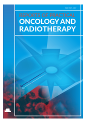

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RESEARCH PAPER

Surface-guided radiotherapy systems in locoregional deep inspiration breath hold radiotherapy for breast cancer — a multicenter study on the setup accuracy

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ABSTRACT

Background: Daily image-guided radiotherapy (IGRT) and deep inspiration breath hold (DIBH) technique are recommended for locoregional RT of breast cancer. The optimal workflow for a combination of surface-guided RT (SGRT) with DIBH technique is of current clinical interest.

Materials and methods: The setup accuracy at three hospitals was evaluated using different SGRT workflows. A total of 150 patients (2269 image pairs) were analyzed in three groups: patient setup with the AlignRT® SGRT system in Tampere (Site 1, n = 50), the Catalyst™ SGRT system in Turku (Site 2, n = 50) and the Catalyst™ SGRT system in Jönköping (Site 3, n = 50). Each site used their routine workflow with SGRT-based setup and IGRT positioning. Residual errors of the bony chest wall, thoracic vertebra (Th 1) and humeral head were evaluated using IGRT images.

Results: Systematic residual errors in the cranio-caudal (CC) direction and in pitch were generally larger at Site 2 than those at Sites 1 and 3 ($p = 0.01–0.7$). With daily IGRT, only a small difference ($p = 0.01–0.9$) was observed in residual random errors of bony structures in other directions between sites.

Conclusion: The introduction of SGRT and the use of daily IGRT lead to small residual errors when combining the best workflow practices from different hospitals. Our multicenter evaluation led to improved workflow by tightening the SGRT tolerances on Site 2 and fixation modification. Because of mainly small random errors, systematic posture errors in the images need to be corrected after posture correction with new setup surfaces. We recommend tight SGRT tolerances, good fixation and correction of systematic errors.

Key words: breast cancer; locoregional radiotherapy; surface-guided radiotherapy; patient positioning; deep inspiration breath hold

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Introduction

Postoperative radiotherapy (RT) after breast-conserving surgery or mastectomy reduces the risk of ipsilateral breast cancer recurrence and reduces breast cancer-specific mortality [1]. Breast irradiation may, however, lead to late radiation-induced cardiac effects [2]. Deep inspiration breath hold (DIBH) technique increases the volume of the lungs and moves the heart further away from the chest wall [3]. The radiation dose to the heart and lung is reduced, and DIBH is therefore recommended for RT of left-sided breast cancer patients [4, 5]. Irradiation of locoregional lymph nodes usually increases the heart and lung dose, and the use of DIBH is preferred [6–8]. Recently, surface-guided RT (SGRT) is becoming the standard of care for patient positioning in DIBH [9–12].

The advantage of SGRT in DIBH is that it monitors thousands of points on the patient's skin. With SGRT, chest location, posture and movement are monitored in six dimensions (6D) during treatment in both free breathing (FB) and DIBH. SGRT can help detecting 6D intrafractional errors and false breathing patterns. SGRT for whole breast patients is straightforward because the breast surface correlates well with the planning target volume (PTV) [13, 14]. RT of locoregional breast cancer patients is, however, more complicated because the location of the lymph node regions cannot always be accurately predicted on the patient's surface. The position of the arm also affects the accuracy of the lymph node dose [15].

Breath hold level (BHL) errors during DIBH have been reported to significantly increase cardiac dose in some patients [16]. Tangential imaging and central lung distance are not sufficient estimators of lung filling, and a lateral planar image or cone-beam computed tomography (CBCT) is required for BHL evaluation [17, 18]. BHL control with Varian's Real-time Position Management (RPM™) or respiratory gating for scanners (RGSC) system improves repeatability and is easy to use, but only controls chest movement in the anterior-posterior (AP) direction. The use of SGRT improves reliability with 6D monitoring of the whole chest. In phantom studies, submillimeter accuracy is achieved with the two common SGRT systems used in this study (AlignRT and Catalyst) [19, 20].

In SGRT, the user can choose whether to use an optical body surface from Sentinel (C-Rad) or structure from a computed tomography (CT) structure set, all recorded during planning; or an optical surface acquired using Catalyst or AlignRT, recorded during a treatment course. These reference surfaces can occasionally lead to systematic errors due to e.g. tissue swelling after CT or wrong position of the arm during surface capture. Systematic posture accuracy can be improved by acquiring a new optical reference surface after image-guided radiotherapy (IGRT) based corrections.

Numerous variables can affect the accuracy of DIBH treatment: the amount of operator experience, DIBH patient selection and guidance, inspiratory level selection, fixation devices, SGRT tolerances, SGRT software, and IGRT workflow.

The aim of this multicenter study was to evaluate the setup accuracy of locoregional breast cancer patients treated with DIBH at three hospitals using different SGRT and daily IGRT workflows. Residual setup errors in the isocenter and patient posture were measured using orthogonal and tangential kilovoltage (kV) images that were acquired after SGRT setup.

Materials and methods

Patient selection, CT acquisition and treatment planning

The study consisted of 150 randomly selected breast cancer patients treated with adjuvant DIBH-RT, including regional nodes: 75 patients with whole breast + lymph nodes (WBLN) and 75 patients after mastectomy (M). The ethical committee of each hospital granted permission for retrospective image analysis. 50 patients [mean patient age 59 years, n(WBLN) = 25, n(M) = 25] were treated at Site 1 (Tampere, Finland) using AlignRT® (version 5.1, Vision RT Ltd., London, UK), 50 patients [mean age 60, n(WBLN) = 25, n(M) = 25] at Site 2 (Turku, Finland) using Catalyst HD™ (version 5.3, C-RAD AB, Uppsala, Sweden) and 50 patients [mean age 59, n(WBLN) = 25, n(M) = 25] at Site 3 (Jönköping, Sweden) using Catalyst HD™ (version 5.3).

At Site 1, an indexed SaBella Flex™ (CDR Systems Inc., Calgary, AB, Canada) positioning system with a 10° tilt was used to immobilize the patient. At Site 2, the WingSTEP™ (Elekta AB, Stockholm, Sweden) was used without tilting together with the Civco kneefix (CIVCO Medical Solutions, Coralville, IA, USA). At Site 3, the WingSTEP™ device was used with a soft wedge and feet on the Elekta Prostep to immobilize the patient. The immobilization devices are shown in supplementary material.

