

Implementing Deep Inspiration Breath-Hold (DIBH) for Left-Sided Breast Cancer Radiotherapy at the Anbar Cancer Center, Iraq: Early Report

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Abstract

Background: Deep inspiration breath-hold (DIBH) is an established cardiac-sparing technique for left-sided breast radiotherapy; however, its implementation can be challenging in routine practice, particularly in resource-constrained settings. **Methods:** We conducted a retrospective cohort study at Anbar Cancer Center (Iraq) after DIBH introduction (August-November 2025). Forty-three consecutive women with left-sided breast cancer treated with adjuvant radiotherapy after breast-conserving surgery or modified radical mastectomy were evaluated for DIBH. Patients achieving a reproducible ≥ 20 s breath-hold received DIBH ($n = 33$), whereas those unable to do so were treated using free breathing (FB) and served as a pragmatic comparator ($n = 10$). Dosimetric endpoints included PTV coverage (V95%), cardiac indices (mean heart dose, Heart V3/V5, maximum LAD dose), and lung/contralateral structures metrics; workflow measures included scan and treatment times. **Results:** DIBH significantly improved target coverage (median PTV V95% 94.0% vs 90.5% with FB; $p < 0.001$) and reduced cardiac exposure, including mean heart dose (median 2.0 vs 4.0 Gy; $p < 0.001$), Heart V3 (median 8.0 vs 11.0; $p = 0.018$), Heart V5 (median 3.0 vs 5.5; $p = 0.027$), and maximum LAD dose (12.67 ± 6.31 vs 31.00 ± 7.73 Gy; $p < 0.001$). Contralateral breast mean dose was lower with DIBH ($p = 0.006$), while contralateral lung V4 was slightly higher ($p = 0.043$). Ipsilateral lung dose-volume metrics did not differ significantly. Workflow analysis showed longer total scan time ($p < 0.001$) and total treatment time ($p = 0.001$) with DIBH, while CT acquisition time was similar

($p = 0.130$). **Conclusion:** In routine clinical implementation, DIBH provided substantial cardiac/LAD sparing and improved PTV coverage with minimal change in ipsilateral lung dosimetry, but with increased workflow time and minor contralateral low-dose trade-offs.

Keywords

Deep Inspiration Breath-Hold (**DIBH**), Free Breathing (**FB**), Mean Heart Dose (**MHD**), Left Anterior Descending Artery (**LAD**)

1. Introduction

Radiotherapy (RT) is a cornerstone in the multidisciplinary management of breast cancer, significantly reducing the risk of local recurrence and improving overall survival mainly in high risk patients [1]. With the advancement of early cancer detection and implementation of the screening programs and better cancer treatment, breast cancer patients are becoming long survivors; thus the focus has therefore shifted to long-term treatment-related toxicity and to minimize the adverse events associated with radiation therapy doses delivered to the organs at risk (OAR) [2].

For left-sided breast cancer, the heart and coronary arteries (especially the Left Anterior Descending artery) frequently fall within the simple tangential radiation fields; consequently, long-term survivors may develop late cardiovascular toxicity [3].

During the second part of the 20th century, the radiation doses delivered to these structures were high; it was estimated that breast or chest wall radiotherapy resulted in whole heart doses of 0.9 to 14.0 Gy and internal mammary chain (IMC) radiotherapy delivered heart doses of 3 to 17 Gy for left-sided breast irradiation [4].

Research has established a direct correlation between mean heart dose during breast radiotherapy and cardiotoxicity. A large study from Sweden and Denmark, found a 7.4% increase in major coronary events per Gy, while another study estimated the risk increase at 4% per Gy [5] [6].

Regarding the lung toxicity, old studies from the 1980s and 1990s consistently showed that a large proportion of patients developed radiographic and symptomatic radiation pneumonitis in the ipsilateral lung and some patients showed a significant decline in pulmonary function tests and second lung cancer [7].

The main factor associated with the occurrence and the degree of lung toxicity is the volume of lungs receiving a certain dose of radiation and the mean radiation dose (D_{mean}) to the lungs [8]. The meta-analysis of Gokula *et al.* [9], recommended thresholds of V₂₀ Gy not exceeding 30% and D_{mean} not exceeding 15 Gy. Other studies found that locoregional lymph nodes irradiation is a strong clinical risk factor.

