

Measurement-Based Evaluation of the Robustness of Virtual Bolus–Generated Skin Flash in Breast Volumetric Modulated Arc Therapy

Ryohei Yamauchi¹, Fumihiro Tomita¹, Fumiki Ito², Yujiro Nakajima², Yukio Fujita², Naoki Tohyama², Satoshi Ishikura¹

¹ Department of Radiation Oncology, St. Luke's International Hospital, Tokyo, Japan

² Department of Radiological Sciences, Komazawa University, Tokyo, Japan

1. INTRODUCTION

Background

- Breast volumetric modulated arc therapy (VMAT) requires sufficient skin flash to maintain target coverage [1].
- Virtual bolus (VB) optimization is widely used to generate pseudo skin flash [2].

Previous evidence

- Previous studies have optimized VB/optimization bolus thickness and HU values for breast VMAT [3,4].
- Most studies evaluated robustness using TPS-based dose recalculation under setup shifts or anatomical change scenarios.

Research gaps

- Few studies have performed direct measurement-based evaluation under respiratory motion.
- The influence of VB density on measured motion robustness remains unclear.

2. PURPOSE

This study directly evaluated the motion robustness of VB-generated skin flash in breast VMAT using an anthropomorphic phantom, respiratory motion platform, and film dosimetry.

3. METHODS AND MATERIALS

STEP 1. Fabrication of a custom anthropomorphic phantom

- The phantom represented the average body shape of Asian females (Fig. 1).
- The phantom was composed of water-, lung-, and bone-equivalent materials.
- It was designed to accommodate an ionization chamber or film (mid-breast axial plane).

STEP 2. Target and virtual bolus settings

- Target settings:
 - CTV: whole breast
 - PTV: CTV + 5 mm
 - PTV_Eval: PTV excluding 5 mm from the skin surface, heart, and lungs
- VB settings
 - VB thickness: PTV + 5 mm into air (= 10-mm skin-flash region)
 - VB densities: 0.4, 0.7, and 1.0 g/cm³

STEP 3. VMAT planning

- Treatment planning systems: RayStation 10ASP1 and Eclipse 16.1.
- Beam: TrueBeam 6 MV (Varian Medical Systems), four split partial arcs (Fig. 2).
- Prescribed dose: 50 Gy / 25 fractions to PTV_Eval D50%.
- All plans were optimized to meet identical clinical goals.
- VB was used during optimization; the final doses were calculated without VB.

STEP 4. Film measurement

- Radiochromic film: Gafchromic EBT4 dosimetry film (Ashland).
- Motion platform: 4D-KAMUI four-axis moving platform (Anzai Medical).
- Measurement conditions: static and sinusoidal respiratory motion.
- Motion setting: 0 to +5 mm anterior displacement with a 4 s period (Fig. 3).
- This motion pattern simulated a worst-case anterior displacement scenario during respiration.
- Measurements were performed three times per plan.

STEP 5. Film analysis

- Film scan: 75 dpi, 48-bit red-channel images.
- Film analysis software: DD-System version 18 (R-TECH).
- Global gamma analysis: 3%/2 mm criteria with a 30% threshold.

