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Original paper

Robustness of VMAT and 3DCRT plans toward setup errors in radiation therapy of locally advanced left-sided breast cancer with DIBH

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ABSTRACT

Purpose: The aim of our study was to evaluate and compare the robustness of treatment plans produced using the volumetric modulated arc-therapy (VMAT) and the standard three-dimensional conformal radiotherapy (3DCRT) techniques by estimating perturbed doses induced by localization offsets for deep inspiration breath-hold (DIBH) in locally advanced breast cancer radiation therapy.
Methods: Twenty patients with left breast carcinoma requiring radiation therapy were analysed in this planning study. Robust VMAT plans regarding minimum CTV doses and standard 3DCRT plans were produced, and perturbed doses were calculated in accordance with localization values from the weekly offline imaging protocol. Offsets from 5 weeks were summed to a perturbed overall treatment plan. Dose criteria for evaluation were coverage and homogeneity of the target, as well as doses to organs at risk.
Results: VMAT plans resulted in significantly better target coverage compared to 3DCRT, as well as lowered doses to heart and left anterior descending artery, while the perturbed doses were less variable for VMAT than 3DCRT plans. Homogeneity was significantly improved in VMAT plans. The statistical analysis taking all organs into account found that VMAT plans were more robust than 3DCRT to localization offsets ($p = .001$). The overall mean setup-deviation for the DIBH-patients was less than 2 mm in all directions.
Conclusions: VMAT plans were more robust on average than conventional 3DCRT plans for DIBH when localization errors were taken into consideration. The combination of robust VMAT planning and DIBH generally improves the homogeneity and target doses.

1. Introduction

Radiation therapy (RT) is an integral part of most breast cancer treatments. Irradiation of the breast and regional lymph nodes after breast-conserving surgery in locally advanced breast cancer is standard care, as RT improves local control and overall survival [1]. Radiation-induced heart diseases and cardiovascular events are however well documented side effects of left-sided breast cancer (LSBC) irradiation [2–4]. RT can also lead to secondary malignancies (SM) [5]. Women with breast cancer are at greater risk of developing second primary cancer of the breast as well as of other organs [6]. This may suggest there are risk factors related to the appearance of first primary cancer, and the patient's life culture.

External beam RT for LSBC will to some extent deliver a dose to the heart and lung. Excluding the heart from the field might compromise the dose to the target, but by means of the deep inspiration breath hold (DIBH) technique it is possible to reduce the cardiopulmonary doses while maintaining the prescribed dose to the breast and regional lymph nodes. DIBH has rapidly become the gold standard when treating LSBC patients with radiation therapy, due to the ability to lower doses to the heart [7,8]. A deep inspiration breath will raise the chest wall and expand the volume of the lungs, thereby pushing the heart away from the chest wall and increasing the distance between the target and the heart. The method is well established and several groups have previously reported beneficial results using this technique [7,9–11].

Volumetric modulated arc therapy (VMAT) has not been widely used in breast cancer RT, but there are some studies that have investigated the technique for standard use in breast cancer [12–15].

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Three-dimensional conformal radiotherapy (3DCRT) with opposed beams using a flash has been the traditional technique for locally advanced breast cancer. The flash intends to ensure good breast coverage even when intra- or interfractional movement should occur, or in the case of breast swelling or deformation during the RT course. It has been shown that intensity modulated radiation therapy (IMRT) has a better skin-sparing effect than traditional 3DCRT as well as improving the target homogeneity [16,17]. Treatment plans using the VMAT technique will typically try to achieve good target coverage of planning target volume (PTV), but intra- and interfraction setup variation as well as changes in breast contour might jeopardize the coverage. VMAT has the advantage of optimizing plans with respect to clinical goals, fast planning and treatment delivery, more homogenous target doses and tailored doses to organs at risk (OAR). Some dosimetry studies have found that VMAT improves target coverage and lowers dose to organs at risk in LSBC compared to 3DCRT [12,13,17–19]. However, since the target is close to the external contour, it is important to be cautious with complex modulations in order to ensure target dose due to lack of build-up and lateral scatter [20,21]. Some studies have used a virtual bolus outside the breast contour to ensure coverage, and then removed it before the final dose calculation [22–24]. The term robust in this study refers to the stability of dose when variations in patient setup position occur; less dosimetric variability is said to be more robust [22]. Inter- and intrafraction variation can to some extent be accounted for with traditional target margins, but there is also another possibility for compensating some of the displacements without significantly increasing the target margins using the shape of the target position uncertainty when optimizing VMAT plans [25]. RayStation (Raysearch Laboratories, Stockholm, Sweden) features a robustness functionality which calculates dose for different scenarios, each of them with the target and the OAR at different possible positions so setup errors can be accounted for while planning criteria are satisfied. This yields to lower dose to normal tissue when compared to using margins generated from overlapping possible target positions, without compromising dose to the target [22].

