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Surface guided 3DCRT in deep-inspiration breath-hold for left sided breast cancer radiotherapy: implementation and first clinical experience in Iran

Sara Abdollahi[1, 2], Mohammad Hadi Hadizadeh Yazdi[1], Ali Asghar Mowlavi[1], Sofie Ceberg[3], Marianne Camille Aznar[4], Fatemeh Varshoee Tabrizi[5], Roham Salek[5, 6], Alireza Ghodsi[7], Farideh Jamali[2]

[1]Physics Department, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran
[2]Medical Physics Department, Reza Radiotherapy and Oncology Center, Mashhad, Iran
[3]Department of Medical Radiation Physics, Lund University, Lund, Sweden
[4]Division of Cancer Sciences, Faculty of Biology, Medicine and Health, University of Manchester, Manchester, United Kingdom
[5]Radiotherapy and Oncology Department, Reza Radiotherapy and Oncology Center, Mashhad, Iran
[6]Radiotherapy and Oncology Department, Mashhad University of Medical Science, Mashhad, Iran
[7]Department of Statistics, Hakim Sabzevari University, Sabzevar, Iran

ABSTRACT

Background: The aim of the study is to evaluate the overall accuracy of the surface-guided radiotherapy (SGRT) workflow through a comprehensive commissioning and quality assurance procedures and assess the potential benefits of deep-inspiration breath-hold (DIBH) radiotherapy as a cardiac and lung dose reduction approach for left-sided breast cancer irradiation.

Materials and methods: Accuracy and reproducibility of the optical surface scanner used for DIBH treatment were evaluated using different phantoms. Patient positioning accuracy and reproducibility of DIBH treatment were evaluated. Twenty patients were studied for treatment plan quality in target dose coverage and healthy organ sparing for the two different treatment techniques.

Results: Reproducibility tests for the surface scanner showed good stability within 1 mm in all directions. The maximum position variation between applied shifts on the couch and the scanner measured offsets is 1 mm in all directions. The clinical study of 200 fractions showed good agreement between the surface scanner and portal imaging with the isocenter position deviation of less than 3 mm in each lateral, longitudinal, and vertical direction. The standard deviation of the DIBH level showed a value of < 2 mm during all evaluated DIBHs. Compared to the free breathing (FB) technique, DIBH showed significant reduction of 48% for heart mean dose, 43% for heart V25, and 20% for ipsilateral lung V20.

Conclusion: Surface-guided radiotherapy can be regarded as an accurate tool for patient positioning and monitoring in breast radiotherapy. DIBH treatment are considered to be effective techniques in heart and ipsilateral lung dose reductions for left breast radiotherapy.

Key words: motion management; surface imaging; DIBH; cardiac sparing

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Address for correspondence: Mohammad Hadi Hadizadeh Yazdi, Physics Department, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran; e-mail: mhhadi@um.ac.ir

Introduction

Cardiotoxicity, lung pneumonitis, and lung cancer are still the major topics of concern in left breast radiotherapy [1–6]. Morbidity and mortality have been shown to increase proportionally to the mean heart dose. It has been shown by Darby et al that the rate of major cardiac events increases linearly with the mean heart dose by 7.4% per Gray [2]. Moreover, the risk of radiation pneumonitis shows also a correlation with the mean lung dose or irradiated lung volume [3–5]. In addition to the proximity of the chest wall and heart in left breast radiotherapy, an important trade-off is related to internal mammary node (IMN) irradiation for patients with higher stage tumors that increase the heart dose due to the close proximity of the internal mammary chain. Following new clinical studies, the interest for IMN irradiation in breast radiotherapy has been increased recently with recommendation for advanced radiation techniques to manage the potential increase in pulmonary complications and cardiac toxicity [7–10]. A new retrospective cohort study of 1294 patients has demonstrated a similar effect of increasing mean heart dose between women without or with minimal risk factors and women with multiple risk factors in left breast radiotherapy. Therefore, it has been suggested that heart dose reduction strategies need to be implemented in the routine practice even in patients without any risk factor for cardiac disease [1]. Several radiotherapy techniques are used for more effective healthy organ sparing in left breast irradiation such as intensity-modulated radiation therapy (IMRT), prone position breast irradiation, and deep-inspiration breath-hold (DIBH) treatment [11–13]. DIBH radiotherapy can be used for further heart and ipsilateral lung dose reduction by creating an increased separation between the heart and the treatment volume. Studies have shown that the mean heart and LAD dose can be reduced by more than 50% as compared to the free-breathing technique [6, 14–19]. During implementation of a new technology like surface-guided DIBH radiotherapy, thorough quality control and frequent quality assurance measures should be carried out before the new technique becomes a well-integrated part of routine clinical practice. It has been emphasized by several international guidelines that implementing new advanced technologies in radiotherapy needs greater accuracy than conventional techniques and oversight in the treatment workflow to improve the treatment outcome [20, 21]. As recommended by Task Group 147 of the American Association of Physicists in Medicine (AAPM), the commissioning of a patient positioning and monitoring system requires system accuracy measurements, determining system limitations, and developing standard operating procedures and quality assurance programs [22]. In addition, quality management in radiotherapy specially with introducing new technology to the department will not be effective if it is not supported by a systematic and dynamic training program. This study aims to validate the overall accuracy of the surface-guided radiotherapy workflow through a comprehensive commissioning procedure and assess the potential benefits of DIBH radiotherapy as a cardiac and lung dose reduction approach for left-sided breast cancer irradiation. After safe implementation and safety validation, creating and maintaining a quality culture for motion management workflow is the final purpose of the current research.

Materials and methods

As a continuous quality improvement program, an effective heart-sparing radiotherapy technique incorporating DIBH was implemented for left-breast treatment in Reza Radiotherapy and Oncology Center (RROC), Mashhad, Iran, in 2019. About 770 breast cancer patients are treated each year using the 3DCRT treatment technique during free breathing; however, the surface guided DIBH technique using optical surface scanning (Catalyst™, C-rad Positioning AB, Uppsala, Sweden) has been commissioned on one linac (Siemens, Medical Solutions, Erlangen, Germany) in the clinic.

Commissioning and evaluation

The coincidence of the CT scanner isocenter and Sentinel™ optical surface scanner (C-rad Positioning AB, Uppsala, Sweden) isocenter were checked to stay within 1mm using a daily check device provided by the C-Rad company and any drift in the hardware causing changes to the coordinate system was inspected on a daily basis. A simulated couch profile for a real patient scan was obtained by placing weights on the treatment couch.

