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Cardiac dosimetry in breast cancer

Inter-observer variation in delineation of the heart and left anterior descending coronary artery in radiotherapy for breast cancer: A multi-centre study from Denmark and the UK

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ABSTRACT

Background and purpose: To determine the extent of inter-observer variation in delineation of the heart and left anterior descending coronary artery (LADCA) and its impact on estimated doses.
Methods and materials: Nine observers from five centres delineated the heart and LADCA on fifteen patients receiving left breast radiotherapy. The delineations were carried out twice, first without guidelines and then with a set of common guidelines.
Results: For the heart, most spatial variation in delineation was near the base of the heart whereas for the LADCA most variation was in its length at the apex of the heart. Common guidelines reduced the spatial variation for the heart and the length of the LAD, but increased the variation in the anterior–posterior/right–left plane. The coefficients of variation (CV) in the estimated doses to the heart were: mean dose 7.5% without and 3.6% with guidelines, maximum dose 8.7% without and 4.0% with guidelines. The CVs in the estimated doses to the LADCA were: mean dose 27% without and 29% with guidelines, maximum dose 39% without and 31% with guidelines.
Conclusions: For the heart, there was little inter-observer variation in the estimated dose, especially when guidelines were used. In contrast, for the LADCA there was substantial variation in the estimated dose, which was not reduced with guidelines.
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Contouring of organs at risk plays an essential role in modern three-dimensional (3D) radiotherapy planning based on computerised tomography (CT), both in order to maximise tumour control and to limit radiation-related toxicity. When tumour control and radiation-related toxicity need to be balanced against each other, models providing normal tissue complication probabilities (NTCP) for specific organs are useful. Accurate NTCP models can, however, be developed only if there is sufficient consistency in the way that different individuals delineate critical organs and structures to enable the relevant doses to be estimated reliably. Lack of consistency in contouring organs at risk among investigators was pointed out by the QUANTEC group [1] as one of the challenges in developing NTCP models.

In breast cancer, evidence is accumulating that radiotherapy can increase the risk of heart disease [2–8], and an increased risk of stenosis in the left anterior descending coronary artery (LADCA) for left-sided radiotherapy compared to right-sided has been reported [9,10]. Contemporary techniques usually deliver lower mean doses to the heart than they did in the past, but some parts of the heart may still receive high doses [11,12] including the LADCA, which is located near the left breast and may receive a high dose in left-sided radiotherapy. Consequently in many centres it has become part of daily clinical practice to contour the heart, and in some centres also the LADCA so that dose to these structures can be estimated and limited. Substantial inter-observer variation may, however, be present in the delineation [13,14]. The aim of this study was to determine the extent of inter-observer variation in delineating the heart and the LADCA and to ascertain the resulting variation in the estimated doses to these structures from CT-based left-tangential breast radiotherapy. Delineations were performed first without, and secondly with a common set of guidelines that were made available to all observers.

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Methods and materials

Patients

Fifteen patients were selected at random from women who received adjuvant radiotherapy to the conserved left breast at the Odense University Hospital in 2010. The patients were scanned on a Phillips Bigbore with voxel size $0.9866 \times 0.9866 \times 3$ mm. Contrast was not used, as it was not clinical practice in any of the participating centres. Each patient received radiotherapy according to the 2010 guidelines from the Danish Breast Cancer Cooperative Group (DBCG) (http://www.dbcg.dk). The field configuration was patient-specific, but consisted in general of two 6 MV tangential beams with one or two supplementary 18 MV fields delivering 10–20% of the prescribed dose. Shielding of the heart and LADCA was adjusted to comply with the DBCG dose constraints for the heart (i.e. percentage of volume receiving 40 Gy or more $V_{40\,Gy} \leqslant 5\%$ and $V_{20\,Gy} \leqslant 10\%$) and LADCA ($V_{20\,Gy} = 0\%$ and $V_{10\,Gy} \leqslant 5\%$). The delineations previously used clinically for the dose planning were not included in this study. Dose planning was done in Pinnacle[3] using the collapsed cone algorithm [15].

Delineation without and with common guidelines

The fifteen patients were contoured by nine experienced observers (four radiation oncologists, five radiographers) from four centres in Denmark and one centre in the UK. The observers received the CT-scans of the patients in DICOM-format and were asked to delineate the heart and the LADCA in their treatment planning system according to their own practice. At least two months after completion of the delineations, each observer received a set of common guidelines for contouring the heart and LADCA and was asked to repeat the delineations using the instructions in the guidelines. The guidelines were based on the publication by Feng et al. [16] except that in the guidelines the LADCA contour included the left main coronary artery. Each observer performed the delineations independently from the other observers.

