Evaluation of the clinical implementation of a tattoo-free positioning technique in breast cancer radiotherapy using ExacTrac

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Abstract

Purpose:

Conventionally, tattoos and temporary skin marks are used in patient positioning procedures for breast cancer radiotherapy. However, many patients dislike these marks because their daily lives are affected by them. Therefore, we developed a new positioning technique using ExacTrac (BrainLAB AG, Munich, Germany). This study aimed to evaluate the clinical implementation of a tattoo-free positioning technique for breast cancer radiotherapy using ExacTrac.

Methods:

We included 35 patients with breast cancer, 14 with tattoo-based positioning and 21 with tattoo-free positioning using ExacTrac. In this ExacTrac-based positioning technique, the patients were aligned around the mamilla of the ipsilateral breast, and 6D registration was performed later at the virtual isocenter, which was placed at the spinal cord. The target displacement relative to the treatment isocenter was identified and then compensated for using robotic couch translations and rotations.

The gamma index method analyzes the integrated dose images of the transmitted radiation dose through patients to investigate the irradiation accuracy of the two positioning techniques. The clinical implementation of the ExacTrac-based positioning technique was evaluated by comparing the gamma passing rate of the tattoo-based and ExacTrac-based positioning techniques.

Results:

The mean gamma passing rates of the tattoo-based and ExacTrac-based positioning techniques were 86.0±10.2% and 90.9±6.9%, respectively.

Conclusion:

The ExacTrac-based positioning technique provided positioning comparable to that of the tattoo-based positioning technique. Consequently, the clinical implementation of the tattoo-free positioning technique in breast cancer radiotherapy using ExacTrac was demonstrated.

Keywords: motion management, patient positioning, breast cancer, ExacTrac

1. Introduction

Radiotherapy evidently reduces breast cancer recurrence and mortality. The Early Breast Cancer Trialists' Collaborative Group reported that radiotherapy reduced the ten-year risk of any first recurrence from 35.0% to 19.3% and reduced the 15-year risk of death from 25.2% to 21.4% in breast cancer [1]. Consequently, radiotherapy is considered an essential component of breast cancer treatment.

Conventionally, tattoos and temporary skin marks have been used for patient positioning in breast cancer radiotherapy [2-5]. Daily patient positioning is performed by aligning these marks with lasers in the treatment room. However, many patients disliked these recommendations. For example, as tattoos do not disappear, they become a lasting reminder of cancer treatment, causing patient distress. Conversely, temporary skin marks disappear easily, making it difficult for patients to retain them throughout the treatment period. At the 2018 Annual Young Survival Coalition meeting in Orlando, Florida, women treated with radiotherapy for breast cancer were interviewed for the elucidation of their thoughts regarding tattoos and temporary skin marks. Resultantly, approximately 70% of the interviewed women expressed negative opinions about these marks [6], and 78% stated they would choose another positioning technique, even if it demanded additional effort.

Therefore, we developed a new positioning technique, without using tattoos or temporary skin marks, using the BrainLAB ExacTrac® X-ray 6D stereotactic image-guided radiation therapy (IGRT) system (BrainLAB AG, Munich, Germany). ExacTrac is an IGRT system that enables users to easily and precisely set up patients. ExacTrac comprises two-kV X-ray units recessed into the treatment room floor, two silicon flat-panel detectors, and infrared cameras mounted on the treatment room ceiling. It provides fast and highly accurate patient positioning via a gradient correlation for 2D-3D registration based on the bony anatomy [7-9]. The target displacement relative to the isocenter can be accurately detected by two kV X-ray imaging systems and then compensated for using robotic couch translation and rotation.

This study aimed to evaluate the clinical implementation of this tattoo-free positioning technique in breast cancer radiotherapy using the ExacTrac. To investigate the irradiation accuracy of the tattoo-based and ExacTrac-based positioning techniques, integrated dose images of the transmitted radiation dose penetrating patients were analyzed using the gamma index method. The clinical implementation of the ExacTrac-based positioning technique was evaluated by comparing the gamma passing rate of the tattoo-based and ExacTrac-based positioning techniques.

2. Materials and Methods

A total of 35 patients were treated with two different patient positioning techniques: 14 with tattoo-based positioning using temporary skin markers and 21 with ExacTrac-based positioning.

The integrated images of the transmitted radiation dose penetrating the patients were analyzed using the gamma index method.