The couch sag compensation was also checked on a daily basis for a deviation of less than 1mm with the calibrated couch profile. A full end-to-end test from CT through treatment was also performed to check the accuracy of all the systems and appropriate data transfer between simulation, planning, and treatment delivery systems. For the end-to-end test, the CT image of CIRS IMRT thorax phantom (Model 002LFC, CIRS Inc, Norfolk, VA) and Alderson RANDO anthropomorphic phantom (Radiology Support Devices, Long Beach, CA, USA) were acquired using a Siemens Somatom Definition AS Open scanner (Siemens Medical Solutions, Erlangen, Germany). The isocenter coordinate of the CT scanner and Sentinel scanner were marked using radiopaque markers on the surface of the phantoms. CT images were transferred to the Prowess Panther (Prowess inc., Concord, CA) treatment planning system (TPS). The plan isocenter and phantom surface contour were then transferred from TPS to the catalyst optical surface scanner in the treatment room. According to the recommendation of the AAPM Task Group 147, the accuracy of all treatment machine components which may consider as a reference for optical scanner performance evaluation such as radiation and mechanical isocenter, localizing lasers and coach digital readout were checked [22]. The Catalyst (single camera configuration) system was tested for accuracy and reproducibility before clinical use. For the reproducibility test, a CIRS IMRT thorax phantom was scanned 30 times every 15 seconds, and the differences were recorded. For the accuracy test, both, the CIRS phantom, and the Alderson RANDO anthropomorphic phantom were manually shifted 30 times from 0.3 cm to 10 cm in each x, y, and z direction, and the offsets were compared with the measured shifts of the Catalyst™ scanner, as shown in Figure 1. Finally, the measured shifts by the Catalyst™ system were validated with Siemens Artiste electronic portal imaging (Optivue 1000ST, 41 cm × 41 cm active detector area with a matrix of 1024 × 1024 pixels) and Siemens Somatom Definition AS Open CT on Rail (Siemens Medical Solutions, Erlangen, Germany).

Patient inclusion/selection

A total of 23 patients were recruited to be treated with 3DCRT_DIBH for cardiac dose sparing when the heart dose criteria has failed at their free breathing (FB) plans. The inclusion criteria were that more than 10% of the heart volume receives 25 Gy in the 3DCRT_FB plan and that the patient is able to perform four consecutive DIBHs of 25 s each at a coaching session. The exclusion criteria were that the heart dose was not significantly reduced to meet the dose constraint in DIBH plan for any reason, and this decision was made qualitatively by radiation oncologist and medical physicist based on their best judgment. Three patients could not meet the inclusion criteria of DIBH treatment. Two patients could not comply with stable DIBH for 25 seconds at a coaching session, and one patient´s body costume obscured her chest which made it impossible to use the motion management system. Twenty patients receiving radiotherapy for left breast cancer in DIBH were prospectively included in this study, three patients without positive nodes received tangential treatment after breast-conserving surgery and seventeen patients with positive lymph nodes received locoregional treatment after either breast-conserving surgery (6 patients) or mastectomy (11 patients). All patients were treated with a conventional fractionated regimen (2 Gy in 25 fractions) and if indicated sequential boost to the tumor bed was applied with a dose of 5 × 2 Gy. The use of the radiotherapy database for this study has been approved by RROC research

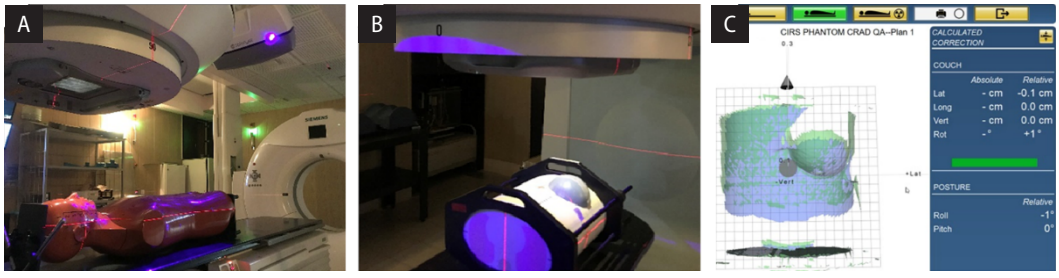

Figure 1. Accuracy and reproducibility tests for surface scanner using different phantoms

and education committee and the research ethics committee of the Ferdowsi University of Mashhad (IR.UM.REC.1400.317).

Patient coaching and CT simulation

To check if the patient had adequate DIBH chest breathing reproducibility, a coaching session was set for each patient. In the patient position the same as in FB planning CT, a reference surface was created using the Sentinel scanner where the Sentinel laser (Class 2M laser with λ = 635–690 nm) then swept over the patient surface and captured the skin within the scan volume. With optimum camera settings when the surface is as complete as geometrically possible with minimum noise, the "Prospective" (coached deep inspiration) study was performed with the Sentinel™ scanner. The location for a primary signal was established on the surface of the skin above the xiphoid process and the breathing baseline which is the maximum expiration during FB was assessed for each patient. Patients were then trained to inhale deeply through the nose, fill in the chest, and hold the breath for 25 seconds without any visual feedback and when the breathing was reproducible, a gating window of 3 mm was set about the patient-specific vertical displacement. The duration of breath-hold was limited to 25s, for fear that patients may lift their back from the treatment couch instead of filling the lungs with air during prolonged breath-holding. The gating window determines at what breathing amplitude registered at the primary gating point, the CT images should be acquired. When the gating window was set, the procedure was repeated using full audio-visual feedback (video goggles) and chest breathing reproducibility was assessed. If the patient's compliance for good DIBH was confirmed, an extra scan in DIBH was scheduled in a position similar to that of the FB planning scan. All patients who fulfilled the inclusion criteria were positioned using Orfit AIO breast and lung board (Orfit Industries NV, Wijnegem, Belgium) with their arms raised over the head and positioned on arm support. The medial tattoo for patient positioning during radiotherapy was placed at the midline of the patient in the plane of the greatest breast contour, and two lateral tattoos were placed at the same level (same transverse cut) as the medial tattoo. When the patient transits from free breathing to DIBH, the medial tattoo moves superiorly, and the lateral tattoos move anteriorly. Medial and lateral tattoos' displacements were measured and documented at the CT simulation session. Patients underwent supine computed tomography in free breathing and DIBH. The scan protocol was set to 3 mm slice thickness and images were acquired using a Siemens Somatom Definition AS Open scanner. The gating window, the surface scan, and the breathing baseline recorded by Sentinel™ would also be accessible by the scanner software in the linac room for treatment guidance. Selected patients were given video instruction for the DIBH technique and information regarding the limitations and benefits of the technique.

