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Original Research Article

Magnitude and dosimetric impact of inter-fractional positional variations of the metal port of tissue expanders in postmastectomy patients treated with radiation

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ABSTRACT

Background and purpose: Postmastectomy breast reconstruction involves the insertion of a temporary tissue expander, which contains a metal injection port. The purpose of this study was to determine the magnitude and dosimetric impact of the inter-fractional positional variations of the port for patients treated with radiation.
Materials and methods: For nine breast cases treated on Tomotherapy, the deviation of the port in the daily MVCT from its reference position was measured in the three cardinal directions. The dosimetric effects of the measured errors were evaluated for two classes of error: Internal Port Error (IPE) and Patient Registration Error (PRE). For each class, dose accumulation was done for daily measured errors and a systematic error.
Results: Inter-fractional positional errors of the port were small, with 87% of the deviations below 5 mm, but errors larger than 1.5 cm were observed. The cumulative effect of the daily measured and systematic IPE decreased target coverage by as much as 2.8% and 3.5%, respectively. The cumulative effect of the daily measured PRE decreased target coverage by an average of 3.5%. The cumulative effect of a systematic PRE significantly decreased target coverage by an average of 16%.
Conclusion: The presence of IPE over the course of treatment had minimal clinical impact while PRE had a greater impact on clinically-relevant regions. The robustness of treatment delivery can be improved by assigning the port its appropriate density during planning despite contouring uncertainties due to metal artefacts, and by prioritizing anatomical alignment over port alignment during daily registration.

1. Introduction

Mastectomy is one of the main treatment procedures for breast cancer and the primary preventative procedure for patients at a higher risk of developing breast cancer [1]. The percentage of patients who undergo breast reconstruction after mastectomy is increasing, with a rising trend towards implant-based reconstruction [2]. Immediate breast reconstruction improves the psychological morbidity of patients and was shown to improve health-related quality of life over the first postoperative year [3]. A common technique for immediate breast reconstruction involves the insertion of a temporary tissue expander at the time of mastectomy to stretch the overlaying skin. The most commonly-used expander contains a metal port made of a rare earth magnet encapsulated in a titanium shell that is accessed with an external magnet and used for saline injections. For patients with T3 to T4 breast cancer, postmastectomy radiation therapy was proven to reduce locoregional recurrence and prolong survival [4–6]. Some of these patients receive radiation treatment with the tissue expander and its metal port in the radiation field. Perturbations in the dose distribution occur if the presence of the metal port is not accurately modelled in the treatment planning system, or if its location at the time of treatment is different from its location in the simulation scan that is used for treatment planning.

The dosimetric effect of the presence of the metal port during radiation therapy has been previously studied using Monte Carlo and film dosimetry ex-vivo and in-vivo [7–16]. Some groups showed that the presence of the metal port can produce underdosage in the shadow of the port and lead to underdosage of the skin [9–11], and to a decrease in the percent target coverage at the prescription dose by up to 11.7% [8]. Other studies reported significant perturbations in the dose distribution

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but concluded that the dose reduction in the shadow of the port is inside the non-biological implant, with minimal clinical significance [7,12–16]. Chen *et al* [8] recognized that the metal port has the potential to migrate within the tissue expander, which may affect the dose distribution. However, no study investigated the magnitude or the dosimetric effect of the inter-fractional positional variations of the metal port.

The objective of this study was to use real patient registration data at the time of treatment to determine the magnitude and dosimetric impact of the inter-fractional positional variations of the metal port. Relative changes in target coverage and doses to relevant Organs At Risk (OARs) were analyzed when port positional variations based on real patient registration data were simulated.

2. Methods and materials

2.1. Patient population

Following all ethics and confidentiality protocols of the institution for handling patient data, this study analyzed six patients with tissue expanders who received radiation treatment on Tomotherapy. Two of the six patients had a bilateral reconstruction and received bilateral treatment. All patients received 25 fractions to a total prescription dose of 50 Gy. Each breast was investigated independently, resulting in eight data sets and a total of 200 independent fractions, 193 of them were included in this study.

A special *additional* case with 25 fractions was investigated in this study and was analyzed separately. For this additional case, the tissue expander was loose within the breast pocket, causing the implant to flip from fraction to fraction.