2.1. Tattoo-based positioning

A tattoo-based positioning technique using temporary skin marks was used for breast cancer radiotherapy. Four markers were used for each patient. Two of the four markers were cross-shaped and marked on both sides. These two markers indicate vertical, longitudinal, roll, and pitch rotations, respectively. The remaining two markers were line-shaped and were marked above and below the ipsilateral breast surface. These two markers indicate lateral position and yaw rotation, respectively. The positions of the markers are shown in Figure 1.

Patients were treated in the supine position with both arms raised on a breast board (ESF-WGS, Engineering System Co.). A breast board and bowl-shaped pillow were used as immobilization devices (Figure 2). To improve the reproducibility of chin and arm positioning, the patient laid on their back, with the top of their head on a bowl-shaped pillow, and their eyes turned toward the ceiling. After checking that the top of the head was in contact with the bowl-shaped pillow, the patients grabbed the grip and relaxed. After the initial positioning, these temporary skin marks were aligned with the lasers in the treatment room and the planned shift was manually implemented by radiological technologists. To ensure accurate alignment to the treatment isocenter, verification portal images were obtained and matched to digitally reconstructed radiographs (DRRs) by rigid bone matching and breast surface matching.

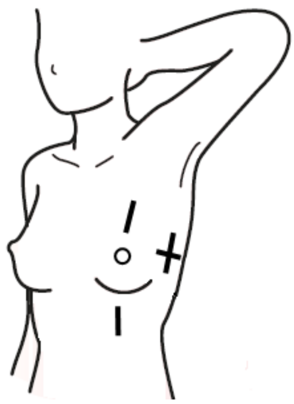

Figure 1: Location of the temporary skin markers. Two of the four markers are cross-shaped and marked bilaterally on the patient. The remaining two markers are line-shaped and marked above and below the ipsilateral breast surface

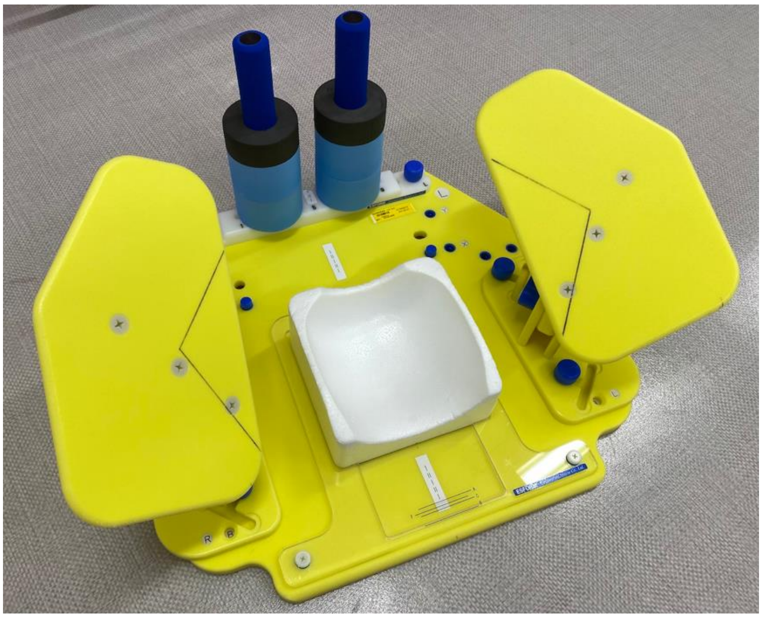

Figure 2 (color): A breast board and a bowl-shaped pillow are used as immobilization devices

2.2. Tattoo-free positioning technique using ExacTrac

Patient positioning using ExacTrac is generally performed at the treatment isocenter. Registration based on the bony anatomy is typically useful for the cranium, spine, head, and neck. However, the treatment isocenter for breast cancer radiotherapy is located at the chest wall. Therefore, the skeletal anatomy of the ribs or shoulder joints, which can change due to respiration or arm extension, was included in the kV X-ray images for registration based on the bony anatomy. These deformations between the skeletal anatomies of the reference and present states interfere with the registrations, rendering them inaccurate. To avoid this issue, a virtual isocenter was used. When no explicit bony landmarks were available for 6D registration around the isocenter, a virtual isocenter was placed at a location with an explicit bony landmark and used for 6D registration. It was presented at an academic conference that the ExacTrac system calculated the shifts and located the planned isocenter within approximately 1 mm when the virtual isocenter was placed on a spine and located approximately 10.8 cm away from the planned isocenter [10]. 6D registration at the virtual isocenter occurred in three patient-positioning steps. Step 1: Patient setup around the treatment isocenter. Step 2: Shift to the virtual isocenter and 6D registration at the virtual isocenter. Step 3: Shift from the virtual isocenter to the treatment isocenter. The translation vector and misalignment between the treatment isocenter and virtual isocenter were calculated using ExacTrac, and the patient was translated automatically by robotic couch translations and rotations.

