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Patient setup accuracy in DIBH radiotherapy of breast cancer with lymph node inclusion using surface tracking and image guidance

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ABSTRACT

Studying setup accuracy in breast cancer patients with axillary lymph node inclusion in deep inspiration breath-hold (DIBH) after patient setup with surface-guided radiotherapy (SGRT) and image-guided radiotherapy (IGRT). Breast cancer patients (N = 51) were treated (50 Gy in 25 fractions) with axillary lymph nodes within the planning target volume (PTV). Patient setup was initiated with tattoos and lasers, and further adjusted with SGRT. The DIBH guidance was based on SGRT. Orthogonal and/or tangential imaging was analyzed for residual position errors of bony landmarks, the breath-hold level (BHL), the skin outline, and the heart; and setup margins were calculated for the PTV. The calculated PTV margins were 4.3 to 6.3 and 2.8 to 4.6 mm before and after orthogonal imaging, respectively. The residual errors of the heart were 3.6 ± 2.2 mm and 2.5 ± 2.4 mm before and 3.0 ± 2.5 and 2.9 ± 2.3 mm after orthogonal imaging in the combined anterior-posterior/lateral and the cranio-caudal directions, respectively, in tangential images. The humeral head did not benefit from daily IGRT, but SGRT guided it to the correct location. We presented a slightly complicated but highly accurate workflow for DIBH treatments. The residual position errors after both SGRT and IGRT were excellent compared to previous literature. With well-planned SGRT, IGRT brings only slight improvements to systematic accuracy. However, with the calculated PTV margins and the number of outliers, imaging cannot be omitted despite SGRT, unless the PTV margins are re-evaluated.

Introduction

In the adjuvant radiotherapy of breast cancer, high doses are spread to the healthy tissue, especially to the heart and ipsilateral lung.[1] Deep inspiration breath-hold (DIBH) is commonly used to decrease the dose to the healthy lung and, in the case of left-sided treatments, to the heart. Errors in breath-hold level (BHL) during DIBH have been reported to increase the heart dose significantly for part of the patients because insufficient BHL may leave part of the heart within treatment fields.[2] Positioning errors in the anterior-posterior (AP) direction have been reported to cause the largest dosimetric effect.[3] The reproducibility of the BHL may be improved using commercial systems, such as optical tracking of a point on the chest wall with real-time position management (RPM™, Varian Medical systems, Palo Alto, USA), or spirometry-based active breathing control (ABC, Elekta, Stockholm, Sweden).

More recently, surface tracking has been developed by several companies. These include optical tracking (AlignRT®, VisionRT, London, Great Britain; Sentinel/Catalyst™ C-Rad, Uppsala, Sweden; and Identify, Varian Medical Systems, Palo Alto, USA) and thermal tracking (ExacTrac Dynamic, Brainlab AG, Munich, Germany). Instead of 1D or 3D tracking of a single point, this enables 6D tracking of a large surface. Moreover, patients can be positioned using the skin surface, possibly eliminating the need for tattoo marks.[4] The inter-fraction positioning errors are traditionally the main source of error; however, with the increasing amount of intensity modulation in modern planning, also the dosimetric effect of intra-fraction motion increases.[5] The use of surface monitoring may help radiotherapy clinics to develop their DIBH treatment workflows for both reducing inter-fraction position variability and detecting intra-fraction motion. Surface-guided radiotherapy (SGRT) for the node-negative (N0) patients is straightforward as the surface of the whole breast correlates well with the planning target volume (PTV).[6-7] However, the positioning of the node-positive (N+) and mastectomy patients is more complicated because of the inclusion of the axillary lymph node volume, turning the increased focus on the correct arm position.[8]

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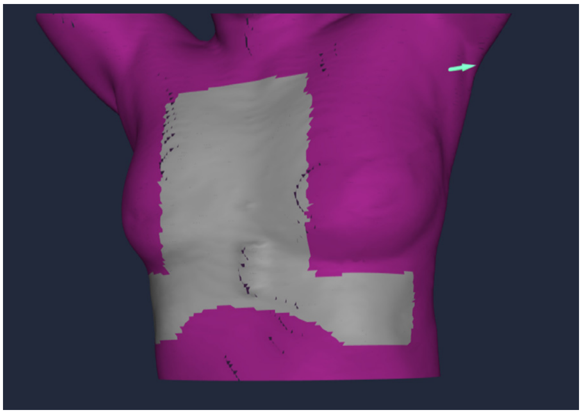

Fig. 1. The region of interest used for surface tracking reminded letter T upside-down. (Color version of figure is available online.)

