POTENTIAL OF HYBRID COMPUTATIONAL PHANTOMS IN RADIOTHERAPY FOR HEART AND CORONARIES DOSIMETRY

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Faire avancer la sûreté nucléaire

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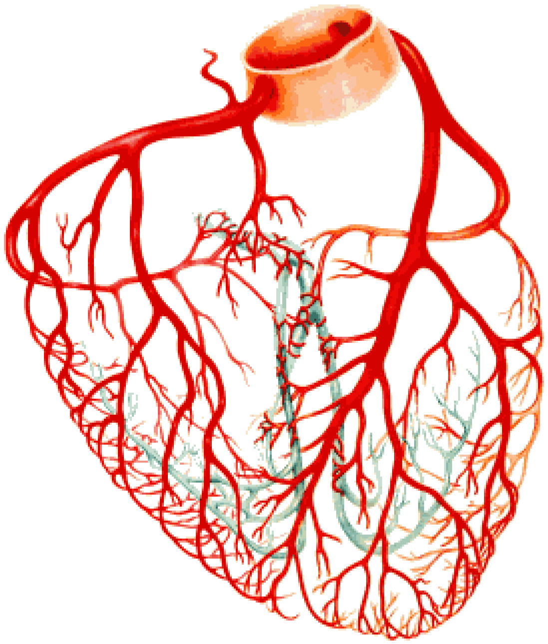


ICRS & RPSD 2012, Nara, Japan

Context

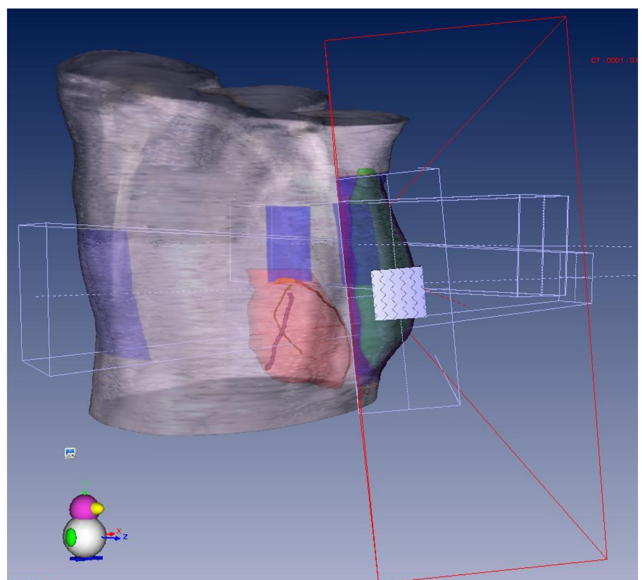
- Travis et al., Journal of the National Cancer Institute [1]:
  - "Second malignant neoplasms (SMNs) and cardiovascular disease (CVD) are among the most serious and life-threatening late adverse effects experienced by the growing number of cancer survivors worldwide and are due in part to radiotherapy"
  - The National Council on Radiation Protection and Measurements: one research priority is to characterize risks of SMNs and CVD in terms of radiation dose and type
- Current retrospective cardiovascular dosimetry studies are based on a representative patient [2] or simple mathematical phantoms [3]

[1] Travis et al. JNCI. 2012
[2] Taylor CW et al. Int. J. Radiol. Biol. Phys. 2007
[3] Shamsaldin A et al. Radiother. Oncol. 1998

Aims

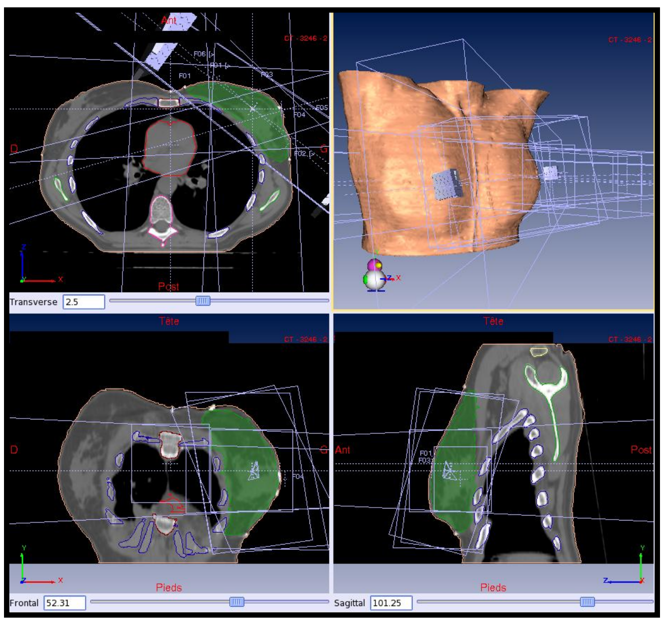
- Exploite the potential of the hybrid computational phantoms to improve the cardiovascular dosimetry in radiotherapy (RT)