Treatment planning

All the targets and organs at risk (OARs) were delineated in both the DIBH and FB CT sets by radiation oncologists and all the delineated structures for all patients were reviewed to reduce the inter-observer and intra-observer variability. The breast clinical target volume (CTV) was delineated following the Radiation Therapy Oncology Group (RTOG) guidelines [23]. For node positive patients, ipsilateral axillary lymph nodes level II–III and lymph nodes in the supra- and infraclavicular fossa were also included in the CTV. For high-risk patients, IMN was also delineated and added to the CTV. Planning target volume (PTV) was then defined as a 5 mm margin to the whole CTV and CTV and PTV were retracted 3 mm from the skin surface. Bilateral lungs, contralateral breast, heart, LAD, and spinal canal were outlined as OARs. The heart was delineated from the apex to the inferior border of the left pulmonary artery and included all great vessels except the inferior vena cava [24]. The LAD arteries were delineated using a 6-mm brush considering the motion uncertainties from the left side of the ascending aorta as far as it could be visualized, often to the middle of the heart. All the DIBH and FB treatment plans consisted of 3DCRT plans using two parallel opposed tangent beams for the breast and chest wall, as well as anterior-posterior fields for regional lymph nodes irradiation. One or two additional segments were used for each tangent beam to improve the dose homogeneity. For FB plans, a combination of electron and photon beams was used for high-risk patients with central and medial lesions and pos-

itive axillary nodes. The Prowess Panther version 5.5 (Prowess inc., Concord, CA) treatment planning system was used for organ delineation and 3DCRT dose planning with Collapsed Cone Convolution Superposition (CCCS) algorithm using a dose grid resolution of 0.3 × 0.3 × 0.3 cm. The linac which has been modeled in Prowess was Siemens Artiste with 160 MLC and each leaf projects a 5 mm thickness at isocenter. The dose rate was 300MU/min for 6MV photon beam and 500 MU/min for 15MV photon beam. All plans were optimized with at least 95% of the total CTV covered by the 95% of prescribed dose of 50 Gy in 25 fractions. As for plan acceptability analysis, adherence to radiotherapy protocol guidelines was of a major concern for clinicians to reduce the risks of treatment failure and overall mortality. A qualitative assessment was made by evaluating the dose distributions slice-by-slice to assure of adequate target coverage and OAR sparing for each patient. The location and magnitude of "hot" and "cold" spots within the PTVs were also assessed for each plan; *V5*, *V*20, *V*40 and D_{mean} to the ipsilateral lung; *V5* and D_{mean} to the contralateral lung, *V*25, *V5,* and D_{mean} to the heart, D_{mean} to the LAD, and mean dose to the contralateral breast were used for the plan comparisons. Quantitative evaluation of possible protocol deviation was made according to the QUANTEC dose-volume data and Emami normal tissue tolerances (25, 26). V25 <10%, and D_{mean} < 26 Gy were considered for the heart as parameters related to the risk of long-term cardiac mortality and pericarditis. V20 < 30% was assessed for the ipsilateral lung for the risk of symptomatic pneumonitis. There was no reported threshold by QUANTEC and Emami et al. related to a specific endpoint for some of our reported evaluation indexes. However, the mean dose was reported for all the organs at risk, as this is the most used parameter in literature [2, 3]. V5 was also reported as a parameter related to the volume receiving a low dose which may be of further interest for future comparisons of 3DCRT dose delivery with intensity modulation radiation therapy (IMRT) technique.

Statistics

Independent-samples Mann-Whitney U test was used to demonstrate if there is a significant difference between two techniques. The level of statistical significance was set at $p < 0.05$. All statistical tests were performed in SPSS software (v. 27.0, IBM Corporation, Armonk, NY, USA).

The DIBH treatment workflow

After treatment plan approval by a senior physicist and radiation oncologist, the plan data including isocenter and patient body contour were exported to the Catalyst™ system (C-RAD AB, Sweden) in the treatment room. When the patient was well positioned at isocenter according to the plan, an optical scan was performed by Catalyst™ scanner and the offsets were then calculated by the c4D software in 6 degrees of freedom. The position and motion of the patient during the DIBH treatment were tracked online and compared with a reference DIBH image. Before starting the treatment, the calculated offsets by the Catalyst™ were validated by the electronic portal imaging for every fraction of all patients. The clavicular bone, sternum, and thoracic vertebral body were used as bony landmarks for orthogonal megavoltage image registration. During the treatment, the translational and rotational isocenter shifts were continuously reported by the c4D software and the reported target shifts, caused by any motion during the treatment, were analyzed for all fractions. The plan isocenter shifts were assessed to check intrafractional DIBH isocenter reproducibility during the beam-on time during 10 fractions for each patient. The real-time isocenter position during the radiation, the breathing baseline, the width of the gating window, and the beam on/off status were driven from the c4D software (Fig. 2). The maximum difference between different DIBH levels was assessed as the reproducibility of the DIBHs, and the stability was also attributed to the maximum amplitude change between the initial and final points of a DIBH among all the DIBHs for each patient, as defined by Cervino et al. [27].

Continuous quality improvement program

To improve the quality and effectiveness of the new implemented technology, a vigorous program of continuous training for medical physicists and radiation therapists was instituted to help them hone their knowledge and practical skills in motion management applications. After

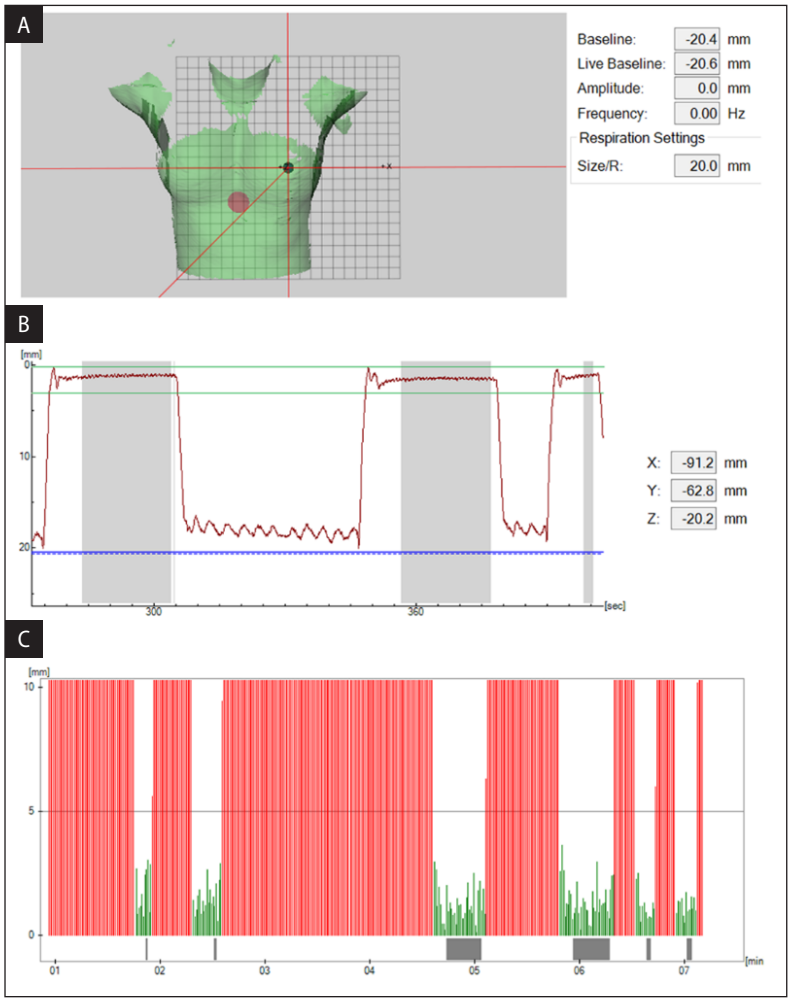

Figure 2. A. patient surface scanned by Catalyst scanner in the treatment room. The red spot on the patient surface is monitored by the scanner for the vertical amplitude; **B.** The respiratory signal recorded by the surface scanner shows the stable deep-inspiration breath-hold (DIBH) during the "beam on time" shown by gray bars; **C.** graphical representation of the isocenter shift recorded by the surface scanner during one fraction illustrates mean deviation of about 1mm during the "beam on time" shown by gray areas