Treatment planning was performed by CT using Philips Brilliance Big Bore (Philips Medical Systems BV, Eindhoven, The Netherlands) (Site 1) or Toshiba Aquilion LB (Toshiba Medical System Corp., Tokyo, Japan) (Site 1, 2, 3) scanners. Slice thickness was 3 mm at Sites 1 and 3 and 2 mm at Site 2. At Site 1, patients were visually guided for DIBH with RPM™ (Varian Medical Systems Inc., Palo Alto, CA, USA) on CT, with RPM box placed onto the xiphoid process of the sternum. At Sites 2 and 3, patients were monitored for DIBH with a C-RAD Sentinel™ optical surface monitoring system and wireless goggles for visual respiratory guidance. The gating point at the CT was a virtual point on the surface acquired by the Sentinel over the xiphoid process at Sites 2 and 3. The FB setup surface was recorded on Sentinel (Sites 2 and 3) and used for daily setup (Site 2). At Sites 1 and 2, the BHL was as deep as comfortably possible. At Site 3, up to 80% maximum breathing level was used for DIBH. The following workflow was used at all sites: a 3 mm BHL window was used. The BH was trained shortly before the CT scan. FB scans were not acquired. Body contours were automatically created in Eclipse (Varian Medical Systems Finland Oy, Helsinki, Finland) treatment planning system using Hounsfield unit values above -350 to detect body contours. Patients were treated with TrueBeam (Varian Medical Systems Inc., Palo Alto, CA, USA) linear accelerators using the field-in-field or volumetric modulated arc therapy (VMAT) technique with 5–12 fields or 4–5 partial arcs to 40.05 or 50 Gy in 15 or 25 fractions, respectively. The clinical target volume (CTV) — PTV margins during the study were 5 mm (Sites 1 and 3) and 7 mm (Site 2).

Setup protocols

All sites defined SGRT protocols at least one year earlier, and the radiotherapy technologists were experienced in SGRT at the time of data collection. The setup protocol of Site 1 has been described earlier in [21]. During the first fractions, FB setup surfaces were captured with optimal overall accuracy with SGRT cameras after kV/kV images (Sites 1 and 3). Additionally, at Site 1, a DIBH setup surface was acquired at the linear accelerator if necessary to bypass the DIBH surface from the CT. Site 2 used Sentinel FB surface for daily setup. If necessary, BHL was corrected by asking the patient to breath in more or less air and by taking a new BH surface at Site 1, or by raising or lowering the BHL window at Sites 2 and 3. In contrast to the other sites, at Site 1, new reference surfaces were acquired if necessary to eliminate systematic errors in the images also during the treatment course, with a 3 mm action level for the isocenter and with the action levels of the IGRT protocol section below (2.5).

Setup process

Patients were positioned with the FB optical reference surface. In FB, the SGRT setup tolerance was 1 mm for translational directions, 1° (Site 1 and 3) or 2° (Site 2) for roll/rot, and 2° for pitch. After manual correction of rotations, the translational position of the patient was automatically corrected by shifting the couch in the anterior-posterior (AP), cranio-caudal (CC) and lateral (LAT) directions according to the SGRT system. However, at Site 1, the couch vertical (VRT) was not moved from the vertebrae-matched couch value from earlier fractions; and the VRT delta of the FB surface was aimed to keep at ±1.5 mm threshold with patient guidance. At Sites 2 and 3, rotations suggested by Catalyst were ignored if the patient surface was within tolerances. The tolerance for the maximum error on the entire surface was 8–12 mm at Site 2 and 8 mm at Site 3.

Visual patient breathing guidance was used in all groups with a 3 mm BHL window. After the FB setup, Site 1 used the previously selected BH surface. When the patient reached the BHL window, the move couch function of AlignRT was used again to correct small isocenter errors (CC, LAT). If the delta values exceeded 4 mm or 1° at this stage, the FB setup was repeated, or the patient was given BH guidance. At Sites 2 and 3, the patient was asked to take a deep breath within the BHL window before the start of each treatment fraction and a new BH surface was automatically created with the Catalyst™. This surface served as the BHL reference for the imaging for that specific treatment fraction. The SGRT regions of interest (ROIs) are shown in Figure 1.