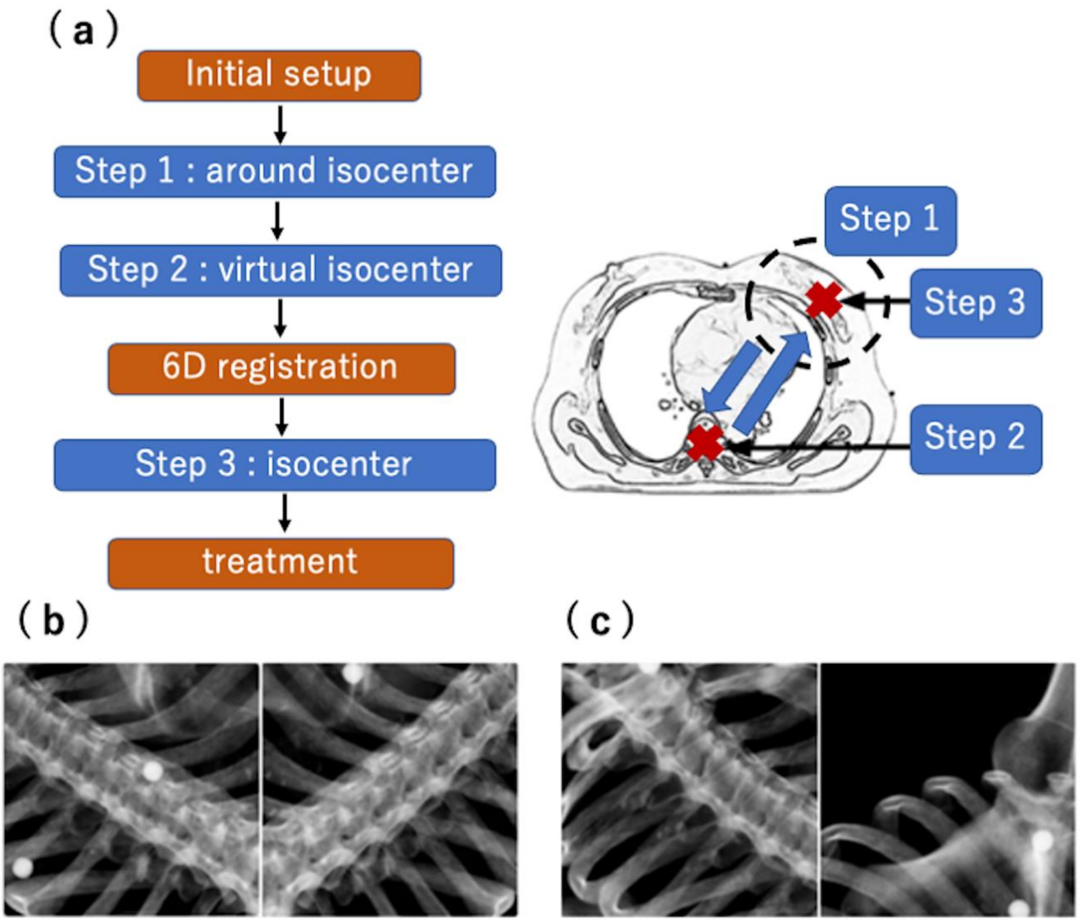

Figure 3 (color): Workflow diagram of the ExacTrac-based positioning technique and X-ray images of ExacTrac at the treatment isocenter and virtual isocenter. (a) The workflow diagram of the ExacTrac-based positioning technique. In the direction of the arrow, the patients are translated automatically. (b) X-ray images of ExacTrac at the virtual isocenter. The virtual isocenter is placed at the spinal cord in the slice coinciding with the treatment isocenter. This skeletal anatomy is static. Therefore, the registration is typically useful. (c) X-ray images of ExacTrac at the treatment isocenter. The skeletal anatomy of the ribs or shoulder joints, which can change due to respiration or extended arms is included in the information for registration. These deformations interfere with inaccurate registrations