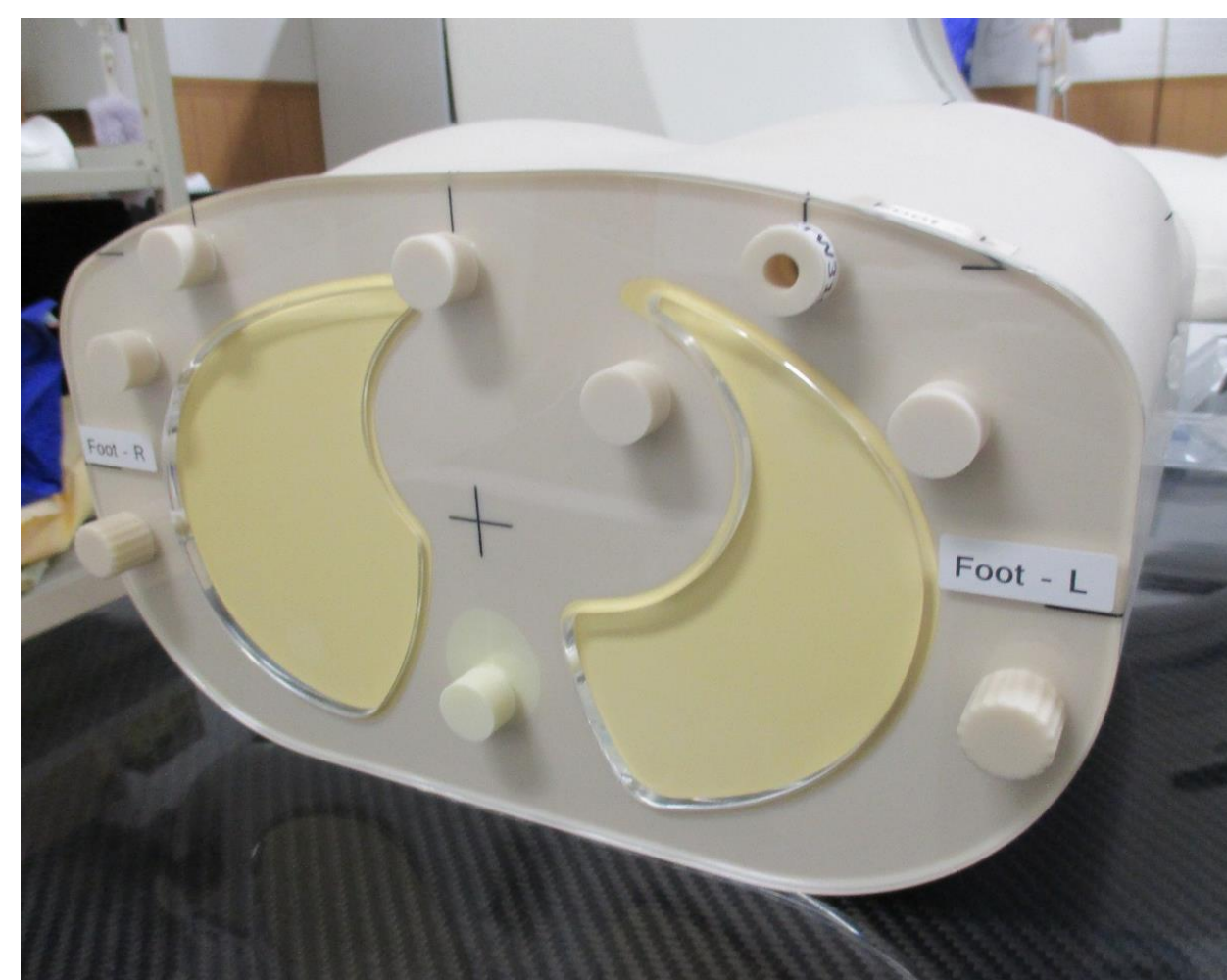


Figure 1. The custom anthropomorphic breast phantom used for film dosimetry.

