Technical Note

Deep Inspiratory Breath-Hold Radiation for Left-Sided Breast Cancer using Novel Frame-based Tactile Feedback

Sapna Nangia[1,2], Robin Khosa[1], Divya Piyushi[1,3], Maneesh Singh[1,4], Grishma Singh[1,5], K. Sreedevi[1], Sunil Kumar Chauhan[1], Sanjay Kumar Rout[1], Saji Oomen[1]

[1]Department of Radiation Oncology, Indraprastha Apollo Hospital, [3]Department of Medical Oncology, Max BLK Hospital, [5]Department of Medical Oncology, Max Hospital Patparganj, [2]Department of Radiation Oncology, Apollo Proton Cancer Centre, Chennai, Tamil Nadu, [4]Department of Radiation Oncology, Tata Memorial Centre, Mumbai, Maharashtra, India

Abstract

A frame providing tactile feedback for the reproducibility of deep inspiratory breath-hold (DIBH) is described. The frame, fitted across the patient, comprises a horizontal bar, parallel to the patient's long axis, and holds a graduated pointer perpendicular to it. The pointer provides individualized tactile feedback for reproducibility of DIBH. Within the pointer is a movable pencil, bearing a 5 mm coloured strip which becomes visible only during DIBH, and acts as a visual cue to the therapist. The average variation in separation in the planning and pretreatment cone-beam computed tomography of 10 patients was 2 mm (confidence interval 1.95–2.05). Frame-based tactile feedback is a novel, reproducible technique for DIBH.

Keywords: Cost-effective, deep inspiratory breath-hold, reproducibility, tactile feedback

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Introduction

Cardiotoxicity of radiotherapy for breast cancer has been correlated with the mean heart dose (MHD)[1] as well as with the dose to cardiac substructures.[2]

Notwithstanding a gradual decline, over time, in the cardiotoxicity of breast radiotherapy,[3] guidelines recommend attention to reducing the dose to the heart.[4] The technique that has had the maximum acceptance in reducing MHD is radiotherapy during deep inspiratory breath-hold (DIBH).[5-7]

The various methods described for DIBH are resource intensive. These include tracking of respiratory excursion and gating using infrared markers devices placed on the patient's chest/abdomen, tracked by a camera[5,6] or using a valve-based spirometer that helps the patient to reach the index lung volume, i.e., the lung volume attained during simulation.[7] In addition to the above-mentioned systems provided by vendors of radiotherapy equipment, there are other techniques based variously on imaging the surface of the patient, i.e., surface guidance,[8] a wearable belt or laser tracking of respiratory movement.[9]

Despite the demonstrable advantage of DIBH, resources, time allocation, difficulties in breath-hold, and anatomical variations are some of the challenges encountered in the implementation in low- and middle-income group countries.[10] Application of DIBH is not universal even in the developed world, resources being a deterrent. In a survey of 82 radiation departments in German-speaking countries, Duma *et al*. noted that the most frequent deterrent to offering cardiac sparing techniques to all patients, noted in 46.5% of participants, was time/resource consumption.[11]

Less resource-intensive methods have been described. A noncommercial, voluntary breath-hold system based on using in-room cameras zoomed in to confirm the matching of in-room lasers with skin marks, the beam being interrupted manually[12] was used in the UK Heart Spare trial and has also been described by Conroy *et al*.[13] This however did

Address for correspondence: Dr. Sapna Nangia, Department of Radiation Oncology, Apollo Proton Cancer Centre, Dr. Vikram Sarabhai Instronic Estate, Taramani, Chennai - 600 096, Tamil Nadu, India.
E-mail: sapna_nangia@outlook.com

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not mandate a feedback; the latter is known to improve reproducibility of breath-hold.

We discuss a cost-effective device, Respiframe (patent application filed), developed in-house in 2017, that helps ensure reproducible breath-hold; the frame provides tactile feedback for reproducibility and a fluorescent strip, acts as a visual cue to the radiotherapy technologist (RTT) that the breath-hold is maintained. While we have used automated gating using the infrared marker system of Novalis Tx, this frame has the potential to be used for manual gating also.

Materials and Methods

Technical innovation

Device to ensure daily replication of DIBH position for gating using Exactrac. The device may also be used for manual gating.

