

Evaluation of abches and volumetric modulated arc therapy under deep inspiration breath-hold technique for patients with left-sided breast cancer

A retrospective observational study

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Abstract

Radiotherapy after breast-conserving surgery or mastectomy has clinical benefits including reducing local recurrence and improving overall survival. Deep inspiration breath-hold (DIBH) technique using the Abches system is an easy and practical method to reduce radiation dose to the heart and lungs. This retrospective study was proposed to investigate the dosimetric difference between Abches system and free breathing technique in treating left-sided breast cancer.

Eligible patients underwent computed tomography (CT) scans to acquire both free breathing (FB) and DIBH technique data using the Abches. For each patient, both FB and DIBH image sets were planned based on the volumetric modulated arc therapy (VMAT). Radiation dose to the heart, ipsilateral lung, and contralateral lung was compared between the Abches system and FB.

No significant differences in the planning target volume (PTV) (674.58 vs 665.88 cm³, $P = .29$), mean dose (52.28 vs 52.03 Gy, $P = .13$), and volume received at the prescribed dose (Vpd) (94.66% vs 93.92%, $P = .32$) of PTV were observed between the FB and DIBH plans. Significant differences were found in mean heart (6.71 Gy vs 4.21 Gy, $P < .001$), heart V5 (22.73% vs 14.39%, $P = .002$), heart V20 (10.96% vs 5.62%, $P < .001$), mean left lung (11.51 vs 10.07 Gy, $P = .01$), left lung V20 (22.88% vs 19.53%, $P = .02$), left lung V30 (18.58 vs 15.27%, $P = .005$), and mean right lung dose (.89 vs 72 Gy, $P = .03$).

This is the first report on reduced mean left lung, mean right lung dose, and V20 of left lung using VMAT and Abches. The combination of Abches and VMAT can practically and efficiently reduce extraradiation doses to the heart and lungs.

Abbreviations: ABC = active breathing control, CT = computed tomography, DCIS = ductal carcinoma in situ, DIBH = deep inspiration breath-hold, FB = free breathing, Gy = Gray, OARs = organs at risk, PTV = planning target volume, RPM = real-time position management, VMAT = volumetric modulated arc therapy, Vpd = volume received prescribed dose.

Keywords: abches, breast cancer, deep inspiration breath-hold, volumetric modulated arc therapy

1. Introduction

Adjuvant radiotherapy for breast ductal carcinoma in situ (DCIS) or breast carcinomas has shown clinical benefits to reduce local recurrence and improve overall survival.^[1,2] The radiation field covering the whole breast and regional lymph nodes (axillary, supraclavicular, and internal mammary) further decreases local

regional and distant recurrences in node-positive patients. However, low-dose radiation exposure to the heart and lungs increased by regional nodal irradiation.^[3,4] The risk of late cardiac and pulmonary toxicities has been documented many years after the radiation in long-term survivors with previous chest irradiation.^[5,6] Darby et al even reported a 7.4% increase per Gray (Gy) in major coronary events after a radiation exposure to the heart that persists for >10 years.^[6,7] Increased late toxicities raised concerns in treating patients with underlying comorbidities.^[5]

The deep inspiration breath-hold (DIBH) techniques, such as abdominal chest (Abches) system, real-time position management (RPM) system, or active breathing control (ABC),^[8-11] were practical methods used to reduce radiation exposure to the heart and lungs.^[8,12-15] The goal of DIBH was to create maximal separation of the target area (chest wall and regional lymph nodes) from the heart and thus minimize the irradiated heart volume by treating at or near the maximal inspiration. However, DIBH techniques were not routinely used in daily clinical practice, mainly because of the cost of additional equipment and increased workloads.