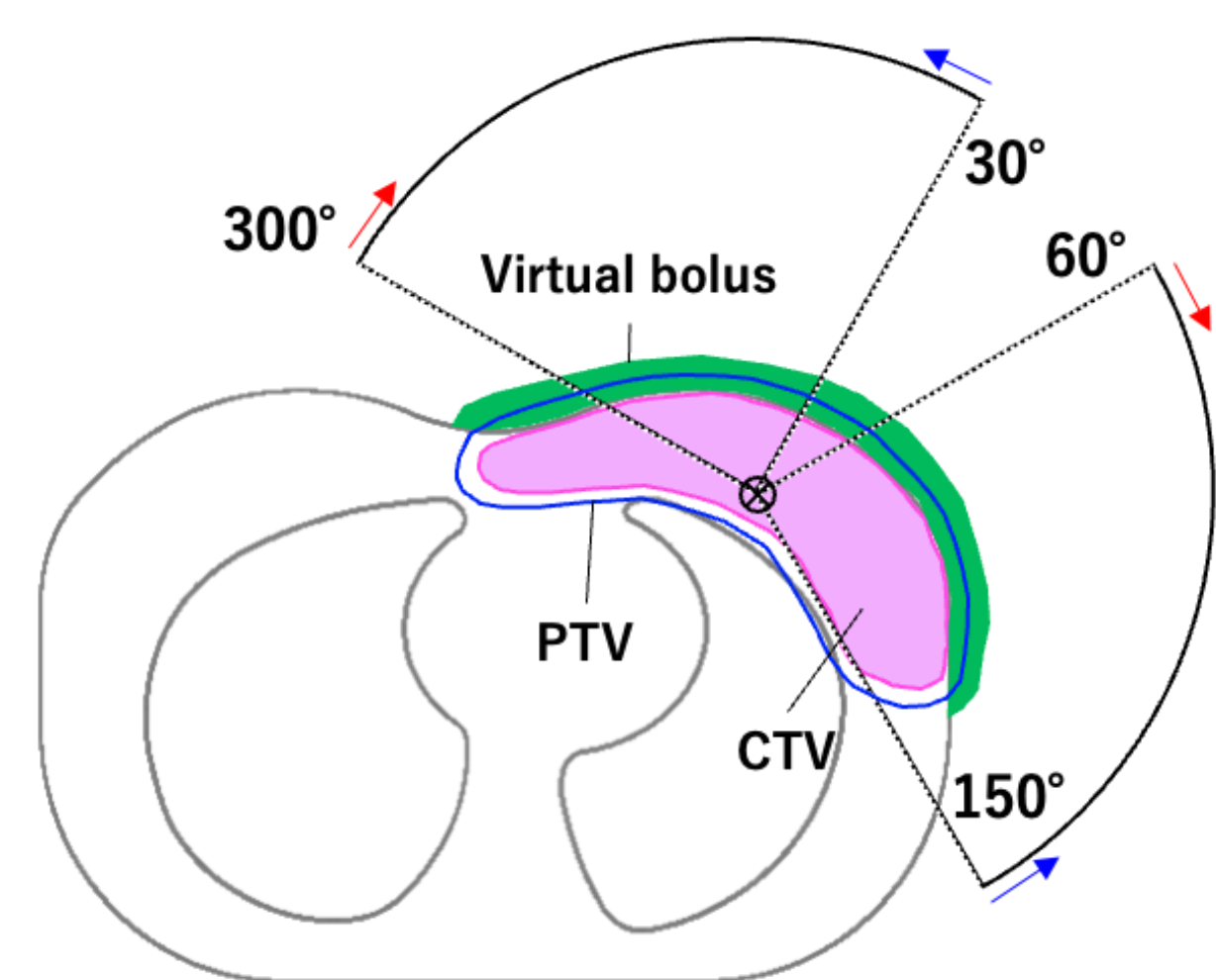


Figure 2. VMAT beam arrangement using four split partial arcs.

