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Original paper

Heart position variability during voluntary moderate deep inspiration breath-hold radiotherapy for breast cancer determined by repeat CBCT scans

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ABSTRACT

Voluntary moderate deep inspiration breath hold (vmDIBH) in left-sided breast cancer radiotherapy reduces cardiac dose. The aim of this study was to investigate heart position variability in vmDIBH using CBCT and to compare this variability with differences in heart position between vmDIBH and free breathing (FB).

For 50 patients initial heart position with respect to the field edge (HP-FE) was measured on a vmDIBH planning CT scan. Breath-hold was monitored using an in-house developed vertical plastic stick. On pre-treatment CBCT scans, heart position variability with respect to the field edge ($\Delta_{HP\text{-}FE}$) was measured, reflecting heart position variability when using an offline correction protocol. After registering the CBCT scan to the planning CT, heart position variability with respect to the chest wall ($\Delta_{HP\text{-}CW}$) was measured, reflecting heart position variability when using an online correction protocol. As a control group, vmDIBH and FB computed tomography (CT) scans were acquired for 30 patients and registering both scans on the chest wall.

For 34 out of 50 patients, the average HP-FE and HP-CW increased over the treatment course in comparison to the planning CT. Averaged over all patients and all treatment fractions, the $\Delta_{HP\text{-}FE}$ and the $\Delta_{HP\text{-}CW}$ was 0.8 ± 4.2 mm (range −9.4–+10.6 mm) and 1.0 ± 4.4 mm (range −8.3–+10.4 mm) respectively. The average gain in heart to chest wall distance was 11.8 ± 4.6 mm when using vmDIBH instead of FB. In conclusion, substantial variability in heart position using vmDIBH was observed during the treatment course.

1. Introduction

Radiotherapy is extensively used for the treatment of breast cancer to reduce the risk of recurrence and death from breast cancer [1]. With improved life expectancies, long term side effects caused by radiotherapy become more important. Patients undergoing radiotherapy for left-sided breast cancer have an increased risk of cardiovascular disease compared to right-sided breast cancer patients [2]. Therefore, breath-hold techniques are often used in radiotherapy to reduce cardiac dose [3].

Several methods are available for monitoring breath hold, such as an active breathing control (ABC) [4], magnetic [5] or mechanical sensors [6], a position management system or optical systems such as the Varian real-time position management respiratory gating system (RPM) (Varian Medical Systems, Palo Alto, CA) [7,8] or the AlignRT system (AlignRT, Vision RT Ltd, London, UK) [9]. Voluntary breath-hold and the use of an ABC device provide comparable results in terms of positional reproducibility of the target volume(s) and normal tissue sparing [10,11], as well as comparable target position reproducibility for free-breathing (FB) [12].

In contrast to positional reproducibility of the target volume(s), it is not clearly known whether the heart position is stable and reproducible during breath-hold radiotherapy. McIntosh et al. studied the heart position variability during voluntary deep inspiration breath hold (vDIBH) using the RPM system and found non-negligible changes in the order of several millimeters in heart position on 2D-2D orthogonal kV-images [13]. Alderliesten et al. calculated the heart position variability by combining 3D breast surface imaging data from the AlignRT system with cone-beam computed tomography (CBCT) data registered to the heart and

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observed heart position changes of approximately 1 cm in left – right (LR) and anterior – posterior (AP) direction, and up to 3.5 cm in cranio – caudal (CC) direction [9]. Comsa et al. used an ABC device for controlling breath-hold position, and from CBCT data found that the largest mean interfraction change in heart position was 6.2 mm when comparing its position during treatment with its position at fraction 1. However, this study concerned a very small group of 5 patients where no strong conclusions about heart reproducibility could be drawn [14].

The aim of this study was to investigate for a large group of patients the interfraction variability in heart position with respect to the field edge and with respect to the chest wall during voluntary moderate deep inspiration breath-hold (vmDIBH). This would reflect the variability of the heart position when using a clinical offline or online setup procedure, respectively. Possible time trends in heart position variability during the treatment course when using vmDIBH were also investigated. This variability in heart position was compared with the gain in heart to chest wall distance when using vmDIBH instead of a free-breathing (FB) procedure.