In many clinics, the use of DIBH relies on the assumption that the equipment guides the patient to take reproducible breath holds. To achieve sufficient BHL, patients might alter the breathing technique, *e.g.,* by lifting their back, and especially with single-point 1D tracking, these false breath holds may not be recognized. This underscores the importance of imaging in order to assure proper sparing of the heart. However, even with a well-aligned patient position, confirmed by pre-treatment imaging, multiple breath-holds may induce positional changes during the fraction; especially in the cranio-caudal (CC) direction.[9] Furthermore, if the planned BHL is not achieved during pre-treatment imaging, or even checked, this might be ignored and image match be based on the position of the sternum. Some clinics monitor the central lung distance (CLD), *i.e.,* the distance of chest wall from the medial field border on a tangential portal image.[7,10] However, the CLD does not show the BHL completely, and it is difficult to differentiate between lateral and vertical errors using a tangential image. Furthermore, tangential images underestimate the setup errors, especially in the CC direction.[11] The heart may receive higher doses than planned if the correct BHL is not achieved.[2]

The purpose of this study was to evaluate the positioning accuracy of optical surface tracking with and without image-guided radiotherapy (IGRT) in DIBH treatment of N+ and mastectomy patients. We evaluated both bony structures and soft tissue around the PTV, and the heart position in pre-treatment images. The SGRT patient positioning was performed with AlignRT®.

Materials and Methods

This study included 51 breast cancer patients, with either mastectomy (n = 26) or with N+ conserving surgery (n = 25). All patients had adjuvant radiotherapy with axillary lymph node inclusion, with 50 Gy delivered in 25 fractions. The patients were imaged with computed tomography (CT) using Philips Brilliance Big Bore (Philips Medical Systems, Eindhoven, The Netherlands) or Toshiba Aquilion LB (Toshiba Medical System, Tokyo, Japan) scanner with 3-mm slice thickness. Patients were positioned arms above their heads with Sabella Flex Positioning System (CDR Systems, Canada) using 10° tilt, and with a round knee cushion. The DIBH technique was used for all patients with gating window tolerance of 3-mm. No surface tracking was available at the CT, but patients were guided with RPM™ (Varian Medical Systems, Palo Alto, USA) using patient monitor for visual guidance. The gating points were two dot markers on the sternum. The BHL was instructed for the patients as the highest comfortably possible.

Initial positioning

The patients were treated on a TrueBeam (Varian Medical systems, Palo Alto, USA) linear accelerator with a 4D couch, and patient monitor for BHL guidance. For the SGRT, an inverse T-shaped region of interest (ROI) was used (Fig. 1). This is suggested by the vendor in DIBH treatments because such ROI emphasizes the position of sternum and lower ribs.

The patient positioning was initiated with tattoos for straightness. The patient was then asked to inhale to the CT-based DIBH surface, and the position was confirmed with AlignRT®. The couch was moved to the SGRT-based treatment isocenter during DIBH. The couch needed to be moved during DIBH because the SGRT surface from the planning CT was acquired in DIBH. The patient was then allowed to breathe, but the inhale was repeated to check the arm position during DIBH using treatment capture, and large errors were corrected. During initial SGRT positioning, the aim for isocenter error was < 1 mm, and for rotations < 1°. For rotations this was not always achieved. The yaw could be corrected with couch rotation, but for the roll and pitch patient re-positioning or guidance on breathing technique was needed.

After IGRT, the free breathing (FB) surface in the correct position was acquired on the first fraction. This FB surface was used for the initial patient setup in future fractions so that not everything needed to be done during DIBH. However, also in future fractions, the position was verified in DIBH and the couch was moved or patient position was corrected if needed.

