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RESEARCH PAPER

AlignRT®, Catalyst™ and RPM™ in locoregional radiotherapy of breast cancer with DIBH. Is IGRT still needed?

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ABSTRACT

Background: In locoregional radiotherapy of breast cancer with deep inspiration breath hold (DIBH), setup accuracy may depend on hospital protocol. At present, comparison between different positioning devices is challenging due to differing hospital protocols. The aim of this study was to evaluate the setup accuracy obtained with surface-guided radiation therapy (SGRT; AlignRT®, Catalyst™) or with lasers and real-time position management (RPM™) in DIBH.

Materials and methods: A total of 1692 image pairs were analyzed in three groups: positioning using AlignRT® surface guidance system (Group A, n = 45), Catalyst™ (Group C, n = 50) and conventional lasers and tattoos (Group L, n = 46). We evaluated residual errors for the bony chest wall, th1 and humeral head in kV images with laser- or SGRT-based setup with and without daily image-guided radiation therapy (IGRT).

Results: Less isocenter variance was found in Group A than in Group L or C ($p \leq 0.05$) and in Group C than in L ($p = 0.02$–0.6). With SGRT only, the smallest random rotation error was found in Group A ($p = 0.01$). With daily IGRT, only a small difference was found for residual errors between the groups.

Conclusion: Setup with SGRT improves the isocenter reproducibility compared to lasers and RPM™. Only small differences were found in setup accuracy between the SGRT devices. Due to improved isocenter accuracy, daily orthogonal IGRT is suggested in all the groups.

Key words: breast cancer; locoregional radiotherapy; surface-guided radiotherapy; patient positioning

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Introduction

Radiation therapy (RT) in deep inspiration breath-hold (DIBH) is recommended for almost all left-sided breast cancer patients due to improved lung- and heart-sparing compared to free breathing (FB) [1, 2]. In a recent study, also patients with right-sided locoregional breast cancer benefitted from the use of DIBH due to decreased doses to the lung and liver [3]. In DIBH, it is essential that the breath-hold level (BHL) is repeated accurately to achieve optimal reduction in the heart dose [4]. It is possible that external surrogates, such as marker box with Real-Time Position Management (RPM™), guide the BHL to small systematic errors, and the BHL should be corrected at the beginning of the treatment when necessary [5]. There are various ways to accurately evaluate the actual BHL, such as measuring the distance between the spine and sternum [6, 7], the position of the diaphragm [8], or central lung distance (CLD) in relation to the treatment field [9].

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The common matching location in orthogonal images is a compromise between the sternum and ribs for optimal accuracy of the ribs in tangential image. In conventional tangential field arrangement, the soft tissue must be inside the treatment field; and in modulated treatments, the position of the soft tissue is emphasized [10]. To achieve good accuracy in both the chest wall and soft tissue, surface guided RT (SGRT) is a good tool [11].

Radiotherapy in DIBH of both patients following mastectomy and patients with whole breast with locoregional lymph node irradiation is more complex than standard whole breast (WB) RT with tangential fields, with increased accuracy requirements for the bony structures, such as the humeral head or th1 [12]. In the literature, significant movement of the axillary lymph node levels has been observed during DIBH [13]. In addition, the image matching based on the chest wall may not be optimal for lymph nodes if the bony structures in the cranial parts of PTV are misaligned. Therefore, added with large daily isocenter variation (up to 4.4 mm), daily IGRT is recommended in locoregional radiotherapy of breast cancer with laser setup and RPM™ [7].

The advantage of SGRT setup over laser setup is that SGRT utilizes thousands of points on the patient's body for monitoring, while conventional tattoo-based setup relies typically on three or four tattoos. Therefore more accurate patient positioning and intrafractional monitoring is possible with SGRT than with lasers [14]. With both AlignRT® and Catalyst™, the shoulder area is visible on the reference surface and the arm can be positioned in a live view. With SGRT, the initial patient setup is performed with FB surfaces. After this, AlignRT® and Catalyst™ have different methods to guide the patient to a correct BHL and isocenter. Catalyst™ relies on a BHL window with an individual vertical distance from the breathing baseline, similarly to RPM™, and a new BH surface is created for each fraction. In AlignRT®, the BH window is a 6D BH reference surface relative to isocenter, and the CT-based surface can be used on multiple fractions; or a new surface can be created for single or multiple fractions. Small automatic isocenter and rotation corrections can be done during BH with AlignRT®. In phantom studies, both SGRT-systems represent sub-millimeter accuracy [15, 16].

In recent years, it has been reported that with SGRT, the accuracy of positioning is comparable or improved when compared to laser-based setup in both FB [11, 17, 18] and DIBH [19, 20]. However, the setup accuracy of patients with locoregional radiotherapy of breast cancer is not yet widely reported with SGRT. Based on Crop et al., time-consuming imaging increased the total treatment time and finally SGRT offers similar accuracy for the rigid residual errors (translation and rotations) compared to CBCT based setup in lymph node positive breast TomoTherapy treatments [21]. Recently, DIBH has been shown to be accurate and reliable using AlignRT [22, 23]. However, daily IGRT is recommended [22, 24].

