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Original Article

Comparison of Radiotherapy Treatment Plans for Left-sided Breast Cancer Patients based on Three- and Four-dimensional Computed Tomography Imaging☆

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Abstract

Aims: The target volume for breast radiotherapy after conservative surgery for breast cancer may be affected by breathing motion. We investigated differences between conventional and four-dimensional computed tomography-based treatment planning and whether gating could improve dose volume parameters.
Materials and methods: Ten patients with left-sided breast cancer and surgical clips at the excision site had conventional treatment planning computed tomography and four-dimensional computed tomography. Treatment plans using two tangential beams (6 MV X-rays) were optimised for target coverage and homogeneity using a field in field technique for the three-dimensional scan. This plan was applied directly to four-dimensional datasets representing individual phases of the breathing cycle and combinations thereof (average and maximum intensity projection). Optimised plans were generated for the maximum inhalation scan to study what could potentially be achieved in gated radiotherapy.
Results: Four-dimensional computed tomography with effective doses of around 10 mSv proved to be adequate for treatment planning in all patients. The average motion of the surgical clips was 3.7 mm (range 1.7–6.5 mm), which was similar to the movement of the chest wall. With a margin of 7 mm for the whole breast to planning target volume, conventional three-dimensional computed tomography-based planning was found to adequately cover the target as seen on four-dimensional computed tomography without significant differences in normal tissue sparing. Improved sparing of the heart and lung could only be achieved by reducing the posterior margin of the target volume, which may be justified if four-dimensional computed tomography is used to determine the target and its motion.
Conclusion: No significant benefit has been shown for the use of four-dimensional computed tomography-based planning if motion management is not implemented concurrently with a reduced posterior margin between clinical and planning target volumes.

Key words: Breast cancer; breathing motion; four-dimensional computed tomography; radiotherapy planning

Introduction

Adjuvant radiotherapy for breast cancer is highly effective in decreasing the risk of local recurrence [1,2]. Many advances have taken place in the delivery of adequate dose to the target volume, such as inverse and forward planned intensity-modulated radiation therapy [3]. However, patient-related factors, such as immobilisation and respiration-related motion of the breast, remain a challenge [4,5]. Although inter-fraction motion is typically larger than intra-fraction motion [6,7], the effect of inter-fraction set-up variations can be reduced using image guidance [8,9].

Therefore, the present study aimed to investigate differences between conventional and time resolved four-dimensional computed tomography-based treatment planning [10,11]. This involved the determination of the

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magnitude of intra-fraction motion in patients receiving breast radiotherapy using four-dimensional computed tomography and the investigation of whether treatment planning, which does not take respiration-related breast movements explicitly into account, resulted in suboptimal treatment plans. In addition, the potential benefit of using gated delivery in one phase of the breathing cycle was investigated.

In order to evaluate primary tumour bed motion, only patients with surgical clips in the excision site were included [12]. We aimed to restrict the dose in four-dimensional computed tomography to the equivalence of not more than twice the dose of a conventional computed tomography scan to minimise the dose from imaging to the patients. Of particular interest in the context of plan optimisation is the dose to the ipsilateral lung and the heart [13,14]. With the increased use of cardiotoxic systemic agents, such as anthracyclines and trastuzumab, the risk of cardiac toxicity has assumed increasing significance [15]. Therefore, we focused our study on patients with left-sided breast cancer.

Plans were generated to assess how representative three-dimensional dosimetry resembled dose throughout the breathing cycle. This involved consideration of an internal target volume [16] and gated delivery in maximum inhalation [17,18] with particular consideration of the dose to the heart [19]. We also studied if a reduction of the posterior margin of the breast tangential beams, as a result of four-dimensional computed tomography planning and gated delivery, would improve the dose volume parameters for the heart and ipsilateral lung.

Materials and Methods

Patients

Ten patients with histologically proven invasive or intraductal carcinoma of the left breast were enrolled in the study after providing informed consent in an Institution Review Board-approved study over a period of about 6 months. Patients must have had breast-conserving surgery with surgical clips placed to outline the surgical cavity and deemed suitable for postoperative whole breast radiotherapy. The median age of patients was 59 years (range 39–74 years).

Imaging

Patients were imaged using a Philips Brilliance 16 slice wide-bore computed tomography scanner. Patients were positioned supine on a breast board with arms above their head. All patients first had a conventional three-dimensional computed tomography scan (5 mm slice thickness/5 mm slice spacing) as per our clinical protocol. This scan was used for planning of the patient's radiotherapy treatment.

In addition, all patients were imaged directly after the conventional computed tomography scan using a four-dimensional computed tomography protocol. Motion management was based on the Varian Real-time Position Management system interfaced to the computed tomography scanner. The Real-time Position Management system consists of an infrared marker that was placed on the patient's chest or abdomen. The marker box, which was monitored in real time using an infrared camera system, was placed by the operator in a location that clearly displayed motion during breathing. The location was related to anatomical marks and 5 cm below the xyphoid process was chosen for most patients.

Computed tomography scans during 10 phases of the breathing cycle were acquired. In helical four-dimensional computed tomography the couch speed must be adjusted to the breathing rate of the patient to ensure each part of the anatomy is visible on sufficient projection images for each phase of the breathing cycle. As such, the couch pitch factor (forwards movement as a function of fan beam thickness) of the scan was adjusted to suit the patient's breathing rate and ranged from 0.065 to 0.12 for slow and fast breathing patients, respectively.

For four-dimensional computed tomography acquisition, the beam current of the X-ray tube was reduced by a factor of about five compared with the three-dimensional computed tomography scan to limit the effective dose to the patient due to the additional four-dimensional computed tomography scanning procedure to about 10 mSv. Both the three- and four-dimensional computed tomography scans used automatic mA selection in the craniocaudal direction (Philips Z-DOM) and automatic current selection. The computed tomography dose index (CTDI) and the dose length product (DLP) were recorded for all scans. The CTDI is a dose measure that quantifies the typical dose received in any part of the imaged volume. DLP also includes the length in the superior–inferior dimension of the irradiated volume, which provides an estimate of integral dose and therefore radiation-related risk to the patient.

From the 10 phases of the breathing cycle, an average (mean computed tomography number of all the 10 scans in each voxel) and the maximum intensity projection (MIP) image (maximum computed tomography number of all the 10 scans in each voxel) [20] were created using Philips 'tumor loc' software. The MIP image, which shows high-density structures in all phases of the breathing cycle, is commonly used for target contouring in radiotherapy planning [21], whereas the average image shows the image of the target smeared out over all phases of the breathing cycle [22]. The average image is useful for comparison with other slow imaging modalities, such as cone beam computed tomography and positron emission tomography and is usually used for dose calculations.

Treatment Planning

Treatment plans were created using the Varian Eclipse 7.5 computerised treatment-planning system employing a pencil beam dose calculation algorithm. All plans were created using a field in field technique consisting of two tangential beams of 6 MV photons encompassing the whole breast with a non-divergent posterior edge and dynamic wedges customised to the anatomy of individual patients. A static multileaf collimator was used for collimation. In order