CARDIOVASCULAR DOSIMETRY FOLLOWING RADIOTHERAPY USING HYBRID COMPUTATIONAL PHANTOMS

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CONTEXT AND OBJECTIVE

Many studies have shown an increased risk of cardiovascular diseases following radiotherapy. To date, cardiovascular retrospective dosimetry is based on the use of a "representative" patient's CT images or simple mathematical phantoms.
Here, patient modelling is performed with hybrid computational phantoms in order to achieve personalized and detailed heart dose calculation, particularly for the coronary arteries.

MATERIALS AND METHODS

Overview

Radiotherapy treatment data of patients suffering from a left-side breast cancer were collected in the radiotherapy department of the Pitié-Salpêtrière hospital. First, the modelling process was assessed by performing it with complete anatomical information (CT images) of 3 patients ("A" patients). Second, models were built from two low-contrast orthogonal digitally reconstructed radiographs (DRRs) of 3 patients' chest ("B" patients) to assess it in the case of restricted anatomical information as in old radiotherapy charts. The DRRs were performed with a home-made script from the CT images and the first "A" patient's model used as template, was deformed to best fit the radiographs. In this case, CT images were only used to validate the modelling. Models were inserted in DICOM format into the Treatment Planning System (TPS [1]) by generating pseudo-CT images.

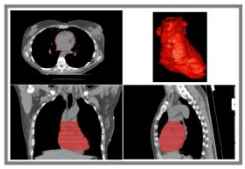
Model creation process from CT images

TPS
CT images
Delineation of the organs of interest
Contour exportation

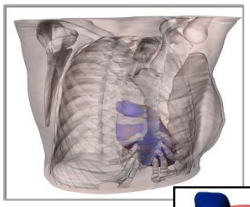
RHINOCEROS 3D [2]
Creation of the hybrid computational phantom
Inclusion of a detailed heart model [3]

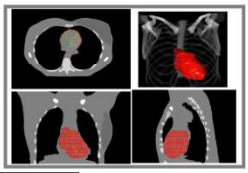
BINVOX [4]
Voxelization

DCMTK [5] **+ TPS**
Insertion of the pseudo-CT images in DICOM format into the TPS

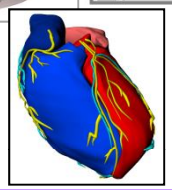


CT images with heart contours of the radiotherapist





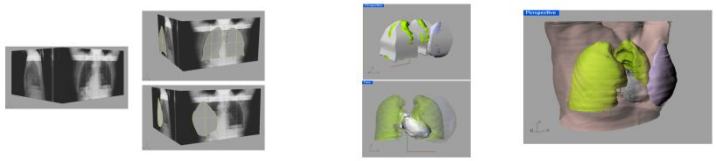
Pseudo-CT images with heart model contours



Heart model adapted for each patient (anterior view)

Model building from two orthogonal radiographs

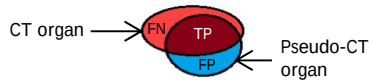
Display of the radiographs
Masks covering organs of interest
Creation of mask intersections
Scaling of template organs
Fitting of the heart model between the lungs
Resulting model (without bones)



Validation of the models

Morphology Volume comparison (ΔV) and Dice Index (DI) [6]

$$DI = \frac{2\,TP}{2\,TP + FP + FN}$$



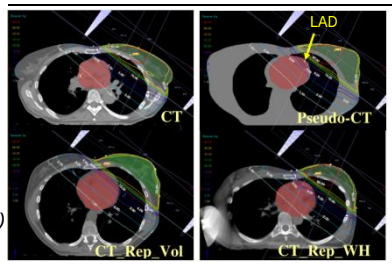
Dosimetry Dose distribution and dose-volume histograms comparisons between the CT and the pseudo-CT

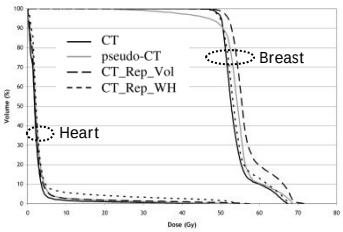
Results

Morphological and dosimetric comparison between CT and pseudo-CT

Patient	A1		A2		A3		B1		B2		B3	
	ΔV (%)	DI	ΔV (%)	DI	ΔV (%)	DI	ΔV (%)	DI	ΔV (%)	DI	ΔV (%)	DI
External contour	-0.5	0.98	-5.6	0.97	-3.0	0.98	-2.1	0.89	-0.8	0.94	-5.6	0.88
Breast	0.1	0.96	0.1	0.97	-0.4	0.95	3.2	0.54	31.5	0.71	22.1	0.60
Left lung	-0.3	0.96	0.2	0.95	-0.3	0.97	10.4	0.75	21.2	0.79	14.6	0.73
Right lung	0.4	0.96	2.1	0.96	-0.8	0.97	-14.7	0.68	-14.4	0.83	23.4	0.70
Heart	-8.9	0.87	7.3	0.87	-1.2	0.87	26.1	0.41	-28.8	0.68	-11.3	0.76

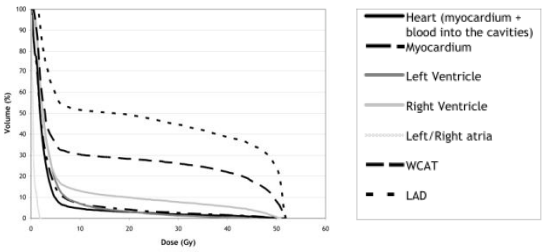
Dosimetric reconstruction for the B2 patient (LAD = Left Anterior Descending coronary artery)





⇨ For the "A" patients, good morphological and dosimetric agreements validated the method. For the B patients, differences between CT and pseudo-CT were more significant. A dosimetric reconstruction with CT images of two kinds of "representative" patients (one in terms of breast and heart volumes – CT_Rep_Vol; the other in terms of weight and height – CT_RepWH – as in Taylor's method [7]) highlighted that the models were not systematically better than a "representative" patient.

Cardiovascular dosimetry for the A2 patient



WCAT = Whole Coronary Artery Tree

⇨ In the left-breast radiotherapy context and for the studied cases, the heart was located in a high dose gradient.
⇨ Coronary mean doses were at least 5-fold higher than heart mean doses.
⇨ The LAD coronary artery, located near from the inter-ventricular groove, had higher mean dose than the right and circumflex ones.

Conclusion

- Created from CT images, hybrid computational phantoms are interesting because of the insertion of a detailed heart model that allows to identify and delineate the heart substructures, particularly the coronary arteries.
- Built from two orthogonal radiographs, these phantoms can be seen as a representative patient with the possibility of morphological deformations depending on the available anatomical data (orthogonal and/or beam field control radiographs, some external contours, etc). If a library of chest female phantoms is used to reconstruct the doses of a large number of patients, it can be expected that the doses will be more accurate than in current practice.
- The whole heart is not a good surrogate to assess the doses to the coronary artery.

References

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