The aim of this study was to evaluate the setup accuracy and the influence of daily IGRT on the accuracy of locoregional radiotherapy of breast cancer DIBH with either SGRT (AlignRT®, Catalyst™) or lasers and RPM™. The setup errors in isocenter and patient posture were measured using orthogonal and tangential kV-images, with SGRT/laser setup together with daily IGRT and with SGRT or laser setup only.

Materials and methods

Patient selection and treatment planning

The study consisted of 141 consecutive breast cancer patients treated with regional nodes irradiation [80 whole breast + lymph nodes (WBLN) and 61 patients following mastectomy (M)] receiving RT in DIBH following breast surgery. The images were analyzed retrospectively, and a permission for data collection was obtained from the hospital ethics committee. 46 patients (Group L, mean patient age 59 years, n = 26 WBLN, 20 M) were treated using conventional laser-based setup, 45 patients (Group A, mean age 60, n = 25 WBLN, 20 M) using AlignRT® and 50 patients (Group C, mean age 57, n = 29 WBLN, 21 M) using Catalyst™. Indexed Sabella Flex Positioning System (CDR Systems, Canada) with a 10° tilt and with a buttock stopper was used for patient immobilization (Fig. 1). Both arms were lifted above the head.

Treatment planning was done with computed tomography (CT) imaging using Philips Brilliance Big Bore (Philips Medical Systems, Eindhoven, The Netherlands) scanner with 120 kVp and slice thickness of 3 mm. All patients were visually guided at the CT with RPM™ (Varian Medical Systems, Palo Alto, CA) with 3 mm BHL window. CT was

Figure 1. Indexed Sabella Flex Positioning System (CDR Systems, Canada) with 10° tilt and with buttock stopper was used for patient immobilization

imaged in BH, no FB scan was acquired. The body outlines were created automatically in the Eclipse treatment planning system (TPS) (Varian Medical Systems, Palo Alto, CA) using values above -350 Hounsfield Units (HU) for body contour detection. Patients were treated with TrueBeam (Groups A, C) or with CD2100 (Group L) (Varian Medical Systems, Palo Alto, CA) using the Field-in-Field or VMAT technique with 5–7 fields or partial 4–5 arcs to 40.05 Gy in 15 fractions.

Setup protocol

Three first fractions

The three first fractions were used to find optimal SGRT surfaces and to acquire the vertical couch value for optimal isocenter accuracy for the following fractions. During the first fraction, the errors in patient isocenter position were aimed to correct with 0 action level (AL) in all three groups, and FB setup surfaces were created with SGRT after IGRT. Corrections were performed during the next two fractions to gain optimal setup surfaces (FB in Group C and FB + BH in Group A) or setup settings (Group L) for the upcoming fractions with ALs 3 mm for isocenter, 1° for the rotation (th1–th 8/10), 3 mm for the BHL (distance between vertebrae and sternum) and 5 mm for the humeral head (th1 *vs.* humeral head). In all the groups the couch vertical value was acquired based on the vertebrae match during the first fractions and this value was used daily in the setup. BHL was corrected based on vertebrae match with 3 mm AL on the sternum. In Groups C and L, BHL was corrected by raising or lowering the BHL window. In Group A, the BHL was corrected by asking the patient to inhale more or less air and by taking a new BH surface. Only the results after the SGRT setup surface update are given in this study, thus excluding fractions 1–3.

Setup process after first fractions for data collection

Group L: The patients were positioned to four tattoos with couch at zero laterally and rotationally. Three of the tattoos were at the level of the breasts: one was placed sternally (mid tattoo) and two on the lateral-dorsal side from the breast. The fourth tattoo was located on the sternum 10–15 cm caudally from the mid tattoo to improve the straightness. The middle tattoo was indexed with the fixation device. The couch was shifted automatically to the planned isocenter position, excluding the couch VRT, using Delta Couch function (Varian Medical Systems, Palo Alto, CA). RPM™ baseline was calculated after patient positioning, and during DIBH, 3 mm (± 1.5 mm) BHL window was used.

Groups A and C: Patients were positioned based on AlignRT® or Catalyst™ with FB SGRT surface.