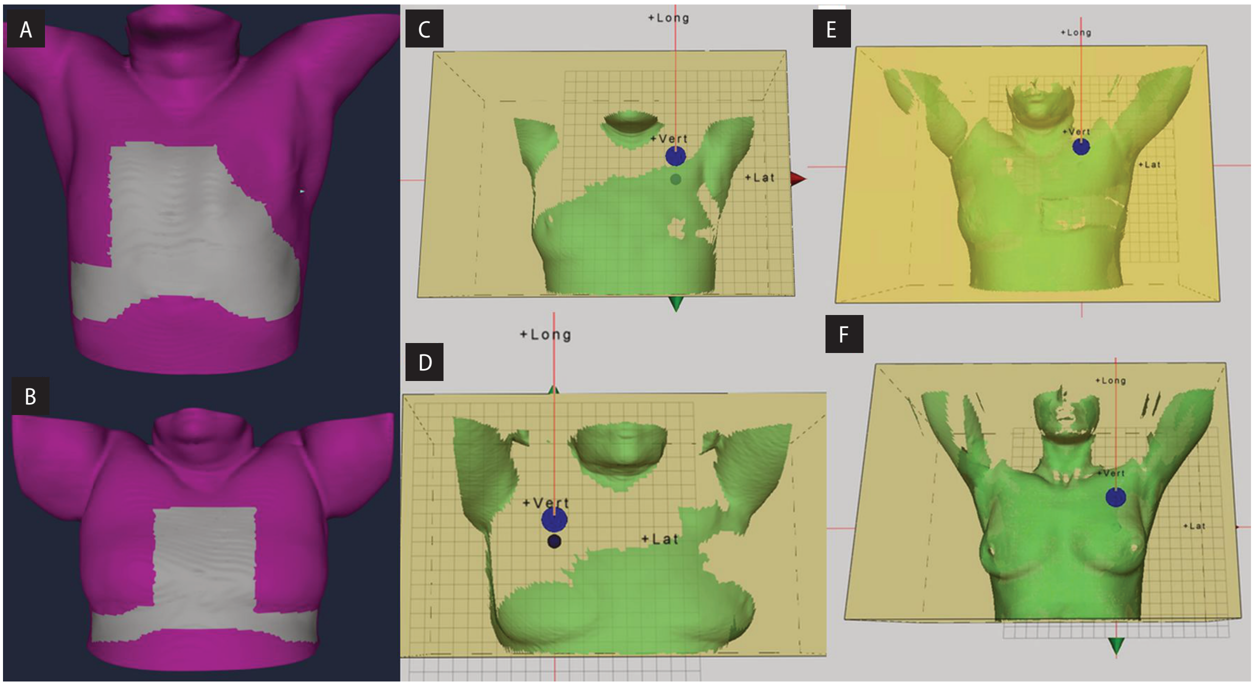

Figure 1. In Site 1 two different regions of interest (ROIs) were used: **A.** for chest wall for mastectomy; **B.** for whole breast and lymph nodes. The corresponding ROIs for site 2 are showed in figure **C**) and **D**) and in figure **E**) and **F**) for site 3

Arm positioning

At Site 1, the arm position was based on an AlignRT snapshot of the patient's posture (treatment capture) compared to setup surface. At Site 2, the arm position was verified with the Sentinel reference surface taken on CT and at Site 3 with the FB surface taken from the first treatment fractions, both sites in live view.

IGRT protocol

Verification kV image pairs [Site 1: n(M) = 265, n(WBLN) = 273, Site 2: n(M) = 625, n(WBLN) = 564, Site 3: n(M) = 250, n(WBLN) = 250] were acquired with a TrueBeam linear accelerator. In the online match, translational and rotational corrections of the isocenter were based on orthogonal setup images; sternum (AP), ribs (LAT) and sternum-ribs compromise (CC). Accuracy of 1° (Site 1, 3) and 2° (Site 2) for yaw (thoracic vertebrae Th 1–Th 8/10), 3 mm (Site 1) and 5 mm (Sites 2 and 3) for BHL in the AP-direction (vertebral-to-sternal distance) were accepted in the images for the use of future reference surfaces (Site 1) or BHL windows (Sites 2 and 3). Additionally, action level values of 5 mm (Site 1 and 3) and 7 mm (Site 2) in the CC and LAT directions were used for residual errors at Th 1. In the humeral head, the action level was 7 mm in the CC and LAT directions (all the sites). At Site 1 with AlignRT, where the couch VRT value was fixed to the vertebral match during the first fractions, only VRT errors ≥ 3 mm were corrected in the online match. At Site 3, where a 6D couch was available, pitch correction was performed with an aimed accuracy of 1°. Either a tangential kV image (Site 1, 2) or a tangential megavoltage image (Site 3) was acquired during the first three or four fractions and additionally at Site 1 at least weekly thereafter [Site 1: n(M) = 241, n(WBLN) = 234, Site 2: n(M) = 101, n(WBLN) = 114, Site 3: n(M) = 86, n(WBLN) = 84]. At Site 2, a 1 cm action level was used for breast contour for further evaluation. At Sites 1 and 3, the breast had to be within the treatment field, but at Site 1, an 8 mm action level was used for VMAT.

Treatment time

The patients were normally scheduled for 30-min (Sites 1, 2) or 40-min (Site 3) slots for the first fraction, and 20-min (Site 1, 3) or 15-min (Site 2) slots for the following fractions. This included setup, imaging and treatment.

Offline image analysis

The orthogonal (n = 2227) and tangential images (n = 860) were matched retrospectively, by ML

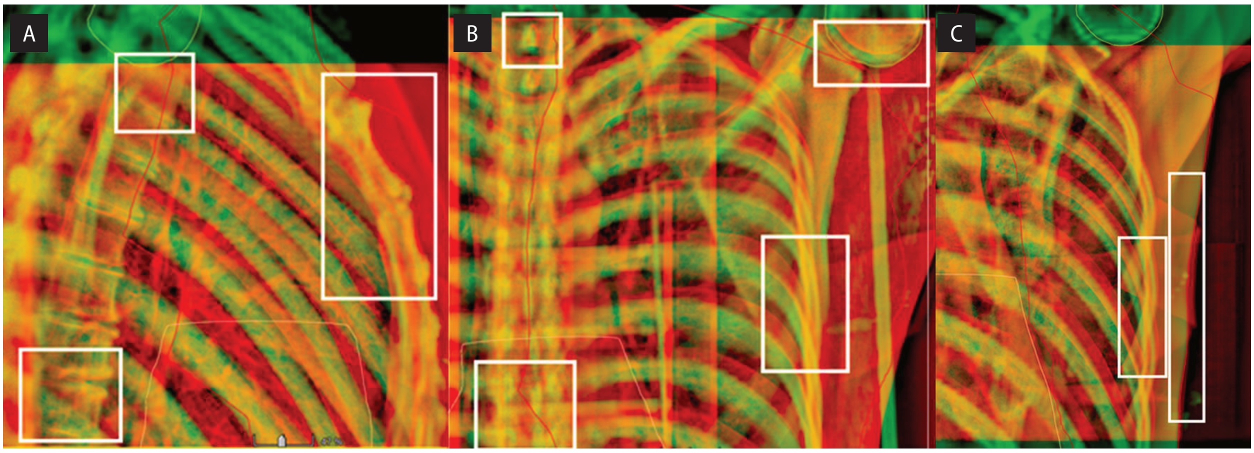

Figure 2. Evaluated landmarks were Th 1 and Th 8/10, sternum in the lateral (LAT)-image (**A**) TH1 and th8/10, ribs and shoulder joint in the anterior-posterior (AP)-image (**B**) and ribs and the soft tissue (**C**) in the tangential image

at Sites 1 and 2 and by SS at Site 3. Orthogonal images were matched to the sternum, ribs, Th 1 (excluding AP at Site 3), humeral head, and Th 8–10. The average, i.e. midpoint, of the sternum and ribs was calculated in the CC direction. The tangential images were matched to the mid chest wall and breast contour after daily orthogonal imaging (Fig. 2). Isocenter accuracy was evaluated based on the couch shifts after the online match. Additionally, inter-structural positional errors were evaluated in vertebrae rotation (Th 1–Th 8/10), BHL (mid-vertebra-sternum), and arm position (Th 1–humeral head).