Verification and corrections in positioning

Even though the aim during setup was as accurate as possible, the SGRT tolerances during IGRT and treatment allowed for slightly more movement. This was to avoid constant beam-holds due to inevitable intra-fraction motion, which would lead to unacceptably long treatment times. During imaging and treatment, the SGRT tolerance for the pitch, roll, and yaw was ± 3°, tolerance for lateral and longitudinal translation was ± 4 mm, and tolerance for the BHL was ± 2 mm (4-mm gating window).

The positions used for image matching and residual position error evaluation are shown in Fig 2. The anterior-posterior (AP) kV image was matched to the mid-PTV (Fig. 2 B), with slight emphasis on the ribs. The lateral (LAT) kV image was matched to the spine to ensure the correct BHL (Fig. 2A).[12] The IGRT tolerance for the BHL (measured between Th6-7 and sternum) was ±3 and ±4 mm in the AP and CC directions, respectively, and for the isocenter ±4 mm. If the BHL tolerance was exceeded, the patient was advised to inhale above or below the tolerances to acquire a new surface with the correct BHL. If the isocenter tolerance was exceeded, the necessary couch shifts were performed during DIBH, and a new surface was acquired prior to allowing the patient to breathe again. A new lateral kV-image was acquired to verify isocenter and/or BHL corrections.

Other IGRT tolerances were 10 mm for patient yaw rotation (measured between Th1 and Th10) and 8 mm for the humeral head. The AP and LAT images were acquired on the three first fractions and after this at least weekly. Each day at least a tangential image was acquired, (Fig. 2 C) with tolerances of 5 mm in the CC direction, and 4 mm in the combined LAT and AP direction. After the three first fractions, the vertical position of the couch was acquired as the average of the 3 first fractions to have a better starting point for IGRT. The CT-based SGRT surface was preferred, but if systematic errors occurred, a new surface (FB and/or DIBH) was created.

Image evaluation

The cases were evaluated retrospectively in Offline Review (Varian Medical systems, Palo Alto, USA). The isocenter corrections were recorded from the online-match-based couch movements stored in Offline Review. The patient overall posture was measured in the AP-LAT kV-images. The yaw and pitch were measured as match error between Th1 and Th10. The BHL was measured between Th6-7 and sternum in the AP and CC directions. The position error of humeral head was measured relative to Th1. The residual position errors were measured in Th1, sternum, humeral head, and ribs. These residual position errors were calculated both before and after the isocenter corrections based on retrospective analysis of the couch movements to evaluate the need for IGRT if SGRT is used. Furthermore, in tangential kV-images, the residual position errors were measured for the ribs, soft tissue, the vertebrae, the humeral head, and the heart. The results from tangential images are shown separately for fractions when kV-kV images with isocenter corrections were or were not acquired prior to tangential images.

The position accuracy was compared before and after the couch movements to evaluate the impact of IGRT. The equality of variances between these situations was tested with Levene's f-test. Based on the normality of the data given by the Kruskal-Wallis test, the equality of means was compared with the paired t-test or Wilcoxon test. The PTV margins for planning were calculated using the van Herk's formula $(2.5\Sigma + 0.7\sigma)$ where Σ denoted the systematic error and σ the random error, both expressed as one standard deviation.[13]

Results

Overall position

The patient overall position after SGRT based on kV-kV imaging is presented in Table 1. The systematic isocenter corrections and rotational errors were at sub-millimeter level, but included slightly larger random corrections. In the AP, CC, and LAT directions 3%, 13%, and 14%, respectively, of all fractions exceeded 3-mm isocenter error. The respective 5 mm exceedings were 0.3%, 3.0%, and 2.3%. The systematic and random BHL errors and residual position errors of the humeral head were mainly below 2 mm (Table 1). In the AP and CC directions, respectively 17% and 20% exceeded 3 mm and 3.2% and 6.7% exceeded 5 mm BHL error. Rotational errors, measured as the difference between th1 and th10, were exceeding 5 mm in