Respiframe [Figure 1] is a C-shaped rectangular frame made of PA12 (Polyamide 1200, engineering grade nylon, from HP Development Co. LP Dallas, USA), designed to fit into slots of the baseplate of the All in One System (Orfit Industries, Wijnegem, Belgium). It has a horizontal extension bar, with centimeter-spaced, toothed markings, extending forward from the middle arm of the C frame, parallel to the patient's body, positioned lateral to the midline, on the right side. The extension of the bar can be varied in a reproducible manner using a gear-based mechanism. This horizontal bar holds a graduated pointer with a tapered end, perpendicular to the bar; this pointer has a scale and fixation slots every 5 mm. Within the pointer is a movable pencil, that touches the patient's skin. The lower end of this pencil extends 5 mm below the pointer and is tapered to a smooth point; the superior end has a 5 mm fluorescent yellow strip [Figure 1].

Figure 1: Respiframe (a). Horizontal bar (b). Pointer with scale to provide individualized tactile feedback to replicate DIBH position (c). Movable pencil in expiration (d). Movable pencil in DIBH position revealing (e). Fluorescent strip. DIBH: Deep inspiratory breath-hold

Workflow

Training for deep inspiratory breath-hold

Patients with left-sided breast cancer requiring radiotherapy as per usual recommendations, previously assessed and noted to be able to hold their breath in deep inspiration for at least 15 s, were taken up for DIBH training. The Respiframe was used as noted below.

Replication of deep inspiratory breath-hold using frame

The frame was placed across the patient. Each patient held her breath in deep inspiration as coached and the position of the pointer was adjusted such that its lower end touched the patient when she held her breath in deep inspiration. The position was documented on a graduated scale on the pointer.

The height of the movable pointer was fixed depending on the depth of inspiratory breath hold for each patient individually. The movable pencil, which protrudes 5 mm outside the lower end of the pointer, was pushed up vertically within the pointer, when the patient inspired, which in turn, made the fluorescent strip, at its opposite end, visible. The pointer-pencil combination provided tactile feedback to the patient regarding the position of the breath-hold. This ensured that the breath-hold position could be reproduced for each treatment fraction.

Planning computed tomography scan

Patients underwent a helical computed tomography (CT) scan from chin to umbilicus in DIBH as well as while breathing freely. A radiopaque wire was used to help identify the mastectomy/lump excision scar. Besides external fiducials for triangulation, a radio-opaque marker was placed in the infra-clavicular region, as required for the ExacTrac software. A 5 mm bolus was placed on the chest wall in postmastectomy patients.

Planning

Treatment was planned on the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, USA) utilizing the AAA algorithm and RapidArc technique, using partial arcs. The frame was included in the external contour for calculation.

Treatment using the frame and BrainLab gating system

Patients were treated on a Novalis Tx linear accelerator after informed consent. To ensure replicability of breath-hold as during simulation, each patient was prompted to take a deep breath and hold her breath to touch the pointer which was positioned in the previously noted graduated marking.

This defined the breath-hold level for the ExacTrac system, using a combination of the static IR markers, placed on a horseshoe frame and movable IR markers, placed on the patient's trunk. The breath-hold was tracked using the gating software of the Brainlab system which tracks markers placed on the patient's body, using a ceiling-mounted infrared camera, both during imaging and treatment delivery.

Cone beam CT/orthogonal Kv images were verified before the delivery of radiation. In orthogonal images, concordance was ensured between Digitally Reconstructed Radiograph (DRRs) and pretreatment images for the vertebral body and sternum in the lateral view and sternum and rib cage in the anteroposterior (AP) view.

Using the gating software in Novalis Tx, the treatment beam was automatically gated for delivery when the breath-hold was within the target range.

Offline analysis

Retrospectively, axial images of planning CT scan and weekly cone-beam computed tomography (CBCT) scans of patients with at least 3 CBCT images were analyzed to ascertain reproducibility. The following measurements were taken [Figure 2a and b].

- AP separation between the posterior edge of the sternum and the anterior edge of the vertebral body in an axial plane, 7 cm inferior to the cranial sternal edge
- Lateral separation of the ribcage, 7 cm posterior to the posterior edge of the sternum, and 7 cm inferior to the cranial sternal edge.