Due to significant improvements and innovations in radiotherapy technology, several strategic approaches have been developed to minimize radiation dose to

the heart and lungs while maintaining a full therapeutic dose to the breast tissue. These advanced strategies can be broadly categorized into techniques such as deep inspiration breath-hold (DIBH), prone positioning, intensity-modulated radiation therapy (IMRT), and accelerated partial breast irradiation, alongside numerous refinements to traditional three-dimensional conformal radiation therapy [10].

Taylor *et al.* [11], confirmed that for modern techniques (with average heart and lung doses of 4.4 Gy and 5.7 Gy, respectively), the absolute risks of radiation-induced mortality have been diminished and are profoundly influenced by smoking status. For nonsmokers, the absolute increases in risk are small, at approximately 0.3% for both lung cancer and cardiac mortality, meaning the survival benefits of radiotherapy decisively outweigh these hazards. Conversely, for long-term continuing smokers, the risks are substantially higher, with an approximate 4% absolute increase in lung cancer mortality and a 1% increase in cardiac mortality; for these individuals, the combined risks could potentially offset the mortality reduction achieved by radiotherapy.

Deep Inspiration Breath-Hold (DIBH) is an advanced radiotherapy technique designed to reduce cardiac dose. During deep inspiration, the heart moves posteriorly and inferiorly due to lung expansion and diaphragmatic movements. This technique displaces the heart away from the chest wall and out of the primary radiation field. This technique requires the patient to take a deep breath and hold it during CT-simulation and radiation treatment delivery each day, which achieves the maximum separation of the breast and heart, allows a high dose to be delivered to the chest wall and to the breast tissue, while reducing the high dose area of the heart [12]. Compared to free-breathing (FB) techniques, DIBH has been consistently shown to markedly reduce the mean heart dose and the volume of the left anterior descending (LAD) coronary artery receiving radiation [13].

Despite its proven dosimetric benefits, the widespread implementation of DIBH faces several challenges. These include the need for specialized equipment (e.g., respiratory-guided radiotherapy systems), increased treatment planning and delivery time, additional training for staff, and patient-related factors such as the ability to consistently reproduce and maintain a stable breath-hold [14]. The perceived complexity and resource demands can be significant barriers to adoption, particularly in busy clinical settings.

This study aimed to evaluate the dosimetric benefits and practical challenges of implementing deep inspiration breath-hold (DIBH) compared to free breathing (FB) techniques in left-sided breast cancer radiotherapy at Anbar Cancer Center. Specifically, we compared cardiac and pulmonary dose parameters between patients treated with DIBH and those unable to perform DIBH and treated using conventional free breathing techniques. In this retrospective cohort, patients treated with FB due to DIBH inability served as a pragmatic comparator group to quantify the dosimetric advantages of DIBH in routine clinical practice at our center.

2. Patients and Methods

Deep inspiration breath-hold (DIBH) was introduced at Anbar Cancer Center (Anbar, Iraq) in August 2025 as a cardiac-sparing technique for radiotherapy in left-sided breast cancer, representing a notable service-development milestone within a post-war healthcare setting. From August 2025 through the end of November 2025, 43 consecutive female patients with left-sided breast cancer who had undergone either breast-conserving surgery (BCS) or modified radical mastectomy (MRM) were referred for adjuvant radiotherapy and were evaluated for eligibility to undergo DIBH.

In the first visit of CT simulation, the radiotherapy team delivered patient-coaching as follows: radiographers showed to the patients how to perform DIBH, and informed them to practice DIBH at home for three to four days. After that home training, the patients had a second simulation visit to attempt the DIBH simulation. Patients were instructed to practice deep inspiration breath-hold at home for approximately 10 - 15 minutes per day over 3 - 4 days, aiming for repeated breath-holds of ≥ 20 seconds with short rest intervals between attempts, to improve reproducibility and comfort prior to simulation.