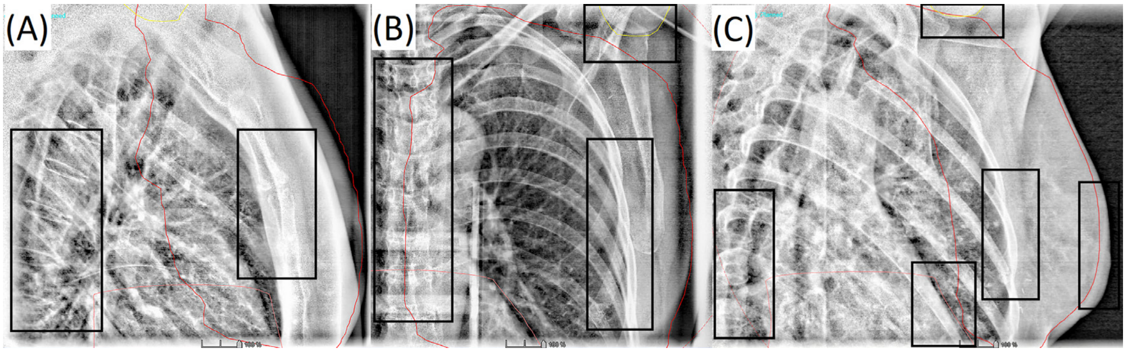

Fig. 2. The positions for matching and evaluation of residual position errors are marked in the kV images. These include the vertebrae and sternum in the lateral image (A), the vertebrae, sternum, ribs and humeral head in the anterior-posterior image (B), and ribs, soft tissue, vertebrae, humeral head and heart in the tangential image (C). (Color version of figure is available online.)

Table 1
Patient position as systematic and random errors ($\Sigma \pm \sigma$) in mm after SGRT, based on orthogonal kV imaging.

Position errors		N+	Mastectomy
Isocenter	AP	0.1 ± 0.7	0.5 ± 0.8
	CC	0.8 ± 1.7	0.7 ± 1.5
	Lat	0.7 ± 1.7	1.0 ± 1.6
Rotation Th1-Th8	AP	0.7 ± 1.1	0.7 ± 1.0
	Lat	1.0 ± 1.4	1.0 ± 1.2
BHL	AP	1.6 ± 1.7	1.1 ± 1.6
	CC	1.0 ± 2.0	1.4 ± 2.0
Th1-humeral head	CC	1.1 ± 2.5	1.8 ± 2.0
	Lat	1.9 ± 2.1	1.5 ± 1.5

0.5% of fractions in the AP (pitch) and LAT directions. The residual position error of humeral head in comparison to th1 exceeded 5 mm in 6.9% and 7.1% of fractions in the CC and LAT directions respectively.

Residual position errors

The residual position errors of the ribs, breast/chest-wall outline, spine, sternum, humeral head, and heart are shown in Table 2, both with and without the IGRT-based isocenter correction. In the kV-kV images, the isocenter correction resulted in statistically significant ($p < 0.01$) decrease of both systematic and random errors on CC and LAT directions for the ribs and th1. Considering th1 as surrogate marker for the axillary lymph nodes, in all fractions 5-mm isocenter error was exceeded in 5.5%, 10.4%, and 6.4% prior to IGRT, and 3.5%, 2.2%, and 1.2% after IGRT, in the AP, CC, and LAT directions, respectively.

In the tangential kV images, statistically significant improvement was seen in the random error of the CC and AP/LAT directions in the ribs and spine, and in the CC direction of the breast outline, when the kV-kV images had been acquired prior to the tangential images. For the vertebrae, small but statistically significant improvement was observed in the AP/LAT direction also in the systematic error. The residual position error of the ribs appeared smaller in tangential images compared to the kV-kV images. The percentage of fractions exceeding 3 mm residual position error in ribs in tangential images reduced from 15.3% and 13.1% to 5.7% and 3.6%, and those exceeding 5 mm from 1.3% and 1.3% to 0.0% and 0.7% in AP/LAT and CC directions, respectively. The heart was difficult to match in the kV images, and no difference was found before and after kV imaging. However, the random error in the CC direction was smaller in mastectomy patients than in N+ patients ($p < 0.05$).

