Automated Triage for Deep Inspiration Breath-Hold Using AI-Based Segmentation and Heart Dose Prediction

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ABSTRACT

Deep inspiration breath-hold (DIBH) is an effective strategy for reducing cardiac exposure during radiotherapy for left-sided breast cancer. However, its implementation requires additional clinical resources, increases treatment complexity, and may not provide the same benefit for all patients. Consequently, the ability to identify patients who are most likely to benefit from DIBH before treatment planning is of considerable clinical interest.

In this study, two artificial intelligence–based approaches were evaluated for predicting patient-specific mean heart dose and supporting DIBH selection: a knowledge-based planning model (RapidPlan) and a deep learning (DL) dose prediction model. Both approaches achieved clinically acceptable accuracy for mean heart dose estimation, demonstrating the feasibility of automated DIBH triage within routine clinical workflows.

Overall, AI-driven dose prediction offers an objective and standardized method for supporting DIBH decision-making. Such a workflow could improve treatment planning efficiency, optimize resource allocation, and reduce unnecessary use of a time-intensive technique while maintaining effective cardiac protection for breast cancer patients.

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INTRODUCTION

External beam radiotherapy is a key component of breast cancer treatment, but cardiac toxicity remains a significant concern, particularly for younger patients receiving treatment for left-sided breast cancer. Deep inspiration breath-hold (DIBH) reduces cardiac exposure by increasing lung volume and displacing the heart away from the treatment field. As illustrated in Figure 1, deep inspiration increases the separation between the heart and the chest wall compared with free breathing, thereby reducing cardiac irradiation [1,2].

However, the benefit of DIBH varies considerably among patients and its implementation increases treatment complexity and resource utilization. Accurate identification of patients who are most likely to benefit from DIBH is therefore essential [3]

Current clinical workflows commonly require both free-breathing (FB) and DIBH CT scans, with dose evaluation relying on manual assessment. To improve objectivity and efficiency, this study investigates two AI-based approaches for mean heart dose prediction—a knowledge-based planning model, RapidPlan (Varian Medical Systems, Palo Alto, CA), and a deep learning (DL) model—to enable automated and reliable DIBH triage.

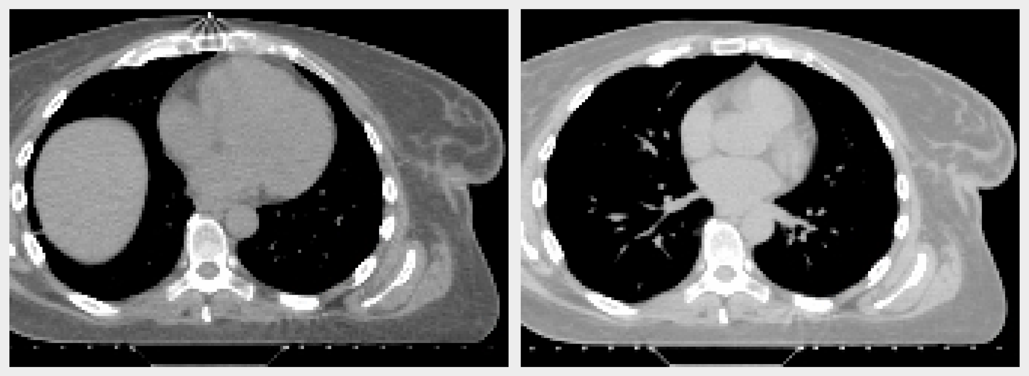

Figure 1: Comparison of CT scans acquired in free breathing (left) and deep inspiration breath-hold (right), illustrating the increased separation between the heart and the chest wall during DIBH.

METHODS AND MATERIALS

Anatomical structures, including the heart and left breast, were automatically segmented using AI-Rad Companion Organs RT (Siemens Healthineers, Erlangen, Germany). A dataset was then generated containing, for each patient, the planning CT, corresponding dose distribution, and anatomical structures.

A deep learning (DL)-based dose prediction model using an HD-UNet architecture [4] was trained, validated, and tested on 113, 20, and 25 left-sided breast cancer patients, respectively, all treated with regional nodal irradiation. In parallel, a RapidPlan knowledge-based planning model was trained on 27 patients and evaluated on an independent cohort of 20 patients, reflecting a typical clinical implementation scenario.

Finally, a pilot clinical validation was conducted on four patients for whom both free-breathing (FB) and deep inspiration breath-hold (DIBH) treatment plans were available, in order to assess the model's ability to predict the potential benefit of DIBH.