general training for 10 medical physicists and 10 radiation therapy technicians, complex parts of the DIBH workflow where errors are more probable were analyzed and identified and the complementary training was implemented accordingly. The effectiveness of the training for each individual was then evaluated by the Chief Quality Officer and new revision on future training programs was considered if needed. Standard operating procedures for patient coaching, use of the optical surface scanners and related quality control checks were created and kept at a shared drive for easy and fast access of the team. As the team experience in system application and patient treatment improve with time, the procedures were updated annually with minor revisions.

Results

Commissioning and evaluation: results of phantom study

For the results of the phantom study, reproducibility tests for the optical surface scanner with CIRS and Rando Alderson phantom showed good stability within 1 mm in all lateral, longitudinal, and vertical directions. Accuracy analysis showed that the maximum position variation is within 1 mm in all directions between applied shifts on the couch and the scanner measured offsets which is consistent with the recommendations of Task Group 142 of AAPM for conventional delivery [28]. The offsets reported by Catalyst, portal imaging, and CT on rail, compared to the CT simulation

baseline, showed good agreement with the isocenter position deviation of less than 2 mm in each lateral, longitudinal, and vertical direction for CIRS phantom and RANDO phantom (Head and Neck, Thorax, and Pelvic scan areas).

Results of patient study

DIBH coaching and patient's compliance

Patient coaching before simulation could potentially reduce the lengthy time in the simulation process for the DIBH technique and improve the reproducibility of DIBH. The audio-visual feedback improves the DIBH stability as shown in Figure 3. This figure shows that the patient drops in her gate continuously without the visual feedback. Such an instability in the gate was not observed for all patients and some of them were more stable at their level even without visual guidance at the first DIBH. This is while they were not able to reproduce it for the consequent DIBHs without visual guidance. In most of the cases both DIBH stability and reproducibility were improved using visual guidance and no patient had problem in interpreting the goggle feedback.

Treatment plan evaluation for different treatment techniques

Compared to the 3DCRT_FB, the lung volumes were increased 58% with a standard deviation of 10% in the 3DCRT_DIBH scans for all patients. Regarding the treatment planning dose-volume metrics, in 3DCRT_DIBH compared to 3DCRT_FB practice, the mean dose V20, and V5 for the left lung were reduced on average about 23%, 33%, and 20%, respectively. The average dose reduction for the mean dose, V25, V5 and D5 of the heart was about 48%, 43%, 33%, and 32%, respectively. The mean dose received by LAD and contralateral lung were also reduced by 27% and 35 % respectively for the 15 patients. The dose homogeneity for the targets was nearly the same for DIBH and FB as the beam setting and the dose calculation algorithm (CCCS) were the same for the two techniques. For high-risk patients, the combination of electron and photon beams reduce the volumes

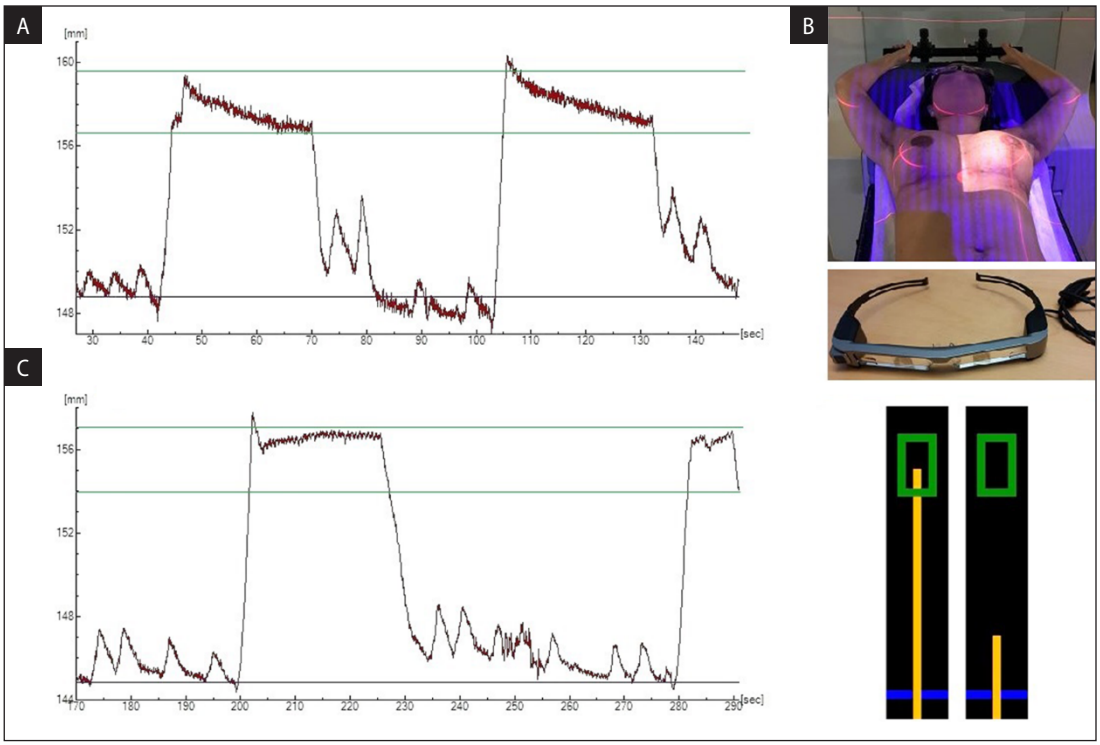

Figure 3. A. The deep-inspiration breath-hold (DIBH) level instability with no visual guidance; **B.** Visual guidance using goggles; The green box is a gate showing the optimal maximum and minimum levels for breathing; the orange bar shows the height of the breathing curve for the primary signal, and the baseline is shown with a blue line. **C.** Goggle visual guidance can improve inspiration level stability significantly

