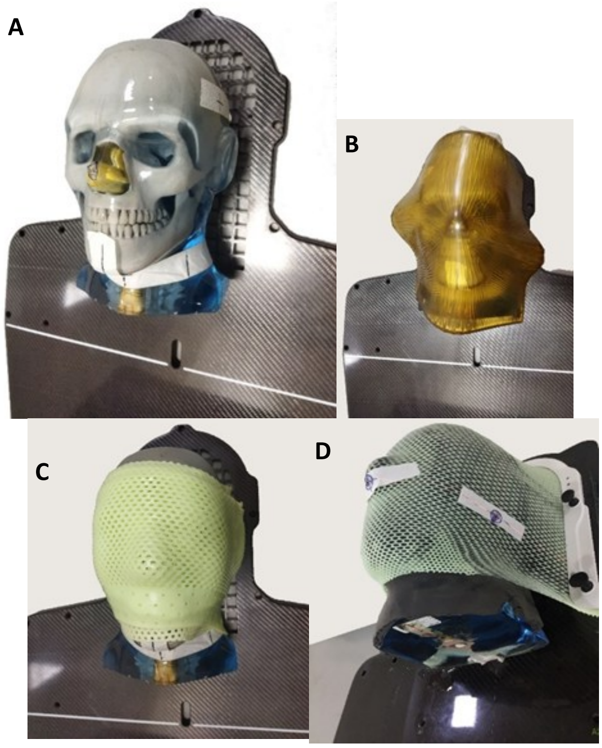

Figure 1. (A) Bolus free, **(B)** Commercial compensator wax mold, **(C)** Thermoplastic masks bolus, **(D)** 3D printed maskbased on FDM ®TPU 92A material, 3D printed mask.

To evaluate the 3D-printed bolus, treatment plans were generated for the blue water phantom bolus-free, with a superflab bolus, and with the 3D printed flat bolus. All target doses were set at 30 Gy with a single 6 MV photon beam.

The plan with the 3D-printed customized bolus was set such that 90% of the prescribed dose was delivered to 90% of the target volume, and the bolus-free plan and the plan with the 3D-printed customized bolus were normalized to the same maximum dose of the target volume. Both plans were compared in terms of the percent depth dose (PDD) at the central axis and the dose volume histogram (DVH) of the target volume. The Dmax, Dmin, Dmean, D90%, and V90% of the treatment plans were compared. These dosimetric parameters are defined below:

Where Dmax was the maximum dose of the target volume, Dmin was the minimum dose of the target volume, Dmean was the mean dose of the target volume,Da% was the dose that covers a% of the target volume and Va% was the target volume that receives over the a% of the prescribed dose

The value of the Homogeneity index (HI) indicates the uniform dose distribution

$$HI = \frac{D_{5\%}}{D_{95\%}} \quad (1)$$

Where D5% was the maximum dose of volume accepted by 5% of PTV, D95% was the maximum dose of volume accepted by 95% of PTV. When HI=1 indicates that there is no drop in the target area, the uniformity is the best.

RESULTS

Figure 1d shows the 3D-printed customized bolus produced using the 3D printer. On visual inspection, the 3D-printed customized bolus was found to fit well against the surface of the RANDO phantom, and this was verified in cross section (figure 2d). For the RANDO phantom study, the dose distributions of the bolus-free and 3D-printed customized bolus plans on the RANDO phantom are shown in figure 5, indicating that the 3D-printed customized bolus is a good buildup material. For the plan with and without bolus, the Max, Mean, D1%, D5%, D95%, D98%, V2700cGy (V90%) V2850cGy (V95%), V3000cGy (V100%) and HI (V5%/V95%) of the target volume are shown in table 1.

For the PTV of the plans, the 3D-printed bolus, commercial bolus (wax) and thermoplastic masks bolus had lower Dmax and D1% than the plan without a bolus. For Dmean and D95%, the results were the opposite. For V90%, V95%, V100% and HI, the plan with the 3D-printed bolus was better than the others, and the plan without the bolus was the worst.

The dose distribution in the target area is

[DOI: 10.52547/ijrr.21.1.21]

displayed in figure 2, which shows that we could obtain five different dose distributions in the target area and could also compare the size of the air gap. The mask printed in 3D with FDM ®TPU 92A material had a better dose distribution in the target area, and the air gap of the 3D-printed bolus was smaller than that of the thermoplastic masks and commercial bolus (Wax).

Table 1. Results of different bolus.