In the second visit of simulation, we used Siemens' Somatom CT scanner (large scanning' field of view) for CT simulation. This technique is monitored and controlled by using the Real-Time Position Management (RPM) system (Varian Medical Systems, Palo Alto, CA, USA). Before CT simulation we asked the patients to do DIBH as a final training just before scanning. During the trial of DIBH CT simulation, the patient was set up in a supine position with hands up in a breast board with chin is centered for more comfortable position. A reflective marker box with reflective dots was placed on the patient, typically at the xiphoid process area, as a surrogate to measure the respiratory motion of the patient chest during simulation. A camera was located on the wall just anterior to the CT Scanner and in front of the patient. Only those patients who can reliably hold their breath for sufficient time (20 s or longer) were selected to undergo DIBH treatment. A DIBH CT scan was performed after instructing the patient to hold breathing several times, till the patients is completely comfortable and can do DIBH, we use slice thickness of 3 mm. Those who couldn't achieve a minimum of 20 seconds of breath-holding, they were shifted to regular, free-breathing simulation.

Most patients were able to achieve an adequate and reproducible breath-hold; however, 10 patients (23.3%) were deemed incapable of performing DIBH reliably and therefore received treatment using the conventional free-breathing (FB) technique.

We followed the RTOG guidelines for the delineation of Clinical Target Volume (CTV) and planning target volume (PTV) and acceptance of the plan. Planning target volume (PTV) margins were applied using the same institutional protocol for both the FB and DIBH cohorts, with a uniform expansion of 5 mm from the CTV to the PTV. Therefore, differences in target coverage metrics were not attributable to differences in expansion margin strategy. PTV is typically 5 mm

around the CTV, lymph node region is irradiated in any patient with pathologically positive lymph nodes. Boost dose to the tumor bed is given in patients younger than 55 years. Dedicated OAR included: ipsilateral lung, heart, the spinal cord, contralateral lung, contralateral breast, and the left anterior descending artery (LAD). All delineated by the radiation oncologist, using Varian eclipse 15.6 treatment planning system (TPS). The center policy stated the use of 3DCRT technique in such patients due its simplicity, which suits the developmental nature of the center. Such simple radiation techniques offer proper coverage of the target volumes and proper sparing OAR [15]. For the treatment session, the total treatment time was defined as the interval from the patient's entry onto the treatment couch (start of setup and positioning) to completion of beam delivery and patient exit from the couch (end of treatment session). This included patient setup, imaging/verification where applicable, breath-hold coaching during delivery (for DIBH), and the full irradiation time.

3. Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (version 20; IBM Corp., Armonk, NY, USA). The primary analytic objective was to compare dosimetric parameters between patients treated using deep inspiration breath-hold (DIBH) and those treated using free breathing (FB) due to inability to achieve an adequate and reproducible breath-hold. Categorical variables were summarized as frequencies and percentages. Normality were assessed using the Shapiro-Wilk test. Between-group comparisons were conducted using the independent-samples *t* test for normally distributed continuous variables and the Mann-Whitney U test for non-normally distributed continuous variables. Continuous variables were summarized as mean \pm standard deviation (SD) for normally distributed data, or median and interquartile range (IQR) for non-normally distributed data. All tests were two-sided, and a *p* value < 0.05 was considered statistically significant.

4. Ethical Considerations

This study was conducted as a **retrospective review** of routinely collected radiotherapy planning and treatment data from female patients treated for left-sided breast cancer at Anbar Cancer Center (Anbar, Iraq). The study protocol was reviewed and approved by the relevant institutional ethics authority (**Ethics Committee of Anbar Cancer Center**). Because the work involved **secondary use of existing clinical data**, posed **no more than minimal risk**, and included **no direct patient contact or deviation from standard of care**, the requirement for individual informed consent was **waived**. All datasets were **anonymized/de-identified** prior to analysis, stored on **password-protected** institutional devices, and accessed only by authorized members of the research team. The study was conducted in accordance with internationally accepted ethical principles for research involving human data, including the **World Medical Association's Declaration of Helsinki** [16].

5. Results

A total of 43 women were included, comprising 10 treated with free breathing (FB) and 33 treated with deep inspiration breath-hold (DIBH). In the FB group, 6 patients (60.0%) underwent breast-conserving surgery (BCS) and 4 (40.0%) underwent modified radical mastectomy (MRM), compared with 14 (42.4%) and 19 (57.6%), respectively, in the DIBH group. With respect to regional nodal irradiation, FB patients received no nodal irradiation in 3 cases (30.0%), axillary/supraclavicular irradiation in 6 (60.0%), and axillary/supraclavicular/internal mammary chain irradiation in 1 (10.0%); the corresponding counts in the DIBH group were 5 (15.2%), 23 (69.7%), and 5 (15.2%). A tumor-bed boost was delivered in 7 FB patients (70.0%) and 18 DIBH patients (54.5%), while no boost was given in 3 (30.0%) and 15 (45.5%) patients, respectively (**Table 1**).