In the tattoo-free positioning technique in breast cancer radiotherapy using ExacTrac, the virtual isocenter was placed at the spinal cord at the slice coinciding with the computed tomography (CT) images containing the treatment isocenter, and 6D registration was performed (Figure 3). The patients were treated in the supine position with both arms raised on a breast board. The initial positioning and immobilization devices for the ExacTrac-based positioning technique were the same as those used for the tattoo-based positioning technique. After the initial positioning, three patient positioning steps were required using the ExacTrac-based technique. In Step 1, patients were aligned around the treatment isocenter, which was located at the middle axillary for the vertical position and at the mammilla of the ipsilateral breast for the long and lateral positions. In Step 1, approximate alignment is sufficient, because 6D registration is performed later using the virtual isocenter. In Step 2, the patients were automatically translated from the isocenter to the virtual isocenter using robotic couch translations. 6D registration was performed at the virtual isocenter, and the target displacement and misalignment were identified. When large rotations that could not be managed by the robotic couch were observed in Step 2, patient repositioning was required. In Step 3, patients were translated automatically from the virtual isocenter to the treatment isocenter, compensating for the target displacement and misalignment by robotic couch translations and rotations. To ensure the alignment with the treatment isocenter, verification portal images were obtained and compared with the DRRs of the breast surface. The comparison was visual and not quantitative, and the patient was not moved.

2.3. Accuracy of the gamma index method

The irradiation accuracies of the tattoo-based and ExacTrac-based positioning techniques were quantified using the gamma-index method [11-13]. The integrated dose images of the radiation dose transmitted through patients were measured using portal dosimetry and evaluated using the gamma index method.

In this study, Adaptivo™ Patient Dosimetry (Standard Imaging Inc., Middleton, WI, USA) was used for the gamma index method. Adaptivo is a standalone software that provides comparative dose information about the daily and cumulative doses received by a patient undergoing radiotherapy relative to their treatment plan. To evaluate the accuracy of the gamma index method by Adaptivo and examine the best criterion for this method, the change in the gamma passing rate was investigated when the phantom was intentionally moved. ArcCHECK® (Sun Nuclear, Melbourne, FL) was used as the test phantom. ArcCHECK is a 4D detector array specifically designed for the quality assurance of arc, helical, and volumetric modulated arc therapy. ArcCHECK is a cylindrical water-equivalent phantom, with a hollow center (15 cm diameter) and designed to accommodate various accessories. In this study, ArcCHECK was used to simulate the patient’s body and lungs using a cylindrical phantom with no accessories in the center. The irradiation plan used a tangential 6-MV beam and an irregular surface compensator (ISC), including the center of the phantom in the irradiation field. The ISC is an electronic compensation algorithm implemented in the Eclipse treatment planning system. ISC modulates the electronic fluence across the radiation fields and improves dose distributions, where the use of simple wedges leads to cold or hot spots, such as in breast treatment [14]. ArcCHECK was intentionally moved by 1, 2, 3, 5, and 10 mm vertically, and the same plan was irradiated. Integrated dose images of the transmitted radiation dose using ArcCHECK were analyzed using the gamma index method. The change in the gamma index passing rate due to the phantom position (1, 2, 3, 5, and 10 mm) and the gamma criterion (1%/1, 2%/2, 3%/3, 4%/4, and 5 m%/5 mm) were investigated. The results are presented in Table 1. From the results, a gamma criterion of 3%/3 mm was chosen for the evaluation of the positioning accuracies of the two positioning techniques, because its gamma passing rate was over 90% when analyzing a phantom movement of 3 mm. The gamma passing rate must exceed 90% [15].

Regarding breath movements, the mean values of the peak-to-peak chest wall motion amplitudes during the irradiation is reportedly 2.0±0.7 mm (range 1.1–3.2 mm) [16], and the X-ray beam constancy should be under ±3% for IMRT in AAPM Task Group 142 [17]. Therefore, we consider a 3-mm DTA and 3% dose to be appropriate for gamma evaluation.