PTV	Commercial bolus (wax)	Thermoplastic masks bolus	Bolus-free	3D-printed bolus
Max	3240.8	3261.3	3682.9	3279.9
Mean	3113.1	3120.3	3006.1	3139.1
D1%	3208.5	3215	3300.7	3230.3
D5%	3198.7	3204	3249.9	3218.6
D95%	2999.1	2999.6	2104.7	3039.1
D98%	2945.1	2947.8	1625.9	2952.8
V2700cGy(V90%)	99.4884	99.4757	90.5398	99.7846
V2850cGy(V95%)	98.9955	99.0852	88.6187	99.0934
V3000cGy(V100%)	94.8852	94.9582	81.2199	97.1373
HI(V5%/V95%)	1.0665	1.0681	1.5441	1.0590

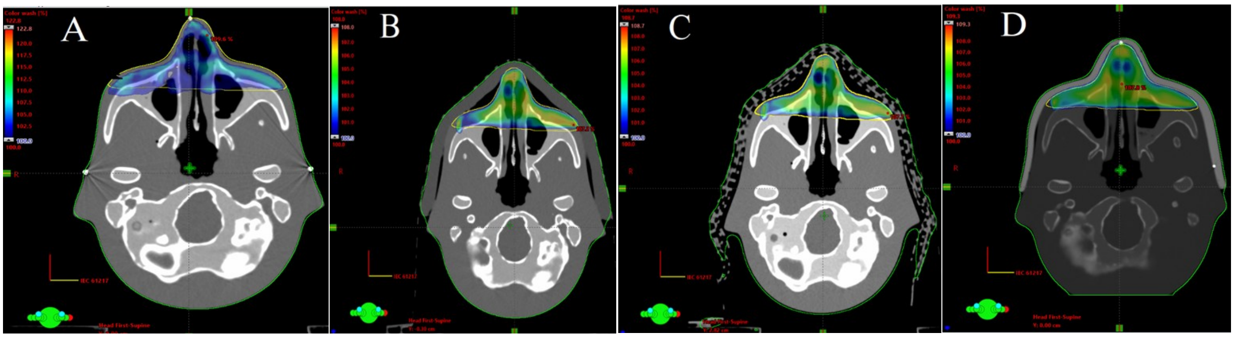

Figure 2. Comparison of plans for simulating nasal radiotherapy with different boluses. **(A)** Bolus free, **(B)** Commercial bolus (wax), **(C)** Thermoplastic masks bolus, **(D)** 3D printing bolus based on FDM ®TPU 92A material.

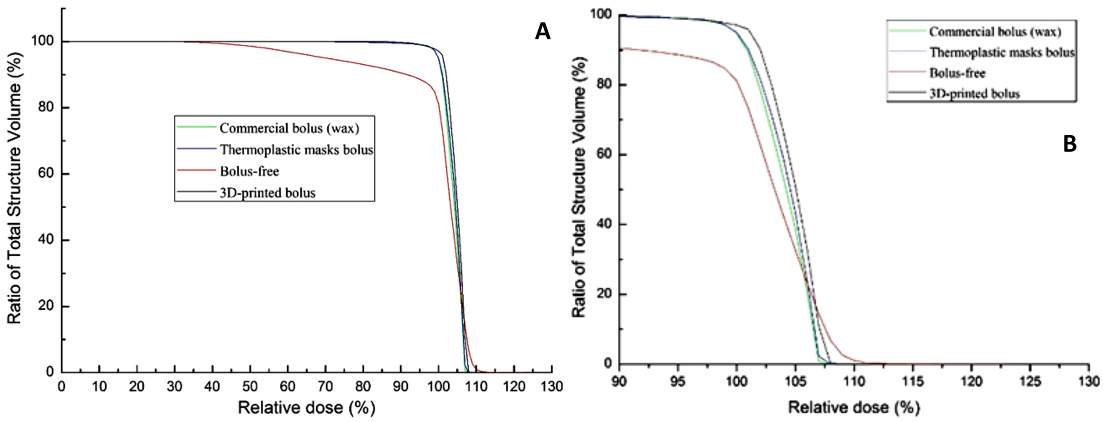

Figure 3. DVH curves for all the plans. **(A)** The figure above shows the relative dose from 0 to the maximum, **(B)** the figure below shows the relative dose from 90% to the maximum.

DISCUSSION

The aim of radiotherapy is to deliver a sufficient radiation dose to a defined tumor while minimizing the dose to the surrounding healthy tissue. High-energy photons are widely used in modern radiotherapy. However, they exhibit a skin sparing effect derived from the buildup region. This is regarded as advantageous when the tumors are in a deep location, as damage to the skin and its resulting complications are avoided. On the other hand, if the tumors are superficial, the skin sparing effect reduces the tumor dose and could result in treatment failure. For the treatment of tumors on or near the skin, the skin sparing effect needs to be overcome to reduce the risk of recurrence. To achieve this, a bolus is placed on the patients' skin. However, commonly used flat bolus materials cannot make perfect contact with this irregular surface, leaving an unwanted air gap between the two. Butson *et al.* reported that approximately 6–10% of the surface dose, depending on the field size and angle of incidence, was reduced when using a 6 MV photon beam in the presence of a 10-mm air gap [6]. Khan et al. studied the dose perturbations of a 6 MV photon beam. They found that the surface dose is significantly affected by air gaps greater than 5 mm [7]. In the case of electron beams, several studies have investigated the dose reduction resulting from air gaps, with similar results to those obtained with photon beams [9, 10]. However,

[DOI: 10.52547/ijrr.21.1.21]

an air gap might be unavoidable in routine daily patient setup. Even more problematic is that the depth of the air gap cannot be anticipated and thus calculated at the treatment planning step. As a result, there might be a discrepancy between the planned and delivered doses.