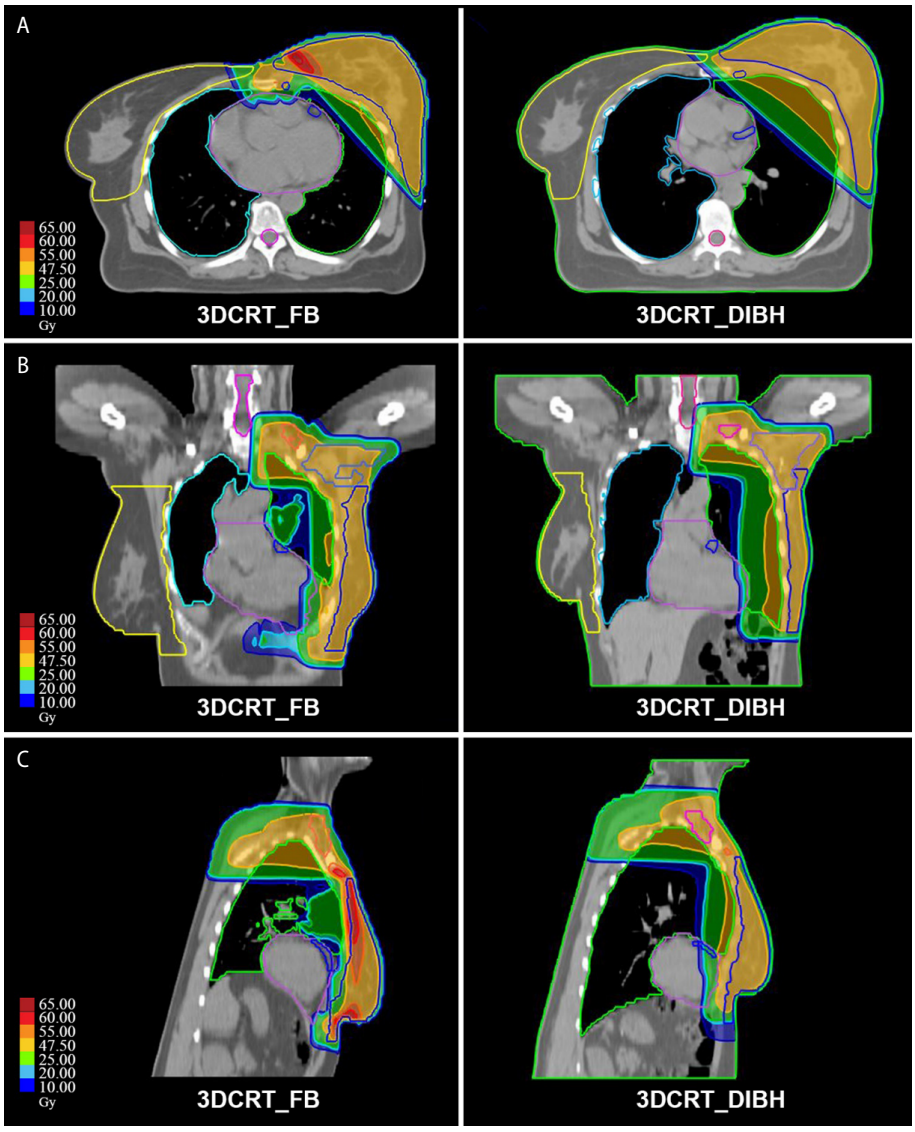

Figure 4. Typical color-wash dose distributions of different treatment plans in the axial, coronal, and sagittal planes. 3DCRT — three dimensional conformal radiation therapy; FB — free-breathing; DIBH — deep-inspiration breath-hold

of the lung and heart receiving the high doses in FB plans. This is while the volumes of the lung and heart which receive low doses were increased compared to the only-photon beam selection. As another caveat, the mismatch of the electron and photon beam penumbras introduced a "cold" area within IMN target and a "hot" area inside the tangential fields irradiated volume as shown in Figure 4. This may be even more prominent when the daily positioning errors at treatment time are added. Choosing only-photon tangential beams for improving the target coverage homogeneity will also compromise the heart and lung doses in 3DCRT_FB plans. This is while this beam arrangement provides reasonable target coverage for both IMN and breast without compromising the heart and lung doses in 3DCRT_DIBH plans as shown in Figure 4.

These statistical results for comparison of DVH values between different techniques are shown in Figure 5. For all of the dosimetric parameters, Independent-samples Mann-Whitney U test shows that 3DCRT_DIBH has significant improvement in normal tissue dose sparing compared to the FB technique ($p < 0.05$). The statistical similarity in dose-volume parameters were indicated by different letters (a, b) in the Box Plots.

Regarding the protocol deviation evaluation, for both 3DCRT_DIBH and 3DCRT_FB techniques, the medial part of the supraclavicular

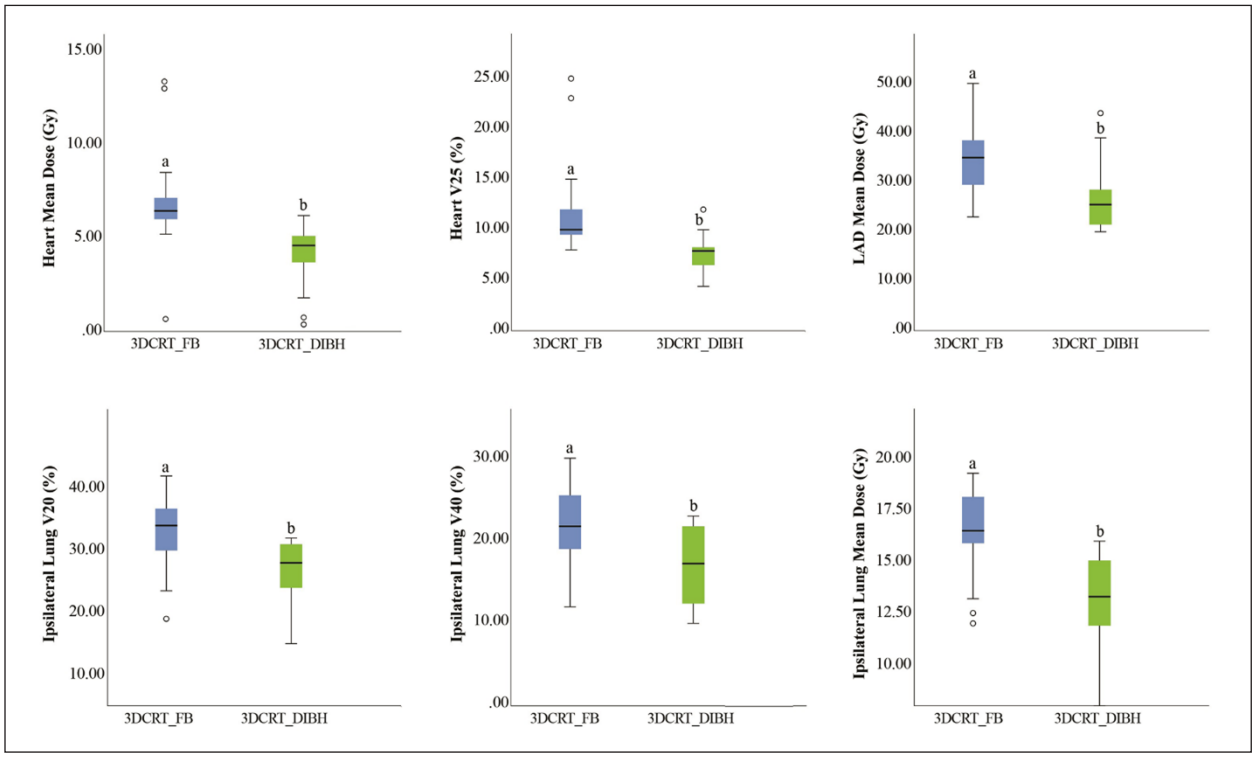

Figure 5. Box plots of mean heart dose, heart V25, mean LAD dose, ipsilateral lung mean dose, and ipsilateral lung V20 and V40. V_x is the volume (%) receiving x dose (Gy) or higher. The circles indicate the outlier values and different letters (a, b) indicate the statistical similarity in dose-volume parameters. 3DCRT — three dimensional conformal radiation therapy; FB — free-breathing; DIBH — deep-inspiration breath-hold