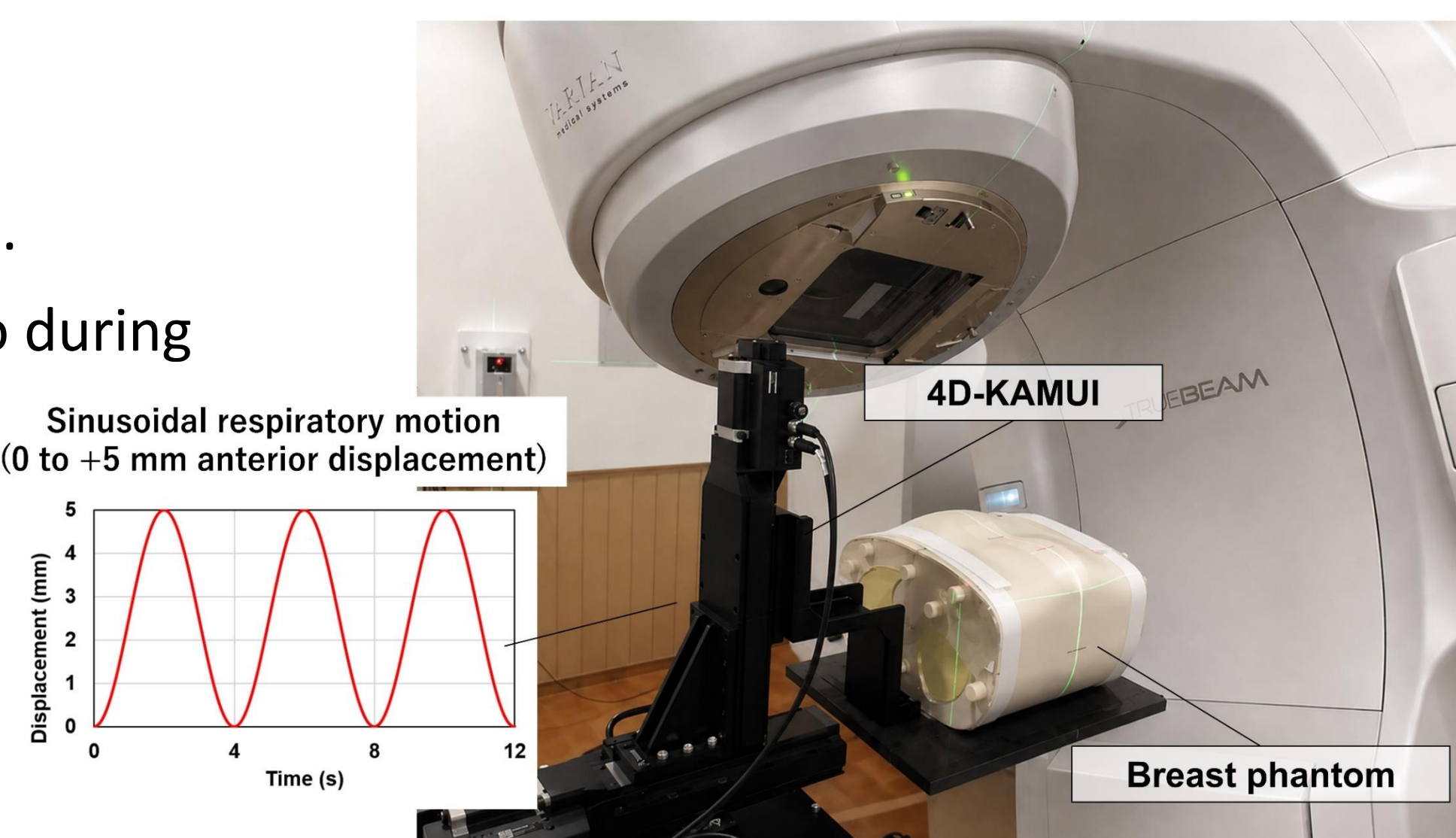


Figure 3. Measurement setup and respiratory motion pattern. Sinusoidal anterior displacement ranged from 0 to +5 mm with a 4 s period.

4. RESULTS

- Static deliveries showed consistently high dosimetric agreement, with mean gamma pass rates of ~90%.
- Static gamma pass rates showed minimal variation among VB densities and TPSs.
- Respiratory motion reduced the gamma pass rates, especially for lower VB density settings.
- The largest motion-related degradation was observed for VB04 using both RayStation and Eclipse.
- Higher VB densities reduced motion-related degradation and improved robustness.
- Similar trends were observed for RayStation and Eclipse, suggesting that the density effect was not TPS-specific.