Abches system, a self-monitoring respiratory device developed by Onishi et al, was a commercially available product from APEX Medical, Inc. Patients were instructed to hold their breath for >15 seconds during deep inspiration while radiotherapy was initiated. The whole treatment course was divided into certain cycles with different respiratory phases. Abches effectively

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decreased the radiation dose exposure in the heart and left anterior descending coronary artery by treating 2 opposing tangential conformal fields.^[8] The volumetric modulated arc therapy (VMAT) is a modern radiotherapeutic technique in changing aperture shapes, dose rates, and gantry rotation speeds according to different gantry angles. It provided better sparing organs at risk (OARs), better dose homogeneity, better target conformity, and shorter treatment time.^[16–21] VMAT using tangential partial arcs for the treatment revealed good target coverage and conformity as well as in decreasing OAR doses.^[22–24] However, treatment using VMAT reported an increased low-dose radiation back to the normal structures.^[25–27] This study aimed to compare the radiation doses in the heart, ipsilateral lung, and contralateral lung while treating patients with left-sided breast cancer using Abches or by free breathing (FB) using the tangential partial VMAT technique.

2. Material and methods

2.1. Patient selection

A total of 12 patients (mean age = 50.2, range: 38–69 years) with left-sided DCIS or breast cancer from stage I to III treated at our department using the Abches system from June 2015 to September 2016 were enrolled in this retrospective study. The chest wall with or without regional lymph nodes comprised the irradiated field (Table 1). Patients were required to hold their breath for at least 25 seconds. All patients underwent non-contrast computed tomography (CT) scans to acquire FB and DIBH using the Abches system. CT slices were obtained using a Discovery RT590 16 Slice CT scanner (General Electric Company, Waukesha, WI) with 5-mm thicknesses. Those who were not able to hold their breath for 25 seconds were excluded.

2.2. Ethical approval

This retrospective study protocol was approved by the Institutional Review Board of Shin Kong Wu Ho Su Memorial Hospital (NO.20170406R).

2.3. DIBH technique using the abches system

Patients were immobilized using an alpha cradle in supine position with left arm over their heads. The main component of Abches was set over the iliac crest with two fulcrums placed and



Figure 1. The Abches system. Outer markers (dark arrows) indicated the end of expiration and inspiration during each regular respiration. The middle marker indicated the inspiration level in which the patients could hold their breath for several seconds, and it was repeatable throughout the treatment course.

marked at the patient’s sternum and abdomen. The Abches system was made from resin without electronic parts; thus, they only had minimal influence on dose calculation. A mirror was placed on the forehead to self-monitor each respiratory cycle by keeping 2 pointers on the body component in a certain point during each treatment cycle (Fig. 1). The outer pointer indicated the end of expiration and beginning of each inspiration; the inner marker was the inspiration level in which the patients hold their breath for >25 seconds. All patients were guided to repeat the sequence “breathe in, hold breath, and breath out” for several cycles. During the “breath in, hold breath” period, patients were instructed to hold their breath close to the maximum inspiration. Before the treatment, breathing exercises were required to achieve good reproducibility. The camera monitor was used to aid technicians in knowing whether the patients lost their breathing controllability and may interrupt the radiation beam immediately if needed.

2.4. Treatment planning

For each patient, the clinical target volume was delineated based on the Radiation Therapy Oncology Group contouring atlas. The planning target volume (PTV) was 1 cm from the anterior and superior–inferior side and 5 mm from the left–right–posterior side. The prescribed dose was 50 Gy in 25 fractions to the PTV with a tumor bed boost of 10 Gy. The plan aimed to cover ≥95% of the PTV administered at the prescribed dose. The OAR goals were to obtain the lowest achievable doses in each structure.

Both FB and DIBH image sets were planned by the Pinnacle treatment planning system (Phillips Healthcare, Andover, MA, ver. 9.8.) using a dose grid size of 3 mm. About 2 to 4 coplanar tangential arcs using 6-MV photon in VMAT base were made in each CT scan delivered by an Elekta machine (Synergy). The average angle of gantry rotated was 45 degree in each arc. The gantry angle of the anterior side ranged between 290 and 310 degree and the opposite angle ranged between 100 and 120 degree.

Table 1		
Patient characteristics included age, stage, and treatment site.		
	Parameter	Patient no.
Age	30–39	3
	40–49	3
	50–59	4
	60–69	2
Stage	Tis	4
	I	4
	II	1
	III	3
Treatment site	Whole breast	7
	Chest wall	2
	Chest wall + SCF + axillary + IM LNs	3

IM LNs = internal mammary lymph nodes, SCF = supraclavicular fossa, Tis = tumor in situ.

