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Visualisation of the left anterior descending coronary artery on CT images used for breast radiotherapy planning

¹S VENNARINI, MD, ¹N FOURNIER-BIDOZ, PhD, ²C ARISTEI, MD, ³C E DE ALMEIDA, PhD, ⁴V SERVOIS, MD, ¹F CAMPANA, MD, ⁵V MOSSERI, MD, ¹A FOURQUET, MD and ¹Y M KIROVA, MD

¹Department of Radiation Oncology, Institut Curie, Paris, France

²Department of Radiation Oncology, University of Perugia, Perugia, Italy

³Laboratorio de Ciencias Radiológicas, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

⁴Department of Radiology, Institut Curie, Paris, France

⁵Department of Biostatistics, Institut Curie, Paris, France

Address correspondence to: Dr Nathalie Fournier-Bidoz

E-mail: nathalie.fournierbidoz@curie.net

Objective: To assess the visualisation of the left anterior descending (LAD) coronary artery on CT images used for breast radiation treatment planning.

Methods: Delineation of the LAD artery was achieved for 25 breast patients by 1 radiologist and 1 radiation oncologist independently on two sets of images for each patient: one pre-operative CT scan using intravenous (IV) contrast media to determine the primary gross tumour volume (GTV) and one post-operative CT scan used for treatment planning. A Student's paired *t*-test was used to compare the number of CT slices in which the LAD was visible for each patient in the two series. Interpolations and extrapolations of the LAD volume were performed for the left-sided cases using

a published heart atlas in order to report doses to the LAD structure.

Results: There was a non-significant difference between the results with and without IV contrast media ($p=0.34$ for the radiologist; $p=0.90$ for the radiation oncologist). The visible LAD artery corresponded to a 30% portion (range 12–47%) of the interpolated structure. The maximum dose to the left artery varied widely, from 2.7 to 41.7 Gy, in the group of patients with left breast tumours. The largest values (>25 Gy) corresponded to those patients in whom the LAD artery distal extremity lay inside the breast fields.

Conclusions: With the current planning CT protocol, only one-third of the LAD artery

could be objectively visualised. Contrast-enhanced imaging used for GTV delineation before the breast surgery did not improve the visualisation of the artery.

Advances in Knowledge: This study has revealed the lack of consistency that may be encountered when contouring heart vessels, thereby questioning the reliability of dose reporting.

Radiotherapy (RT) has demonstrated a strong clinical benefit in patients with breast conservative surgery or patients with radical mastectomy who are at high risk for relapse. Unfortunately, this benefit is counterbalanced by an increased risk of death from cardiac events [1]. Several systemic agents are associated with cardiac toxicity or may increase the toxicity of RT, including endocrine therapy, chemotherapy agents or molecular targeted therapies. Unfortunately, most trials did not consider cardiac toxicity in their entirety [2]. Since the use of CT-based three-dimensional (3D) conformal RT, doses to the heart have been collected and attempts have been made to evaluate their impact on cardiac toxicity [2–4]. Retrospective studies on large populations of patients treated for breast cancer showed a correlation between cardiac mortality and the dose–volume histogram (DVH) or the normal tissue complication probability values of the heart [3–5]. Because RT-induced toxicity depends on the region of the heart that is irradiated, there is a need to improve the imaging protocols to identify the heart substructures, such as the coronary arteries. Recent dosimetric studies showed that evaluating the dose to the left anterior descending (LAD) artery may change the treatment strategy in breast irradiation [6,7]. However, the visualisation of the artery and its delineation for dose reporting may depend on the imaging protocol that is used [8–11]. Feng et al [10] developed a heart atlas with the aim of improving the reproducibility of contouring the heart substructures. However, to our knowledge, there is no published information or recommendation on an imaging protocol to be used in RT planning that enables good visualisation of small structures such as the arteries.

The novel aspect of this study was the assessment of the visualisation of the LAD artery on CT images that were used for RT planning of a homogenous population of patients. These patients had two CT scans in the treatment position, taken before and after surgery. The first CT was performed with contrast media and

the second without. Subsequently, we analysed the doses received by the heart and by the left coronary artery.

METHODS AND MATERIALS

Patients and irradiation technique

25 patients with breast-conserving surgery underwent radiation treatment in our department and were included in a CT-imaging protocol for planning. The aim of this protocol was to help localise the tumour bed to deliver a boost dose to this volume [12–14]. The breast irradiation consisted of the use of tangential fields for whole-breast radiotherapy (WBRT) for a dose of 50 Gy in 25 fractions. A simplified field-in-field technique ensured a level of dose homogeneity within the range –5% to +7% in the whole volume according to the recommendations of the International Commission on Radiation Units [15–17]. Following the WBRT, a boost dose of 16 Gy was delivered to all the patients, using either a direct electron field or, for deep seated tumours, two reduced tangential fields (or a photon/electron mix) in a planning boost volume (PBV) determined with the help of surgical clips and pre- to post-image registration [12,13]. The PBV was defined as the reunion of the gross tumour volume (GTV) and the clip volume, with a margin to account for geometric uncertainties. 11 patients had tumour in the left breast. Among them, 3 underwent irradiation of the internal mammary nodes (IMN) with a mixed photon/electron field weighted 35/65 at a dose of 46 Gy.