Table 1. Cohorts description.

		FB (n = 10)	DIBH (n = 33)
Type of Surgery	BCS	6 (60.0%)	14 (42.4%)
	MRM	4 (40%)	19 (57.6%)
Nodal Irradiation	No LN	3 (30%)	5 (15.2%)
	Axilla and SC	6 (60%)	23 (69.7%)
	Axilla, SC and IMC	1 (10%)	5 (15.2%)
Boost vs No Boost	Boost	7 (70%)	18 (54.5%)
	No Boost	3 (30%)	15 (45.5%)

Mean PTV volume was larger in the FB group (1342 ± 753 cc) compared with the DIBH group (841 ± 367 cc). Boost volume was similar between groups (FB: 39 ± 25 cc; DIBH: 40 ± 23 cc). Mean ipsilateral lung volume was higher in the DIBH group (1958.030 ± 355.073 cc) than in the FB group (1117.400 ± 110.353 cc) (**Table 2**).

Table 2. PTV, boost and ipsilateral lung volumes.

	FB (Mean \pm SD)	DIBH (Mean \pm SD)
PTV Volume (cc)	1342 ± 753	841 ± 367
Boost Volume	39 ± 25	40 ± 23
Mean Lung Volume (cc)	1117.400 ± 110.353	1958.030 ± 355.073

In **Table 3**, dosimetric indices and workflow metrics were compared between the free-breathing (FB) and deep inspiration breath-hold (DIBH) groups. The definitions of the variables in table 3 are as follows: **PTV V95%** denotes the percentage of the planning target volume receiving $\geq 95\%$ of the prescribed dose; **mean heart dose**, **contralateral breast mean dose**, and **mean ipsilateral lung dose** represent organ mean doses (Gy), while **maximum LAD dose** represents the maximum dose to the left anterior descending coronary artery (Gy). **Heart V3** and **Heart V5** indicate the percentage of heart volume receiving ≥ 3 Gy and ≥ 5 Gy,

respectively; **contralateral lung V4** and **ipsilateral lung V5/V10/V17/V20** indicate absolute lung volumes (cc) receiving $\geq 4/\geq 5/\geq 10/\geq 17/\geq 20$ Gy. Workflow metrics included **CT simulation scan time** (s; CT acquisition time), **total scan time**.

Target coverage was significantly higher with DIBH, with PTV V95% increasing from a median of 90.5% (IQR 90.0 - 91.0) in FB to 94.0% (IQR 92.0 - 95.0) in DIBH ($p < 0.001$). With respect to cardiac sparing, DIBH was associated with markedly lower cardiac dose exposure: the median mean heart dose decreased from 4.00 Gy (IQR 3.00 - 5.00) in FB to 2.00 Gy (IQR 1.00 - 2.00) in DIBH ($p < 0.001$). Similarly, dose-volume indices reflecting low-dose cardiac irradiation were significantly reduced with DIBH, including Heart V3, which declined from 11.00 (IQR 9.25 - 31.00) to 8.00 (IQR 4.00 - 11.00) ($p = 0.018$), and Heart V5, which decreased from 5.50 (IQR 4.00 - 10.25) to 3.00 (IQR 1.00 - 6.00) ($p = 0.027$). In addition, DIBH substantially reduced coronary irradiation, with the maximum LAD dose falling from 31.00 ± 7.73 Gy in FB to 12.67 ± 6.31 Gy in DIBH ($p < 0.001$). For non-target contralateral structures, DIBH was associated with a lower contralateral breast mean dose, decreasing from 0.50 Gy (IQR 0.00 - 1.00) in FB to 0.00 Gy (IQR 0.00 - 0.00) in DIBH ($p = 0.006$), while contralateral lung V4 was slightly higher in DIBH (1.0 cc [IQR 0.0 - 1.0]) compared with FB (0.0 cc [IQR 0.0 - 0.0]) ($p = 0.043$).