2.5. Anatomic and dosimetric evaluation

Anatomic characteristics including the volume in the PTV, heart, left lung, and right lung between FB and DIBH scans were compared. For PTV, the mean dose, the volume received at the prescribed dose (Vpd%), and the near maximum dose that represented the highest dose received by 1% of the PTV volume were compared. For OARs, the mean dose in the heart; the volume of the heart receiving 5 Gy, 20 Gy, and 30 Gy; the mean dose in the left lung; the volume in the left lung receiving 5 Gy, 20 Gy, and 30 Gy; the mean dose in the right lung; and the volume in the right lung receiving 1 Gy were compared.

2.6. Statistical analysis

Dosimetric parameters and relative dose volume histograms between the treatment techniques were analyzed using Excel 2013 (Microsoft, Redmond, WA). Student paired *t* test (paired, 2-tailed) was used to compare each evaluation parameter at a significance level of *P* < .05.

3. Results

No significant differences in the PTV volume (674.58 vs 665.88 cm³, *P* = .29) and heart volume (595.17 vs 571.00 cm³, *P* = .15) were observed using the Abches system or FB. Significant enlargement of the left lung (1065.67 vs 1671.08 cm³, *P* < .001) and increase in right lung volume (1348.75 vs 2007.08 cm³, *P* < .001) were observed using the Abches (Table 2). The total lung volume increased from an average of 2414 (range: 1851–2866) mL in FB to 3678 (2474–5020) mL in DIBH. The CT scans of FB and DIBH of 1 patient are shown in Figure 2. The lung volume was expanded using the Abches, and the heart was shifted away from the chest wall. The arrows in Figure 2 pointed areas with lower radiation dose exposure to the heart in DIBH compared with that in FB. Within the prescribed dose of 5000

Table 2

Comparison of volume parameters in cubic centimeters of 12 patients with left-sided breast cancer.

Parameter	FB	DIBH	<i>P</i>
PTV	674.58 ± 255.86	665.88 ± 251.48	.29
Heart	595.17 ± 92.32	571.00 ± 117.16	.15
Left lung	1065.67 ± 181.75	1671.08 ± 309.06	<.001
Right lung	1348.75 ± 179.82	2007.08 ± 369.80	<.001

DIBH=deep inspiration breath-hold, FB=free breathing, PTV=planning target volume. Data are shown as mean values with one standard deviation.

cGy, the radiation isodose lines showed both the high (2000 cGy and 3000 cGy) and low-dose regions (500 cGy) of the heart.

No significant differences were found in the PTV including the mean dose (52.28 vs 52.03 Gy, *P* = .13), Vpd (94.66% vs 93.92%, *P* = .32), and D1% (53.35 vs 54.10 Gy, *P* = .20) (Table 3). The lower dose exposure to the mean heart dose (6.71 vs 4.21 Gy, *P* < .001), heart V5 (22.73% vs 14.39%, *P* = .002), heart V20 (10.96% vs 5.62%, *P* < .001), heart V30 (8.33% vs 3.83%, *P* < .001), mean left lung dose (11.51 vs 10.07 Gy, *P* = .01), left lung V20 (22.88% vs 19.53%, *P* = .02), left lung V30 (18.58% vs 15.27%, *P* = .005), mean right lung dose (.89 vs 72 Gy, *P* = .03), and right lung V1 (26.24% vs 20.62%, *P* = .04) in Abches was significant. The overall treatment time was 10 to 15 minutes in FB and 15 to 20 minutes in Abches.

4. Discussion

A significantly reduced mean heart and lung dose can be achieved using the Abches even in an extended radiotherapy field covering the regional lymph nodes. Both high (20 and 30 Gy) and low (5 Gy) dose to the heart were decreased. The DIBH technique for patients with left-sided breast cancer displaced the heart from the breast radiation field to reduce the heart and coronary artery



Figure 2. Computed tomography scans for both free breathing (FB) (left) and deep inspiration breath-hold (DIBH) (right) in 1 patient. The arrows pointing the heart were shifted away from the chest wall and received lesser radiation dose exposure in DIBH than in FB.