CT-scanning

A pre-operative (pre-op) CT scan in the treatment position using intravenous (IV) contrast media was performed to localise the GTV. 90–120 ml of iomeprol 350 mg I ml^{–1} was administered at the rate of 1.5–2 ml s^{–1}, at a start time of 2–3 min. A post-operative (post-op) CT scanner, also in the treatment position, was used for the treatment planning. The imaging protocol involving pre- and post-op CT conformed to our standard practice, which was approved by the Breast Board of the Institut Curie, Paris, France, for the population of

patients receiving a dose to the surgical bed of 66 Gy or more. The CT scanner of the RT department is a Toshiba Aquilion® LB (Toshiba Medical, Puteaux, France) with a large bore of 90 cm and a 16-detector row. Acquisition was performed with a field of view of 550 mm. The reconstructed slice thickness/interval was 3 mm/3 mm. For both CT scans, the patient was supine on an angled breast board, with one arm up on the side of the treated breast. The second CT scan without contrast media was performed 4–5 weeks after surgery and used for the treatment planning.

Left anterior descending delineation

The contouring of the LAD coronary artery was performed using the Eclipse® treatment planning system (TPS; Varian Medical Systems Inc., Palo Alto, CA). Contouring was attempted on each CT image (50 image series) using the heart atlas proposed by Feng et al [10].

The delineation of the LAD artery was performed independently by 1 radiologist and 1 radiation oncologist on the pre-op CT scan with IV contrast media and on the post-op CT scan without IV contrast media. A comparative analysis of the number of slices showing where the LAD coronary artery was visible (N_{LAD}) was performed to determine whether the IV contrast media helped with the delineation. Every patient was presented as his or her own control. The statistical method used was a Student's paired *t*-test, with $p < 0.05$ indicating a significant difference.

In the second part of our work, only the left-sided breast cancer patients were considered. For this group of 11

patients, 3D reconstructions of the entire LAD artery were performed using a linear interpolation that was available in the TPS when the artery was not contiguous, owing to a lack of visibility on some slices. When not visible, the location of its cranial extremity could be extrapolated to the left main coronary artery situated in the groove between the ascending thoracic aorta and pulmonary trunk and the transition between the left atrium and the left ventricle. Similarly, when the LAD artery caudal extremity was not visible, it was extrapolated to the anterior part of the last slice of the anterior interventricular sulcus. The DVHs were calculated. Doses to 2% of the interpolated LAD artery volume ($D_{2\%}$) and the heart volumes receiving >5 Gy ($V_{5\text{Gy}}$) and >25 Gy ($V_{25\text{Gy}}$) were reported.

RESULTS

The Hounsfield units' window that was selected to facilitate the visualisation of the heart structures was set at a level of 50 with a width of 300–400 for the 50 image series. The 3D reconstruction of the artery showed artefacts on its cranial extremity, leading to a structure with a thickness greater than its actual thickness. In addition, the reconstructed structure presented some missing segments, especially in the caudal part of the artery (Figure 1a). The number of slices where the left artery was visible is shown in Figure 2a,b for the two observers, respectively. In general, the radiation oncologist had a little more difficulty in discerning the LAD artery on some slices. For the radiologist, the median N_{LAD} was 12 (range 4–24) on the contrast-enhanced CT and 11 (range 5–20) on the CT without IV contrast media. For the radiation oncologist, the median N_{LAD} was 9

Figure 1. Three-dimensional reconstruction of the heart and the left anterior descending coronary artery without interpolation (a) and with interpolation (b).

Figure 2. Number of CT slices in which the left anterior descending artery was visible (N_{LAD}) for (a) the radiologist and (b) the radiation oncologist; IV, use of intravenous contrast.

(range 4–18) for CT with IV contrast media and 9 (range 5–19) for CT without IV contrast media. The paired Student's *t*-test indicated that there was a non-significant difference between the results with and without IV contrast media ($p=0.34$ for the radiologist; $p=0.90$ for the radiation oncologist).

The cranial and caudal extremities of the LAD artery could not always be observed. The extrapolations of their respective locations for the group of left-sided tumour patients led to positions on the CT image separated by 35 slices on average. Figure 1b shows an example of the interpolation results. The median number of slices where the LAD artery was objectively observed relative to the extrapolated structure was 30% (range 12–47%) for the radiologist on the contrast-enhanced CT image, meaning that less than one-third of the artery could be objectively observed in most cases.