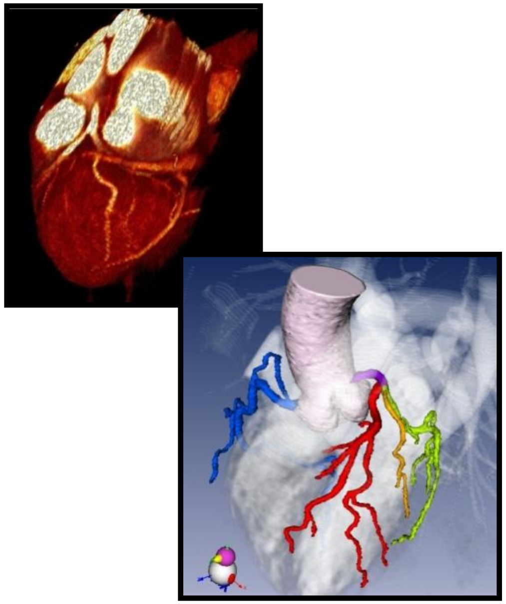
- Carry out sensitivity studies: here, dose sensitivity due to the coronary topology

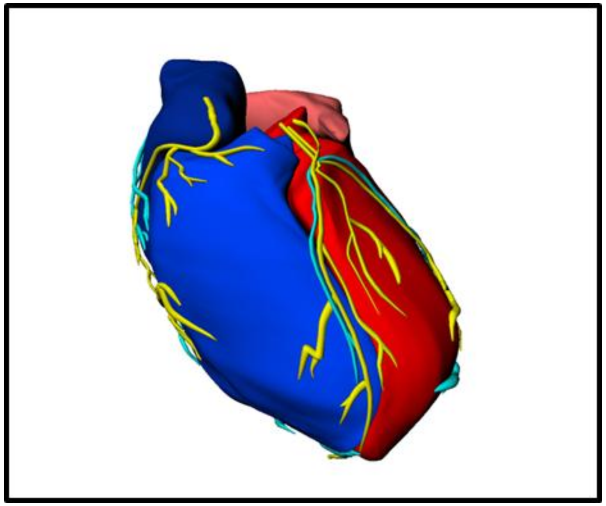


Database

- 83 RT records of women with a breast cancer
- 20 CT angiography records of patients with coronary lesions following Hodgkin lymphoma RT
- A detailed heart model from Anatomium 3D