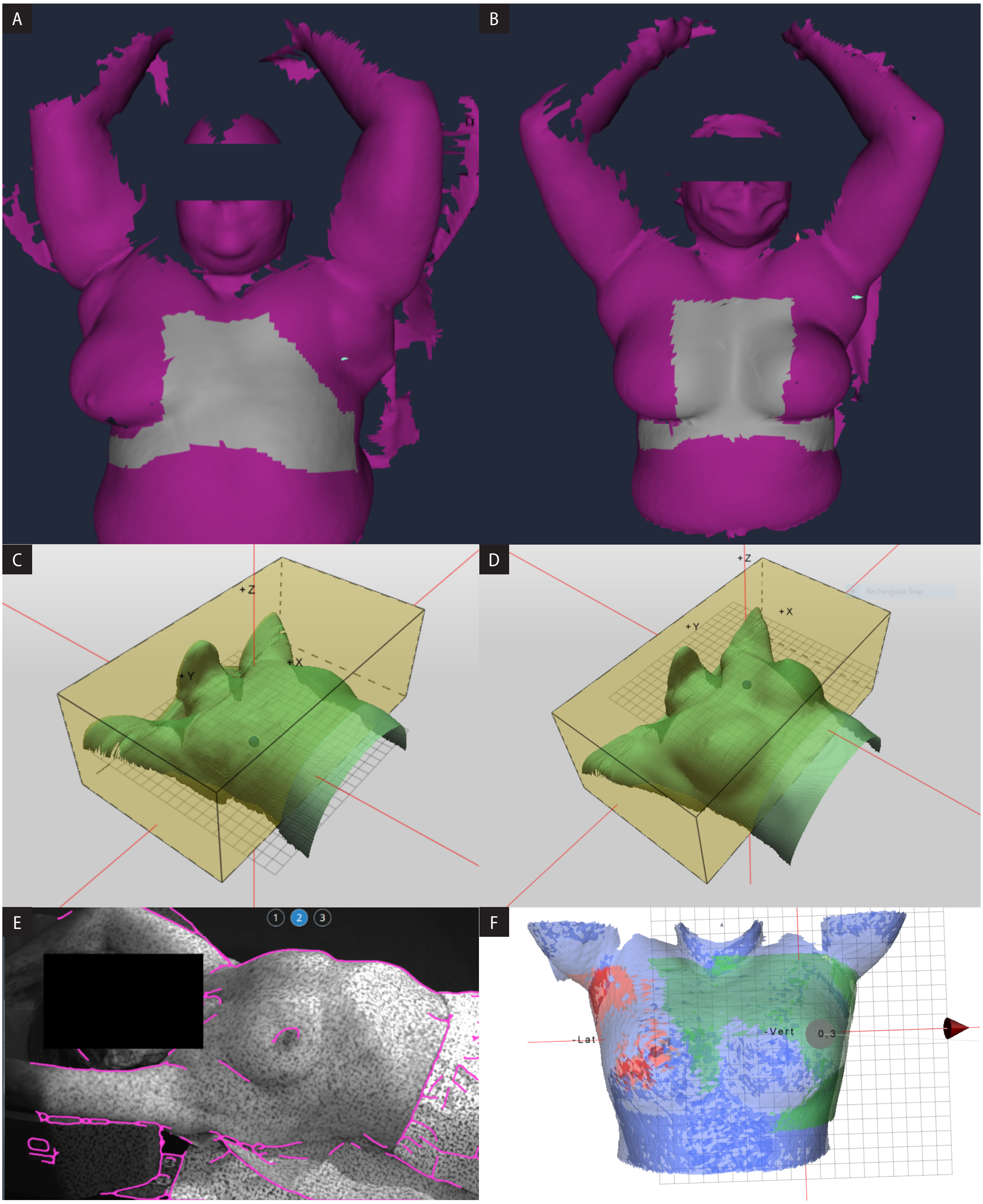

Figure 2. Three regions of interest (ROIs). **A.** Chest wall for patients following mastectomy and **B.** T-ROI for whole breast and lymph nodes in Group A and correspondingly **C.** and **D.** in Group C. **E.** In Group A, the arm position was verified with postural video during free breathing (FB); **F.** In Group C, the arm position was verified with the aid of FB surface

SGRT setup tolerance in FB was 1 mm for translations, 1° for ROLL/ROT and 2° for pitch in FB setup. When the rotations were inside thresholds, the SGRT send-to-couch function was used to shift the couch automatically to the SGRT-based isocenter in the CC- and LAT directions; in the AP