Patient-specific mean and standard deviation (SD) were calculated for each parameter. The hospital-specific systematic error (Σ) for each anatomical location was estimated by calculating the SD of the patient-specific mean errors. The hospital-specific random error (σ) was calculated as the root mean square of the patient-specific SD values.

Van Herk's formula ($m = 2.5\ \Sigma + 0.7\ \sigma$) [22] was used to calculate the PTV setup margins for positional errors. Moreover, the percentages of residual errors exceeding 3–8 mm were calculated for each site.

Statistical analysis

Statistical analyses were performed using the R (v 4.1.3) software environment for statistical computing and graphics. The normality of the data was tested with the Shapiro-Wilk test. Non-parametric tests were chosen for further statistical analysis. Levene's test was used to compare the systematic error component, i.e. the equality of the variance of the means of the M and WBLN groups. Levene's test with Holm's correction was used to compare the systematic error component between the hospitals. The Mann-Whitney *U* test was used to compare the random error component, i.e. SD values between the M and WBLN groups. The Kruskal-Wallis test was used to compare the random error component between the hospitals. In case of a statistically significant difference, post-hoc analysis was performed using Dunn's test with Holm's correction.

Results

Mastectomy and whole breast + lymph nodes groups

At Site 1, the random errors in shoulder position (LAT, $p = 0.01$) and vertebrae pitch ($p = 0.03$) were greater in the WBLN than in the M group. Also at Site 2, the random error in vertebrae pitch was greater in the WBLN than in the M group ($p = 0.04$). At Site 3, the random error in yaw was slightly greater in the M than in the WBLN group ($p = 0.04$). Because the differences between the groups were small, the M and WBLN groups were combined for site comparison.

Residual errors

Table 1 shows the residual errors for bone sections after daily IGRT and the residual errors of the ribs and soft tissues of the tangential images. The estimated margin requirements according to van Herk`s formula are shown in Table 2.

Table 1. Systematic and random errors (Σ ± σ) of the patient posture in [mm] after surface-guided radiotherapy (SGRT) setup, based on orthogonal and tangential kV imaging

Residual errors		Site 1	Site 2	Site 3
Rotation Th 1-Th 8	AP (pitch)	0.7* ± 1.0**	1.0 ± 1.2	
	LAT (yaw)	1.0 ± 1.2**	1.1 ± 2.0††	1.2 ± 1.6$^{¥¥}$
BHL	AP	1.3 ± 1.5	1.8 ± 1.7	2.1$^{¥}$ ± 1.7
	CC	1.3** ± 2.0**	3.4††±2.5††	2.3$^{¥¥}$± 1.8
Th 1-Humeral head	CC	1.5** ± 2.1**	4.0†± 3.1††	3.0$^{¥¥}$ ± 2.4$^{¥}$
	LAT	1.7 ± 1.7*	2.1 ± 1.9†	2.7 ± 1.7
Sternum	AP	1.2 ± 1.5	1.5 ± 1.6††	1.1 ± 1.3¥¥
	CC	1.2** ± 1.9**	2.7† ± 2.4††	2.0¥¥ ± 1.8
Ribs	LAT	0.7* ± 1.3**	0.5 ± 1.0††	0.4¥¥ ± 0.8¥¥
Sternum/ribs	CC	0.9* ± 1.5	1.5 ± 1.7††	1.1 ± 1.2¥¥
Humeral head	CC	1.5** ± 2.0**	2.7 ± 2.6	2.6¥¥ ± 2.2
	LAT	1.5* ± 1.8	2.1 ± 2.0	2.7¥ ± 1.9
Th 1	AP	1.2** ± 1.4**	2.4 ± 2.2	
	CC	1.0** ± 1.5**	1.7†† ± 1.8††	1.2 ± 1.1¥¥
	LAT	1.1 ± 1.5*	1.1 ± 1.7	1.1 ± 1.6
Ribs/tangential	AP/LAT	0.8** ± 1.3	1.4 ± 1.1	1.4¥¥ ± 1.3¥¥
	CC	0.6** ± 1.0	1.1†† ± 1.2††	0.7 ± 0.3¥¥
Skin/tangential	AP/LAT	2.2 ± 1.6	1.9 ± 1.7	2.7 ± 1.4
WBLN	CC	2.3 ± 1.8	2.1 ± 1.7	3.9 ± 1.5

Statistical difference between Site 1 and 2 (*p < 0.05, **p < 0.01), Site 1 and 3 ($^{¥}$, $^{¥¥}$) and Site 3 and 2 (†, ††). In Site 3, TH1 was not visible in the lateral image and the AP results are missing. Skin in the tangential images was evaluated from the WBLN groups only. BHL — breath hold level; AP — anterior-posterior; CC — cranio-caudal; LAT — lateral; WBLN only — whole breast + lymph nodes

Table 2. Planning target volume–clinical target volume (PTV-CTV) and margin requirements in [mm] after image-guided radiotherapy (IGRT) couch movements. Margins are estimated with the Van Herk formula

Margins		Site 1	Site 2	Site 3
Isocenter	AP (sternum)	4.1	4.8	3.7
	CC (sternum/ribs)	3.3	5.0	3.5
	LAT (ribs)	2.6	2.0	1.7
Th 1	AP	4.1	7.4	-
	CC	3.5	5.5	3.7
	LAT	3.8	3.9	4.0
Ribs/tangential	AP/LAT	3.0	4.2	4.5
	CC	2.3	3.7	2.0
Skin/tangential	AP/LAT	6.6	6.0	7.6
WBLN only	CC	7.1	6.4	10.8

AP — anterior-posterior; CC — cranio-caudal; LAT — lateral; WBLN only — whole breast + lymph nodes

Table 3 shows the percentages of fractions exceeding the given threshold values.