fossa target had not been fully covered by 95% of the prescribed dose for the majority of the patients as the anterior beam was angled for spinal cord sparing and the medial of the CTV was placed at the beam penumbra region. Therefore, there is a concern that 3DCRT planning with almost margin free nodal irradiation at medial part may lead to inadequate coverage of supraclavicular fossa CTV to spare the spinal canal. In 3DCRT_FB plans, the heart dose constraint (V25 < 10%) was not met for any patient, and the ipsilateral lung dose objective of (V20 < 30%) was only met for three out of twenty patients. The heart dose objective was met for all patients in 3DCRT_DIBH plans. Regarding the ipsilateral lung, the dose objective of (V20 < 30%) was met for fifteen out of twenty patients, and V20 was between 30 to 33% for five patients, which shows a maximum violation of about 3% from the protocol.

Although all patients can benefit from DIBH in heart and lung dose reduction, the amount of the benefit depends on the depth of DIBH. Patients who can perform appropriately both thoracic and abdominal deep inspiration would have the most dose reduction in the heart and lung. Figure.6. showed free breathing and DIBH CTs in fusion overlay demonstration for three different patients. Patient (A) and patient (B) can get the most benefit from DIBH in both heart and lung dose reduction due to the significant chest and diaphragm displacement. Patient (B) and patient (C) had less dose reduction due to in adequate abdominal breathing but still had less heart and lung dose compared to the free breathing plans. For both patients we considered an extra coaching session to improve the breathing technique and both attempts were not successful as it is not easy to change the normal breathing pattern and it may not be a good solution as it may cause non-reproducible DIBH in treatment sessions.

Treatment Delivery in DIBH

Regarding the DIBH stability analysis, vertical deviations in mm over time were plotted in one treatment fraction for one patient consisting of 7 DIBHs in Figure 7.

For clinical practice, the 20 patients treated in DIBH, could effortlessly perform the reproduc-

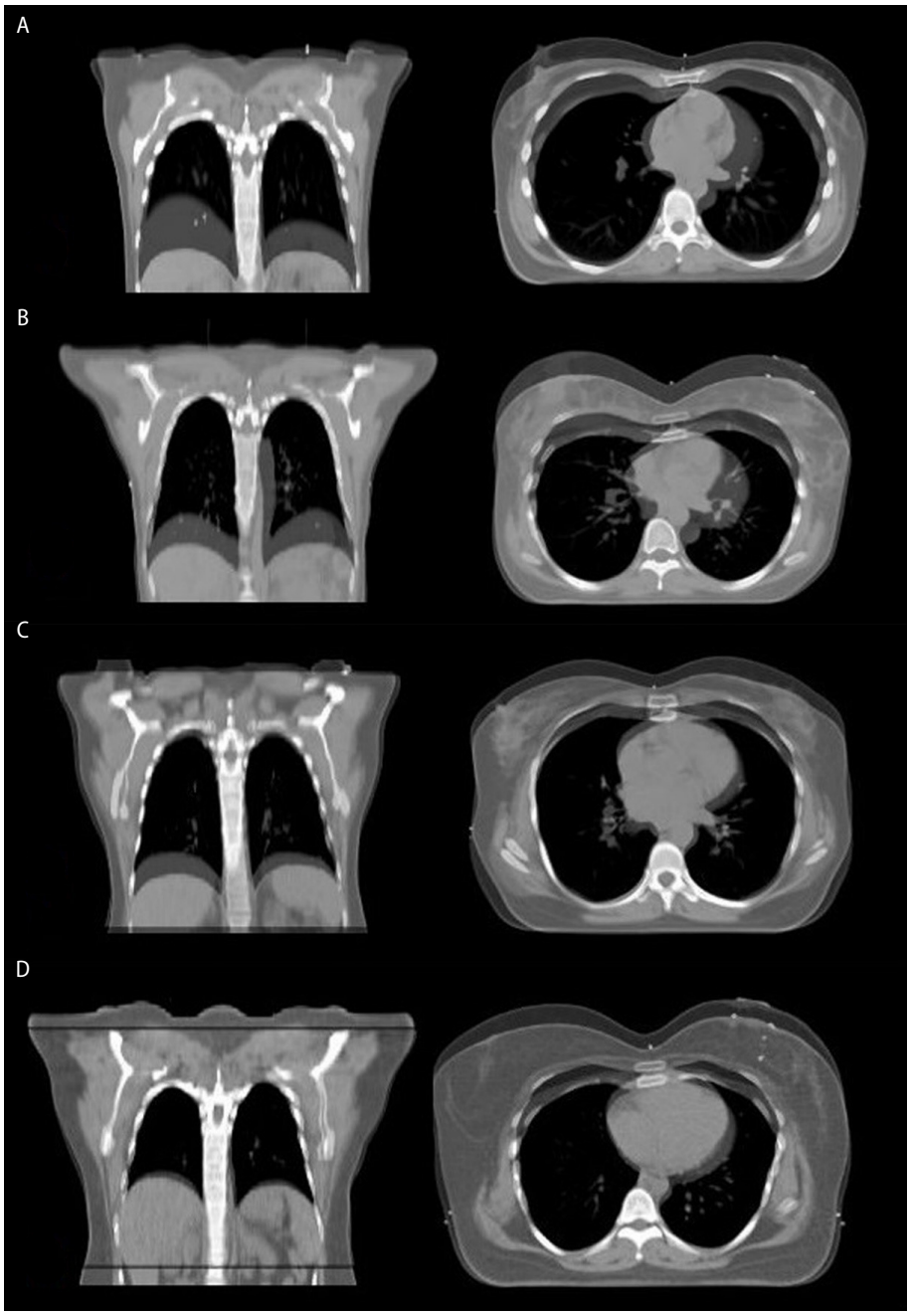

Figure 6. Chest and diaphragm movements during deep-inspiration breath-hold (DIBH) for different patients. **A, B.** Patients with significant heart and lung dose reduction in DIBH; **B, C.** Patients who had less heart and lung dose reduction in DIBH due to the inadequate diaphragm movement

ible DIBH workflow in all treatment fractions with a mean breathing amplitude of 14mm (range: 9 to 22 mm). The clinical study of 200 fractions also showed good agreement between Catalyst™ and portal imaging, with the isocenter position deviation of less than 3mm in each lateral, longitudinal, and vertical direction for all fractions. The standard deviation of the DIBH level showed a value of < 2mm during all evaluated DIBHs as shown in Figure 8. The differences between the maxima and minima amplitudes of breathing for all DIBHs of a patient were calculated. The average of all differences for all patients showed a mean value of 1.6 ± 0.6 mm. The average isocenter deviation recorded by scanner online monitoring was 2 ± 0.9 mm for all the recorded fractions.