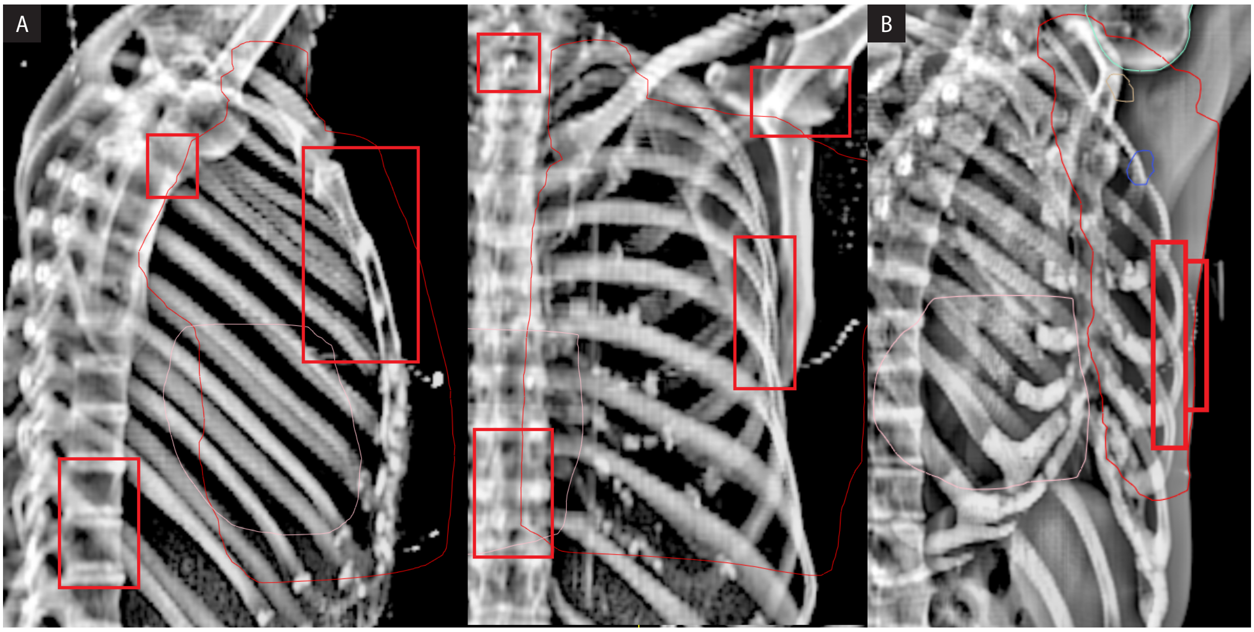

Figure 3. Evaluated landmarks were TH1 and th8/10, ribs and shoulder joint in the AP-image, th1 and th8/10, sternum in the LAT-image (**A**) and ribs and the soft tissue in the tangential image (**B**)

direction, the acquired couch VRT was used. Patients were asked to hold their breath with visual BHL guidance. In group C, a new BH surface for the treatment was automatically generated in the Catalyst™ interface, whereas in Group A, the previously selected BH surface was used. In Group A, after the patient reached the BHL window (± 2 mm), the send-to-couch function was used to correct small isocenter errors (CC, LAT) and 0–1° in rotations. If the delta values exceeded 4 mm or 1° at this point, FB setup was repeated or patient guidance was given for BH. The SGRT regions of interest (ROIs) are shown in Figure 2AB to Group A and in Figure 2CD to Group C.

Arm positioning

In Group L, the arm position was mainly based on indexing of the fixation device and lateral tattoos. In addition, some patients had a setup note if kV-imaging showed systematic errors. In Group A, the arm position was verified with postural video during FB and BH (Fig. 2E). In Group C, the arm position was verified with the aid of FB surface (Fig. 2F).

IGRT protocol

Verification kV-images were acquired with TrueBeam system or with OBI (TrueBeam, CD2100 Obi, Varian Medical Systems, Palo Alto, CA) at 80 kV and 8–10.4 mAs for anterior images, at 95 kV and 8–16 mAs for lateral images and at 70 kV and 2.2 mAs for the tangential images. The daily isocenter translational and rotational corrections were based on daily orthogonal setup images on the online isocenter match of bony landmarks at the chest wall, sternum and ribs (Fig. 3A) with 0 AL. In Group A, errors in the vertical direction in the online match were corrected only if the sternum displacement was ≥ 3 mm. Daily tangential images were acquired after the couch corrections to verify the location of the chest wall and breast in the tangential treatment field (Fig. 3B).

Time used for imaging and treatment

The duration from the first image acquisition to the beginning of the treatment was evaluated at 8 fractions for each patient. The total treatment time from the first image acquisition to the end of the last treatment field was measured in all groups.

Offline image analysis

The orthogonal and tangential images (n = 5076) were matched retrospectively by an experienced radiotherapist (ML). Images were individually matched to the sternum, the ribs (chest wall), th1, humeral head, th8-10 in the AP-LAT images, and mid chest wall and breast in the tangential images (Fig. 3) to evaluate the residual errors after daily IGRT. The isocenter accuracy on the setup was defined based on the actual couch shifts after the online match. This shift was added to the residual errors of the landmarks after daily IGRT to evaluate residual errors in the potential case of SGRT/laser setup only. Finally, the positional errors in the rotation (th1–th8/10), BHL (mid-vertebra-sternum) and arm position (th1-humeral head) (Fig. 3) were evaluated. The setup margins for positional errors were calculated using the van Herk's formula ($m = 2.5\ \Sigma + 0.7\ \sigma$), where Σ is systematic error and σ is random error. Σ is defined as a standard deviation of average errors. σ is calculated as root-mean-square value over all displacements around the systematic setup errors [25]. The setup margin currently used at the hospital is 5 mm.

Statistical analysis

Residual errors to evaluated landmarks with SGRT/laser setup only were individually compared within all three groups to residual errors with daily IGRT to estimate the impact of daily IGRT. The setup accuracy was compared between Groups A, C and L with SGRT/laser setup only and with SGRT/laser setup + daily IGRT. Statistical analysis was calculated with SPSS (v22, IBM corp., USA). Two-tailed F-test was applied for systematic errors (test for equality of variances). The Wilcoxon rank sum test was applied for the random errors (test for equality of means). A p-value ≤ 0.01 was considered statistically significant.