PTV margins

The calculated PTV margins are shown in Table 3. The margins for the PTV (min-max) decreased with daily kV-kV imaging from 4.3-6.2 mm to 2.8-4.6 mm based on the bony anatomy in the kV-kV images, and from 6.0-7.6 mm to 3.7-6.3 mm based on the soft tissue in tangential images.

Discussion

This study investigated breast cancer patients with lymph node inclusion treated with radiotherapy in DIBH with the guidance of both SGRT and IGRT. Time and effort was spent on the first fractions for finding a good SGRT reference surface in order to minimize the need for isocenter corrections in future fractions. This resulted in a low percentage of fractions exceeding 5 mm isocenter discrepancy between SGRT and IGRT; however, 3-mm exceedings were above 10% in the CC and LAT directions. The isocenter corrections were omitted in the AP direction if the images were within tolerances. This was due to the complexity of isocenter shifts and BHL corrections which required first couch movements during DIBH or breath-hold outside the BHL window, then a new SGRT surface, and lastly new kV-images for confirmation. This workflow led to rare need for isocenter corrections after SGRT, especially in the AP direction. Previous studies have shown 0.6 to 6 mm systematic and 2 to 4.9 mm random 3D isocenter corrections.[14-19] If our couch shifts are calculated into 3D, they result in 1.2 ± 2.4 mm. However, these are not directly comparable, because

Table 2
Residual position errors as systematic and random errors ($\Sigma \pm \sigma$) in mm, based on orthogonal and tangential kV imaging. The errors are presented for the overall position and for specific bony landmarks

Residual errors (kV-kV)		Before kV-kV	After kV-kV
Th1‡	AP	1.5 ± 1.6	1.4 ± 1.5
	CC	1.5* ± 2.3†	1.0 ± 1.6
	Lat	1.7* ± 2.3†	1.2 ± 1.5
Sternum‡	AP	1.4 ± 1.7	1.3 ± 1.6
	CC	1.5 ± 2.4	1.2 ± 1.9
Ribs AP‡	CC	1.4* ± 2.4†	1.0 ± 1.8
	Lat	1.4* ± 2.2†	0.7 ± 1.3
Residual errors (Tangential kV)		Without kV-kV	With kV-kV
Ribs‡	AP/Lat	1.1 ± 1.5†	0.9 ± 1.3
	CC	0.9 ± 1.7†	0.8 ± 1.1
Spine‡	AP/Lat	1.6* ± 1.7†	1.2 ± 1.4
	CC	1.4 ± 2.0†	1.3 ± 1.7
Soft tissue (mastectomy)	AP/Lat	2.0 ± 1.5	1.3 ± 1.6
	CC	2.0 ± 1.8†	1.1 ± 1.2
Breast tissue (N+)	AP/Lat	2.4 ± 1.9	1.9 ± 2.0
	CC	2.5 ± 2.0†	1.9 ± 1.5
Humeral head‡	AP/Lat	2.5 ± 2.1	2.2 ± 1.9
	CC	2.2 ± 2.3	1.9 ± 2.2
Heart‡	AP/Lat	3.6 ± 2.2	3.0 ± 2.5
	CC	2.5 ± 2.4	2.9 ± 2.3
Heart (mastectomy)	AP/Lat	2.9 ± 2.0	2.7 ± 2.2
	CC	1.6 ± 2.0	1.4 ± 1.7
Heart (N+)	AP/Lat	4.1 ± 2.4	3.3 ± 2.7
	CC	3.2 ± 2.7	3.8 ± 2.8

Statistical difference ($p < 0.01$) between before and after kV-kV imaging in
* systematic residual errors
† random residual errors
‡ N+ and mastectomy combined

Table 3
PTV margins in mm based on landmarks close to the PTV. In the kV-kV imaging the margins are calculated before and after IGRT-based couch movements. In tangential imaging the margins are calculated on fractions without and with orthogonal imaging.