Table 1: Gamma index passing rate depending on the phantom movement and gamma criteria (%)

Phantom movement / Gamma criterion	1 mm	2 mm	3 mm	5 mm	10 mm
1%/1 mm	**89.23**	**66.33**	**59.59**	**57.01**	**49.48**
2%/2 mm	**100.00**	**89.97**	**71.22**	**61.80**	**57.31**
3%/3 mm	**100.00**	**100.00**	**90.90**	**68.33**	**61.35**
4%/4 mm	**100.00**	**100.00**	**99.93**	**82.64**	**64.85**
5%/5 mm	**100.00**	**100.00**	**100.00**	**93.77**	**67.81**

2.4. Patient data and planning CT

Ethical approval for this study was granted by the institution, Toyota Memorial Hospital. A total of 35 patients, 14 with tattoo-based positioning using temporary skin markers and 21 with ExacTrac-based positioning, treated with external beam radiotherapy on TrueBeam (Varian Medical Systems, Palo Alto, CA, USA) between March 2018 and January 2020 were selected. No patients had surgical clips available for X-ray image registration. Both left-sided (n=15) and right-sided (n=20) breast cancers were included, but patients treated with deep inspiration breath-holding were excluded. The median patient age was 57 years (range, 42–77 years). The reproducibility of patient positioning is affected by differences in breast volume. Hence, the planning target volumes (PTVs) of all patients were investigated. The median PTV volume of tattoo-based positioning using temporary skin markers was 501.2 (range, 174.5–939.3) cm^3. The median breast volume of ExacTrac-based positioning was 448.5 (range, 187.4–747.3) cm^3.

All patients underwent a free-breathing planning CT scan using a 16-low multi-slice CT Optima CT580W (GE Electronic Medical Systems, Waukesha, WI, USA) with 1.25-mm slice thickness.

2.5. Dosimetric planning

The treatment plan was implemented using the Eclipse Treatment Planning Station (version 13.6, Varian Medical Systems, Inc., Palo Alto, CA, USA). The PTV was defined as the ipsilateral whole breast, and the PTV-Opt was defined by subtracting the areas within 5 mm of the skin and lung from the PTV. The treatment plan prescription was 50 Gy in 25 fractions, which was normalized to PTV-Opt. The at-risk organs were the lungs and heart. All plans used two opposing tangential 6-MV beams and an ISC for dose homogenization.

2.6. Evaluation of irradiation accuracy

To investigate the irradiation accuracy of the tattoo-based and ExacTrac-based positioning techniques, integrated dose images of the radiation dose transmitted through patients were evaluated using the gamma index method by Adaptivo. This study compared the integrated dose images calculated using Adaptivo with those measured using portal dosimetry. We analyzed 1,750 images (35 patients × 25 fractions × 2 beams). Of these, 700 images used the tattoo-based positioning technique and 1,050 used the ExacTrac-based technique. We used a low-dose threshold of 10% of the prescription dose and a gamma criterion of 3%/3 mm.

3. Results

In this study, 35 patients completed breast cancer radiotherapy, and 1,750 integrated dose images were acquired via portal dosimetry. An example of an integrated dose image is shown in Figure 4. Using the gamma index method, the integrated dose images measured using portal dosimetry were compared with those calculated using Adaptivo. An integrated dose image analyzed using the gamma index method is shown in Figure 5. In this image, the area that delivered a high dose of radiation is represented in red and the area that delivered a low dose of radiation is represented in blue. By overlapping the dose distribution with portal dosimetry, the locations of the dose differences were easy to determine, leading to better positioning for subsequent irradiation appointments. In many cases, the patient setup in Step 1, such as the arm positioning and body distortion by manual alignment, causes the low gamma passing rate. The following day, we applied this information to the patent setup for better positioning.

At our institution, the patients were repositioned when the rotation requiring management by the robotic couch exceeded 3°. Few cases required repositioning of patients. Most rotations managed by the robotic couch were under 3° of pitch, yaw, and roll rotation.

The mean values and standard deviations were analyzed using the gamma index method. The mean gamma passing rate of the tattoo-based positioning technique was 86.0±10.2%, while that of the ExacTrac-based technique was 90.9±6.9%. The gamma passing rate of both techniques tended to be low at the end of the treatment period due to breast deformation and skin shift. The difference in breast volume affected the gamma index passing rate. Hence, the results of the gamma index method were stratified by the PTV volume. The median PTV volume in all patients was 479 cm^3. Therefore, patients were stratified into two groups: PTV < 500 cm^3 and PTV > 500 cm^3. The distribution of the gamma passing rates of these two groups are shown in Figures 6 and 7 using histograms.