I. IMPROVE THE CURRENT RETROSPECTIVE DOSIMETRY

First, Modeling from CT images

RHINOCEROS 3D

CT images
Segmentation
ISOgray TPS

→

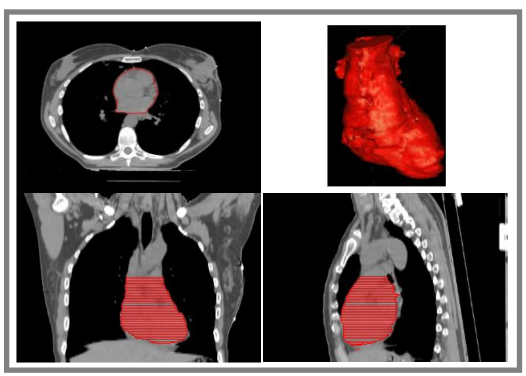
NURBS/Mesh model
Detailed heart model

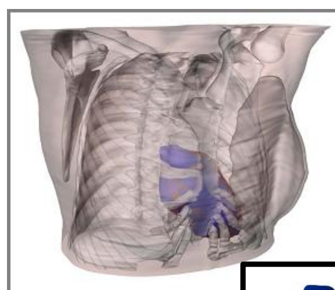
→

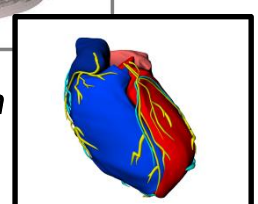
Voxelisation
Pseudo-CT images

→

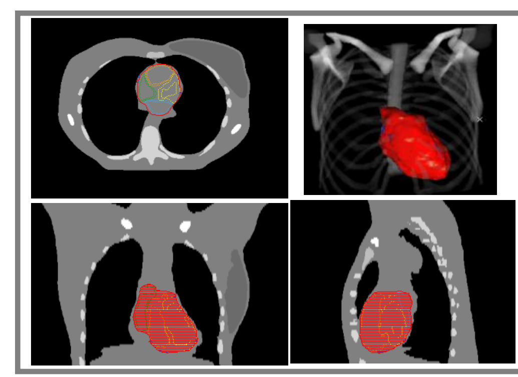
DICOM images



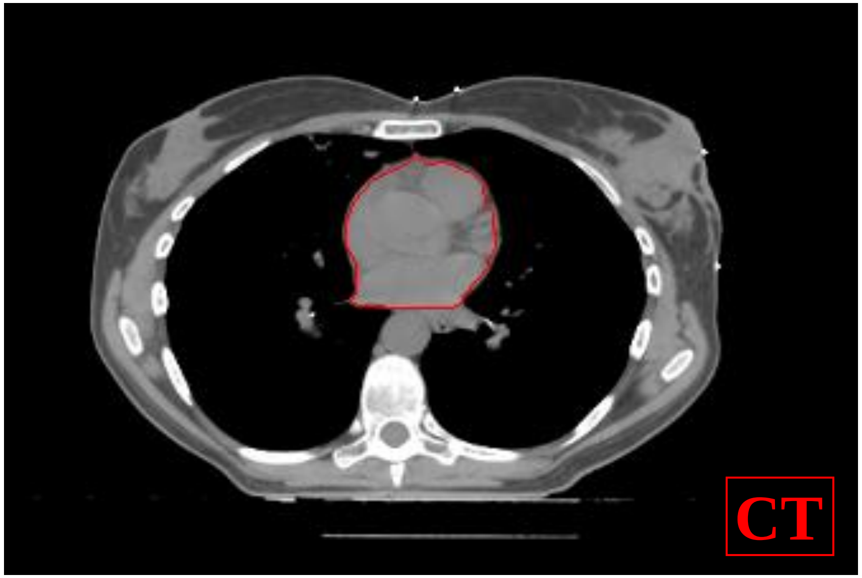


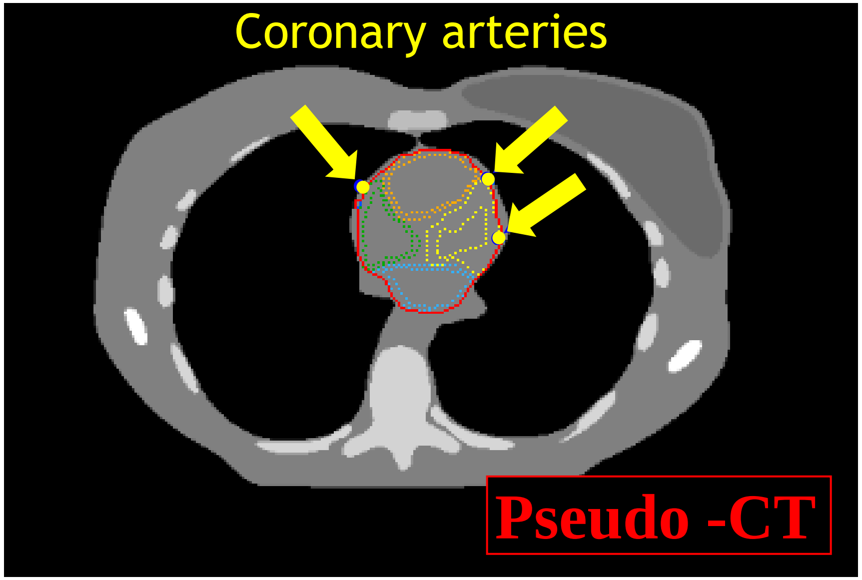


Heart model from Anatomium 3D

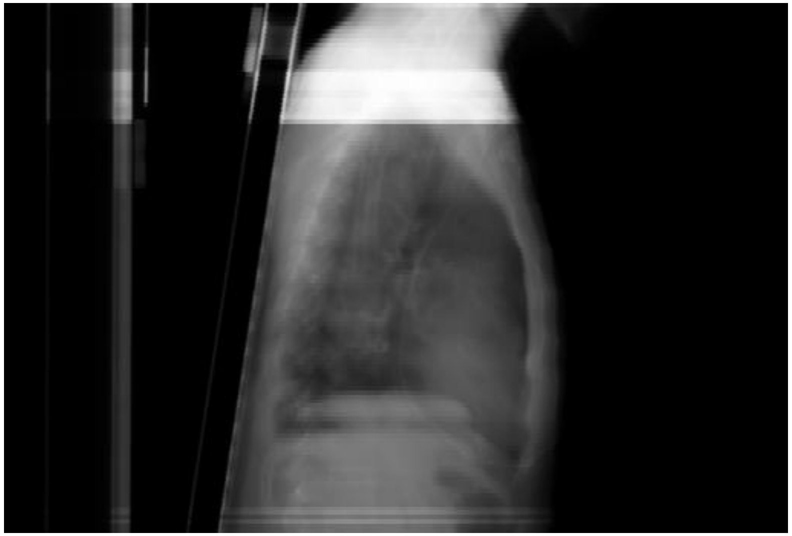