RESULTS

On the test cohorts, the mean error in predicted mean heart dose was 38.98 cGy for the DL model and 54.51 cGy for RapidPlan. In the four-patient subset, the DL model more accurately predicted DIBH-associated dose reduction, with a lower mean absolute error (**45.1 cGy**) and negligible bias (**+0.9 cGy**). RapidPlan showed larger errors (**60.2 cGy**) and a systematic negative bias (**−58.9 cGy**).

Figure 1 illustrates the performance of both models on the test cohorts, comparing the mean heart dose predicted by the DL model and RapidPlan with the actual dose calculated in the clinical treatment planning system. Table 1 summarizes the dose difference Δ between free breathing (FB) and breathhold (BH) obtained during the pilot clinical evaluation of the four patients.

Patient Id	Δ = FB - BH		
	Ground truth	RapidPlan	Deep Learning
1	239,7	100,7	225,97
2	118,03	31,6	43,45
3	11,36	14	54,33
4	27,67	15	76,59

Table 1 : Comparison of the DIBH benefit (Δ = FB − BH) expressed as the difference in mean heart dose between Free Breathing (FB) and Breath Hold (BH).

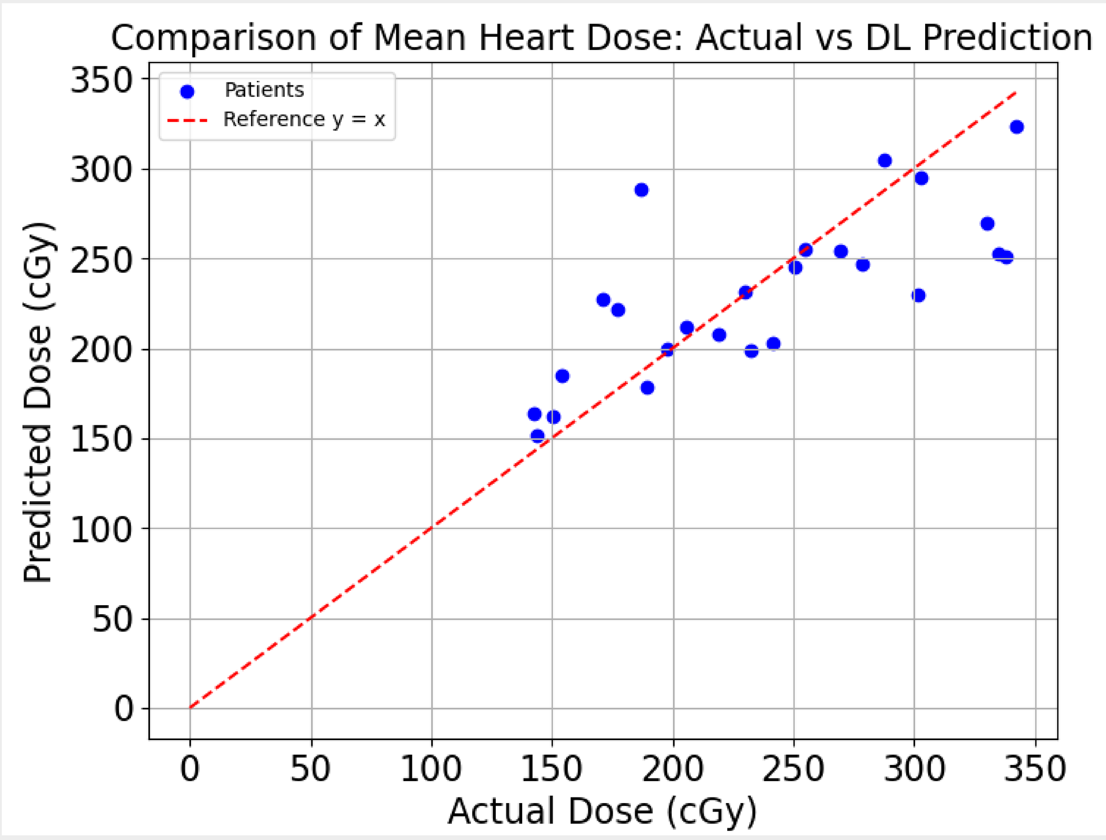

Figure 2 : Comparison between the deep learning–predicted mean heart dose prediction and the ground truth value calculated in Eclipse.