Results

Isocenter corrections in the online match

Table 1 shows the isocenter agreement between orthogonal kV-kV images and laser (Group L) or SGRT (Groups A, C) setup. The couch shifts in the AP direction were smaller in both systematic and random movements in Group A compared to Groups L and C. Random errors were smaller in Group A in the CC and LAT direction in comparison to Groups C and L, and smaller in Group C in comparison to Group L.

Errors between the structures

In Table 1, random rotation error was slightly smaller in Group A than Groups C and L with SGRT/laser setup only. The random rotation error was smaller with daily IGRT than with SGRT/laser setup in all groups.

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

Position errors	AlignRT	Catalyst	Laser
Isocenter			
AP	0.5* ± 0.5*	1.5 ± 2.1	1.4† ± 2.1†
CC	1.4 ± 2.0*	1.7 ± 2.4¥	1.7 ± 3.3†
LAT	1.4 ± 1.3*	1.3 ± 2.2¥	1.6 ± 2.7†
Rotation Th1–Th8			
AP	1.2 ± 1.1	1.0 ± 1.0	1.2 ± 1.1
LAT (SGRT)	1.8 ± 2.0*	2.0 ± 2.6	1.6 ± 2.7†
LAT (IGRT)	1.1‡ ± 1.2‡*	1.0‡ ± 1.5‡	1.1 ± 1.6‡
BHL			
AP	1.8 ± 1.4	2.0 ± 1.7	1.9 ± 1.6
CC	2.4 ± 1.8*	3.2 ± 2.3	2.6 ± 2.1
Th1-humeral head			
CC	2.8 ± 2.5	2.3± 2.8	3.2 ± 2.9
LAT	2.2 ± 1.7	2.3 ± 1.8	2.2 ± 2.0

Statistical difference ($p < 0.01$) between *AlignRT and Catalyst, ¥Catalyst and laser and †laser and AlignRT; ‡Statistical difference ($p < 0.01$) between daily image-guided radiation therapy (IGRT) and SGRT or laser setup only within a setup machine. AP — anterior-posterior; CC — craniocaudal; LAT — lateral; BHL — breath-hold level

In the BHL, no difference was found between the groups. BHL errors exceeding 4 mm in the AP direction were 11%, 15% and 11% of the fractions in Groups A, C and L, respectively. The BHL errors exceeded 5 mm in the CC direction in 9%, 21% and 12% of the fractions in Groups A, C and L, respectively. In the humeral head relative to th1, no difference was found between the groups. Errors between th1 and humeral head exceeded 7 mm in the CC direction in Group A, C and L in 6%, 6% and 8% of the fractions, respectively.

Residual errors with daily IGRT

Table 2 shows the residual errors after daily IGRT. The systematic error to the sternum in the AP direction was smaller in Group L and C than in Group A. The required PTV-CTV margins are shown in Table 3. The errors in the ribs in the LAT direction were similar in all groups. These errors are reflected in the percentage of fractions exceeding given thresholds in Table 4.

Tables 2 and 4 also show the accuracy to structures close to the supraclavicular lymph nodes. The smallest random errors to the th1 (AP) were found in Group A.

Table 2. Residual position errors as systematic and random errors (Σ ± σ) in mm, based on orthogonal and tangential kV imaging. The errors are presented for the overall position and for specific bony landmarks