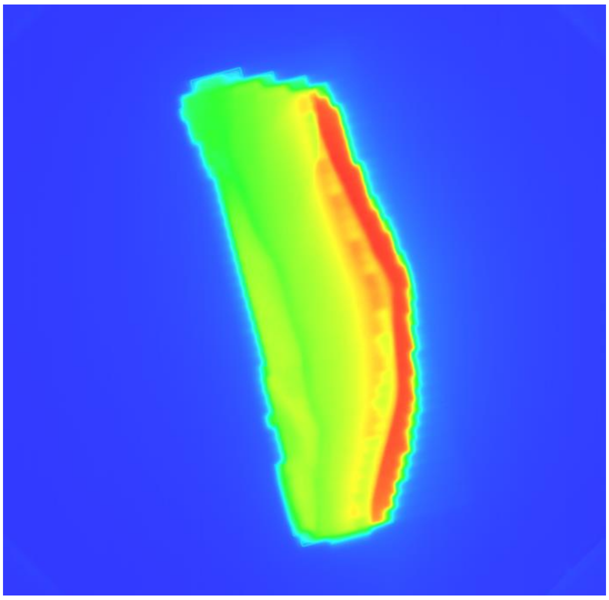

Figure 4 (color): An integrated dose image acquired during irradiation. The area that delivered a high dose of radiation is represented in red, and that which delivered a low dose is represented in green and blue.

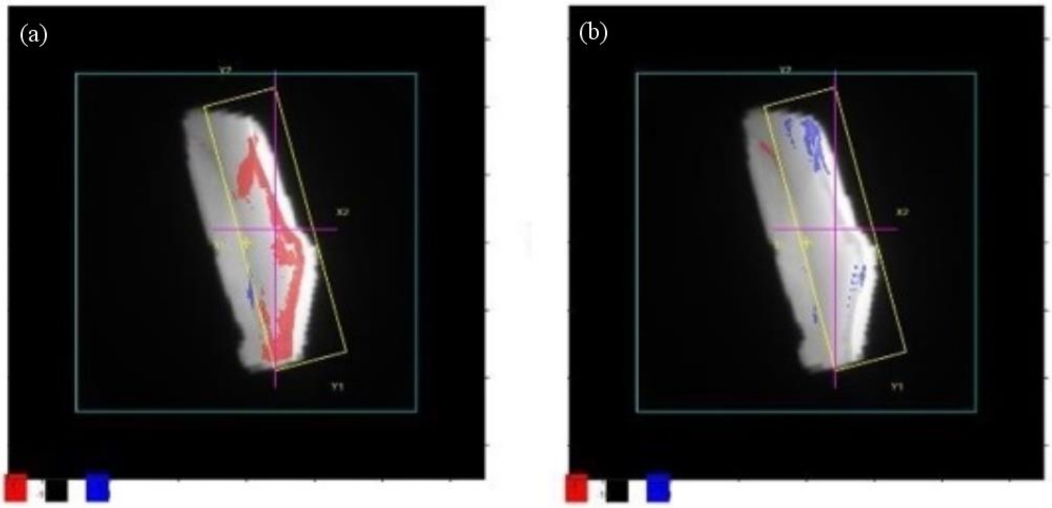

Figure 5 (color): Integrated dose images analyzed by the gamma index method over verification portal images. The area that delivered high doses of radiation is represented in red. The area that delivered low doses of radiation is represented in blue. (a) This image indicates that a high dose was delivered to the breast margin due to breast shape changes or poor reproducibility of patient positioning. (b) This image indicates that a low dose was delivered to the axilla due to poor reproducibility of patient positioning.

