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CLINICAL INVESTIGATION **Physics**

RAPID AUTOMATED TREATMENT PLANNING PROCESS TO SELECT BREAST CANCER PATIENTS FOR ACTIVE BREATHING CONTROL TO ACHIEVE CARDIAC DOSE REDUCTION

Wei Wang, M.B.B.S.,*† Thomas G. Purdie, Ph.D.,*† Mohammad Rahman, B.Sc.,* Andrea Marshall, B.Sc.,* Fei-Fei Liu, M.D.,*† and Anthony Fyles, M.D.*†

*Radiation Medicine Program, Princess Margaret Hospital, University Health Network, Toronto, ON, Canada; and †Department of Radiation Oncology, University of Toronto, Toronto, ON, Canada

Purpose: To evaluate a rapid automated treatment planning process for the selection of patients with left-sided breast cancer for a moderate deep inspiration breath-hold (mDIBH) technique using active breathing control (ABC); and to determine the dose reduction to the left anterior descending coronary artery (LAD) and the heart using mDIBH.

Method and Materials: Treatment plans were generated using an automated method for patients undergoing left-sided breast radiotherapy (*n* = 53) with two-field tangential intensity-modulated radiotherapy. All patients with unfavorable cardiac anatomy, defined as having >10 cm^3 of the heart receiving 50% of the prescribed dose (V_{50}) on the free-breathing automated treatment plan, underwent repeat scanning on a protocol using a mDIBH technique and ABC. The doses to the LAD and heart were compared between the free-breathing and mDIBH plans.

Results: The automated planning process required approximately 9 min to generate a breast intensity-modulated radiotherapy plan. Using the dose–volume criteria, 20 of the 53 patients were selected for ABC. Significant differences were found between the free-breathing and mDIBH plans for the heart V_{50} (29.9 vs. 3.7 cm^3), mean heart dose (317 vs. 132 cGy), mean LAD dose (2,047 vs. 594 cGy), and maximal dose to 0.2 cm^3 of the LAD (4,155 vs. 1,507 cGy, all p <.001). Of the 17 patients who had a breath-hold threshold of ≥0.8 L, 14 achieved a ≥90% reduction in the heart V_{50} using the mDIBH technique. The 3 patients who had had a breath-hold threshold <0.8 L achieved a lower, but still significant, reduction in the heart V_{50}.

Conclusions: A rapid automated treatment planning process can be used to select patients who will benefit most from mDIBH. For selected patients with unfavorable cardiac anatomy, the mDIBH technique using ABC can significantly reduce the dose to the LAD and heart, potentially reducing the cardiac risks. **© 2012 Elsevier Inc.**

Breast cancer, Radiotherapy, Moderate deep inspiration breath hold technique, Active breathing control, Automated planning, Cardiac toxicity.

INTRODUCTION

Previous studies have demonstrated increased cardiac mortality and morbidity after left-sided breast radiotherapy (RT) (1–8). The volume of heart within the radiation field is a key factor that results in radiation-induced perfusion defects in the irradiated myocardium (9–12), which, in turn, can lead to future cardiac morbidity and mortality. The left anterior descending artery (LAD) is frequently encompassed within the tangential radiation field, potentially resulting in coronary artery stenosis (6), and further contributing to the development of heart disease and premature cardiac death. The potential detrimental cardiac effect from RT can be amplified by the widespread use of anthracycline-based chemotherapy and trastuzumab.

A moderate deep inspiration breath-hold (mDIBH) technique using active breathing control (ABC) for left-sided breast RT can displace the heart out of the breast radiation field, significantly reducing the dose to the heart and coronary artery (13–17), with the potential to reduce the cardiac morbidity and mortality associated with left-sided breast RT. However, this technique has largely been used on an *ad hoc* basis and has not been routinely implemented in many breast cancer treatment centers. The failure to adopt

Reprint requests to: Anthony Fyles, M.D., Department of Radiation Oncology, Princess Margaret Hospital, 610 University Ave., Toronto, ON M5G 2M9 Canada. Tel: (416) 946-6522 ; Fax:(416) 946-2111; E-mail: anthony.fyles@rmp.uhn.on.ca

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mDIBH into routine practice has been due to the lack of consistent evidence-based criteria to select patients who would benefit most from a breath-hold technique, and concerns about the increase in the required resources and workload.

The overall aims of our project were to develop and implement a prospective mDIBH protocol for left-sided breast RT and to incorporate this into routine clinical practice, using evidence-based patient selection criteria and an automated planning process to address these two concerns. We also performed dosimetric evaluations to assess the extent of the dose reduction to the heart, focusing on the LAD. The overall resource and workload requirements were also assessed.

METHODS AND MATERIALS

Patients and RT technique

Beginning in November 2009, we implemented an mDIBH technique using ABC at Princess Margaret Hospital (PMH) for selected patients undergoing adjuvant RT for left-sided breast cancer. The overall outline of the patient selection, planning, and treatment process is shown in Fig. 1. Automated breast RT planning software has been in routine clinical practice at PMH and was used in the present study for rapid assessment of the dose received by the heart (18). The software is built into the clinical treatment planning system, Pinnacle^3 (Philips Radiation Oncology Systems, Milpitas, CA), and has dramatically reduced the time needed to complete two-field tangential intensity-modulated RT (IMRT) planning and automated plan evaluation to approximately 9 min.