Workflow metrics demonstrated a clear time burden associated with DIBH. Although CT simulation scan time did not differ significantly between groups ($p = 0.130$), both the total scan time and total treatment time were significantly longer with DIBH. Specifically, total scan time increased from 11.5 s (IQR 11.0 - 13.0) in FB to 62.0 s (IQR 55.0 - 71.0) in DIBH ($p < 0.001$), and total treatment time increased from 47.5 s (IQR 41.3 - 57.3) to 90.0 s (IQR 70.0 - 110.0), respectively ($p = 0.001$). By contrast, the remaining non-significant comparisons collectively indicate that ipsilateral lung exposure metrics were broadly comparable between techniques in this cohort. Specifically, there were no statistically significant between-group differences in ipsilateral lung V5 ($p = 0.210$), V10 ($p = 0.221$), V17 ($p = 0.241$), V20 ($p = 0.241$), or mean ipsilateral lung dose ($p = 0.363$).

Table 3. Dosimetric comparison.

		FB	DIBH	p value
PTV V95 (%)		90.5 (90.0 - 91.0)	94.0 (92.0 - 95.0)	<0.001
Contralateral breast mean dose (Gy)		0.50 (0.00 - 1.00)	0.00 (0.00 - 0.00)	0.006
Mean heart dose (Gy)	Mann-Whitney U test (Median [IQR])	4.00 (3.00 - 5.00)	2.00 (1.00 - 2.00)	<0.001
Heart V3		11.00 (9.25 - 31.00)	8.00 (4.00 - 11.00)	0.018
Heart V5		5.50 (4.00 - 10.25)	3.00 (1.00 - 6.00)	0.027
CT simulation scan time (s)		11.5 (11.0 - 13.0)	11.0 (11.0 - 12.0)	0.130
Total scan time (s)		11.5 (11.0 - 13.0)	62.0 (55.0 - 71.0)	<0.001

Continued

Total treatment time (s)		47.5 (41.3 - 57.3)	90.0 (70.0 - 110.0)	0.001
Contralateral lung V4 (cc)		0.0 (0.0 - 0.0)	1.0 (0.0 - 1.0)	0.043
Ipsilateral lung V5 (cc)		43.0 (32.5 - 66.8)	36.0 (32.0 - 41.0)	0.210
Ipsilateral lung V10 (cc)		28.40 ± 9.83	24.85 ± 7.28	0.221
Ipsilateral lung V17 (cc)		22.20 ± 7.96	19.61 ± 5.38	0.241
Ipsilateral lung V20 (cc)	Independent t-test (Mean ± SD)	20.20 ± 7.21	17.79 ± 5.09	0.241
Mean ipsilateral lung dose (Gy)		10.10 ± 3.28	9.06 ± 2.03	0.363
Maximum LAD dose (Gy)		31.00 ± 7.73	12.67 ± 6.31	<0.001

6. Discussion

Our retrospective cohort provides “real-world” evidence that implementing deep inspiration breath-hold (DIBH) in a newly developing radiotherapy service can yield substantial cardiac and coronary dose sparing without compromising ipsilateral lung dosimetry, albeit at the cost of increased workflow time. Importantly, this experience comes from a post-war healthcare environment where advanced techniques are often introduced under practical constraints, making feasibility and operational impact as relevant as the dosimetric endpoints themselves.

A principal finding was the significant reduction in cardiac exposure with DIBH, demonstrated by a halving of the median mean heart dose (4.0 Gy in free breathing vs 2.0 Gy in DIBH) and significant reductions in low-dose cardiac exposure indices (Heart V3 and Heart V5). This pattern is highly consistent with the broader evidence base indicating that DIBH reliably displaces the heart posteriorly and inferiorly during inspiration, thereby reducing the proportion of the heart included in tangential fields. A large systematic review has confirmed that, compared with free-breathing approaches, DIBH consistently reduces mean heart dose across modern breast radiotherapy planning paradigms [17]. The clinical relevance of such reductions is supported by the landmark population-based work by Darby *et al.*, which demonstrated a linear increase in major coronary events proportional to mean heart dose, beginning within a few years after exposure and persisting for decades [5]. Although the present study is dosimetric and does not assess long-term outcomes, the observed reduction in mean heart dose is directionally aligned with strategies intended to mitigate late radiotherapy-associated cardiac morbidity.