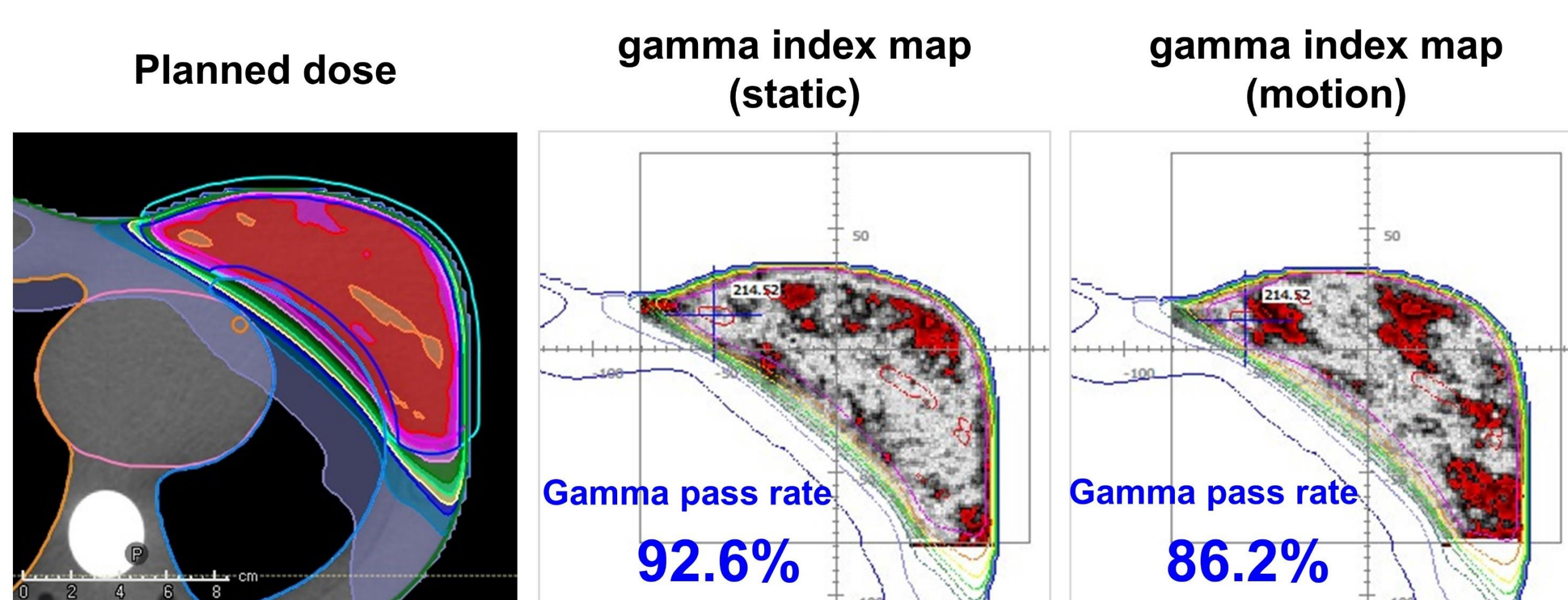


Figure 4. Representative dose distribution and examples of gamma analysis under static and respiratory motion conditions.