2.2. Measuring inter-fractional positional errors

Tomotherapy utilizes daily megavoltage CT (MVCT) imaging for guidance. MVCT imaging produces substantially less artefacts than conventional kilovoltage CT imaging when high atomic number materials are present in the imaging field of view. For a given patient fraction, the daily acquired MVCT image was co-registered with the reference CT, after the metal artefacts were overridden by the radiation treatment planner. The deviation in the position of the metal port was determined by measuring the distance from the center of core magnet in the MVCT scan to its center in the reference CT in the three cardinal directions. The roll corrections that was used during the delivery (Tomotherapy feature) was kept unchanged. This process was repeated for all fractions per patient.

For the special case, the whole implant was inverted, which also changed the orientation of the port. To avoid complex modelling of the rotation of the port, shifts in the three cardinal directions only were applied. The alignment of the metal port in the MVCT and the reference CT was therefore performed by matching the center of the core magnet.

2.3. Dosimetric impact of the measured port positional errors

The measured positional errors of the metal port can be the result of two “classes” of errors. The first class is port positional error relative to the internal anatomy of the patient, referred to herein as Internal Port Error (IPE). IPE can be caused by anatomical changes of the patient throughout the course of treatment [17,18], and/or the migration of the whole tissue expander. The second class is port errors due to the displacement of the patient relative to the radiation beam, referred to herein as Patient Registration Error (PRE). PRE can be caused by necessary compromises made during daily patient registration.

2.3.1. Modeling internal port error (IPE)

To simulate IPE (port error relative to internal anatomy), for every fraction in each patient treatment the reference CT was modified by directly editing voxel values such that the metal port was artificially shifted by the measured magnitude of the port positional error for that fraction. This was done using in-house software developed for this study. First, the voxels inside the contour of the metal port were identified using the clinically defined contours of the port. Voxels that were inside the titanium shell and the magnet were assigned Hounsfield Unit (HU) values corresponding to their nominal densities. To correct for metal artefacts in the reference CT scan, tissue density override was performed around the metal port using a mean HU value of nearby breast tissue that is free from artefacts. This was repeated for all fractions for each patient. An example of a corrected CT slice is shown in Fig. 1.

The Data Quality Assurance station of Tomotherapy was used to calculate the dose distribution from the original helical plan on the CT scans with modified port positions. The dosimetric effect of IPE was evaluated for two scenarios. The first scenario is the cumulative effect of the measured daily positional errors of the metal port throughout the course of the treatment. For this scenario, the original plan was calculated on each of the 25 modified CT scans per patient and summed for a cumulative dose distribution. The second scenario is the cumulative effect of a systematic realistic large error. The magnitude of the systematic error was derived from the largest positional error measured during metal port registration from Section 2.2. This represents a change in port position after the reference CT scan was acquired that persisted throughout the course of treatment. For this scenario, the original plan was calculated on one modified CT scan, and the dose distribution was multiplied by the number of fractions to represent a full course of treatment. The cumulative dose distribution for each scenario was compared with the originally planned dose.

2.3.2. Modelling patient registration error (PRE)

To simulate PRE for every fraction per patient, the density overrides in the reference CT for the metal port and its artefacts were performed following the same procedure described in Section 2.3.1 while keeping the position of the metal port unchanged. For a given fraction, the corrected CT was repositioned relative to the beam by the magnitude of the measured daily positional errors from Section 2.2. This was repeated for all 25 fractions per patient to simulate the cumulative dosimetric effect of the measured positional variations. To simulate the cumulative effect of a systematic PRE, the original plan was recalculated with the entire CT scan repositioned relative to the beam by the same magnitude of the systematic realistic large displacement used in Section 2.3.1. The cumulative dose distribution for each scenario was compared with the originally planned dose.