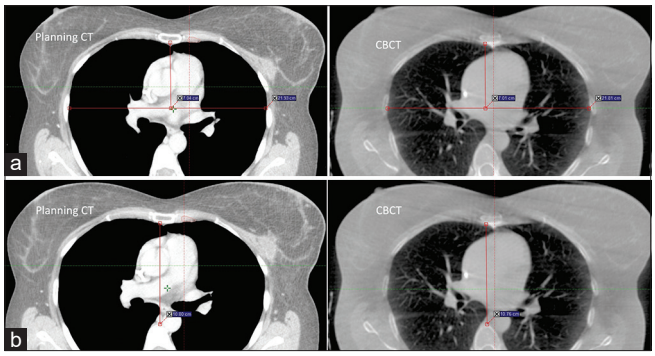

Figure 2: (a) Lateral separation of the ribcage measured, 7 cm posterior to the posterior edge of the sternum, and 7 cm inferior to the cranial sternal edge in the planning CT and CBCT. (b) AP separation measured between the posterior edge of the sternum and the anterior edge of the vertebral body in an axial plane 7 cm inferior to the cranial sternal edge in the Planning CT and CBCT. AP: Anteroposterior, CT: computed tomography, CBCT: Cone-beam computed tomography

The mean deviation from the separation noted in the planning scan was calculated, using Xcel software. Institutional Ethics Committee approval was taken for the retrospective analysis.

Results

The weekly CBCT images of 10 patients were reviewed to assess interfraction reproducibility. The results are documented in Table 1. Sixty measurements were performed. The average variation between separations in the planning CT scan and pretreatment CBCT was 2 mm (confidence interval 1.95–2.05). The difference between planning CT and CBCT was ≤3 mm in 92% and ≤5 mm in 95% of images. Reproducibility was ≤3 mm in all measurements in 6 of 10 patients and ≤5 mm in 8 of 10 patients. In one patient, a mismatch >5 mm was noted in two consecutive AP measurements, although no mismatch was noted in the lateral measurements and the first AP measurement [Table 1].

Discussion

We have shared the workflow of a frame providing tactile feedback for reproducible breath-hold for DIBH-based radiation for left-sided breast cancers.

Reproducibility of the DIBH position helps ensure that the radiotherapy plan, i.e., target coverage and cardiac sparing, is replicated during each treatment fraction. Matching rigid bony anatomy using orthogonal X-rays taken in DIBH has been noted by McIntosh *et al*.,[14] in a study comprising 10 patients, to have good concordance with the position of the heart and left anterior descending (LAD). The variation in the position of the heart and LAD accounted for small variations in the dose received by these structures.

Table 1: Lateral and anteroposterior separations at prespecified planes

	A-AP separation				B-Lat separation				C-Difference between simulation and CBCT-AP separation			D-Difference between simulation and CBCT-Lat separation		
	Simulation	CBCT 1	CBCT 2	CBCT 3	Simulation	CBCT 1	CBCT 2	CBCT 3	CBCT 1	CBCT 2	CBCT 3	CBCT 1	CBCT 2	CBCT 3
Patient 1	10.16	9.96	10.05	10.12	21.51	21.18	21.25	21.17	−0.2	−0.1	0.0	−0.3	−0.3	−0.3
Patient 2	9.33	9.24	9.2	9.23	21.51	21.32	21.56	20.61	−0.1	−0.1	−0.1	−0.2	0.0	−0.9
Patient 3	11.06	11.06	10.9	11.05	21.7	21.97	21.64	21.9	0.0	−0.2	0.0	0.3	−0.1	0.2
Patient 4	10.24	10.31	10.23	10.06	21.63	21.44	21.46	21.56	0.1	0.0	−0.2	−0.2	−0.2	−0.1
Patient 5	9.27	9.3	10	10.04	21.78	21.67	22.03	21.92	0.0	0.7	0.8	−0.1	0.3	0.1
Patient 6	9.19	9.1	8.93	8.86	21.94	22.02	22.11	22.11	−0.1	−0.3	−0.3	0.1	0.2	0.2
Patient 7	9.68	9.9	9.93	9.74	20.58	20.66	20.72	20.67	0.2	0.3	0.1	0.1	0.1	0.1
Patient 8	9.18	9.7	9.39	9.46	22.22	22.15	21.98	21.98	0.5	0.2	0.3	−0.1	−0.2	−0.2
Patient 9	8.81	9.04	8.99	9.01	22.75	22.58	22.66	22.89	0.2	0.2	0.2	−0.2	−0.1	0.1
Patient 10	11.6	11.6	11.52	12.09	19.9	19.56	20.13	19.8	0.0	−0.1	0.5	−0.3	0.2	−0.1