Evaluation of delineations

The delineations were imported and analysed in Matlab R2007b using the open-source tool CERR [17] and in-house code. No delineation was designated as true or as a gold standard, as all observers were experienced and promoting any one set of delineations as a gold standard would be arbitrary.

The heart and LADCA represent very different delineation problems, with the heart being large, easy to visualise (at least in some regions) and approximately spherical, whereas the LADCA is small, difficult to visualise and has a long thin cylindrical shape. Different measures were therefore used to evaluate the inter-observer variation for the two structures, as described below. For each patient the mean value of a given measure was calculated by averaging the estimates from all nine observers (e.g., mean volume). Mean values were then averaged across all patients (e.g., average mean volume).

Volume and spatial overlap

For each patient the mean volume and the spatial overlap of all the heart delineations were calculated. For easy comparison with other studies, two commonly used indexes of spatial overlap, the Sørensen-Dice similarity index (DSI) and the Jaccard similarity index (JSI), were evaluated. They were defined as

$$\mathrm{DSI}(A,B) = \frac{2A \cap B}{A+B} \qquad \mathrm{JSI}(A,B) = \frac{A \cap B}{A \cup B} \tag{1}$$

where A and B represent the volumes delineated on a patient by two different observers. For each patient these similarity indexes were calculated for all possible combinations of two observers, and the patient-specific mean value was calculated. Due to its small volume and the low overlap of the delineations by different observers, neither the volume nor the similarity indexes were evaluated for LADCA delineations, see [19] for further discussion.

Spatial distance variation

In order to locate where any spatial differences between observers in the heart delineations occurred, the local distance variation in heart delineations was mapped. The method is illustrated in Fig. 1a together with the median heart (which consisted of the voxels delineated as heart by more than half the observers). The distance to each observer's heart delineation is determined along a set of directions, illustrated by the arrows in Fig. 1a, starting in the centre of the median heart. The variation in these distances was determined as the inter-quartile range (IQR), i.e. the distance between the 25th and 75th percentiles of delineations.

For the LADCA the spatial distance variation between the delineations was evaluated by two measures: the variation in the cranial–caudal (CC) direction and the variation in the anterior–posterior (AP)/right–left (RL) plane. The variation in the CC-direction was evaluated as the IQR in length along this direction and the variation in the LR/AP-plane as the mean distance between the centres of the LADCA delineations, see Fig. 1b.

Estimated dose

In order to evaluate the inter-observer variation in terms of estimated dose, the dose distribution from the patient's clinical treatment plan was used. The mean and maximum doses to the heart and LADCA were calculated for each observer's delineations performed first without and then with the guidelines. The inter-observer variation was then taken to be the coefficient of variation (CV) defined as the standard deviation divided by the mean value.

The surface dose to the median heart was calculated and mapped in order to visualise the irradiation of the heart. The variation in the mean heart dose, due to a spatial variation in a region on the surface, depends on the local dose in the region. This can be described mathematically by considering a heart delineation with volume V_0 and mean dose $D_{\mathrm{mean},0}$. If the heart delineation is subject to a spatial change in a surface region, the change in mean dose can be described as:

$$\Delta D_{\mathrm{mean}} = \frac{V_0 D_{\mathrm{mean},0} + D\Delta A\Delta R}{V_0 + \Delta A\Delta R} - D_{\mathrm{mean},0} \tag{2}$$

where ΔA is the surface area of the region, ΔR the extent of the change perpendicular to the surface and D the local dose in the region. Using a first order Taylor expansion Eq. (2) can be approximated as:

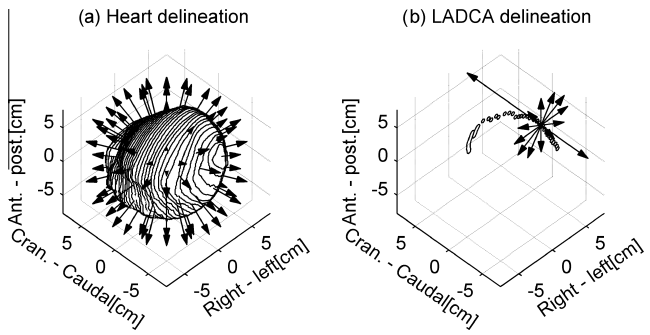

Fig. 1. Evaluation of the spatial distance variation for heart and LADCA delineations. (a) For the heart the variation in all directions covering the surface of the heart was determined, as illustrated by the arrows. (b) For the LADCA, the variations in the cranio–caudal (CC) direction and in the anterior–posterior (AP)/right–left (RL) plane were evaluated separately, as illustrated by the arrows.