Discussion

This study evaluated the accuracy of three different SGRT setup workflows in locoregional RT of breast cancer at DIBH with daily IGRT. In the literature, the results of breast RT setup errors are typically presented only as translations and rotations [15, 23–26]. Locoregional and whole breast RT groups can be combined [26, 27], although PTV delineations and, thus, accuracy requirements are different between groups. Typically, in the publications

Table 3. Percentage of the fractions where the residual errors exceeded given thresholds after image-guided radiotherapy (IGRT)-based couch movements

Residual errors		Site 1	Site 2	Site 3
Sternum, 4/3 mm	AP	7.8%/19.7%	10.7%/18.8%	2.8%/6.6%
Sternum/ribs, 5/4 mm	CC	2.0%/5.0%	4.5%/9.9%	0.4%/2.4%
Ribs, 4/3 mm	LAT	0.7%/3.5%	0.4%/1.3%	0.2%/0.4%
Th 1, 5/4 mm	AP	2.6%/6.3%	10.8%/20.2%	
	CC	2.0%/4.8%	4.5%/11.7%	0.6%/2.4%
	LAT	1.5%/3.7%	1.3%/4.3%	2.0%/5.2%
Humeral head, 7/5 mm	CC	1.3%/4.8%	6.2%/15.2%	4.8%/13%
	LAT	1.9%/5.6%	1.9%/8.3%	7.0%/15.4%
Th 1–Th 10 (rotation), 5 mm	LAT	0.6%	2.7%	1.2%
(pitch), 4 mm	AP	1.3%	3.0%	
Th 10-sternum (BHL), 4 mm	AP	6.9%	10.1%	11.4%
5 mm	CC	5.8%	21.9%	9.2%
Th 1-humeral head, 7 mm	CC	2.0%	17.4%	7.6%
Ribs/tangential, 4/3 mm	AP/LAT	2.1%/9.9%	3.9%/11.0%	3.5%/10.0%
5 mm	CC	0.4%	2.2%	0.6%
Skin/tangential, 8/5 mm	AP/LAT	3.4%/8.1%	0.8%/5.7%	2.4%/9.4%
WBLN only, 8/5 mm	CC	2.1%/11.9%	0.8%/8.2%	4.7%/9.4%

AP — anterior-posterior; CC — cranio-caudal; LAT — lateral; WBLN only — whole breast + lymph nodes

the results are also combined between the mastectomy and whole breast + lymph nodes groups [21, 28–29]. This study included only locoregional patients. The differences between the M and WBLN groups were mostly insignificant and the groups were thus combined. Compared to previous literature with conventional IGRT with RPM, the residual errors were mainly similar or better in the current study with IGRT and SGRT [16, 17, 21].

The postural and residual errors reported in this study reflect the workflows and action levels of each hospital. For example, Site 1 has a workflow that pays special attention to the accuracy of BHL both in the AP and CC directions, which obviously leads to smaller errors in those areas. However, if one area is heavily prioritized during the match, some other areas may be compromised. Site 1 seems to have quite a balanced matching procedure, but they might benefit from focusing more on the correct AP position of the sternum. Site 2 had CC-errors in BHL, which resulted in the largest residual errors in several structures in that direction, even though the daily image guidance reduced the errors. At Site 3, the workflow focuses on the ribs and sternum, and the patient positioning had the lowest random errors of the three sites. Both sites 2 and 3 might benefit from paying more attention on the correct BHL and arm position in the beginning of the treatment course to reduce the systematic errors.

Postural errors

Catalyst uses a baseline-based BHL-window for DIBH guidance while AlignRT BHL results from the difference between FB and BH surfaces. The random AP errors of the BHL in the lateral kV images did not differ significantly between the sites. However, slightly larger systematic errors at Sites 2 and 3 than at Site 1 indicate a need to correct BHL in the beginning of the RT course. This would improve the control on the location and radiation dose of the heart [16]. It is important to note that the chest wall (*i.e.* sternum) moves not only in the anterior but also in the cranial direction during DIBH; possibly even more in the CC than AP direction. Site 1 verified the BHL in both AP- and CC-directions from a lateral kV image and corrected the BHL when needed, which resulted in significantly lower systematic error in the CC-direction. If the BHL repeatability in the CC direction is not controlled, it causes compromises in image matching and increases residual errors.

The pitch in the vertebrae was small in all groups. However, incorrect breathing patterns may lead to BHL errors in the CC-direction, and pitch in the sternum. It is possible to reduce the BHL-related pitch errors in DIBH. The pitch can be corrected with 6D couch. SGRT may aid in correcting the pitch already during the FB setup. IGRT-based BHL correction may also correct the pitch [16]. Smaller BHL at 70–80% of maximum at the CT may reduce errors during treatment [30]. Baseline drift prior to baseline (re-)calculation may affect the BHL and, thereby, the pitch and should be verified with IGRT [31]. Unstable or uncomfortable fixation devices should be upgraded. Finally, patient breath hold guidance in all the phases of the workflow is effective in the correction of the pitch and CC-position of the sternum.

Rotations

Errors in vertebrae rotation weakens the PTV accuracy and may increase the dose to the heart, ipsilateral lung and even to the spinal cord. In all the groups residual rotations were acceptable after daily image guidance. At Site 3, 2D/3D correction has been included in online match workflow after this study to improve orthogonal imaging accuracy not only in rotation and pitch but also in the roll.

Chest wall accuracy in orthogonal images

With daily IGRT, for all sites, the chest wall accuracy on the sternum/ribs in orthogonal images was good with small residual errors, in accordance with the literature [21, 23, 28]. This led to acceptable 2–5 mm margin on the chest wall.

Online match was instructed to be based on the sternum (AP) in the matching guidelines of each hospital. However, at Site 1, a 3 mm action level was used in the online match in the AP direction in the sternum. This led to 19.7% of fractions exceeding 3 mm in the online match. This was comparable with Site 2 (18.8 %), using a 0 mm action level. In both sites improvements are thus needed. At Site 3 with smaller BHL of 70%–80% of the maximum, only 6.6% of the fractions exceeded the 3 mm error (Tab. 3). In the LAT direction, the chest wall CTV–PTV margins were between 1.7–2.6 mm which demonstrates excellent accuracy. This is similar to earlier results in the literature [21, 28, 32]. The good accuracy of the sternum (AP) and the ribs (LAT) are essential to ensure the position of the chest wall in relation to the treatment field. In the CC direction, the online compromise was good at Site 2. Even though BHL showed the largest percentage of 5-mm exceedings (21.9% of the fractions), residual errors ≥ 5 mm to the chest were found in 4.5 % and to Th 1 in 4.5 % of the fractions, only slightly larger than at Sites 1 and 3. This highlights the importance of daily IGRT.