Residual errors	SGRT or laser setup only			Daily IGRT		
	AlignRT	Catalyst	Laser	AlignRT	Catalyst	Laser
Sternum						
AP	1.8 ± 1.3*	1.6 ± 2.2	1.6 ± 2.1†	1.6* ± 1.2	0.7‡ ± 1.1‡	0.7†‡ ± 1.2‡
CC	2.3 ± 2.1*	2.9 ± 2.6¥	2.4 ± 3.4†	1.6 ± 1.7‡	2.3 ± 1.9‡	1.7 ± 1.9‡
Ribs						
LAT	1.4 ± 1.4*	1.3 ± 2.3¥	1.8 ± 2.8†	0.5‡ ±1.0‡	0.5‡ ± 0.9‡	0.5‡ ±1.0‡
Sternum/ribs						
CC	1.9 ± 2.0*	1.9 ± 2.4¥	1.9 ± 3.3†	1.2‡ ± 1.5‡	0.9‡ ± 1.6‡	0.8‡ ± 1.6‡
Humeral head						
CC	2.6 ± 2.6	2.1 ± 2.6	2.4 ± 3.2†	2.3 ± 2.3	1.7 ± 2.4	2.3 ± 2.6‡
LAT	2.3 ± 1.8*	2.0 ± 2.4¥	2.1 ± 3.2†	2.0 ± 1.7	1.9 ± 1.7‡	1.8 ± 1.9‡
Th 1						
AP	1.6 ± 1.4*	2.0 ± 2.1	2.5† ± 2.0†	1.5 ± 1.4*	2.0 ± 1.8	2.0 ± 1.7†
CC	2.2 ± 2.3	2.4 ± 2.6¥	2.3 ± 3.5†	1.2‡ ± 1.5‡	1.4‡ ± 1.7‡	1.3‡ ± 1.6‡
LAT	1.9 ± 1.7*	1.6 ± 2.5	2.0 ± 3.0†	0.8‡ ± 1.1‡	1.1‡ ± 1.3‡	1.1‡ ± 1.4‡†
Ribs/tangential						
AP/LAT	1.5 ± 1.8*	2.2 ± 3.2	2.4 ± 3.9†	0.8‡ ± 0.8‡*	0.8‡ ± 1.2‡	0.5‡ ± 1.2‡†
CC	1.6 ± 2.0*	1.9 ± 2.5¥	2.2 ± 3.3†	0.6‡± 0.6‡*	0.8‡ ± 1.0‡	0.7‡† ± 1.2‡†
Skin/tangential						
AP/LAT	1.6 ± 1.8*	2.6 ± 3.0	3.4† ± 3.8†	1.4 ± 1.2‡*	1.9 ± 1.6‡	2.3† ± 1.9‡†
CC	1.9 ± 1.9*	1.4¥ ± 2.5¥	2.7 ± 3.4†	1.4 ± 1.2‡*	1.4 ± 1.6‡	1.4‡ ± 1.4‡

Statistical difference ($p < 0.01$) between *AlignRT and Catalyst, ¥Catalyst and laser and †laser and AlignRT; ‡Statistical difference ($p < 0.01$) between daily IGRT and SGRT or laser setup only within a setup machine. SGRT — surface-guided radiation therapy; IGRT — image-guided radiation therapy; AP — anterior-posterior; CC — craniocaudal; LAT — lateral

Table 3. Planning target volume–clinical target volume (PTV-CTV) margins in mm before and after image-guided radiation therapy (IGRT)-based couch movements

Residual errors	SGRT or laser setup only			Daily IGRT		
	AlignRT	Catalyst	Laser	AlignRT	Catalyst	Laser
Orthogonal imaging						
AP (Sternum)	5.4	5.6	5.5	5.0	2.5	2.6
CC (Sternum/ribs)	6.2	6.5	7.1	4.1	3.5	3.2
LAT (Ribs)	4.5	4.9	6.3	1.9	1.9	1.9
Tangential imaging						
AP/LAT (Ribs)	5.1	7.5	8.3	2.5	2.8	3.1
CC (Ribs)	5.8	6.7	8.3	1.9	2.7	3.1
AP/LAT (Skin)	5.8	8.3	10.2	4.4	5.8	7.0
CC (Skin)	6.1	6.1	8.9	4.3	4.5	4.6

Residual errors with SGRT or laser setup only

Table 2 shows the residual errors also prior to IGRT. Random error to the sternum (AP, CC) was smaller in Group A than in Groups C and L. Random error in the ribs in the LAT direction was smaller in Group A than in Group C or L and the error in Group C was slightly smaller than in Group L. In the CC direction (ribs/sternum), in Group A the random error was smaller than in Groups C

Table 4. Residual errors exceeding given thresholds before and after image-guided radiation therapy (IGRT)-based couch movements

Residual errors		SGRT or laser setup only			Daily IGRT		
		AlignRT	Catalyst	Laser	AlignRT	Catalyst	Laser
Sternum, 4/3 mm	AP	12%/23%	12%/23%	10%/20%	9%/19%	1%/3%	2%/6%
Sternum/ribs, 5/4 mm	CC	12%/21%	14%/24%	17%/26%	2%/6%	1%/5%	1%/2%
Ribs 4/3 mm	LAT	4%/15%	13%/22%	15%/26%	0%/1%	0%/0%	0%/0%
Th 1, 5/4 mm	AP	4%/10%	11%/18%	11%/17%	3%/8%	12%/20%	6%/10%
	CC	13%/21%	15%/24%	17%/26%	2%/7%	3%/9%	3%/6%
	LAT	4%/11%	11%/18%	13%/19%	0%/1%	1%/3%	2%/3%
Humeral head, 7/5 mm	CC	6%/18%	4%/15%	6%/15%	3%/12%	2%/9%	3%/12%
	LAT	3%/9%	3%/12%	5%/13%	1%/7%	2%/6%	1%/4%
Th1-Th10 (rotation) 5 mm	LAT	8%	14%	12%	1%	2%	2%
Ribs/tangential 4/3 mm	AP/LAT	11%/23%	28%/46%	43%/58%	0%/3%	2%/6%	2%/4%
5 mm	CC	7%	13%	17%	0%	1%	2%
Skin /tangential 5/8 mm	AP/LAT	7%/0%	25%/3%	28%/9%	2%/0%	7%/1%	6%/2%
5/8 mm	CC	9%/1%	7%/1%	21%/8%	3%/0%	6%/1%	4%/0%

SGRT — surface-guided radiation therapy; AP — anterior-posterior; CC — craniocaudal; LAT — lateral

and L, and the error in Group C was smaller than in Group L.