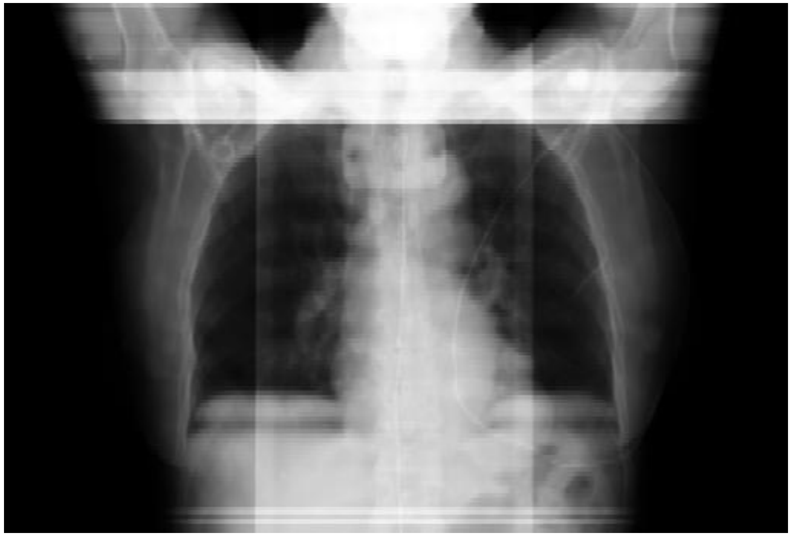
First, Modeling from CT images





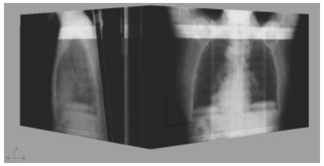
Second, Modeling from radiographies

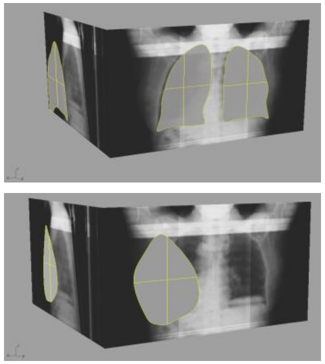


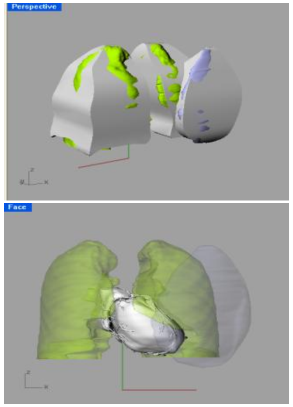


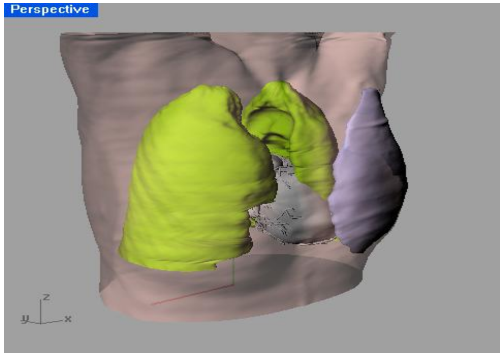
Second, Modeling from radiographies

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









Main results

- *Modeling from CT images:*
  - Validation of the method in terms of morphology and dosimetry
  - Mean dose to the IVA is at least 5 fold the heart dose (3 models)