Accuracy of lymph nodes in orthogonal images

For the lymph node area, Th 1 was considered as a surrogate in the orthogonal images due to the lack of CBCT images. At Sites 1 and 3, a 5 mm margin was sufficient. However, even with daily IGRT, workflow improvements are needed to retain the 5 mm CTV-PTV margin at Site 2. Reducing the BHL-related errors leads to improved Th 1 accuracy (AP, CC). At Site 1, the CC of the BHL was controlled during BH setup already and at Site 3, the CC and pitch of the entire patient was corrected using a 6D couch. Margins in Th 1 (LAT) were 3.8–4.0 mm due to successful rotation corrections at all three sites.

The shoulder joint in relation to the PTV is not the primary matching location in the images [28, 29]. However, the shoulder position is important not only to avoid side-effects to the humeral head but also to optimize the position of the LN within PTV. With daily IGRT, only small differences have been found in the repeatability of the arm position both between the tattoo marking based laser setup and SGRT-based setup; and between different SGRT systems [21, 32]. In the current study, the systematic errors were the smallest at Site 1, but the random errors were almost similar. The humeral head (CC) showed rather large variation relative to Th 1 at Site 2, but again, after accurate daily IGRT, the discrepancy in relation to Sites 1 and 3 was reduced (Tab. 1). At Site 3, a wider portion of the arm was included to SGRT scanning volume of Catalyst, leading to smaller random errors in shoulder position than at Site 2 (Fig. 1). Therefore, a longer SGRT scanning volume could be advantageous in the CC direction with Catalyst. Systematic arm position errors require re-setup of the arm and new reference setup surface thereafter.

Tangential image accuracy

There is often need for compromise in the orthogonal image match due to errors in BHL, pitch or even arm position. Therefore, we suggest that an additional tangential image should always be acquired if orthogonal images show structure displacements; or if a new DIBH surface (AlignRT) or baseline (Catalyst) has been acquired. Additionally, it is possible to evaluate the soft tissue location based on tangential images. After orthogonal images, it takes on average less than one minute to acquire and analyze the tangential image [32].

Even though the percentages exceeding 3- and 4-mm residual errors in the tangential image ribs (AP/LAT) were nearly equal between all sites (Tab. 3), Sites 2 and 3 showed slightly larger systematic errors and margins (Tab. 1 and 2) in the AP/LAT directions than Site 1. A possible reason may be a small baseline drift during the delay between orthogonal and tangential image acquisition for some patients. This may lead to small errors in both BHL and isocenter due to baseline recalculation after couch shift with Catalyst. This highlights the importance of guiding the patient to keep the same baseline, acquiring tangential images and evaluating the images offline [21]. After daily orthogonal imaging, the residual CTV-PTV margins on the chest wall in the tangential images were ≤ 5 mm in this study in all the sites, which is in accordance with earlier publications [3, 11, 21, 23, 32].

The allowance for soft tissue deformation depends on the planning technique. If the breast fits within the treatment field, up to 1.0–1.5 cm swelling or displacement of the breast is typically accepted with static gantry angles. For VMAT, an 8 mm optimizing bolus is suggested for the allowance for typical soft tissue deformations [33, 34] (Tab. 2). With AlignRT, rigid chest ROI (Fig. 1A–B) correlated well with the bony structures but was limited in its ability to show the soft tissue deformations. Deformation workspace, additional breast ROI or postural video could have shown swelling or displacement of the soft tissue [35, 36]. With Catalyst, swelling can be seen with color codes on patient's skin if the isocenter is correct. The downside of taking new setup reference surfaces during the treatment course to eliminate systematic posture errors is the loss of information on original breast shape at CT.

Workflow improvements

At Site 1 with AlignRT, there was a high number of 3 mm exceedings in the sternum position. Those need to be corrected according to the action level in the AP direction despite the complicated workflow. At Sites 2 and 3, during the first fractions, new FB setup reference surfaces need to be created to include the arm to decrease systematic errors. Since the data collection for this study, Site 2 has added a 10° wedge to their fixation as at Site 3. This also improves the SGRT camera visibility in the cranial scanning area, and the shadow region in Figure 1 C–D improves towards Figure 1 E–F. In addition, Site 2 has now started to acquire a new reference surface after image guidance to override the Sentinel surface at the beginning of the treatment course. Site 2 has also reduced the surface tolerance to 5 mm for positioning. These changes may improve the pitch related errors and lymph node accuracy. All the sites decided to correct the BHL systematically during the first fractions based on IGRT with a 3 mm (Sites 1 and 3) and with a 5 mm (Site 2) action level. Pitch correction in IGRT improved CC accuracy in general at Site 3, and using the correction is recommended if a 6D couch is available. At Sites 2 and 3, a possible baseline drift between orthogonal imaging and couch-movement-induced new baseline generation and, thereby, the new BH reference surface should be verified with lateral or tangential imaging after couch shift. In addition to daily orthogonal IGRT, imaging of tangential treatment field during the first fractions and at least weekly thereafter is suggested to monitor baseline shift and soft tissue position. The soft tissue position and deformation should be evaluated with SGRT.

Conclusion

Setup errors at three sites using different SGRT and daily image-guided workflows were evaluated retrospectively in locoregional breast cancer patients receiving DIBH RT. The random setup errors at Sites 1 and 3 were almost equal and lower than those at Site 2. This indicated that setup errors are mostly influenced by differences in workflows rather than differences in SGRT systems. Site 2 has now changed their workflow towards Site 1 and 3 based on these early findings. At Site 1, the reference surfaces were updated during the first three fractions and/or during subsequent fractions based on the IGRT, reducing systematic setup errors. BHL control with Catalyst resulted in comparable BHL (AP) alignment accuracy compared to AlignRT which used a combination of FB and BH surfaces. However, the authors recommend paying attention also to the CC direction of DIBH. Improvements to SGRT workflows are suggested for all sites, as 5 mm CTV-PTV margins and patient position action level values were partially exceeded regardless of daily IGRT. The retrospective setup image analysis reported in this study is recommended to all RT sites as it helps to identify and improve the weak areas of the treatment workflow. We recommend accurate patient positioning, tight SGRT tolerances, good fixation and the correction of systematic posture errors for the best possible treatment position.