All patients underwent whole breast RT using a two-field tangential IMRT technique, with segment apertures and weights determined by the optimization, and one open-field segment covering the whole breast volume as determined by the automated planning script. The open field segment typically contributed 75–85% of the total beam weighting, and no manual manipulation of the segment apertures or segment weights was done. The whole breast volume received 92–108% of the prescribed dose, and the surgical cavity received ≥95% of the prescribed dose. The institutional research ethics board approved the present study. Patients undergoing regional lymph node RT were excluded.

Patient selection according to cardiac dose using automated planning software

Using the following predetermined selection criteria, the patients were selected for the mDIBH technique using ABC. We used the absolute volume of the heart receiving ≥50% of the prescribed dose (V_{50}) as the criterion to select patients with unfavorable cardiac anatomy who would benefit the most from mDIBH. Marks *et al.* (9) showed that if >5% of the left ventricle (LV) were included within the radiation field, the incidence of cardiac perfusion defects increases dramatically from 10–20% to 50–60%. Depending on the delineation protocol, the LV volume constitutes approximately 50% of the cardiac volume, and as most of the heart within the tangential radiation field consists of the LV, we estimated that 5% of the LV volume within the radiation field would approximate 2.5% of the whole heart volume. Volumetric analyses on a previous cohort of patients treated at PMH showed that the mean heart volume as determined by computed tomography (CT) contouring was approximately 600 cm^3 (standard deviation, 100). Therefore, >95% of population should have a CT-based heart volume of >400 cm^3. Thus, we deduced that 10 cm^3 (2.5% of 400 cm^3) of the heart within the radiation field (*i.e.,* heart V_{50} >10 cm^3) should be used as the

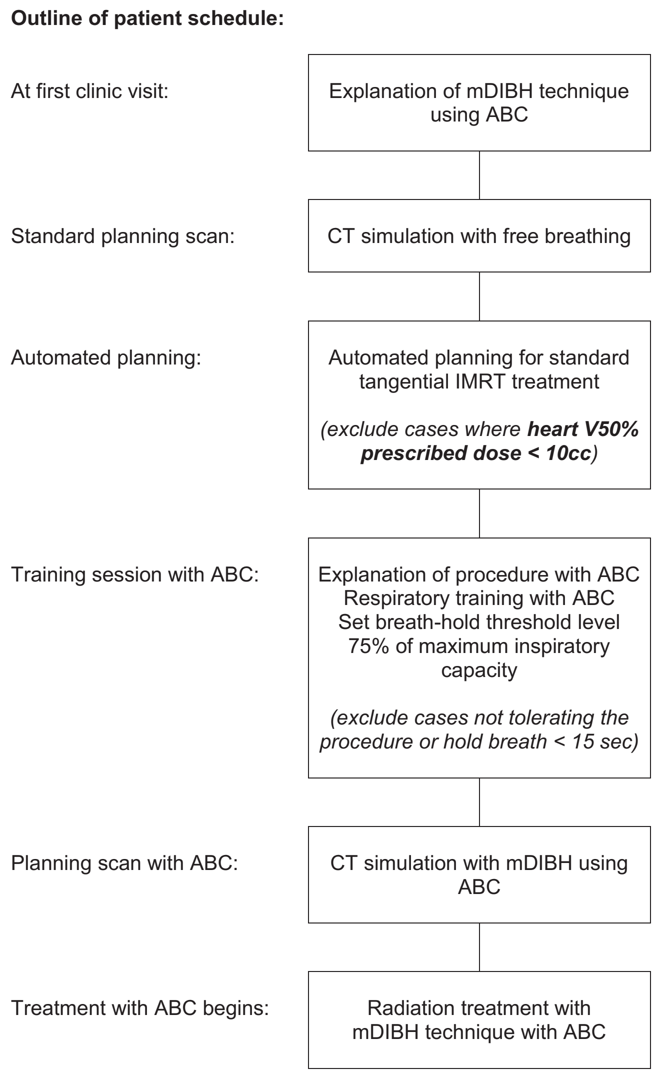

Fig. 1. Outline of patient selection, planning, and treatment process.

threshold for patient selection. Using this threshold, most patients (>95%) excluded from the mDIBH technique would not have >5% of the LV within the radiation field.

Planning and treatment process

Using this threshold, the selected patients underwent repeat scanning with mDIBH using ABC. The inspiration breath-hold threshold was set at approximately 75% of the maximal inspiration capacity. The maximal inspiration capacity was determined as the average of at least three separate measurements during the ABC education session immediately before the repeat CT scan. Subsequent RT sessions were performed using the same inspiration breath-hold threshold. The planning and treatment delivery of mDIBH RT was similar to that described by Remouchamps *et al.* (13, 15). The treatment setup was performed with the patient at inspiratory breath hold, and daily electronic portal images were acquired using onboard imaging before the delivery of each treatment fraction. The pretreatment electronic portal image was visually compared with the digitally reconstructed radiograph from the treatment plan before treatment delivery, with a maximal acceptable tolerance of 5 mm.