Table 3
Comparison of dosimetric parameters in 12 patients with left-sided breast cancer.

	Parameter	FB	DIBH	P
PTV	Mean dose, cGy	5228.26 ± 40.40	5203.44 ± 31.10	.13
	D1%, Gy	5434.93 ± 57.52	5410.05 ± 36.29	.20
	Vpd (%)	94.66 ± 1.40	93.92 ± 2.81	.32
Heart	Mean dose, cGy	671.01 ± 264.16	421.36 ± 207.15	<.001
	V5 (%)	22.73 ± 10.82	14.39 ± 8.33	.002
	V20 (%)	10.96 ± 5.18	5.62 ± 4.55	<.001
	V30 (%)	8.33 ± 4.07	3.83 ± 3.40	<.001
Left lung	Mean dose, cGy	1150.74 ± 394.01	1006.53 ± 338.28	.01
	V5 (%)	34.77 ± 11.43	34.24 ± 10.11	.73
	V20 (%)	22.88 ± 8.65	19.53 ± 7.79	.02
	V30 (%)	18.58 ± 7.75	15.27 ± 6.41	.005
Right lung	Mean dose, cGy	88.85 ± 62.16	72.42 ± 54.09	.03
	V1 (%)	26.24 ± 27.97	20.62 ± 23.31	.04
	V5 (%)	1.36 ± 1.68	.81 ± 1.33	.12

DIBH=deep inspiration breath-hold, FB=free breathing, PTV=planning target volume.

Data are shown as mean values with one standard deviation; D1%: dose to 1% of the volume; Vpd (%): percentage of volume receiving prescribe dose; V1 Gy, V5 Gy, V20 Gy, and V30 Gy: percentage of volume receiving >1 Gy, 5 Gy, 20 Gy, and 30 Gy, respectively.

dose.^[12] DIBH, irrespective of the technique chosen, lowered the mean heart dose.^[8,12,28] The only topic that should be investigated using the Abches system was reported by Lee et al,^[8] which assessed Abches combined with 3D tangential technique for the treatment of patients with left breast cancer. The study demonstrated a lower mean heart (2.52 vs 4.53 Gy) and lower mean left anterior descending artery dose.

The absolute volumes in both lungs were increased in DIBH. The lung density was decreased while expanding the lung volume; thus, a reduced fraction of a normal lung was irradiated.^[29,30] This was the first study to report a decreased mean left lung (1007 vs 1151 cGy), mean right lung (72 vs 89 cGy), and left lung V20 (19.5 vs 22.9%) using the Abches. Compared with the 3D technique and VMAT, tangential VMAT planning produced lower OAR doses.^[25] This may be the reason that our study showed a lower mean lung dose than 3D planning.

As expected, the exposed right lung dose was low in both arms. However, differences in the mean right lung and V1 were still significant. The mean right lung dose was also reduced by treating the right-sided breast cancer using a respiratory gating system.^[31,32] Therefore, the Abches system was assumed to be also beneficial for the treatment of patients with right-sided breast cancer.

A reproducible inspiratory control was key in making maximal use of the DIBH technique, including the Abches, RPM systems, or ABC.^[8–11,33] The high compliance level can be produced by repeating the pretreatment simulation trainings.^[11] The planning physicists and technicians will be familiar with the daily setup and can provide correct instructions in a short time period. A longer overall treatment time is inevitable because the whole treatment course is divided into fractions. In our own experience, the extra time was short (10–15 minutes in FB and 15–20 minutes in Abches) and thus acceptable in daily clinical practice.

This retrospective study has several limitations. First, it was not a randomized study and the patients independently chose the Abches. Second, different radiation oncologists delineated the contours; thus, some personal variations exist. Third, treatment results and real long-term side effects were not reported because of the short follow-up period.

Our study showed that radiation doses to the heart, mean left lung, V20, and right lung were significantly decreased by the Abches system using the tangential partial VMAT technique. This may decrease the risk for radiation pneumonitis and future cardiac events. Therefore, the Abches system is recommended in treating patients with left-sided breast cancer and selected right-sided breast cancer.

Author contributions

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