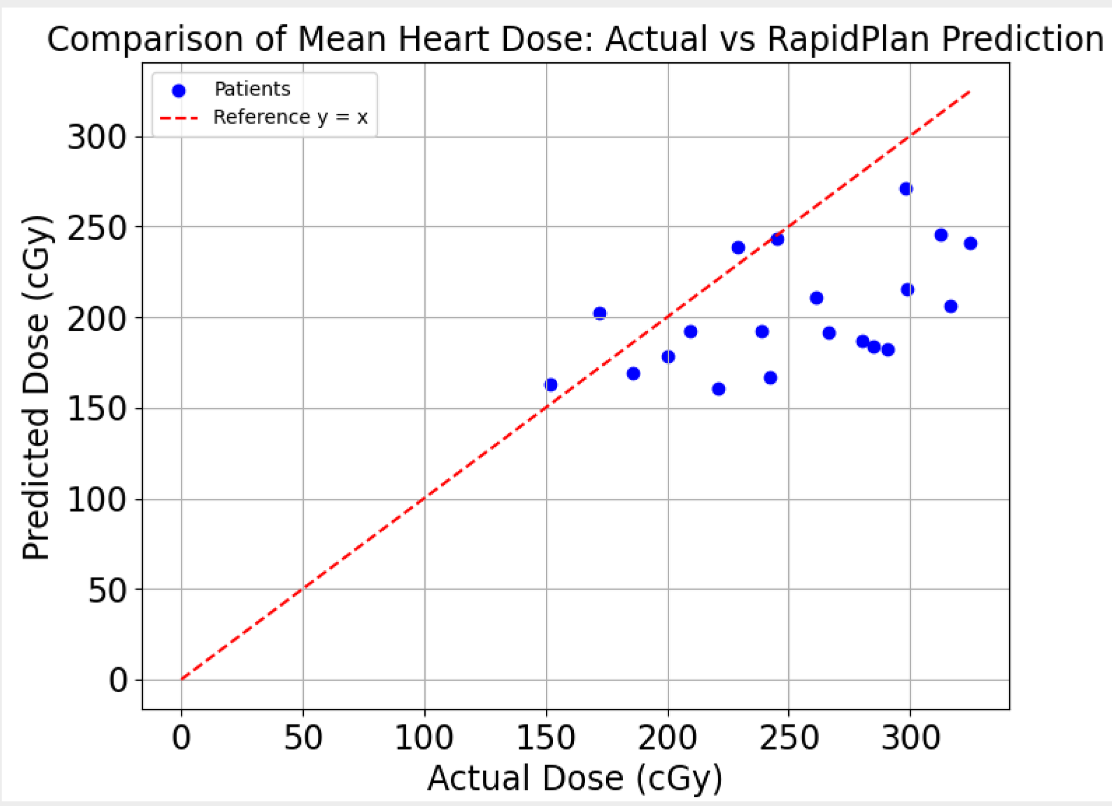

Figure 3 : Comparison between the RapidPlan mean heart dose prediction and the ground truth value calculated in Eclipse.

DISCUSSION

We present a fully automated, clinically deployable decision-support workflow for Deep Inspiration Breath Hold (DIBH) selection in left-sided breast cancer patients treated with regional nodal irradiation, built on commercially available software (RapidPlan in Eclipse and OrgansRT). By enabling pre-treatment, patient-specific prediction of cardiac dose benefit, this approach supports selective deployment of a resource-intensive technique, improving workflow efficiency and patient experience. We further demonstrate that a deep learning–based dose prediction model provides modestly improved estimation of DIBH benefit compared with knowledge-based planning, illustrating the potential performance gains of DL methods while recognizing the additional complexity associated with clinical integration.

In Figure 2, the DL method shows predictions that are well distributed around the reference line (y = x), indicating good agreement with the true values. In contrast, in Figure 3, RapidPlan tends to underestimate higher mean heart doses. This is particularly evident for Patient 1 in Table 1, who had a true value of 391.4 cGy but a RapidPlan prediction of only 264 cGy for the FB scan. However, these results should be interpreted with caution. In a real clinical context, a difference of approximately 100,7 cGy (or 225,97 for the DL prediction) between free breathing and DIBH would typically lead to recommending the DIBH technique for the patient regardless of the exact absolute value.

CONCLUSIONS

Both AI-based approaches achieved accuracy within clinically reasonable ranges for mean heart dose prediction. The DL model demonstrated superior performance for estimating DIBH benefit, supporting further evaluation for selective DIBH triage and avoidance of unnecessary, time-intensive DIBH treatments. RapidPlan, while slightly less accurate, offers the advantage of full integration into clinically available software. Both methods could streamline clinical workflows while ensuring that DIBH is reserved for patients most likely to derive a meaningful cardiac benefit.

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