Close to the lymph nodes, smaller systematic error to the th1 (AP) was found in Group A compared to Group L (Tab. 2). The random errors were smaller in all translational directions in Group A compared to Groups C and L, except in (CC) to C. In the LAT directions, smaller random error was found in Group C than L. SGRT was better than Group L in humeral head random error in the CC and LAT directions, and in the LAT direction, Group A was better than Group C.

Tangential images

In the ribs, no difference was found between Groups in the systematic errors neither with nor without IGRT (Tab. 2). In the random errors, Group A was better than Group C and L, and Group C was better than L. The PTV-margins for tangential images are presented in Table 3 and the percentage of fractions exceeding given thresholds in Table 4.

Time used for imaging and treatment

In Group L, it took on average 5.26 minutes to acquire and analyze the three images (AP, LAT, tangential) and 9.47 min for the entire treatment. The corresponding values in Group C were 4.13 min and 8.31 min and in Group A 4.01 min and 7.46 min. The average time to acquire and analyze only the tangential image with SGRT was 55 seconds.

Discussion

We have evaluated the accuracy of three different DIBH setup methods in locoregional radiotherapy of breast cancer with and without daily IGRT. To our knowledge, there is no previous study comparing these three DIBH methods at the same hospital, thus minimizing workflow differences between the methods. The fixation method, workflow at the CT, BH training, protocols and tolerances for IGRT are similar. However, there are some differences between the SGRT-systems concerning the patient positioning process or possibilities to create ROIs or manipulate SGRT tolerances.

Tight ALs were used during the first three fractions to gain adequate setup surfaces for the daily setup. Despite that, in all the groups there was an increase in the percentage of fractions with residual errors exceeding given thresholds with SGRT only when compared to daily IGRT (Tab. 4). This was due to the addition of systematic and random errors in the isocenter. This highlights the importance of daily orthogonal imaging. The 5-mm setup margins currently used at our hospital are feasible only with daily imaging. If starting with SGRT only, the margins would need to be increased in locoregional radiotherapy of breast cancer.

Chest wall accuracy

On the chest wall, 1.4 - 2.9 mm isocenter random error (SD) on WB RT has been reported with SGRT setup only [14, 19, 22, 26]. In the literature, the match is usually based on the whole PTV, including soft tissue [26, 27], whereas in our study, where the supraclavicular lymph nodes are included, the results of the bony structures and soft tissue are separated. In our study, the random isocenter error in the orthogonal images on the bony chest wall varied between 1.3–2.0 mm (Group A) and 2.2–2.6 mm (Group C) with SGRT only; compared to 2.1–3.4 mm with laser setup only (Group L). In accordance to previous literature [16, 18], the setup accuracy is thus improved with SGRT compared to laser setup prior to IGRT. With daily IGRT, the chest wall accuracy was on a high level in all the groups since the residual errors were around 1 mm (AP, LAT) and 1.5 mm (CC), similarly with the literature [19, 22].

In the AP direction, Group A had the highest isocenter repeatability. However, the sternum had systematic errors even with daily IGRT, since 0–3 mm errors were allowed in online match in Group A in the AP direction. With AlignRT®, we found it difficult to correct such small errors in the AP direction by shifting the couch while the patient was in BH. It was also challenging to correct sternum displacement (BHL) accurately by asking the patient to inhale more or less air into lungs. Adaptive thresholds could be useful for these corrections. Our setup workflow in the AP direction was similar between Groups C and L using only the planned couch vertical value and the errors were similar.

On the chest wall in the LAT direction, Group A had less variance (SD 1.4 mm) with SGRT only than Group C (2.8 mm). Previous literature shows variance between these results, with 2 mm using Catalyst™ and AlignRT® in WB DIBH [19], or 2.2 mm with AlignRT® for patients undergoing locoregional radiotherapy of breast cancer in DIBH [22]. The ROI with AlignRT® was not covering the lateral parts of the deforming breast, and the possibility to create ROI to the rigid area of the chest seems useful. In the CC direction, SD errors of 1.5–2.9 mm are found with AlignRT® [14, 19, 22, 26] and 2.1 with Catalyst™ [19] with SGRT only. Our SGRT results are closely similar. With laser setup, the random errors were larger than with SGRT, but the systematic errors were similar. In general, the send-to-couch function during BH was found practical for correcting small translational and rotational errors before image guidance.

Lymph node accuracy

To the best of our knowledge, this is the first study to investigate the accuracy of setup with locoregional radiotherapy of breast cancer in DIBH with all Catalyst™, AlignRT® and RPM™ in one clinic. In these treatments, with laser setup and RPM™, reports suggest daily IGRT, mainly due to large isocenter variation [5, 7, 12]. Similarly, in our latest paper handling patients undergoing locoregional radiotherapy of breast cancer, we suggest daily IGRT with AlignRT®, even though with well-planned SGRT workflow it brings only slight improvements to systematic accuracy [22]. Here, we agree with the earlier literature, since with daily IGRT, improvement was shown in all evaluated sub-regions in Tables 2–4.