Conflict of interests

Authors declare no conflicts of interests.

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References

1. McGale P, Taylor C, Correa C, et al. EBCTCG (Early Breast Cancer Trialists' Collaborative Group). Effect of radiotherapy after mastectomy and axillary surgery on 10-year recurrence and 20-year breast cancer mortality: meta-analysis of individual patient data for 8135 women in 22 randomised trials. Lancet. 2014; 383(9935): 2127–2135, doi: 10.1016/S0140-6736(14)60488-8, indexed in Pubmed: 24656685.
2. Rong Yi, Walston S, Welliver MXu, et al. Improving intra-fractional target position accuracy using a 3D surface surrogate for left breast irradiation using the respiratory-gated deep-inspiration breath-hold technique. PLoS One. 2014; 9(5): e97933, doi: 10.1371/journal.pone.0097933, indexed in Pubmed: 24853144.
3. Register S, Takita C, Reis I, et al. Deep inspiration breath-hold technique for left-sided breast cancer: An analysis of predictors for organ-at-risk sparing. Med Dosim. 2015; 40(1): 89–95, doi: 10.1016/j.meddos.2014.10.005, indexed in Pubmed: 25534166.
4. Duma MN, Baumann R, Budach W, et al. Breast Cancer Expert Panel of the German Society of Radiation Oncology (DEGRO). Heart-sparing radiotherapy techniques in breast cancer patients: a recommendation of the breast cancer expert panel of the German society of radiation oncology (DEGRO). Strahlenther Onkol. 2019; 195(10): 861–871, doi: 10.1007/s00066-019-01495-w, indexed in Pubmed: 31321461.
5. Batista V, Gober M, Moura F, et al. Surface guided radiation therapy: An international survey on current clinical practice. Tech Innov Patient Support Radiat Oncol. 2022; 22: 1–8, doi: 10.1016/j.tipsro.2022.03.003, indexed in Pubmed: 35402740.
6. Peters GW, Gao SJ, Knowlton C, et al. Benefit of Deep Inspiratory Breath Hold for Right Breast Cancer When Regional Lymph Nodes Are Irradiated. Pract Radiat Oncol. 2022; 12(1): e7–ee12, doi: 10.1016/j.prro.2021.08.010, indexed in Pubmed: 34508890.
7. Lin A, Sharieff W, Juhasz J, et al. The benefit of deep inspiration breath hold: evaluating cardiac radiation exposure in patients after mastectomy and after breast-conserving surgery. Breast Cancer. 2017; 24(1): 86–91, doi: 10.1007/s12282-016-0676-5, indexed in Pubmed: 26886584.
8. Giantsoudi D, Lalonde A, Barra C, et al. Tattoo-Free Setup for Patients With Breast Cancer Receiving Regional Nodal Irradiation. Pract Radiat Oncol. 2023; 13(1): e20–e27, doi: 10.1016/j.prro.2022.08.001, indexed in Pubmed: 35948179.
9. Simonetto C, Eidemüller M, Gaasch A, et al. Does deep inspiration breath-hold prolong life? Individual risk estimates of ischaemic heart disease after breast cancer radiotherapy. Radiother Oncol. 2019; 131: 202–207, doi: 10.1016/j.radonc.2018.07.024, indexed in Pubmed: 30097250.
10. Vuong W, Garg R, Bourgeois DJ, et al. Dosimetric comparison of deep-inspiration breath-hold and free-breathing treatment delivery techniques for left-sided breast cancer using 3D surface tracking. Med Dosim. 2019; 44(3): 193–198, doi: 10.1016/j.meddos.2018.06.002, indexed in Pubmed: 30078605.
11. Schönecker S, Walter F, Freislederer P, et al. Treatment planning and evaluation of gated radiotherapy in left-sided breast cancer patients using the Catalyst/Sentinel system for deep inspiration breath-hold (DIBH). Radiat Oncol. 2016; 11(1): 143, doi: 10.1186/s13014-016-0716-5, indexed in Pubmed: 27784326.
12. Steffal C, Schratter-Sehn A, Brinda-Raitmayr K, et al. 5 years of experience with DIBH (Deep inspiration breath-hold) combined with SGRT (Surface-Guided Radiation Therapy) in left-sided breast cancer. Senologie. 2020; 17(01): 14–23, doi: 10.1055/a-0849-0524.
13. Deantonio L, Masini L, Loi G, et al. Detection of setup uncertainties with 3D surface registration system for conformal radiotherapy of breast cancer. Rep Pract Oncol Radiother. 2011; 16(3): 77–81, doi: 10.1016/j.rpor.2011.02.003, indexed in Pubmed: 24376961.
14. Rong Yi, Walston S, Welliver MXu, et al. Improving intra-fractional target position accuracy using a 3D surface surrogate for left breast irradiation using the respiratory-gated deep-inspiration breath-hold technique. PLoS One. 2014; 9(5): e97933, doi: 10.1371/journal.pone.0097933, indexed in Pubmed: 24853144.
15. Neubauer E, Dong L, Followill DS, et al. Assessment of shoulder position variation and its impact on IMRT and VMAT doses for head and neck cancer. Radiat Oncol. 2012; 7: 19, doi: 10.1186/1748-717X-7-19, indexed in Pubmed: 22316381.
16. Skyttä T, Kapanen M, Laaksomaa M, et al. Improving the reproducibility of voluntary deep inspiration breath hold technique during adjuvant left-sided breast cancer radiotherapy. Acta Oncol. 2016; 55(8): 970–975, doi: 10.3109/0284186X.2016.1161823, indexed in Pubmed: 27070120.
17. McIntosh A, Shoushtari AN, Benedict SH, et al. Quantifying the reproducibility of heart position during treatment

and corresponding delivered heart dose in voluntary deep inhalation breath hold for left breast cancer patients treated with external beam radiotherapy. Int J Radiat Oncol Biol Phys. 2011; 81(4): e569–e576, doi: 10.1016/j.ijrobp.2011.01.044, indexed in Pubmed: 21531087.

