The effect of systematic set-up deviations on the absorbed dose distribution for left-sided breast cancer treated with respiratory gating

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Abstract. The aim of this study was 1) to investigate interfraction set-up uncertainties for patients treated with respiratory gating for left-sided breast cancer, 2) to investigate the effect of the inter-fraction set-up on the absorbed dose-distribution for the target and organs at risk (OARs) and 3) optimize the set-up correction strategy. By acquiring multiple set-up images the systematic set-up deviation was evaluated. The effect of the systematic set-up deviation on the absorbed dose distribution was evaluated by 1) simulation in the treatment planning system and 2) measurements with a biplanar diode array. The set-up deviations could be decreased using a no action level correction strategy. Not using the clinically implemented adaptive maximum likelihood factor for the gating patients resulted in better set-up. When the uncorrected set-up deviations were simulated the average mean absorbed dose was increased from 1.38 to 2.21 Gy for the heart, 4.17 to 8.86 Gy to the left anterior descending coronary artery and 5.80 to 7.64 Gy to the left lung. Respiratory gating can induce systematic set-up deviations which would result in increased mean absorbed dose to the OARs if not corrected for and should therefore be corrected for by an appropriate correction strategy.

1. Introduction
Several studies show a decrease in recurrence using postoperative radiotherapy for breast cancer [1-2]. But studies also show an increased cardiac morbidity and mortality in patients treated with radiotherapy for left-sided breast cancer compared to right-sided [3-4], due to the higher cardiac absorbed dose for the left-sided patients, implying that increased absorbed doses to the heart increase cardiac complications. One way of reducing the absorbed dose to the heart is by using breathing adapted radiotherapy [5]. One example of such technique is free breathing respiratory gating. The patient then breathes freely, however a bit deeper than normal. The beam is only on during end-inspiration, when the treatment volume and heart are furthest apart. Due to this increased spatial distance the absorbed dose to the heart can be decreased [5].

There are several uncertainties in radiotherapy that lead to that the absorbed dose is not delivered where it is intended. One such uncertainty is patient set-up, were the set-up deviation consists of a systematic and a random component [6]. The systematic part of the set-up deviation can be corrected for by using an appropriate correction strategy, such for example the no action level (NAL) protocol [7]. The mean deviation of the first n treatment fractions is calculated and applied as a correction for the remaining treatment fractions. In our clinic n equal to three is used. To avoid overcorrection an
adaptive maximum likelihood (AML) factor has been introduced and can be combined with the correction strategy [8-9]. Today an AML factor of 0.75 is used at our clinic.

For the patients treated with respiratory gating at our clinic systematic set-up deviations are induced due to the set-up procedure used. During CT-scanning skin markers are made on the patient during normal free breathing. A treatment plan is made in a CT-set acquired during deep breathing. Before treatment the patient is positioned according to lasers. These laser lines marks the correct patient position during deep breathing. The patient is positioned during normal free breathing and the deep breathing then leads to a deviation in the set-up.

The aim of this study was to investigate the set-up deviations for the patients treated with respiratory gating for left-sided breast cancer and the effect of these set-up deviations on the absorbed dose distribution for the heart, left anterior descending coronary artery (LADCA) and left lung. To evaluate the impact of the systematic set-up deviations on the absorbed dose to the organs at risk (OAR) simulations were made in the treatment planning system (TPS) (Eclipse version 10.0.28, Varian medical systems; CA) and measurements were carried out using the biplanar diode array Delta4 (ScandiDos, Inc.; Sweden). The effect of two correction strategies, NAL with an AML factor of 0.75 and NAL without AML factor, to correct for the systematic set-up deviations was also investigated.

2. Material and methods

2.1. Acquiring set-up images and calculating set-up deviations
Prospectively, 18 patients treated with respiratory gating for left-sided breast cancer using the real-time positioning management system (RPM, Varian medical systems; CA) were enrolled in this study. The patient’s position at every fraction was verified with two orthogonal kilovolt (kV) set-up images using the on-board imager (OBI, Varian medical systems; CA). All together 352 orthogonal image pairs were acquired. The kV set-up images were manually matched with digitally reconstructed radiographs (DRR) that have been reconstructed from the gated CT-set. The set-up deviations for every treatment fraction were obtained and the overall mean systematic deviation, \( m_{\text{overall}} \), was calculated as the mean deviation for all patients and all treatment fractions [10]. The NAL correction strategy with AML factor 0.75 and the NAL correction strategy without AML factor were simulated and corrected deviations obtained. The \( m_{\text{overall}} \) was calculated also for the corrected deviations.