Two recent studies have reported clinical benefit of including the internal mammary nodes in the clinical target volume, and this might lead way for VMAT as a future gold standard for locoregional patients with internal mammary nodes [26,27]. It is crucial that the prescribed and planned dose are consistent, thereby requiring a robust plan in which the delivered dose does not deteriorate throughout the treatment course due to localization offsets and possible changes in the volume of the breast.

The aim of our study was to evaluate the robustness of 3DCRT and VMAT plans. CTV minimum doses were used in robust VMAT optimization. Perturbed dose was calculated for both VMAT and conformal 3DCRT techniques with respect to the actual localization of the patient during the treatment sessions, and the VMAT technique doses were evaluated against the current 3DCRT technique.

2. Materials and methods

2.1. Patient selection and training

A total of 20 patients referred to Ålesund Hospital with stage pT1c-T3N1 left breast carcinoma requiring RT were recruited during the period from June 2014 to February 2015. All patients returned written consent to participate in the Regional Ethics Committee approved protocol. The patients had a median age of 58 (range 25–86) years. In order to be eligible for the DIBH treatment utilizing an in-house laser system, patients had to be able to maintain a stable breath hold for at least 20 s during training at the CT appointment [28]. There were no limitations regarding age or other diseases. The patients received training for breath hold technique as part of the 30 min CT acquisition slots. Patients underwent the first part of the DIBH training without visual guided breathing, and their maximum breathing amplitudes were measured. The DIBH-amplitude was chosen as 80% of maximum inhale amplitude, and a gating window of ± 1 mm was established. Patients were then trained through audio-visual guidance to ensure a stable breath hold during CT-scanning. All patients were immobilized with a WingSTEP© (IT-V, Innsbruck, Austria) breast board in the supine position, no tilt was used as the small bore opening of our CT-scanner could not accommodate this. The CT scanner was a 16 slice multi-detector MX8000 Brilliance IDT (Philips Medical Systems, Eindhoven, Netherlands), and images were obtained with 3 mm slice thickness. Images were transferred to Oncentra Masterplan v 3.4 (Elekta, Crawley, UK) and RayStation v 5.0 (Raysearch, Stockholm, Sweden) treatment planning systems (TPS).

2.2. Delineation of target and OARs

The clinical target volume (CTV), heart and left anterior descending artery (LAD), were delineated by a radiation oncologist, while radiation therapists contoured the lungs, spinal canal, contralateral breast and external contour. The CTV included the left breast/chest wall and the supraclavicular and axillary level I-III nodes. The heart and LAD were delineated according to published international guidelines [29]. PTV was automatically generated, derived from CTV with 10/5/5 mm extension in the superior-inferior/anterior-posterior/left-right directions (SI/AP/LR). The first 5 mm inside the external contour were excluded both from the CTV and the PTV.

2.3. 3DCRT treatment planning

The radiation therapists produced a 3DCRT DIBH treatment plan in accordance to national guidelines based on an in-house protocol, and the duration of the planning process was recorded. Mono-isocentric photon beams with an isocenter below the clavicular head and inside the lung were used. Two wide opposing tangential fields were used; the medial field covered the parts of the target below the isocenter, while the lateral wedged field covered the entire target volume including locoregional periclavicular nodes. Above the isocenter, an anterior wedged field was abutted to the caudal medial field. In addition, some segment beams with low weight were used as aids to achieve dose homogeneity. The clinical goal for target coverage was minimum 95% of the prescribed dose to the CTV. The national guidelines at the time of inclusion stated that the mean dose of the heart should be under 2 Gy, that less than 35% of the left lung should receive more than 20 Gy, and that the mean dose to the CTV should be 50 Gy in 25 fractions (from which only 46 Gy to the axilla region in 23 fractions). No national guidelines for doses to LAD, spinal canal, contralateral lung or breast were available at the time of the study, so these were planned according to an in house protocol based on the ALARA principle. The modelled machine in the TPS was an Elekta Synergy with a 10 mm MLC. The treatment plans were calculated with the Collapsed Cone algorithm, and transferred to the record and verify system Mosaiq (Elekta, Crawley, UK) for treatment delivery.

2.4. VMAT treatment planning

The VMAT-DIBH treatment plans were generated retrospectively using RayStation. The modelled machine in RayStation was an Elekta VersaHD with a 5 mm MLC. The VMAT plans were optimized according to the same clinical goals as the original 3D-conformal plans in order to establish if VMAT was suitable for this group of patients, nevertheless, some extra clinical goals, see Table 1, were necessary and included for the optimization process. To achieve the prescribed dose, two partial 6 MV photon arcs with arc length of 240°, where the start/stop angle was 170°/290° and collimator angles were 355°/5°. The maximum delivery time was stablished as 90 s.

The robust optimization feature in RayStation is based on the minmax optimization, where a plan is optimized in multiple geometries