In this study, for the 3D printing method, the maximum air gaps of the boluses based on high-resolution surface scans were always smaller than those based on other methods. For the PTV, the 3D-printed bolus, commercial bolus (wax) and thermoplastic masks bolus plans had lower Dmax and D1% than the plan without a bolus. For Dmean and D95%, the results were the opposite. For V90%, V95%, V100% and HI, the plan with the 3D-printed bolus was better than the others, and the plan without the bolus was the worst.

For a patient, the bolus might be of lower quality because of the difficulties in pressing and shaping the wax or thermoplastic mask bolus on soft tissue, especially if it is also damaged by the tumor. Therefore, 3D-printed boluses created from CT data in the clinic are likely superior to hand-made boluses, as confirmed by Canters *et al.* [12] in the case of electron treatments.

Comparing the 3D-printed bolus to the commercial bolus, the skin fit is noticeably better, ensuring an acceptable dose of radiation. Richard A. Canters and colleagues examined the dose coverage differences between a conventionally produced silicon bolus and a 3D-printed silicon bolus in 11 nonmelanoma skin cancer cases. They found that CTV (V85%) increased from 88% to 97% (p = 0.006), highlighting the superior advantage of 3D-printed bolus dosimetry distribution [15]. A cast silicon bolus was shown by Tsuicheng Chiu, Zhang Min, and others to have great homogeneity and exceptional patient fit and to enable reproducible and predictable dosimetry [16, 17].

In a study by Magdalena Lukowiak *et al.*, boluses were created for 11 patients with basal cell carcinoma of the eye. They discovered that the 3D-printed bolus had a better fit than the artificial paraffin bolus (92.5-98.4% vs. 28.2-99%). The artificial paraffin bolus was as high as 24% and 8%, while the minimum and maximum dose differences between the actual dose and the reference dose were 5% and 2.5%, respectively. This highlighted the benefits of the adhesion and dose uniformity of the 3D-printed bolus [18]. In this study, for maximum dose and V100%, the differences between 3D-printed and commercial compensators were 1.19% and 2.32%, 12.29% and 16.39% with bolus-free, 0.57% and 2.24% with thermoplastic masks bolus, respectively.

In nasal radiotherapy (table 1), the 3D-printed bolus was much better than the commercial bolus (wax), thermoplastic mask bolus or bolus-free bolus. The commercial bolus (wax) was a square with a thickness of 5 mm, which had a gap of more than 5 mm when placed on an irregular surface (figures 2(b) and 2(c)). The air gaps of the 3D-printed bolus were smaller, which was consistent with other studies [19]. The dose distribution of the 3D-printed bolus was more uniform and was slightly superior in Dmax, Dmean, HI and V95% than the other boluses. The HI value is known to reflect the uniformity of the dose in the target area, as a lower HI value is associated with better homogeneity, consistent with other studies [19, 20]. For the results of this study, we found that the dose characteristics of the thermoplastic mask bolus were second only to 3D-printed compensators, which may have been due to the higher CT of the thermoplastic mask bolus and the smaller gap between it and the skin. If you are not in a condition to print a 3D-printed bolus, you can use a thermoplastic mask bolus.

CONCLUSIONS

In this study, we found that the 3D-printed bolus was good for fit, had a high level of comfort and repeatability, and also had better dose parameters in IMRT plans. The customized bolus produced by a 3D printer could potentially replace and improve upon a commercial bolus (wax). They may replace the commercial bolus (wax) for clinical use.

ACKNOWLEDGEMENTS

The authors thank the Department of Radiotherapy, Tianmen First People's Hospital. Thanks for all colleagues' help and guidance.

Ethics approval and consent to participate: The article does not require ethical approval.

Availability of data and material: The datasets analyzed during the current study are available from the correspongding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

Funding: No funding.

Authors' contributions: SR and LW contributed to conception and design of the study and drafted the manuscript. All authors read and approved the final manuscript.