2.2. Simulating the set-up deviations in the TPS
The effect of the systematic set-up deviation on the absorbed dose distribution to the OARs was investigated by shifting the isocenter of the treatment fields in the TPS, corresponding to \( m_{\text{overall}} \) (table 1). This was made for 19 patients treated with respiratory gating for left-sided breast cancer (not the same patients as above) treated with 50 Gy in 25 fractions.

2.3. Measurement with the Delta4
Delta4 is a biplanar diode array containing two orthogonal detector boards. The center-to-center distance between the diodes is 5 mm in the central 6x6 cm² region and 10 mm in the rest of the array. Six treatment plans were delivered to the Delta4 using the Truebeam (Varian medical systems; CA). Two measurements were carried out for each patient; one without set-up deviations and one where the uncorrected set-up deviations corresponding to the \( m_{\text{overall}} \) (table 1) were introduced. A 3D gamma evaluation was carried out using the dose deviation and distance to agreement (DTA) criteria 3%/2mm.

3. Results and discussion
With the set-up procedure used at our clinic, systematic set-up deviations are induced using respiratory gating in the anterior and cranial direction (table 1). A NAL correction strategy can be used to correct for these set-up deviations. The best set-up results were achieved using the NAL correction strategy without the AML factor.
Table 1: The overall mean systematic set-up deviation. Positive values in the posterior, caudal and right directions.

| Correction Strategy       | Ant-post (mm) | Cran-caud (mm) | Left-right (mm) |
|---------------------------|---------------|----------------|-----------------|
| No correction strategy    | -6.0          | -8.1           | 0.7             |
| NAL AML =0.75             | -1.1          | -3.3           | 1.3             |
| NAL no AML                | 0.5           | -1.0           | 1.2             |

The effect of the systematic set-up deviation was evaluated by shifting the mean absorbed dose in the TPS. This resulted in an increased average mean absorbed dose to the OARs (table 2). When the set-up deviations for the two correction strategies were simulated, a smaller difference in the average mean absorbed dose was observed (table 2). In figure 1, cumulative histograms of the mean absorbed dose to the OARs for all investigated patients are shown.

Figure 1: Cumulative histograms for the mean absorbed dose for the heart (a), LADCA (b) and left lung (c).

The gamma evaluation method takes both dosimetric and spatial accuracy into account when comparing two absorbed dose distributions. A value of $\gamma$ less than one implies that the criteria are fulfilled. When no set-up deviations are introduced, on average 97.3% of the measuring points have a $\gamma<1$. This value was decreased to 64.2% when the uncorrected set-up deviations were introduced, implying that the systematic set-up deviations result in a difference between the two absorbed dose distributions. This difference is a shift in the absorbed dose profiles caused by the systematic set-up deviation (figure 2). The measuring points using the Delta4 were compared to dose profiles acquired from the TPS, both with and without the uncorrected set-up deviations induced. Good agreement between the measurement and the simulation in the TPS were observed (table 2).

4. Conclusion
Using respiratory gating systematic set-up deviations can be introduced. These systematic set-up deviations lead to an increased mean absorbed dose to the heart, LADCA and left lung. This can be
Table 2: Average mean absorbed dose to the OARs. The difference in percent compared to original treatment plan in parentheses.

|                      | Heart (Gy) | LADCA (Gy) | Left lung (Gy) |
|----------------------|------------|------------|---------------|
| No set-up deviations simulated | 1.38       | 4.17       | 5.80          |
| No correction strategy | 2.21 (60.2)| 8.86 (112.7)| 7.64 (31.7)   |
| NAL AML = 0.75       | 1.48 (6.9) | 4.53 (8.8) | 6.00 (3.4)    |
| NAL no AML           | 1.31 (-5.3)| 3.86 (-7.5)| 5.51 (-5.1)   |

corrected for using the NAL correction strategy. For such large systematic set-up deviations seen in this study, not using an AML factor results in better set-up than using an AML factor of 0.75.

Figure 2: Absorbed dose profile for the detector boards showing the shift in the absorbed dose distribution induced by the systematic set-up deviation in the anterior-posterior direction (a) and the craniocaudal direction (b) for one patient in this study.

5. References
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