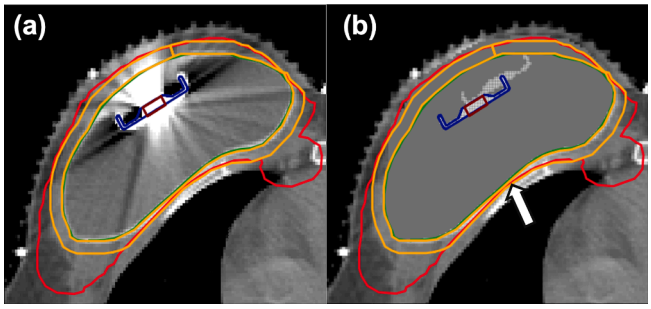

Fig. 1. Transverse view of a CT slice for a representative patient with a tissue expander before (a) and after (b) density corrections of the saline bag, the surrounding tissue, and the metal port. The maroon contour is the magnetic metal port, the blue contour is the titanium shell of the port, the green contour is the saline bag, and the red contour is the PTV. The volume bound by the two orange contours is the ROI (defined as a 5 mm expansion around the saline bag and within the PTV) that is used for the DVH calculations. Note that the ROI is purposely truncated in regions where the 5 mm expansion extends outside the PTV (see arrow)—see Section 2.4 for details. The non-contoured silhouette of the metal port and titanium shell in panel (b) represents a simulated internal port error as discussed in Section 2.3.1.

2.4. Data analysis

Local dose perturbations in the chest wall and skin can be masked if the breast Planning Target Volume (PTV) is used for the analysis because that PTV contains the large non-biological saline bag. For more meaningful dose analysis, a Region of Interest (ROI) within the PTV was defined as a 5 mm expansion around the saline bag which excluded the non-biological bag and its contents, and excluded the metal port (Fig. 1). This ROI included clinically relevant tissue that may contain microscopic disease and is most vulnerable to being affected by the presence of the metal port and its positional errors [19]. Clinically relevant Dose Volume Histogram (DVH) metrics for the newly defined ROI and the neighbouring OARs were used to compare the cumulative dose distributions of the investigated scenarios to the originally planned dose distribution. For the ROI, the percent volume that received 100% of the prescription dose ($V_{100\%Rx}$) was assessed. For the OARs, V_{20Gy} for the ipsilateral lung and V_{5Gy} for the heart were assessed. The analysis of the OARs was limited to the same slices the ROI was defined for. For testing statistical significance, the Wilcoxon rank-sum test was performed. Differences with p values less than or equal to 0.05 were considered statistically significant.

For the special patient, the dosimetric effect was evaluated for the daily measured IPE only. PRE was not modelled since positioning errors of a magnitude equivalent to the measured error for this patient are unlikely to occur.

A potential planning strategy to make treatment delivery more robust against potential port movement is to override the density of the entire tissue expander (including the metal port) with average breast tissue. The validity of this approach was investigated for all patients by comparing the resulting dose distribution against the cumulative dose distribution that accurately modeled the measured daily positional errors.

3. Results

3.1. Magnitude of measured port positional errors

The measured positional errors in all patients were generally small, with 87% of the deviations below 5 mm (Fig. 2). The maximum error measured was 17 mm. The positional error in the lateral, vertical and longitudinal directions ranged from −17 to 11 mm, −10.8 to 7.0 mm and −8.0 to 7.0 mm, respectively.

3.2. Dosimetric impact of port positional errors

From an analysis of all patients, the cumulative effect of the daily measured IPE on the ROI resulted in point dose changes as much as +1% and −2% (Fig. 3). When a systematic IPE was present, point dose changes of up to +/−3% were observed. The cumulative effect of daily measured PRE resulted in point dose changes of +/−4% in the ROI. When a systematic PRE was present, point dose changes ranged from +12% to −20% in the ROI.

From the representative DVH in Fig. 4a, the impact of the daily measured IPE on the DVH was minimal, while the impact of a systematic IPE was slightly more discernible. For PRE (Fig. 4b), the cumulative dose when a systematic error was present resulted in substantial reduction of target coverage as well as larger heterogeneity in the dose distribution within the target.

For the changes in DVH metrics for all patients (Fig. 5), the dose accumulation when daily IPE were present resulted in a mean and maximum reduction of $V_{100\%Rx}$ by <1% and 2.8%, respectively. No change was seen for V_{20Gy} of the ipsilateral lung, nor V_{5Gy} of the heart. When a systematic IPE was present, $V_{100\%Rx}$ of the ROI was decreased by a mean and maximum of 0.9% and 3.5%, respectively. A systematic IPE had minimal dosimetric effect on the dose received by the ipsilateral lung and heart.