2. Methods and materials

2.1. Patient data

Fifty left-sided breast cancer patients treated at the Catharina Hospital with adjuvant radiotherapy between February and August 2013 received a planning vmDIBH CT scan. In total in 50 patients, 349 vmDIBH CBCT scans were made for position verification and to determine the heart position variability with respect to the planning CT. This variability was compared with the heart to chest wall distance using a FB CT scan. Because no FB planning CT scans were made for this group of patients in the Catharina Hospital, a similar group of 30 patients from MAASTRO Clinic was selected, where FB and vmDIBH scans are both made in succession in standard practice. All CT scans in both hospitals were acquired with 3 mm thick slices, and vmDIBH scans were acquired with similar breathing instructions. During CT scanning and treatment, breath-hold was monitored using an in-house developed tool, which consists of a plastic stick fixed in a c-arm attached to the couch top that is vertically adjustable such that it touches the sternum upon a correct inspiration position. Patients were notified by the treating physician about the procedure prior to CT scanning. The patients could practice their breath hold a few times on the CT scanner before the actual scan was made in the same session. No training prior to CT scanning was given. This results in an accurate and reproducible position of the breast and chest wall during vmDIBH. Additional data on this procedure can be found in a recent article of Brouwers et al. [12]. Patients were positioned on a breast board (Civco posiboard™) and marked at the CT with tattoos and ink lines during a breath-hold.

2.2. Treatment planning

Treatment plans were made in Pinnacle (version 9.2, Philips Medical Systems, Fitchburg, WI). The plans included two opposing 6 or 10 MV open tangential beams, followed by two inverse planned IMRT beams to increase dose homogeneity in the breast. Three additional open beams with different gantry angles were used to deliver an adequate dose to the boost volume [15]. The isocentre was placed in the middle of the tumor bed volume. The fractionation scheme was 21 fractions of 2.17 Gy to the breast with an additional simultaneous integrated boost (SIB) of 0.49 Gy to the tumor bed volume, or 23 fractions of 2.03 Gy to the breast with an additional simultaneous integrated boost (SIB) of 0.63 Gy to the tumor bed volume. The fractionation using the SIB technique was based on the fractionation used by Whelan et al. [16] with 16 fractions of 2.66 Gy to the breast and follows the Dutch fractionation guideline for breast irradiation using a SIB. The heart was contoured according to the atlas as proposed by Feng and coworkers [17]. In all our clinical protocols for breast cancer radiotherapy, dose constraints for the heart are defined as constraints based on the mean heart dose (MHD), in accordance with the Dutch guidelines, based on Darby et al. [18].

2.3. Setup verification

Treatments were delivered with Elekta Synergy linear accelerators (Elekta, Stockholm, Sweden), which is equipped with a KV-based CBCT and a multi leaf collimator with 10 mm leaves at the isocentre. The patient was first positioned during free breathing using the lasers to reduce patient rotations. After that, the patient was positioned at a reference point at the sternum during breath-hold. Thereafter, the patient was shifted towards the isocentre. Prior to treatment, CBCT scans were made during vmDIBH for offline position verification and setup correction according to a shrinking action level (SAL) protocol [19]. In this protocol, a maximum number of measurement of three and an initial action level of 10 mm was applied. CBCT scans were standardly made during the first three fractions, and subsequently weekly (i.e. at fraction 1, 2, 3, 8, 13 and 18). If during the protocol a correction was required (i.e. when the 3D translation vector averaged over the last max. 3 fractions was larger than the actual action level), the protocol was restarted. In such cases most likely CBCT scans were taken during different fractions than mentioned above. The CBCT scans took 30 s and consisted of a half rotation. All patients could hold their breath for this time period.

CBCT scans were offline matched with the planning CT on the chest wall and the target volumes (breast and tumor bed boost volume). This was performed using gray-scale automated matching on the PTV volume expanded by 1 cm. Manual adjustments were made if deemed necessary. The prime objective was to irradiate the target volume as accurate as possible. Thus, the heart was not considered during the matching procedure. Consequently, the correction protocol (offline SAL) was applied to accommodate the systematic setup errors of the target volumes. The initial action level of 1 cm was suitable based on setup variation data of a historic group of breast cancer patients in relation to the applied PTV margins. The variation of heart position relative to field edge or relative to the target volumes/chest wall was not known from historic patient data (since it is firstly determined in the present study), therefore it was not possible to estimate on forehand whether an action level of say 1 cm is suitable to also accommodate these variations. Moreover, heart position variation was of no influence on the applied correction protocol, since the heart was not considered during the matching procedure.

For this study, patient setup stability was important, because it might influence the results of the heart position variability. Patient set-up stability was calculated based on the systematic (Σ) and random (σ) geometrical setup uncertainties, calculated according to the method of van Herk [20]. For comparison, these setup variations were also quantified for a group of 50 patients treated without vmDIBH but during free-breathing, i.e. patients treated for right-sided breast cancer, for which the position verification procedure and setup correction protocol was similar.

2.4. Analyses

Heart position with respect to the field edge (HP-FE) was measured on the vmDIBH planning CT in the transversal slice where the heart was nearest to the chest wall at the level of the tangential fields, i.e. nearest to the field edge of the treatment beams, perpen-