In the accuracy of TH1, accurate BHL and small pitch and ROT are essential. Then, the needs to make compromises when selecting matching location between the lymph nodes and chest wall are minor. With daily IGRT, errors in TH1 LAT can be diminished effectively in the online match with couch shifts and rotations.

The residual errors to the humeral head were acceptable with daily IGRT in all the groups. Only moderate improvements were found if daily IGRT was used. The primary matching location in the images is not the shoulder joint and its location varies independently from other structures, which may lead to either increasing or decreasing the error after IGRT [7, 22].

Errors between the structures

The minimal residual rotation of the vertebrae is important, because besides PTV, it affects the dose to the heart and lung and even to the medulla if those rotate towards treatment field. We suggest daily rotation correction for patients with locoregional radiotherapy of breast cancer. Without IGRT, the random error in rotation was the smallest in Group A (2.0 mm). With AlignRT®, worse reproducibility in patient rotations has been seen with breast ROI [26, 27] than with the ROI covering a portion of breast tissue, sternum and the belt of the ribs caudally from breasts [11, 28].

Catalyst™ showed discrepancies between rotation values and the visual surface rotation, leading to different positioning workflows between the RTTs when correcting the rotation, and finally leading to larger random errors in vertebrae rotation in the images with SGRT only workflow when compared to Group A. When IGRT was used, all groups, including the laser setup, were almost similar. The errors in BHL (AP) were acceptable in all the groups. BHL verification and possible correction during the first fractions is an effective method to optimize the systematic position of the heart [5]. Training the BHs before CT could be useful [29]. Also baseline drift during FB needs to be taken into account in the workflows [30]. At the CT, the breathing baseline may be calculated several times before scanning, and with both RPM™ and Catalyst™ both during setup, and possibly after IGRT. It is important to coach the patient to always keep the same baseline in FB with the aid of visual guidance. In the CC direction, the further the sternum moves from its correct location, the larger is the risk for misalignment in locoregional lymph nodes [7]. Lowering the BHL window at the CT-simulation from the maximum inhale could improve the BH repeatability and decrease the possibility that patients lift their back during BH, while still improving the heart dose in comparison to FB [31].

Time used for imaging and treatment

In breast RT with SGRT, the addition of surface-based monitoring did not prolong the clinical workflow or treatment time [32]. In our study, the time used for imaging and treatment was even slightly shorter with the addition of SGRT.

Tangential image accuracy

Orthogonal imaging and couch shifts benefit tangential image accuracy remarkably in all the groups, the most in Group L and the least in Group A. This was shown especially in the percentages of fractions exceeding given thresholds. After daily IGRT, differences between the groups are clinically insignificant and residual errors are minor.

In the tangential images with Catalyst™ setup only, 1.2–1.6 mm SD for CLD is reported [33]. Here, 3.2 mm SD was found in Group C for CLD with SGRT only, due to larger uncertainties in the AP and LAT isocenter. In Group A 1.8 mm SD for CLD is similar with the literature [22]. With daily IGRT in Group A the matching location in the AP direction was systematically less weighted on the sternum. This led to only slightly larger systematic error in the AP/LAT direction in the tangential images, indicating that tangential image underestimates the errors in the sternum (AP). Thus, improvements may be more desirable with VMAT than with the tangential field RT technique. In general, after daily orthogonal imaging, the residual margins (up to 3 mm) on the chest wall in the tangential images were excellent in this study in all the groups, similar with earlier publications [18, 19, 2].

For soft tissue deformations, 8 mm optimizing bolus in VMAT is suggested [34, 35]. Here, the 4.3–7.0 mm margins for the soft tissue in the tangential images were within the optimization bolus thickness with daily IGRT in all the groups. With SGRT only, skin margins below 8 mm were found only in Group A. In Group L, the possibility to detect breast position and posture errors, such as deformation or swelling with laser setup is limited to kV or MV imaging, and even after IGRT, nearly 10% of fractions had misalignment of the breast outline larger than 8 mm.

Conclusion

Setup errors were evaluated with SGRT and with laser setup using RPM™. Using AlignRT® as primary setup tool, smaller variances in isocenter and rotations were found compared to Catalyst™ and particularly to conventional laser-based setup. Daily IGRT reduces the number of fractions with large misalignment in all groups. With daily IGRT, differences in setup errors between groups were mostly clinically insignificant. Daily IGRT is recommendable due to generally improved accuracy on whole PTV and to retain the 5-mm CTV-PTV margins with SGRT. Time used for the imaging and treatment was even slightly longer in DIBH with RPM™ than with SGRT, which strengthens the idea that SGRT can be considered as a better future solution over laser setup and RPM™.

Conflict of interest

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