For 3 patients, an overshoot in respiratory signal was observed at the beginning of the DIBHs,

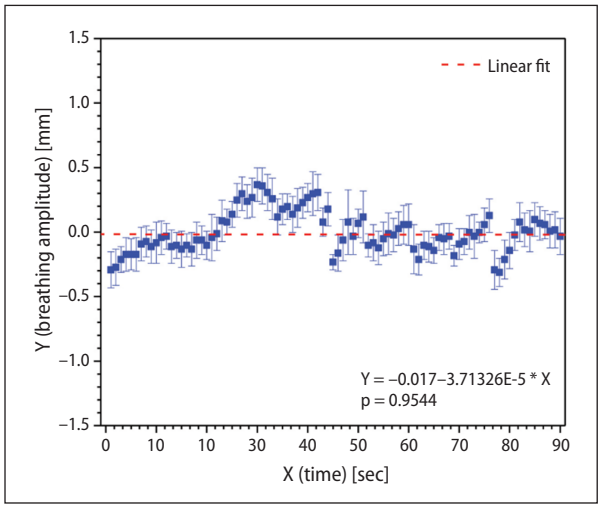

Figure 7. Vertical deviations in mm over time in one treatment fraction. The vertical axis shows the 3 mm gating window and the motion within the gate. The horizontal axis shows the whole treatment time for 7 deep-inspiration breath-holds (DIBHs)

as they reached the DIBH level fast, and then tried to find the middle of the gating window (Fig. 9). The rest of the patients had appropriate control on their DIBHs by slowly breathing up to the gating window.

Regarding the workload comparison for FB and DIBH workflows, both techniques are comparable in the first fraction. The overall treatment time (from when the patient enters the room till she leaves it) required for the first fraction was normally longer than another fraction for both FB and DIBH dose delivery with about 20 minutes. The workflow time may be increased to 30 minutes in both techniques for patients who have setup challenges such as those who have large or pendulous breasts or obese patients who were more prone to more set up errors and whom it took longer to mount and dismount the bed. For the rest of the fractions, DIBH workflow was assessed to be more efficient in time as patients do not need daily electronic portal imaging and can be safely treated by SGRT with less overall dose. The overall treatment time in the normal fractions was between 10 to 15 minutes with 300MU/MIN dose rate which is the highest available dose rate for 6MV photon beam with Siemens Artiste linac.

Continuous quality improvement program

Systematic and dynamic staff training has effectively reduced the gaps in staff's knowledge and provided a continuous quality improvement in the whole workflow. Any changes in the standard workflow of a radiotherapy department would involve operational costs at the initial steps, and our dynamic training program and creating and sustaining a quality culture helped changes take place more easily with minimum cost and maximum patient safety.

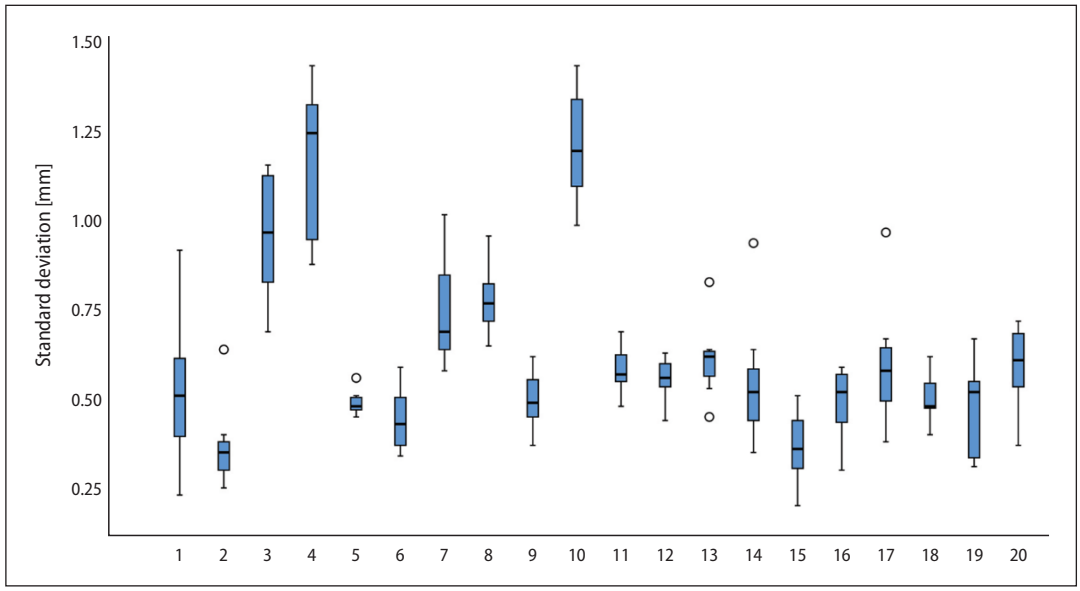

Figure 8. Box plots of standard deviation of the deep-inspiration breath-hold (DIBH) levels for each patient. The circles indicate the outlier values for 5 patients

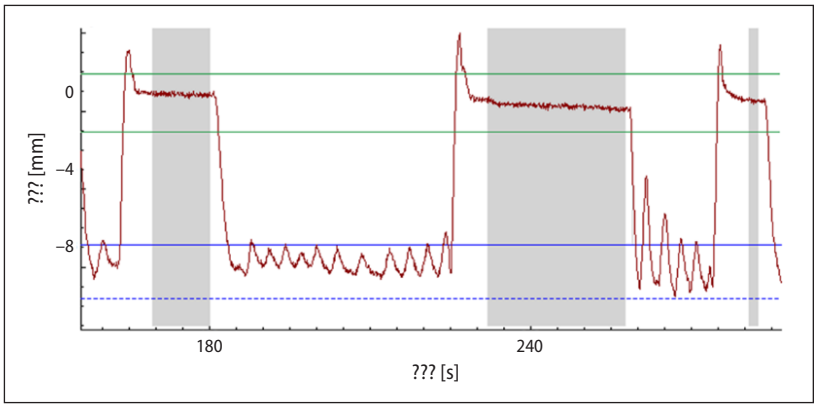

Figure 9. The breathing curve with three breath holds covering 3 radiation beams are shown by the grey bars. An overshoot in respiratory signal can be seen at the beginning of each deep-inspiration breath-hold (DIBH). The radiation is manually controlled to be delivered over the time in which the patient is stable at the gate