REFERENCES

1. Park JW and Yea JW (2016) Three-dimensional customized bolus for intensity-modulated radiotherapy in a patient with kimura's disease involving the auricle. *Cancer Radiother,* ***20****(3): 205-209*.
2. ICRU (1999) ICRU Report 62: Prescribing, recording and reporting photon beam therapy (Supplement to ICRU report 50) Bethesda, MD: International Commission on Radiation Units and Measurements.
3. Dyer BA, Campos DD, Hernandez DD, Wright CL, *et al. (2020) Characterization and clinical validation of patient-specific three-dimensional printed tissue-equivalent bolus for radiotherapy of head and neck malignancies involving skin. Phys Med,* ***77****: 138-145.*
4. Vyas V, Palmer L, Mudge R, Jiang R, Fleck A & Schaly B, *et al. (2013) On bolus for* megavoltage photon and electron radiation therapy. *Med Dosim,* ***38****: 268–273.*
5. Butson MJ, Cheung T, Yu P, Metcalfe P (2000) Effects on skin dose from unwanted air gaps under bolus in photon beam radiotherapy. *Radiat Meas,* ***32****: 201–204.*
6. Khan Y, Villarreal-Barajas JE, Udowicz M, Sinha R, *et al.* (2013)

Clinical and dosimetric implications of air gaps between bolus and skin surface during radiation therapy. *J Cancer Ther,* ***4****: 1251–1255.*

7. Benoit J, Pruitt AF, Thrall DE (2009) Effect of wetness level on the suitability of wet gauze as a substitute for Superflab as a bolus material for use with 6 mv photons. *Vet Radiol Ultrasound,* ***50****: 555 –559.*

8. Sharma SC and Johnson MW (1993) Surface dose perturbation due to air gap between patient and bolus for electron beams. *Med Phys,* ***20****: 377–378.*

9. Kong M and Holloway L (2007) An investigation of central axis depth dose distribution perturbation due to an air gap between patient and bolus for electron beams. *Australas Phys Eng Sci Med,* ***30****: 111–119.*

10. Schubert C, van Langeveld MC, Donoso LA (2014). Innovations in 3D printing: a 3D overview from optics to organs. *Br J Ophthalmol* ***98****: 159–161.*

11. Ju SG, Kim MK, Hong CS, Kim JS, Han Y, *et al. (2014) New Technique for* developing a proton range compensator with use of a 3-dimensional printer. *Int J Radiat Oncol Biol Phys,* ***88****: 453–458.*

12. Canters RA, Lips IM, Wendling M, Kusters M, *et al.* (2016) Clinical implementation of 3d printing in the construction of patient specific bolus for electron beam radiotherapy for non-melanoma skin cancer. *Radiotherapy and Oncology,* ***121****(1)148-153*.

13. Robar JL, Moran K, Allan J, Clancey J, Joseph T, *et al.* (2018) Intrapatient study comparing 3D printed bolus versus standard vinyl gel sheet bolus for postmastectomy chest wall radiation therapy. *Pract Radiat Oncol,* ***8****(4): 221-229*.

14. Michiels S, Barragán MA, Souris K, Poels K, *et al.* (2018) Patient-specific bolus for range shifter air gap reduction in intensity-modulated proton therapy of head-and-neck cancer studied with Monte Carlo based plan optimization. *Radiotherapy and Oncology,* ***128****: 161-166*.

15. Canters RA, Lips IM, Wendling M, Kusters M, *et al.* (2016) Clinical implementation of 3D printing in the construction of patient specific bolus for electron beam radiotherapy for non-melanoma skin cancer. *Radiother Oncol,* ***121****(1): 148–53*.

16. Chiu T, Tan J, Brenner M, Gu X, Yang M, Westover K, *et al.* (2018) Three dimensional printer-aided casting of soft, custom silicone boluses (SCSBs) for head and neck radiation therapy. *Pract Radiat Oncol,* ***8****(3): e167–74*.

17. Zhang M, Zhao B, Yin JP, Liu S, Gao X, Qin S, *et al.* (2017) Application of new three dimensional printed tissue compensators in radiotherapy. *Chin J Radiat Oncol,* ***26****(2): 210–4*.

18. Fujimoto K, Shiinoki T, Yuasa Y, Hanazawa H, Shibuya K (2017) Efficacy of patient-specific bolus created using three-dimensional printing technique in photon radiotherapy. *Phys Med,* ***38****: 1-9*.

19. Kong Y, Yan T,Sun Y， Qian J， Zhou G, , *et al.* (2019) A dosimetric study on the use of 3d printed customized boluses in photon therapy: a hydrogel and silica gel study. Journal of *Applied Clinical Medical Physics,* ***20****(1) 348–355*.

20. Lukowiak M, Jezierska K, Boehlke M, Wiecko M, *et al.* (2017) Utilization of a 3D printer to fabricate boluses used for electron therapy of skin lesions of the eye canthi. *J Appl Clin Med Phys,* ***18****(1):76–8*1.