Beyond whole-heart measures, the most striking dosimetric benefit observed was the pronounced reduction in maximum LAD dose (31.0 ± 7.7 Gy in free breathing vs 12.7 ± 6.3 Gy in DIBH; $p < 0.001$). This finding is concordant with multiple contemporary evaluations showing that DIBH reduces both heart and

coronary artery doses, often by large proportional margins, because LAD position relative to tangential beams is highly sensitive to inspiratory expansion and cardiac displacement [18] [19]. Given increasing recognition that coronary substructure exposure may contribute meaningfully to late ischemic events, coronary sparing is frequently cited as one of the most compelling reasons to adopt DIBH when feasible. In this context, the present results support the argument that even in resource-limited settings, DIBH can substantially improve coronary dosimetry.

Interestingly, DIBH was associated not only with organ-at-risk sparing but also with significantly improved target coverage (PTV V95%). While many studies report that DIBH maintains target coverage comparable to free breathing, some have shown modest but statistically significant improvements in PTV V95% under DIBH, likely reflecting reduced respiratory motion and more stable geometry during beam delivery [20]. The improvement in PTV coverage in your cohort may also reflect practical planning factors, such as the ability to optimize tangential fields when cardiac avoidance constraints are relaxed by geometric heart displacement, particularly relevant in a 3DCRT-based workflow.

In contrast to cardiac endpoints, ipsilateral lung dose metrics (V5, V10, V17, V20, and mean lung dose) did not differ significantly between groups. This is not inconsistent with the literature: although some reports show modest reductions in lung dose with DIBH, lung effects are more variable and strongly dependent on target extent (e.g., inclusion of nodal volumes), beam arrangement, and patient anatomy. It is also well established that DIBH increases total lung volume, which may reduce the *relative* lung dose (percentage volumes), while absolute cc-based metrics can behave differently depending on contour size and planning geometry. Contemporary analyses indicate that the magnitude of lung expansion during DIBH can predict the degree of mean heart dose reduction, reinforcing that inspiratory lung inflation is an important mechanism mediating benefit [21]. In our cohort, the significantly larger mean lung volume in the DIBH group (Table 2) supports this physiologic mechanism, even though absolute ipsilateral lung dose-volume endpoints were not statistically different.

Two additional findings warrant attention: in our cohort, the contralateral breast mean dose was significantly lower with DIBH, whereas contralateral lung low-dose exposure (V4) was slightly higher. Although contralateral lung V4 was statistically higher with DIBH, the absolute magnitude of the difference was extremely small (median 1.0 cc vs 0.0 cc). At such minimal volumes and very low dose levels, this finding is unlikely to translate into a measurable increase in clinical pulmonary toxicity risk, particularly because clinically meaningful lung toxicity correlates more strongly with higher-dose metrics (e.g., V20 and mean lung dose). Nonetheless, reporting this small redistribution is important for transparency and highlights that DIBH can subtly modify low-dose scatter patterns outside the tangential fields. These modest absolute changes are consistent with the broader observation that DIBH can **redistribute low-dose “spill”** outside the pri-

mary tangential fields by subtly modifying thoracic geometry (lung expansion, chest wall curvature, and the relative position of contralateral structures), thereby influencing scatter and beam-edge effects even when the main tangential arrangement is maintained. Importantly, the direction and magnitude of contralateral dose changes with DIBH are **not uniform across the literature**: a large meta-analysis found **no consistent advantage** of DIBH over free breathing for contralateral breast mean dose overall, highlighting technique- and planning-dependence across studies and institutions [22]. In arc-based planning contexts, DIBH has been shown to **reduce low-dose exposure to contralateral breast/implant volumes** (e.g., V3 - V4) by increasing separation during chest wall expansion [23], yet other comparative studies report that DIBH, particularly when paired with VMAT may **increase contralateral breast exposure**, emphasizing the sensitivity of contralateral dose to beam geometry and optimization priorities [24]. Similarly, contemporary technique comparisons indicate that while DIBH reliably improves cardiac sparing, **contralateral breast and lung mean doses may show little systematic improvement**, and low-dose bath patterns can vary across delivery approaches [25]. Although the clinical significance of very small contralateral lung low-dose volumes remains uncertain, transparent reporting of these trade-offs is valuable because it demonstrates a comprehensive appraisal of secondary dose redistribution rather than focusing exclusively on the primary cardiac benefit.