Discussion

Radiation therapy for breast cancer has evolved to decrease cardiac and lung toxicity with deep inspiration breath hold radiotherapy. We strive to evaluate a possible optimized approach to improve the efficacy of left breast irradiation in terms of better tumor dose coverage and normal tissue sparing. In the deep inspiration breath hold condition, intra-fractional monitoring of the patients' surface was performed using an optical surface scanner. As reported by several studies (29-38), this study also shows that optical surface scanning as a non-ionizing motion monitoring technique, could be considered a reliable method for accurate position verification and monitoring. Visual feedback using goggles also assists patients to have stable and reproducible DIBH which allows radiation margin reduction and a better tissue sparing. The advantage of visual feedback in DIBH stability and reproducibility has also been reported by Cervino et al. Vikström et al. and Damkjær et al. [27, 39, 40] Regarding the patient preparation before CT simulation, although several clinical practices and studies suggest 10–15 minutes of coaching before CT simulation, the RROC practice is based on a separated coaching session at least one week prior to the CT simulation appointment. For some patients who need more practice for stability and reproducibility, the workflow consists of several coaching sessions with self-practice at home according to a video instruction. It has also been reported by Kim *et al.* that simple coaching and time for self-practice at home at least 5 days before the CT simulation procedure will gradually improve patients' skills in co-ordinating thoraco-abdominal muscle function and further reduce cardiac dose in patients undergoing DIBH for left breast cancer [41]. In the current study, the majority of the patients who were candidate for DIBH CT simulation could not perform the DIBH practice as per protocol during the first coaching session, while they successfully performed stable and reproducible DIBHs after video coaching and self-practice at home in the second or third coaching session. All the coaching session were supervised by medical physicists. As "Communicating the Role of Medical Physicists to the Public" was the adopted theme of the International Organization of Medical Physicist for 2021, we also believe that patients need medical physicists to allay their safety concerns and answer their highly technical questions. The DIBH workflow at RROC starts by effective role of clinical medical physicists at coaching session to reduce patient anxiety by revealing the mystery of motion monitoring and radiation scan or delivery. By all the efforts the team has made for patients coaching and preparation, three of twenty patients could not comply with the DIBH technique and other possible cardiac and lung dose reduction approaches maybe investigated for these patients. It has also been reported by Gaal et al. that about one-third of 130 patients in their study did not benefit from that otherwise laborious procedure. Twenty-six patients were not suitable for the technique and heart or LAD dose constraints were not met in the DIBH plans for 16 patients [42]. For evaluating the efficacy of DIBH for plan

parameters improvement, 3DCRT_DIBH was significantly effective in dose reduction of normal tissues compared to the 3DCRT_FB technique. The current study shows the average mean dose to the heart of 6.63 ± 2.96 Gy with 3DCRT_FB and4.08±1.82Gywith3DCRT_DIBH.TheLADmean dose is 35.15 ± 7.10 Gy, and 26.63 ± 6.40 Gy for 3DCRT_FB and 3DCRT_DIBH plans respectively. A significant improvement in both mean heart doses (the relative dose reduction range: 25–67%) and mean LAD doses (the relative dose reduction range: 20–73%) in DIBH, compared to FB were also reviewed by Morsy et al. from 16 different studies [43]. The study of different cardiac-sparing optimization methods for early-stage left-sided breast cancer patients done by Mathieu *et.al* showed that the average mean dose to the heart was 3.2 ± 0.8 Gy with FB and 1.1 ± 0.3 with DIBH. The LAD mean dose was 27.0 ± 6.30 Gy and 8.0 ± 7.60 Gy for FB and DIBH plans respectively [14]. The reason for higher heart and LAD mean doses reported in the current study compared to the studies mentioned above is that most of the patients in the current study have locally advanced left breast cancer with supraclavicular, axillary, and internal mammary lymph nodes involved in radiation fields. Another possible reason for more heart and LAD dose reduction in Mathieu *et al* study may be that inverse planning was used for the FB and DIBH plans in the above study while in the current study the treatment planning algorithm is forward planning which is not able to provide intensity modulation and concave shape dose distribution around the LAD and heart. Lung dose reduction in DIBH plans compared to the FB was observed for all patients which makes DIBH an appropriate lung dose reduction approach for right breast irradiation. Heart, LAD, and liver dose reduction in DIBH compared to the FB for right breast irradiation was also reported by other researchers [44, 45]. Regarding the possible target underdosage at the medial part of the supraclavicular fossa or cold area in the superficial regions of the breast in both 3DCRT plans, one may think of implementing IMRT techniques such as Helical Tomotherapy that can overcome the challenge with dose delivery through multiple beam angles. However, there is a trade-off for increasing the low dose received by the contralateral breast and lung due to the multiple beam angle passing through these organs [13, 46]. Authors are interested to evaluate the efficacy of helical tomotherapy for cardiac and lung dose management as well as tumor dose coverage as an alternative for DIBH treatment for patients who cannot comply with DIBH maneuver in the future study. Regarding the dose delivery challenges, for some of the patients in this study a baseline drift of the normal breathing signal has been observed after each DIBH compared to the baseline before starting DIBH maneuver as it takes time for the muscles to be relaxed after each DIBH. This phenomenon has already been reported by other studies [26, 47]. Cervino et al. considered 60 s. rest after each DIBH to be appropriate to avoid fatigue of the individual [27]. In the current study we tried to reduce the drift for each individual via active audio feedback asking the patient to have deep expiration after DIBH and be more relaxed. Changes in DIBH respiratory pattern were also distinguished for three patients in some fractions. Although they were stable at their breathing gate, isocenter position deviations were reported by the scanner as the DIBH position did not match the DIBH reference surface. The majority of the reported out-of-range isocenter shifts were solved with the re-positioning of the patients. For the fractions where re-positioning could not solve the issue, the level of inspiration was verified with portal imaging by comparing the separation between the sternum to the anterior vertebral bodies as per the recommendation of the AAPM Task Group 302 [48].

One limitation of the current study is the small number of patients which did not allow us to make the comparison in subgroups of early-stage/locally advanced patients or targets with or without IMN. Further analysis with enough statistics and less heterogeneous patient characteristics may be of interest for future studies. Current study has not evaluated the temporal accuracy or latency for dynamic radiation delivery. The results of dynamic localization accuracy with a home-made motion phantom would be reported in a future study.

Conclusion

Surface guided radiotherapy as a real-time and non-invasive position and respiratory monitoring technique was successfully implemented with minimal impact on workload and treatment time for left breast radiotherapy at Reza Radiother-

apy and Oncology Center in Mashhad. We have showed that left sided breast cancer patients receiving surface guided radiotherapy in DIBH, will receive decreased mean heart and ipsilateral lung dose compared to the conventional treatment in free breathing. Other alternative for the heart, LAD and lung sparing needs to be investigated for patients who cannot be candidates for DIBH due, for instance, to non-reproducible breathing pattern. Systematic and dynamic training and creating standard operating procedures will improve staff performance, decrease their anxiety in decision-making dedicated to each patient, and ultimately improve treatment quality and patient care.

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