The maximum dose to the LAD artery as measured by $D_{2\%}$ varied widely, from 2.7 to 41.7 Gy, in the left breast group (Table 1). The largest values (>25 Gy) corresponded to Patients 3, 9, 15 and 20, in whom the LAD artery distal extremity lay inside the breast fields (Figure 3a). Patients 9, 12 and 22, who underwent IMN irradiation, had a $V_{5\text{Gy}}$ (heart) $>27.6\%$. As an example, the transverse dose distributions are shown for Patient 9 on the CT slices containing the proximal and distal extremities of the LAD artery and on a CT slice at an intermediate transverse plane (Figure 3b). $V_{25\text{Gy}}$ (heart) never exceeded 6%, and averaged 1.5% (standard deviation 2.1%) for the population of 11 patients. 5 patients had no IMN irradiation and a V_{25} equal to 0%, meaning that no heart was included in the tangential fields (25 Gy corresponding to the field border); however, their LAD artery doses were not null (ranging from 2.7 to 13.1 Gy). One example, given in Figure 3c, shows a transverse dose distribution with the tangent

Table 1. Doses to the LAD coronary artery, $D_{2\%}$ (LAD), and heart volumes receiving >5 Gy, $V_{5\text{ Gy}}$ (heart), and >25 Gy, $V_{25\text{ Gy}}$ (heart), for the 11 left breast tumour patients

Patient number	RT with IMN	$D_{2\%}$ (LAD) Gy	$V_{5\text{ Gy}}$ (heart) %	$V_{25\text{ Gy}}$ (heart) %
3		31.4	41.5	1.4
8		10.3	14	0
9	Yes	25.9	48.8	6
12	Yes	16.9	27.6	2.3
13		2.7	0.8	0
15		41.7	6	1.3
18		13.1	1.8	0
19		6.2	1.1	0
20		36.9	4.1	1.1
22	Yes	15.2	39.8	4.7
23		4.2	0.4	0
Min		2.7	0.4	0
Max		41.7	48.8	6
Mean				1.5
SD				2.1

IMN, internal mammary nodes; LAD, left anterior descending; Max, maximum; Min, minimum; RT, radiotherapy; SD, standard deviation.

borders far from the artery. For 3 patients (Patients 3, 15 and 20), V_{25} was of the order of 1%, although the dose at the artery was 31.4, 41.7 and 36.9 Gy, respectively. [Figure 4a,b](#) shows the maximum dose to the left artery as functions of $V_{5\text{ Gy}}$ (heart) and $V_{25\text{ Gy}}$ (heart), respectively.

DISCUSSION

The technological improvements of breast cancer RT in recent years have led to a significant decrease in the heart dose, suggesting but not demonstrating that cardiac toxicity could be decreased [2,8–10,18–20]. Gauer et al [18] compared the treatment plans of electron intensity-modulated radiotherapy (IMRT) with helical photon IMRT and conventional RT. These authors demonstrated that electron IMRT was superior to conventional RT because it allowed both high-quality target coverage and heart avoidance. Compared with photon IMRT, smaller volumes were exposed to low-dose irradiation, which carries a risk of unknown long-term cardiac toxicity. The next step would be to better

appraise which doses might be safely delivered to specific cardiac structures, especially the coronary arteries [2].

To report doses to the heart and its vasculature, the CT image protocol used in RT needs to be evaluated. The diameter of the LAD coronary artery is approximately 3 mm at its cranial extremity and 1 mm at its distal end. Although our CT image resolution is optimal owing to a detector size of 0.5 mm, the patient's breathing and cardiac kinetics produce image blurring that renders the visualisation of the artery difficult. In this study, we described our institution CT protocol used for breast RT planning and evaluated the difficulty of contouring the left anterior descending artery. We have shown that for both a radiologist and a radiation oncologist only about one-third of the structure could be objectively identified on the images used in routine planning. The use of a contrast-enhanced image series for each of the 25 patients led to a non-significant difference in the paired comparison with the non-enhanced images regarding LAD artery visualisation. The contrast injection protocol used was meant to enhance the GTV before surgery with a late start time of the IV injection. It was shown to be inappropriate for the delineation of heart structures, suggesting that we may need heart-specific contrast-enhanced imaging with a more rapid injection (typically of the order of 15 s for vessel enhancement).