			Mastectomy Before kV-kV	Before kV-kV	Mastectomy After kV-kV	After kV-kV
kV-kV imaging	**PTV** (sternum)	AP	4.5	4.5	4.0	4.4
	PTV (sternum/ribs)	CC	4.6	5.4	3.4	3.2
	PTV (ribs)	Lat	5.1	4.7	2.8	2.8
	PTV (Th1, axillary)	AP	5.4	4.3	4.6	4.2
		CC	5.4	5.3	3.9	3.3
		Lat	6.2	5.6	4.3	3.6
			Without kV-kV		With kV-kV	
Tangential imaging	**PTV** (ribs)	AP/Lat	2.9	3.4	2.4	3.2
		CC	1.8	3.7	3.2	2.7
	PTV (soft tissue)	AP/Lat	6.0	7.3	4.6	6.3
		CC	6.3	7.6	3.6	5.9

minor isocenter errors have been neglected, thus slightly underestimating the result. Nevertheless, as our shifts are in the lower end of the range, even with all couch shift corrections they would not exceed the range in previous literature, because only the smallest errors would be added.

With laser setup, the lateral displacement between upper and lower vertebra has been 2.2 ± 1.9 mm (LAT) and 1.4 ± 1.4 mm (AP).[20] In another study, 50% of rotations have been less than 2°.[21] As approximation between th1 and th10 in this study, the displacement for 2° rotation would be 7 mm over 20 cm distance. With the use of SGRT, yaw of 2.0 ± 2.2 mm (AlignRT®) and 1.6 ± 1.6 mm (Catalyst™) have been shown previously for DIBH of the breast excluding the axillary area.[12] The results of the current study (Table 1) are thus showing further reductions in rotational errors with the use of SGRT.

The BHL in the AP direction in this study (1.4 ± 1.6 mm) was comparable with a previous study with AlignRT® (1.4 ± 2.0 mm)[12]. In the CC direction the accuracy has improved in the current study (1.2 ± 2.0 mm) compared to an earlier SGRT study with only N0 patients (2.5 ± 3.2 mm).[12] This improvement may be explained with the increased user experience with the workflow rather than the inclusion of the supraclavicular lymph nodes. However, there were still fractions exceeding 3 mm and 5 mm BHL errors, and these were not clearly connected to errors in the pitch of the vertebrae. Compared to earlier studies without SGRT, similar systematic and random BHL errors have been reported with 1.4 to 1.7 ± 1.4 mm in the AP direction, and a mean error of 1.4 mm in the CC direction.[2,22]

The cranial part of the PTV was evaluated with th1 and humeral head. In the literature, th1 has been considered surrogate marker for the lymph node volume, and with laser setup, 1.7 to 2.2 ± 1.3-2.3 mm accuracy has been achieved in the CC and lateral directions.[2] Our results were comparable with SGRT only. With the addition of IGRT, the accuracy of th1 improved, especially when considering the decrease in the percentage of fractions exceeding residual position error of 5 mm. For the humeral head, the CC direction improved to 1.5 ± 2.3 mm compared to previous 3.3 ± 3.5 mm.[12] This may be explained by the increased attention to the humeral head in the current study where the axillary lymph nodes are included in the treatment fields. The random errors of the humeral head were moderate, indicating that finding a good arm position during the first fractions affords with reproducibility during the treatment course. The humeral head was the only anatomy that did not gain improvements in the kV-kV images after orthogonal imaging. The initial displacement of the humeral head is random between fractions, possibly varying towards or away from the direction of isocenter correction.

In tangential images, systematic and random errors of 0.8 to 3.0 mm and 1.2 to 2.0 mm, respectively, have been shown on the chest wall after SGRT setup in the combined AP-LAT direction.[12,23-24] With no SGRT, 3 ± 2.6 mm[25] errors have been shown. The results in the current study are similar to previous SGRT studies. Compared to orthogonal images where the systematic LAT error of the ribs was halved by imaging, the tangential images did not show this. Also, the impact of kV-kV isocenter corrections on the required PTV margins was smaller in the tangential images than on the orthogonal images, implying that tangential images underestimate the errors in the AP-LAT direction. In the CC direction, fewer data exist, but systematic and random errors of 0.6 to 2.0 mm and 0.7 to 1.1 mm, respectively, have been reported.[12,24] The tangential imaging seems to underestimate the error also in the CC direction compared to orthogonal imaging, as shown previously by Topolnjak *et al.*,[11] and therefore orthogonal imaging should not be omitted.