A major contribution of our study is the quantification of workflow impact. Although the CT scan time itself was not significantly different, total scan time and total treatment time were significantly longer with DIBH. This aligns with operational and modelling literature indicating that DIBH increases treatment times and can reduce departmental throughput, with measurable effects on efficiency and capacity [26]. From a systems perspective, this is particularly relevant in post-war or resource-constrained settings, where machine availability, staffing levels, and patient volume pressures often limit the ability to absorb time-intensive techniques. Nonetheless, targeted implementation strategies, optimized coaching, and experience-driven streamlining may help mitigate this burden. For example, recent evidence suggests that structured coaching and home practice can improve efficiency and reduce setup/treatment time penalties associated with DIBH [27], a point that directly supports Anbar center's approach of providing printed instructions and home training.

In our cohort, 23.3% of patients were unable to achieve a reproducible ≥ 20 s breath-hold, necessitating free-breathing treatment. This "real-world" exclusion proportion is clinically important because feasibility constraints will inevitably shape how widely DIBH can be applied. Published experiences similarly report that a subset of patients cannot comply due to inability to sustain breath-hold, comorbidity, anxiety, or difficulty understanding instructions [28]. Therefore, an evidence-informed strategy for centers, like Anbar, may involve (i) early identification of patients most likely to benefit (e.g., higher baseline cardiac exposure risk) and (ii) intensified coaching for borderline candidates.

7. Strengths and Limitations

The main strength of our work is that it reflects routine clinical implementation rather than an idealized trial environment, while also incorporating workflow metrics, an outcome domain underreported in many dosimetric comparisons. However, several limitations should be acknowledged: the retrospective design introduces selection bias (patients receiving FB were those unable to perform DIBH, not randomly assigned); the groups are imbalanced in size; and planning was not performed as paired FB vs DIBH plans within the same patient, which is often the most rigorous dosimetric comparison approach. Additionally, dosimetric endpoints are surrogate measures, and no clinical follow-up for cardiac/pulmonary toxicity is presented. These factors do not diminish the clear dosimetric signal for cardiac/LAD sparing, but they should temper causal inference and underscore the need for larger prospective or paired-planning studies in similar settings. An important limitation was that the baseline physiological variables that may influence breath-hold feasibility (e.g., age, BMI, baseline pulmonary function, or inspiratory capacity) were not consistently available in the retrospective dataset. Therefore, residual confounding cannot be excluded, particularly because the FB cohort consisted of patients unable to achieve a reproducible breath-hold.

8. Future Directions

Future work should move beyond dosimetric surrogates toward demonstrating clinical translation of DIBH implementation through larger, preferably multicenter, cohorts with standardized contouring and planning objectives, coupled with longitudinal follow-up for cardiac and pulmonary endpoints, late toxicity, and patient-reported outcomes. Methodologically, prospective collection of breath-hold reproducibility metrics (e.g., intra-/inter-fraction motion surrogates), alongside workflow indicators and resource utilization, would allow more robust assessment of feasibility and cost-effectiveness across different service settings. Additional research is warranted to identify predictors of DIBH non-eligibility or failure (including anatomical, functional, and behavioral factors), enabling development of pragmatic selection tools and tailored alternatives (e.g., modified coaching protocols, surface-guided monitoring, or other heart-sparing strategies) to ensure equitable benefit. Finally, integrating automated or knowledge-based planning and exploring adaptive approaches (e.g. AI-based) may clarify whether the observed reductions in cardiac dose can be maintained consistently while minimizing unintended low-dose exposure to contralateral structures, thereby refining the balance between dosimetric advantage and operational complexity.

9. Conclusion

In this retrospective cohort of left-sided breast cancer patients treated at Anbar Cancer Center, deep inspiration breath-hold (DIBH) achieved **superior target coverage** and **substantial cardiac sparing**, including significantly lower **mean heart dose**, **Heart V3/V5**, and **maximum LAD dose**, compared with free-breath-

ing (FB). DIBH was associated with a **greater workflow time burden** (longer total scan and treatment times), while **ipsilateral lung dose-volume parameters were not significantly different** between techniques. Small but statistically significant differences were also observed in **contralateral breast mean dose** and **contralateral lung low-dose exposure**, underscoring the importance of reporting both benefits and trade-offs when implementing DIBH in routine practice.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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