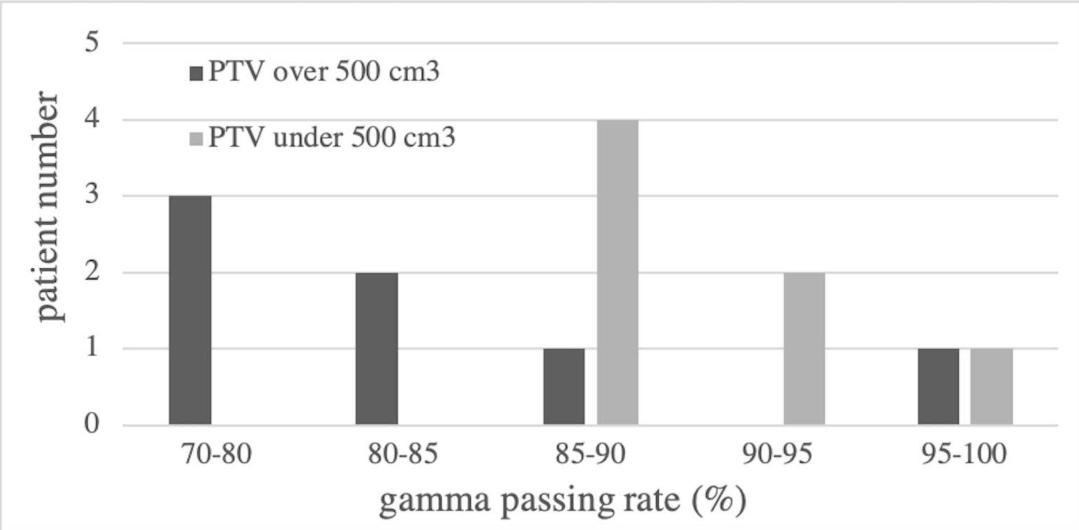

Figure 6: Distribution of the gamma passing rate of tattoo-based positioning using temporary skin markers. The results of the gamma passing rate of tattoo-based positioning using temporary skin markers are stratified into two groups: PTV < 500 cm^3 and PTV > 500 cm^3.

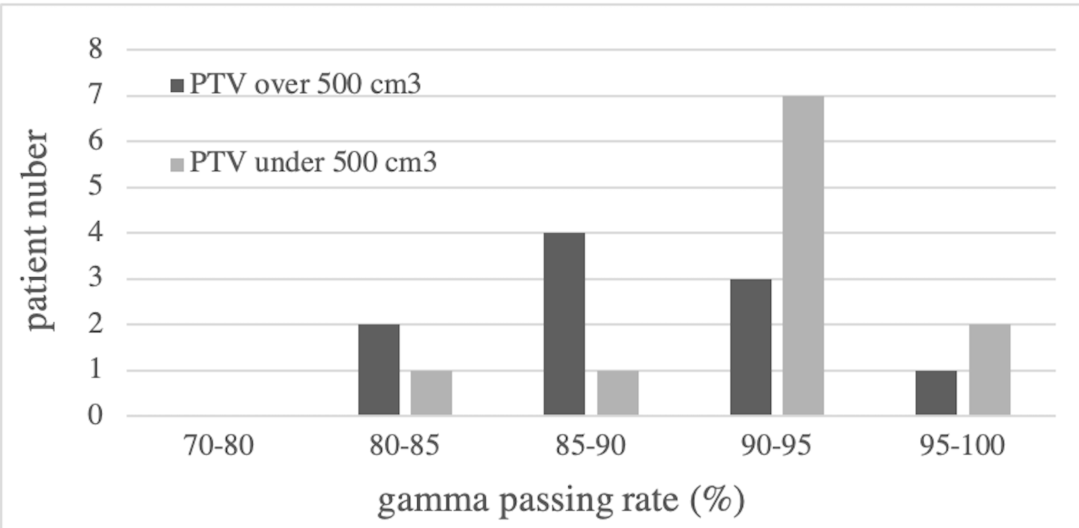

Figure 7: Distribution of the gamma passing rate of ExacTrac-based positioning. The results of the gamma passing rate of ExacTrac-based positioning are stratified into two groups: PTV < 500 cm^3 and PTV > 500 cm^3.

4. Discussion

This study compared two different patient positioning techniques for breast cancer radiotherapy. The gamma index method by Adaptivo was used to compare the ExacTrac-based technique with the tattoo-based positioning technique. The mean gamma passing rate of the ExacTrac-based technique was 90.9±6.9%, whereas that of the tattoo-based positioning technique was 86.0±10.2%, proving that the former could perform positioning as well as the latter. This result included errors arising from both the radiation therapy apparatus and the patients. The errors arising from the radiation therapy apparatus included the output dose and irradiation position errors. The errors arising from patients included patient setup errors, errors due to respiration, errors due to body shape changes, and errors due to changes in the breast volume during the entire irradiation period [18-20]. The results of these integrated dose images directly include free breathing movement during irradiation, and intra-field peak-to-peak chest wall motion amplitudes are reportedly 2.0±0.7 mm [range 1.1-3.2 mm]. Therefore, the integrated dose images measured using portal dosimetry have localization errors. Accordingly, the gamma index method, which includes dose difference and distance-to-agreement distributions, was used in this study. The dose difference results of the integrated dose images tended to be large at the outline of the breast surface and the armpit. This dose difference at the outline of the breast surface implies the influence of free-breathing movements during irradiation. The gamma passing rate results included these errors. However, the gamma passing rate of the ExacTrac-based positioning technique was similar to that of the tattoo-based positioning technique. Therefore, the ExacTrac-based positioning technique was considered sufficient for clinical implementation.