The largest daily differences in soft tissue deformation of 5 mm (range 2 to 33 mm)[26] and 2.4 ± 2.1 mm[27] have been reported in previous literature. The breast deformation requires attention when treated with VMAT, because the skin flash, *i.e.,* margin for PTV swelling outside the body contour, needs to be specifically designed in the plan. Both authors suggest an 8-mm skin flash.[26-27] This seems sufficient based our results of residual position errors of the skin and the PTV margins.

For the PTV margins, previous literature shows 5 to 9 mm margins with SGRT prior to IGRT,[28-29] slightly larger than those in this study(4.5 to 5.4 mm). In this study, residual position errors of bony landmarks in kV-kV imaging were selected for PTV margin calculation because the isocenter corrections were not always shifted with the couch. The residual position error of the Th1 was considered to present the error of the axillary lymph nodes. This was not as accurate as a CBCT analysis would be, and should therefore be considered with caution, but showed a considerable reduction of PTV margins up to 2 mm at fractions with orthogonal imaging compared to those with only tangential imaging.

The heart position was analyzed in tangential images where it is difficult to accurately match the heart position. Earlier studies have shown OAR margins of 3 mm in with Catalyst™ and 7 mm with AlignRT® for the heart in the tangential images.[12] In the current study, the residual errors of the heart were reduced in the AP/Lat direction after kV-kV imaging, but the reduction was not statistically significant. In the CC direction, the residual errors were inconclusive, and proper analysis of the error would require CBCT imaging. The residual errors of the heart were slightly smaller in mastectomy patients than in the N+ patients. There are possibly fewer discrepancies between the bony structures and the SGRT-guidance in mastectomy patients than in N+ patients. In the N+ patients, the soft tissue affects the SGRT surface despite the upside-down T-shaped ROI. The isocenter correction may occur either towards or away from the heart, which may explain why the heart did not benefit from isocenter corrections on average over the fractions. However, the correct position does affect the heart. An earlier study with sternal BHL marker has shown that reducing the BHL error in the AP direction from 2.9 ± 4.1 mm to 1.9 ± 2.7 mm reduced the mean dose of the heart from 2.9 Gy to 2.3 Gy, with a simultaneous reduction in other residual position errors[2] (Skyttä).

The setup errors and PTV margins seen in this study are based on the tolerances set on SGRT and IGRT. The aim during initial setup was to achieve the best possible patient setup, < 1 mm and $< 1°$ when possible with the current patient. However, larger tolerances during IGRT and treatment were forced due to time constraints. With strict tolerances, patient treatment would last unacceptably long due to frequent beam-holds. The larger tolerances used during treatment were used already during IGRT, and therefore, in principle the same intra-fraction motion should be included in the setup images. During the treatment session there is, however, the possibility that some patients get tired, and this might lead to larger deviation from the zero position during the last treatment beam than during the first beam or IGRT.[9] Verifying this difference would require further imaging at the end of each treatment session.

Conclusions

The DIBH workflow with AlignRT® for the breast or chest wall with axillary lymph node inclusion required additional attention to finding an optimal reference surface for each individual patient. The isocenter- and breath hold level corrections required couch shifts during breath hold; or couch shift in free breathing after which the breath hold was performed above or below the previous reference surface to collect a new surface. This induced difficulties in the learning curve of new radiotherapists. Therefore, small isocenter errors were omitted even if they would have been corrected with a simpler workflow. However, the workflow provided trustworthy SGRT surfaces. Indeed, we showed good reproducibility in both BHL and other residual errors compared to previous literature. After SGRT setup, the outliers exceeding 3- or 5-mm errors were further reduced after orthogonal imaging. This reduction was also seen in the tangential images between fractions with or without orthogonal images, emphasizing the importance of orthogonal imaging in DIBH treatments.

Conflict of Interest

The authors declare no conflicts of interest.

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