For PRE, the dose accumulation when daily positional errors were present resulted in a mean and maximum reduction of the $V_{100\%Rx}$ by 3.5% and 21%, respectively. The V_{20Gy} of the ipsilateral lung was minimally affected while the V_{5Gy} of the heart increased up to 11% (10.0 cm^3). The presence of a systematic PRE resulted in a statistically significant ($p < 0.05$) reduction in $V_{100\%Rx}$ of the ROI with a mean and maximum values of 16% and 27%, respectively. In addition, V_{20Gy} of the ipsilateral lung increased up to 10% (25.8 cm^3) and V_{5Gy} of the heart increased up to 20% (51.4 cm^3).

For the special patient (see Section 2.1), the position of the metal port varied substantially, with a maximum displacement of 6.3 cm. In some fractions the metal port was on the same side of the breast as originally in the reference CT, while in other fractions the metal port was at the anterior side of the breast (Fig. 6a). From the cumulative dose difference map in Fig. 6b, $V100_{\%Rx}$ of the ROI was reduced by only 1.8%, while V_{20Gy} and V_{5Gy} of the ipsilateral lung and heart were minimally affected.

Completely overriding the metal port with tissue density as a potential planning strategy, as introduced in Section 2.4 resulted in a mean dose over-estimate of 6% to $V_{100\%Rx}$ of the ROI, with the largest increase being 10%, while no discernible changes were seen for the OARs (Figs. 4a and 5a). This indicates that ignoring the density of the metal

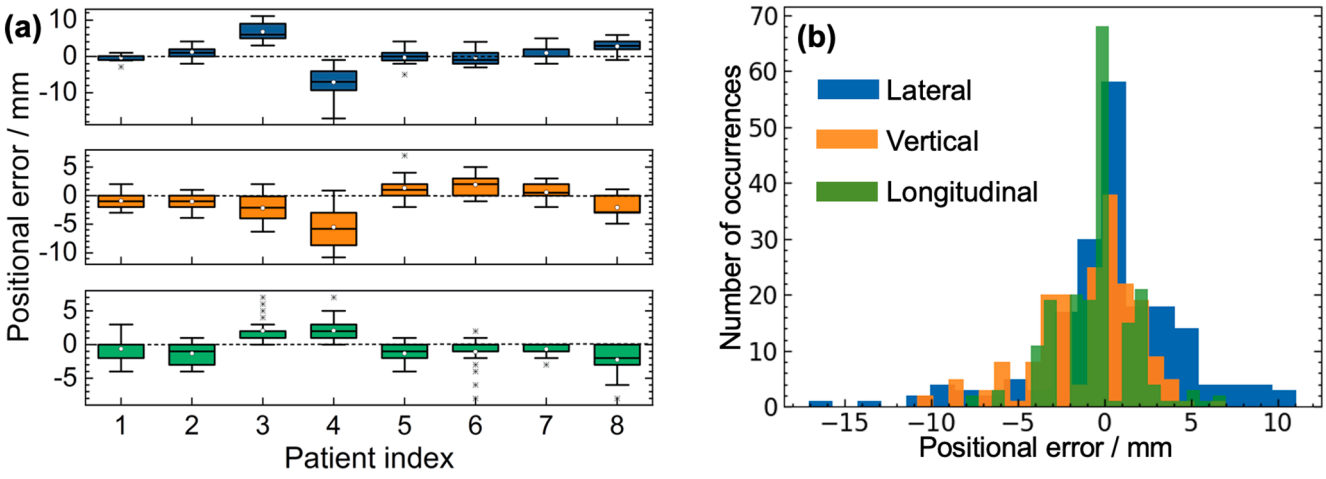

Fig. 2. Distribution of inter-fractional positional errors of the metal port in the lateral (blue), vertical (orange) and longitudinal (green) directions for all fractions. (a) Box plots for all fractions per patient. (b) Histogram of all fractions for all patients (n = 193).