A, B: AP and lateral separations in cm, respectively, at predefined levels, C, D: Difference of separation between simulation scans and CBCT prior to radiation in cm, AP and lateral, respectively. Difference>0.3cm are bold. CBCT: Cone-beam computed tomography, AP: Anteroposterior

We have matched the bony anatomy before each radiotherapy fraction, using orthogonal X-rays. CBCTs have been used at the discretion of the radiation oncologist supervising the treatment. The analysis of these CBCTs confirms the replicability of DIBH. The average variation in separation between planning scan and CBCT images was 2 mm, and 91% of values were ≤ 3 mm, similar to assessments by other groups.[15,16] We believe that this replicability is a function of the robustness of the frame as well as the tactile feedback to the patient.

Reproducibility of DIBH has been noted to be enhanced by feedback to the patient and both audio-visual and audio feedback have been reported. The utility of visual feedback to help the patient reach the optimal volume/surface position using goggles has been documented by Cerviño *et al*. The authors noted that while the average variation in DIBH position was 2 mm without visual feedback, it was 0.5 mm with visual feedback provided by goggles. These were also noted to improve intrafraction stability of breath-hold.[15] The benefit of visual feedback has also been noted with laser-based monitoring of breath-hold, the mean deviation being reduced from 6.6 mm to 2.2 mm.[16] While visual feedback is usually accompanied by an audio command to initiate inspiration, the use of the latter alone has been investigated by Kini *et al*., albeit not exclusively in breast cancer, but in chest malignancies. The authors noted that while an audio command used alone was able to regulate the frequency of breath-hold, it was not useful for replicating the amplitude of inspiration.[17]

The frame was conceptualized and implemented in 2017 and changes were incorporated in subsequent years until its current format. While indigenous devices providing feedback have recently been described, we believe that Respiframe is a unique mechanism for ensuring the replicability of the amplitude of DIBH.[18] It provides tactile feedback to the patient for the amplitude of breath hold. The in-built gear mechanism allows individualization of the positioning of the pointer that is in contact with the patient. In addition, the frame also provides information to the RTT about the status of the breath-hold through a fluorescent strip, visible only in the breath-hold. While this facility may not necessarily be useful when using automated gating, it improves the ease of performing manual gating of radiation by allowing the RTT to observe the breath-hold status using an in-room camera. Manual gating has been previously described in the Heart Spare trial, and we believe that Respiframe may be less cumbersome than observing laser markings on the patient's torso. This would facilitate the availability of DIBH in resource-constrained settings in the developing world such as centers equipped with telecobalt units.[19]

The possible lacunae of this device are mechanical play in the horizontal arm and the patient raising her back to touch the pointer. The latter is not specific to this device and has been noted even with audio-visual feedback.[20] Ongoing improvements in this frame include the substitution of the fluorescent marker by a battery-operated light, placement of the horizontal bar centrally, and the provision of 2 markers, one each for the chest and abdomen regions, respectively, to account for both thoracic and abdominal excursions.

Improvements in diagnostic and treatment modalities have led to excellent outcomes in breast cancer patients, even in the developing world, with 80% of patients with early breast cancer and 67% of women with locally advanced breast cancer alive disease free at 5 years in a large referral hospital in India.[21] Given the rising incidence of obesity and diabetes in India[22] and their known correlation with increased cardiac risk, it is prudent to optimize cardiac dose reduction in left-sided breast cancer. This is also advocated by current treatment guidelines for breast cancer.[4] In this background, Respiframe offers a possibility of improvement in the quality of care.

Conclusion

Access to cardiac sparing techniques remains constrained by resources even in the developed world. We believe that Respiframe, based on tactile feedback to the patient and a visual cue to the RTTs, is a cost-effective device that will expand access to DIBH techniques in small and medium community-based radiation therapy practices in the developing world.

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Nil.

Conflicts of interest

Dr Sapna Nangia has filed a patent application for the device discussed in this article.

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