18. Koivumäki T, Tujunen J, Virén T, et al. Geometrical uncertainty of heart position in deep-inspiration breath-hold radiotherapy of left-sided breast cancer patients. Acta Oncol. 2017; 56(6): 879–883, doi: 10.1080/0284186X.2017.1298836, indexed in Pubmed: 28281859.
19. Mhatre V. Quality assurance for clinical implementation of an Optical Surface monitoring system. IOSR Journal of Applied Physics . 2017; 9(6): 15–22.
20. Pallotta S, Marrazzo L, Ceroti M, et al. A phantom evaluation of Sentinel(™), a commercial laser/camera surface imaging system for patient setup verification in radiotherapy. Med Phys. 2012; 39(2): 706–712, doi: 10.1118/1.3675973, indexed in Pubmed: 22320780.
21. Laaksomaa M, Ahlroth J, Pynnönen K, et al. AlignRT, Catalyst™ and RPM™ in locoregional radiotherapy of breast cancer with DIBH. Is IGRT still needed? Rep Pract Oncol Radiother. 2022; 27(5): 797–808, doi: 10.5603/RPOR.a2022.0097, indexed in Pubmed: 36523797.
22. van Herk M, Remeijer P, Rasch C, et al. The probability of correct target dosage: dose-population histograms for deriving treatment margins in radiotherapy. Int J Radiat Oncol Biol Phys. 2000; 47(4): 1121–1135, doi: 10.1016/s0360-3016(00)00518-6, indexed in Pubmed: 10863086.
23. Kügele M, Mannerberg A, Nørring Bekke S, et al. Surface guided radiotherapy (SGRT) improves breast cancer patient setup accuracy. J Appl Clin Med Phys. 2019; 20(9): 61–68, doi: 10.1002/acm2.12700, indexed in Pubmed: 31478615.
24. Wei X, Liu M, Ding Y, et al. Setup errors and effectiveness of Optical Laser 3D Surface imaging system (Sentinel) in postoperative radiotherapy of breast cancer. Sci Rep. 2018; 8(1): 7270, doi: 10.1038/s41598-018-25644-w, indexed in Pubmed: 29740104.
25. Cravo Sá A, Fermento A, Neves D, et al. Radiotherapy setup displacements in breast cancer patients: 3D surface imaging experience. Rep Pract Oncol Radiother. 2018; 23(1): 61–67, doi: 10.1016/j.rpor.2017.12.007, indexed in Pubmed: 29379398.
26. Sauer TO, Ott OJ, Lahmer G, et al. Prerequisites for the clinical implementation of a markerless SGRT-only workflow for the treatment of breast cancer patients. Strahlenther Onkol. 2023; 199(1): 22–29, doi: 10.1007/s00066-022-01966-7, indexed in Pubmed: 35788694.
27. Betgen A, Alderliesten T, Sonke JJ, et al. Assessment of setup variability during deep inspiration breath hold radiotherapy for breast cancer patients by 3D-surface imaging. Radiother Oncol. 2013; 106(2): 225–230, doi: 10.1016/j.radonc.2012.12.016, indexed in Pubmed: 23414819.
28. Rossi M, Laaksomaa M, Aula A. Patient setup accuracy in DIBH radiotherapy of breast cancer with lymph node inclusion using surface tracking and image guidance. Med Dosim. 2022; 47(2): 146–150, doi: 10.1016/j.meddos.2021.12.003, indexed in Pubmed: 35039223.
29. Laaksomaa M, Kapanen M, Haltamo M, et al. Determination of the optimal matching position for setup images and minimal setup margins in adjuvant radiotherapy of breast and lymph nodes treated in voluntary deep inhalation breath-hold. Radiat Oncol. 2015; 10: 76, doi: 10.1186/s13014-015-0383-y, indexed in Pubmed: 25885270.
30. Wiant D, Wentworth S, Liu H, et al. How Important Is a Reproducible Breath Hold for Deep Inspiration Breath Hold Breast Radiation Therapy? Int J Radiat Oncol Biol Phys. 2015; 93(4): 901–907, doi: 10.1016/j.ijrobp.2015.06.010, indexed in Pubmed: 26530760.
31. Jensen CA, Acosta Roa AM, Lund JÅ, et al. Intrafractional baseline drift during free breathing breast cancer radiation therapy. Acta Oncol. 2017; 56(6): 867–873, doi: 10.1080/0284186X.2017.1288924, indexed in Pubmed: 28464748.
32. Laaksomaa M, Sarudis S, Rossi M, et al. AlignRT and Catalyst™ in whole-breast radiotherapy with DIBH: Is IGRT still needed? J Appl Clin Med Phys. 2019; 20(3): 97–104, doi: 10.1002/acm2.12553, indexed in Pubmed: 30861276.
33. Rossi M, Boman E, Kapanen M. Optimal selection of optimization bolus thickness in planning of VMAT breast radiotherapy treatments. Med Dosim. 2019; 44(3): 266–273, doi: 10.1016/j.meddos.2018.10.001, indexed in Pubmed: 30389413.
34. Seppälä J, Vuolukka K, Virén T, et al. Breast deformation during the course of radiotherapy: The need for an additional outer margin. Phys Med. 2019; 65: 1–5, doi: 10.1016/j.ejmp.2019.07.021, indexed in Pubmed: 31430580.
35. Laaksomaa M, Moser T, Kritz J, et al. Comparison of three differently shaped ROIs in free breathing breast radiotherapy setup using surface guidance with AlignRT. Rep Pract Oncol Radiother. 2021; 26(4): 545–552, doi: 10.5603/RPOR.a2021.0062, indexed in Pubmed: 34434570.
36. Sorgato V, Ghazouani K, Queffelec Y, et al. Benchmarking the AlignRT surface deformation module for the early detection and quantification of oedema in breast cancer radiotherapy. Tech Innov Patient Support Radiat Oncol. 2022; 21: 16–22, doi: 10.1016/j.tipsro.2021.12.002, indexed in Pubmed: 35079643.