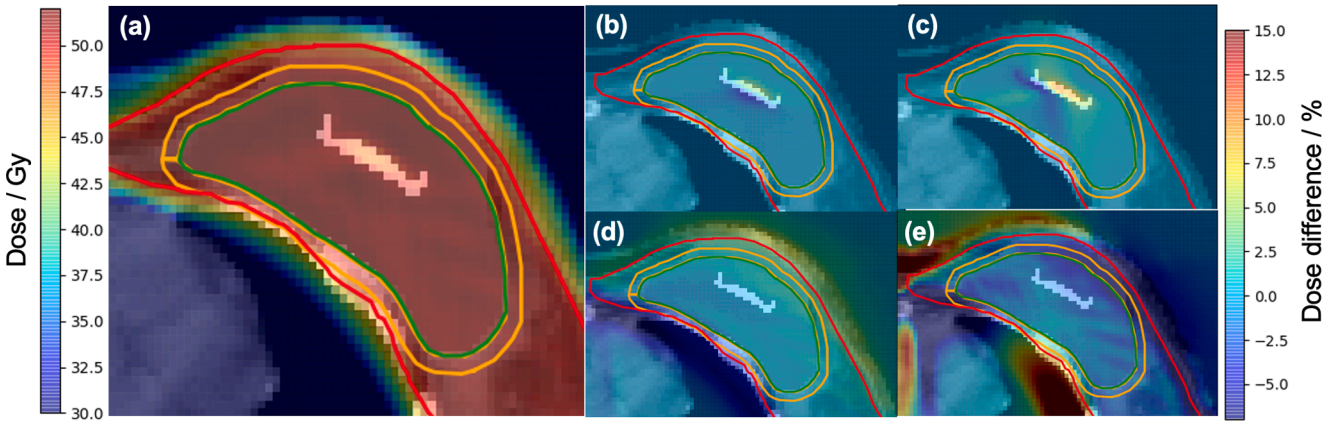

Fig. 3. Representative axial slice of a representative patient for (a) the originally-planned dose distribution for a prescribed dose of 50 Gy (scale on the left), (b to e) the percent dose difference (scale on the right) relative to the originally planned dose for (b) dose accumulation with daily measured Internal Port Errors (IPE), (c) dose accumulation with a systematic IPE, (d) dose accumulation with daily measured Patient Registration Errors (PRE), (e) dose accumulation with a systematic PRE. All percent dose differences are normalized to the prescription dose. Contours are defined as in Fig. 1.

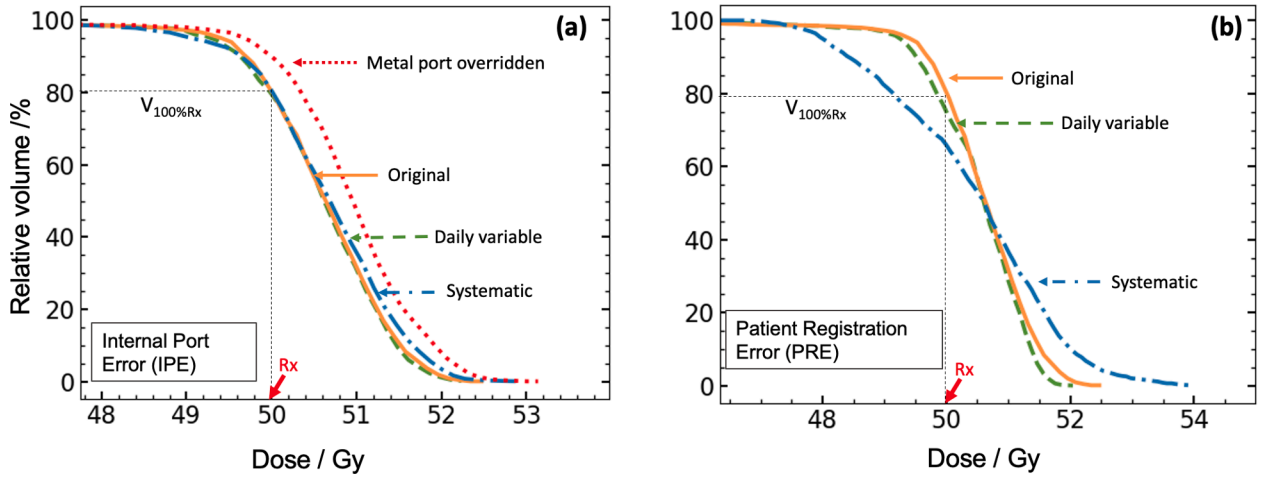

Fig. 4. DVH for the ROI (defined as a 5 mm expansion around the saline bag and within the PTV) for a prescription dose of 50 Gy for a representative patient demonstrating the cumulative dosimetric effect of (a) Internal Port Error (IPE), and (b) Patient Registration Error (PRE). Orange solid: original plan. Green dashed: cumulative dose with daily measured port errors modelled. Blue dash-dotted: cumulative dose with a systematic port displacement modelled. Red dotted: Metal port overridden with tissue density. Note that only the rightmost tail of all the DVHs is shown.