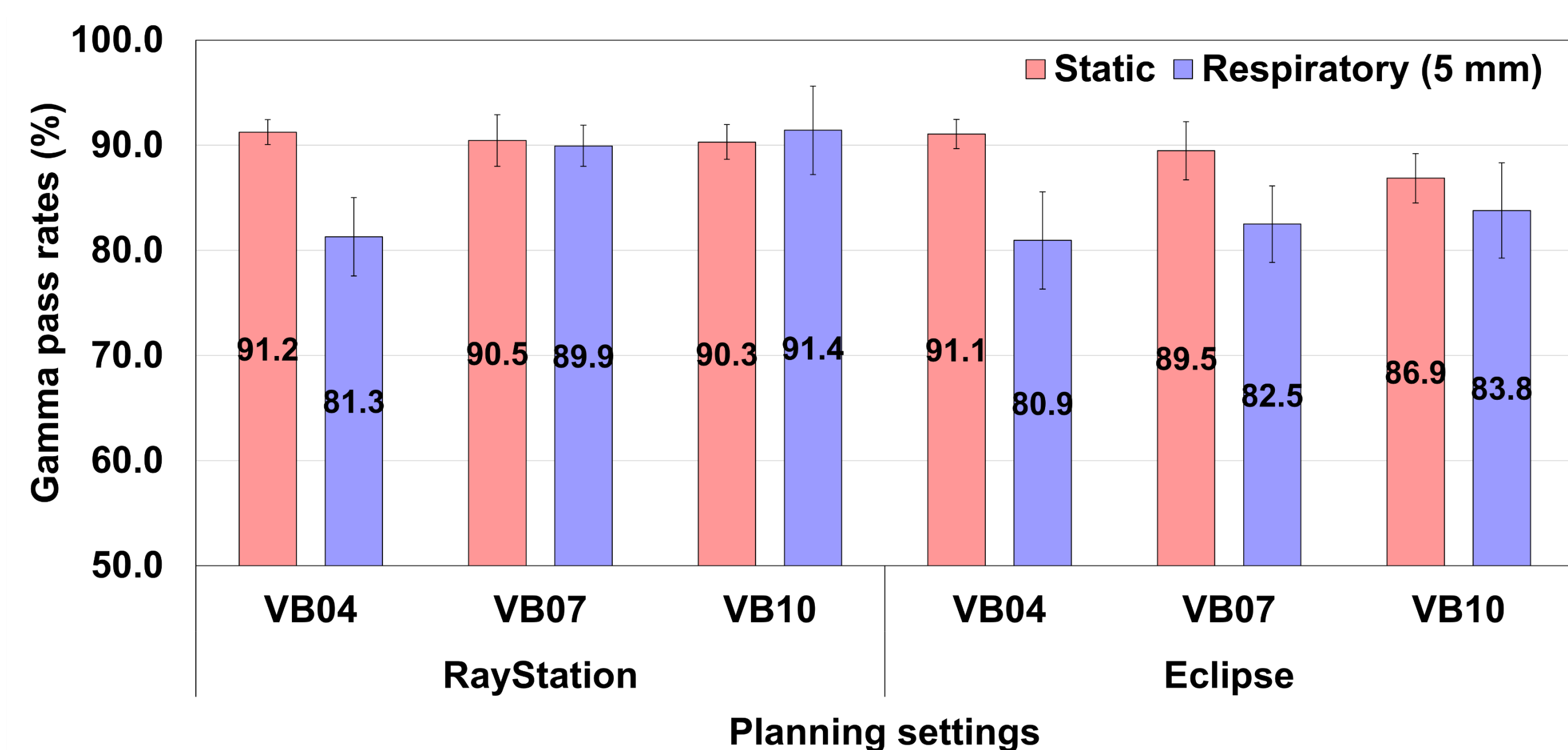


Figure 5. Mean gamma pass rates (3%/2 mm, TH30%) under static and respiratory motion conditions. Abbreviation: VB04, VB07, and VB10 indicate virtual bolus densities of 0.4, 0.7, and 1.0 g/cm³, respectively.

5. DISCUSSION

- Film measurements demonstrated that respiratory motion reduced agreement between planned and delivered dose distributions, particularly in superficial regions associated with tangential beam paths.
- The magnitude of motion-related degradation depended on VB density: Higher VB densities resulted in reduced degradation and improved gamma pass rates under motion.
- Similar trends were observed using the RayStation and Eclipse plans, suggesting that the density effect was not specific to a single TPS.
- These findings suggest that VB density influences the motion robustness of VB-generated skin flash in breast VMAT. Additional evaluations using additional motion patterns, patient-specific anatomy, and clinical scenarios are warranted.

Clinical implications

- VB density is an important planning factor for maintaining robust skin-flash dose delivery under respiratory motion in breast VMAT.

6. CONCLUSIONS

- VB-generated skin flash showed density-dependent robustness under respiratory motion.
- Higher VB densities reduced motion-related degradation in the RayStation and Eclipse plans, supporting the importance of appropriate VB density selection for robust breast VMAT delivery.

7. REFERENCES

- ICRU Report 83: Prescribing, Recording, and Reporting Photon-Beam Intensity- Modulated Radiation Therapy (IMRT). *Journal of the ICRU*.
- Giorgia N, *et al*. Planning strategies in volumetric modulated arc therapy for breast. *Med Phys*. 2011;38(7):4025-31.
- Lizondo M, *et al*. Pseudo skin flash on VMAT in breast radiotherapy: Optimization of virtual bolus thickness and HU values. *Phys Med*. 2019;63:56-62.
- Rossi M, *et al*. Optimal selection of optimization bolus thickness in planning of VMAT breast radiotherapy treatments. *Med Dosim*. 2019;44(3):266-273

COI/IRB/Funding

- There are no conflicts of interest to disclose.
- This study received IRB approval (22-R009).
- This work was supported by JSPS KAKENHI Grant Number JP23K14850.

CONTACT

Ryohei Yamauchi
St. Luke's International Hospital
9-1 Akashi-cho, Chuo-ku, Tokyo 104-8560, Japan
yamauchi.ryouhei@gmail.com