The 3D reconstruction of the LAD artery where it arose from the aorta and bifurcated to the left anterior side of the heart showed volume artefacts owing to breathing and heartbeat movements. In previous works, we have published a reconstruction of the heart of a patient who had a full cardiological examination, including cardiac gating [6,8]. This work showed the reconstruction of the LAD artery at two different phases of the heartbeat and two breathing phases (exhale and inhale), suggesting that the largest movements were on the deep cranial extremity of the artery. Jaggi et al [11] worked on the magnitude of the displacement of the coronary artery based on these movements in a group of 10 patients and demonstrated that the displacement of the LAD artery was greatest in the superior–inferior direction. Because breathing and heart beating blur the heart images, it may be advantageous to do a complementary exploration—limited to the heart region—using breath-hold associated with cardiac gating for the patients who may be at risk of suffering

Figure 3. (a) Patient 15 did not receive internal mammary node (IMN) irradiation; however, part of the artery was included in the tangential fields, resulting in the highest dose to the left anterior descending (LAD) artery [D2% (LAD)=41.7 Gy], as seen on the medial tangent beam's eye view. The LAD artery is indicated by the arrow. (b) Dose distribution for Patient 9, with IMN irradiation. The isodoses from 5 to 50 Gy are shown at three different levels of the heart: (left) at the level of the common trunk of the intraventricular artery; (middle) at the left anterior bifurcation of the LAD artery; and (right) at the caudal part of the LAD artery. The LAD artery is indicated by the arrow. (c) Patient 13 had the lowest D2% (LAD artery=2.7 Gy) at a distance from the tangent field borders. The LAD artery is indicated by the arrow. The isodoses ranged from 5 to 50 Gy.

(a)

(b)

(c)

Figure 4. (a) $D_{2\%}$ [left anterior descending (LAD) artery] as a function of $V_{5\text{Gy}}$ (heart). (b) $D_{2\%}$ (LAD artery) as a function of $V_{25\text{Gy}}$ (heart).

heart toxicity. This implies that the CT used for planning is equipped with a cardiac gating system and that the dose induced by this exploration is acceptable. A planning organ at risk volume (PRV) for the coronary artery could then be created by measuring its movements for the individual patient, on cardiac gated images taken at two extreme points of the breathing cycle amplitude. Our RT protocol used a relatively “long” rotation time of 1.5 s, although our CT scanner could be set at a rotation time of 0.5 s, and it therefore included a part of the patient’s breathing cycle. Our reconstructions of the LAD structure partially integrated the movements owing to breathing and heart-beat, leading to a thickened cranial extremity in the superior–inferior direction (as seen in the example of Figure 1). However, strictly speaking, only a study using cardiac gating could allow the evaluation of the margins needed to construct a PRV of the artery.

The DVHs of the LAD artery that were calculated for the subgroup of the left-sided tumour patients showed that the highest doses to the LAD artery corresponded to four patients who had their artery lying inside the breast field. Even though the heart volumes receiving >25 Gy were very small ($\leq 6\%$), the distal part of the LAD artery was discovered to have lain inside the breast field, resulting in doses >25 Gy for a portion of the artery. A good visualisation of this structure may have induced the dosimetrist to exclude the LAD artery from the irradiated volume. However, in our study, the caudal extremity of the LAD artery was shown to be most difficult to localise. In our series, three patients had a V_{25} of the order of 1% while their LAD artery dose was relatively high; even if a very small portion of the heart is irradiated by the tangent fields, the LAD artery may lie in that portion, so it is better to shield the heart when it is possible. Circling the breast with

a radio-opaque marker and using a good image quality to identify the breast glandular tissues on the planning CT help during the virtual simulation procedure and allow shaping the breast fields to exclude the heart without compromising the breast irradiation when possible.

The use of structure interpolation tools to approximate the LAD artery location and the lack of PRV margins may have led to imprecise dose reporting and inaccurate DVHs. Owing to a large variety of breast RT techniques, including the use of mixed photon/electron fields, large tangents, electron/photon IMRT or arc therapy, doses received by the heart vessels as reported in the literature are very heterogeneous [18–21]. There is therefore a need to improve the imaging protocols commonly used in the RT field to better localise the heart arteries and improve the quality of dose reporting. Unfortunately, thorough information about the imaging protocol used for RT planning is missing in papers reporting heart doses. This paper

aims to encourage radiation oncologists and physicists to exchange information and suggestions on their CT protocols, especially regarding heart vessel visualisation.

CONCLUSION

The present study showed that the reconstruction of the LAD coronary artery was difficult, with some missing segments, stressing the need to improve the RT imaging protocol. With the current RT protocol, only one-third of the structure could objectively be observed. The contrast-enhanced imaging used for GTV delineation before the breast surgery did not improve the visualisation of the artery. The large range of doses to the LAD artery reported in the literature may be partially due to imaging artefacts and consequently to variations in the delineation. This study has revealed the lack of consistency that may be encountered when contouring heart vessels, thereby questioning the reliability of dose reporting.

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