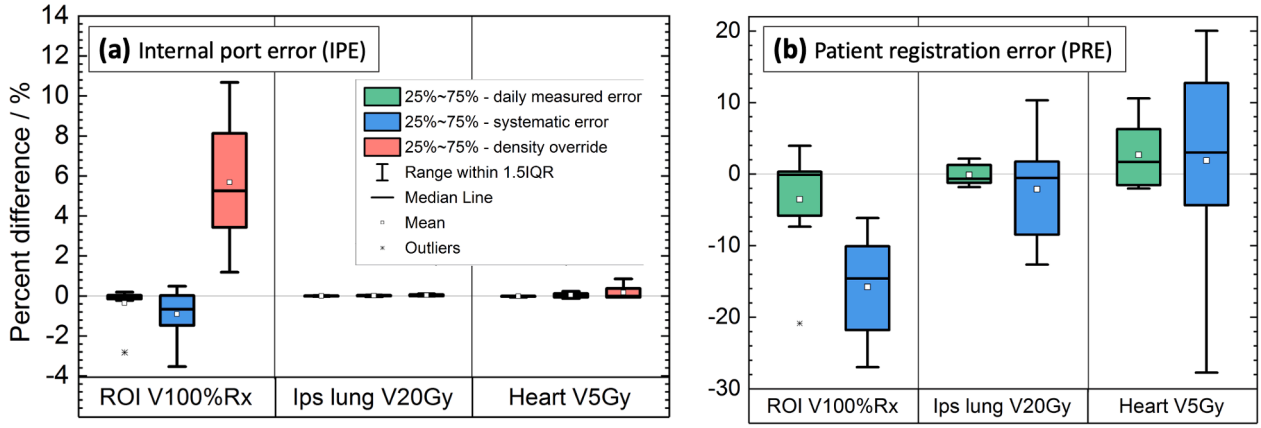

Fig. 5. The change from the original plan in $V_{100\%Rx}$ (volume receiving 100% of the prescription dose) of the ROI, V_{20Gy} (volume receiving 20 Gy) of the ipsilateral lung and V_{5Gy} (volume receiving 5 Gy) of the heart for (a) Internal Port Error (IPE) and (b) Patient Registration Error (PRE). The ROI is defined as a 5 mm expansion around the saline bag and within the PTV. Green: cumulative dose with daily measured port errors modelled. Blue: cumulative dose with a systematic port displacement modelled. Red: metal port overridden with tissue density.

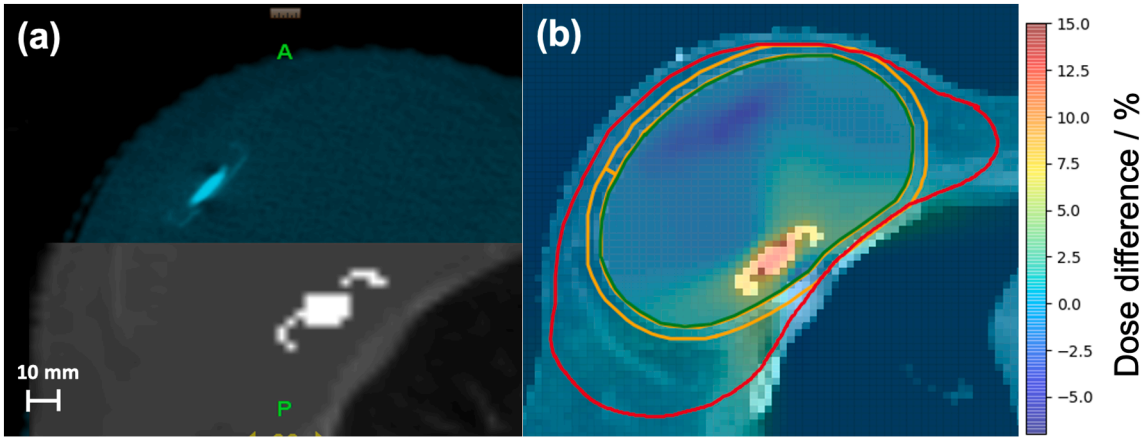

Fig. 6. Special patient with a loose tissue expander. (a) Checkered view of an MVCT image in the treatment position (in turquoise) superimposed on the reference CT image (in gray) showing the large internal displacement of the metal port for that fraction. (b) Percent dose difference (scale on the right) of the cumulative dose distribution with daily measured port displacements modelled relative to the originally planned dose. Contours are defined as in Fig. 1.