From the results of the histograms, the gamma passing rate of patients with a small breast volume (PTV < 500 cm^3) was high for both positioning techniques. However, the gamma passing rate of patients with a large breast volume (PTV > 500 cm^3) was low for both positioning techniques. Large breasts were more deformable throughout the irradiation period than were small breasts. This breast deformation affected positioning reproducibility. Moreover, this tendency was particularly strong in the tattoo-based positioning technique because the body distortion caused by manual alignment caused greater breast deformation. Prone or other positioning techniques are recommended for spinal positioning in patients with very large breasts.

Improvements in the pitch rotational setup were observed in the verification portal images using the ExacTrac-based positioning technique. This improvement was caused by the ExacTrac system, which implements 6D registration and compensates for the rotational setup errors. In particular, it is difficult for a radiological technologist to manually compensate for misalignment of the rotational setup. However, in our ExacTrac-based positioning technique, 6D registration was not performed for the chin and arms. For patient positioning in breast cancer radiotherapy, the alignment of the chin and arms is important [21]. The ExacTrac-based positioning technique is not recommended for patients irradiated with supraclavicular lymph nodes. Furthermore, the ExacTrac-based positioning technique is not recommended for patients who have been treated with deep inspiration breath-hold. In these treatments, the location of the PTV changes significantly depending on the patient setup of the neck and the inspiratory volume at every fraction, and 6D registration at the virtual isocenter cannot compensate for these misalignments.

In the ExacTrac-based technique, radiological technologists and patients did not have to worry about the markers, and the target displacements were compensated for by robotic couch translations and rotations. This process eliminated the manual procedure of aligning the patient with the isocenter. The tattoo-based positioning technique repeatedly demanded careful attention in maintaining the marker to avoid fixing it at every irradiation appointment, and repeated marking led to inaccurate positioning. Surface-guided radiotherapy (SGRT) systems such as AlignRT or Catalyst, monitor the patient’s surface optically and do not require any marks [22,23]. When combined with skin markers, SGRT decreases the setup deviation significantly compared to that associated with the line-based setup for both tangential and locoregional treatments, and daily SGRT improves the patient setup without necessitating additional imaging dose to the patients [24]. However, when not combined with skin markers, little change in setup deviation is observed between the SGRT and line-based setups [25]. Furthermore, SGRT requires a dedicated device. For treatment centers that do not possess dedicated devices, the ExacTrac-based technique can be an option as a tattoo-free technique.

It can be concluded that the ExacTrac-based positioning technique is clinically useful for patient positioning as a tattoo-free technique in breast cancer radiotherapy. However, it should be used with another imaging method to verify the breast positioning and deformation.

In our study, we used two opposing tangential 6-MV beams and an ISC. We do not recommend the ExacTrac-based technique for 3D conformal plans, volume-modulated arc therapy, or stereotactic radiotherapy because the irradiation accuracy of three or more fields has not been proven. We must also consider that the ExacTrac-based technique entails the delivery of additional imaging doses. Murphy et al. reported that the entrance dose measured by ExacTrac was 0.551 mGy, resulting from a pair of oblique beams for the body (140 kV, 125 mA, 125 ms) [26].

5. Conclusions

This study showed that the tattoo-free positioning technique in breast cancer radiotherapy using ExacTrac provided good positioning, similar to that associated with the conventional tattoo-based technique. Consequently, clinical implementation of a tattoo-free positioning technique in breast cancer radiotherapy using ExacTrac was demonstrated.

To provide effective and convenient radiotherapy, this study encourages the acceptance of a tattoo-free positioning technique in breast cancer radiotherapy using ExacTrac worldwide.

Acknowledgments

This work was partially supported by JSPS KAKENHI grant Number JP18K04974. We would like to thank Editage (www.editage.com) for English language editing.

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