port during treatment planning can lead to a clinically significant underdosage of the ROI.

4. Discussion

In this study, the magnitude and the dosimetric effect of the inter-fractional positional variations of the metal port in tissue expanders was investigated in postmastectomy patients receiving radiation therapy. Port positional errors were found to be generally small and centred around zero, but errors larger than 1.5 cm were also observed. The cumulative dosimetric effect of patient registration errors relative to the beam had a greater impact on target coverage and relevant OARs than port positional errors relative to the internal anatomy.

The roll correction determined by the treating therapists before each treatment fraction was left unchanged when measuring the port positional errors, therefore, displacements of the metal port that resulted from roll errors were compensated for with a combination of a vertical and a lateral correction. This explains the skewed distribution of lateral positional errors observed in Fig. 2.

The changes in target coverage were found to be within clinically acceptable range when daily variable and systematic IPE were modelled [20]. On the other hand, the cumulative effect of daily variable and systematic PRE has a greater impact on target coverage and relevant OARs. The high variation in the DVH metrics of the ROI and OARs can be explained by the varying direction of the registration error relative to the radiation beam, which lead to great variability in the dose difference patterns among patients. A clinical implication of this is that in treatment delivery systems where daily image guidance is used, and the metal port is visible, overall alignment of anatomical landmarks should be prioritized at the expense of reasonable misalignment of the metal port.

Assigning the metal port a tissue-equivalent density during treatment planning was found to overestimate the dose delivered to target. Several studies found similar effects for tangential plans [8,23]. Yoon et al showed that the DVH curve of the target, which was defined in a similar manner as in this study, shifted to the right when the density of the metal port was not included in a Volumetric Modulated Arc Therapy (VMAT) plan [11]. In this study, similar effects were observed, as indicated in the DVH curve in Fig. 4a.

The recent recall of one of the main textured implants available in the market due to the increased risk of breast implant-associated anaplastic large cell lymphoma (BIA-ALCL) may potentially increase the use of smooth tissue expanders [21,22]. As migration is more of a concern with smooth expanders, the results of the special case show that internal positional variations of the metal port have no statistically significant effect on target coverage and OARs, and can be viewed as a washout effect of the large internal daily variability in the position of the port.

Several groups recognized the uncertainty associated with contouring the metal port on the reference CT during planning [7,11,23]. The metal artefacts in the reference kilovoltage CT pose a challenge in accurately locating the metal port, which can introduce a systematic error when the metal port is contoured. However, Fig. 4a suggests that contouring the metal port with some uncertainty and assigning its components the appropriate densities better represents the real course of treatment as opposed to overriding the metal port with tissue-equivalent density.

There are a few limitations to this study. While we investigated the most commonly used tissue expander, other models exist or are emerging, and were not analyzed here. Also, this study focused on helical conformal treatments, and did not directly include other methods of treatment such as tangential fields, Intensity Modulated Radiation Therapy (IMRT) and VMAT, although the results can be reasonably extrapolated to VMAT and multiple beam IMRT. The reason for not including them is that Tomotherapy is the only modality that mandates daily MVCT imaging, which was used in this study to measure the positional variations of the metal port without being masked by the metal artefacts.

In conclusion, daily positional variations of the metal port have small effects on target coverage and OARs that fall within the clinically acceptable range. The results indicate that during patient registration, therapists should *not* compromise the accuracy of matching anatomical landmarks for a better alignment of the metal port. Ignoring the metal port and overriding its density during planning is an inadequate strategy for improving the robustness of the treatment delivery. A better strategy is to contour the metal port and assign its components their appropriate densities despite the potential contouring uncertainties that result from the metal artefacts.

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Disclosures

None.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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