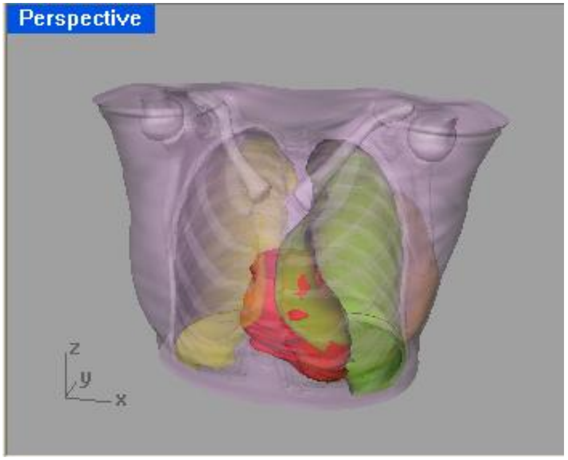
- *Modeling from radiographies:*
  - Morphologically, the model is closer to the patient anatomy than the representative patient
  - Dosimetrically, it is equivalent or slightly better
  - A library of thoracic phantoms can be interesting for dose reconstruction in retrospective studies when only radiographies are available

➚ More details in the Int. J. Radiol. Biol. Phys., 2012, article in press:

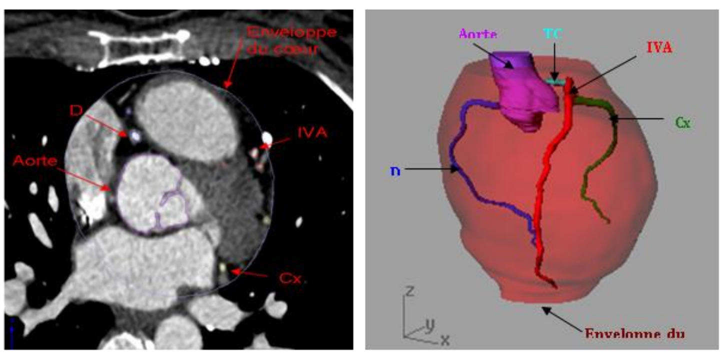
Moignier et al, *Potential of Hybrid Computational Phantoms for Retrospective Heart Dosimetry After Breast Radiation Therapy: A Feasibility Study*

II. DOSE SENSITIVITY TO THE CORONARY TOPOLOGY

Models with different coronary topologies

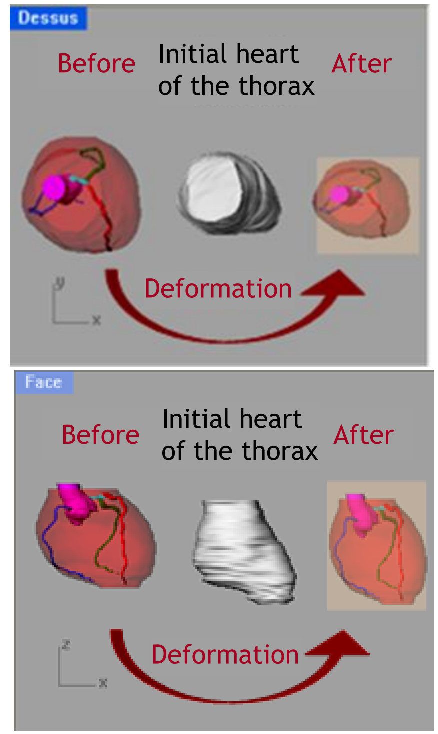


A single representative thorax

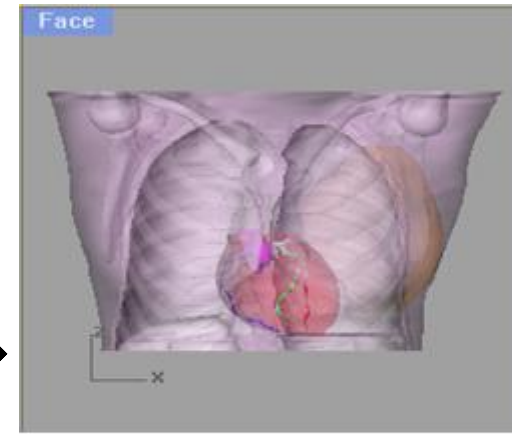


10 hearts with different coronary topologies from CT angiography

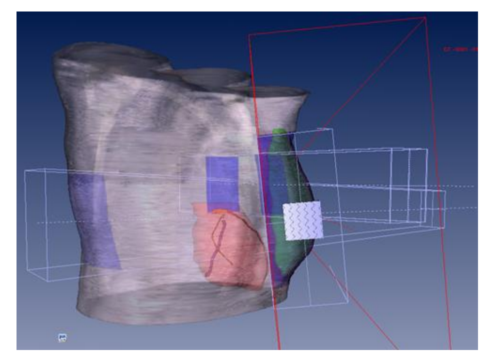
Heart scaling



Resulting model



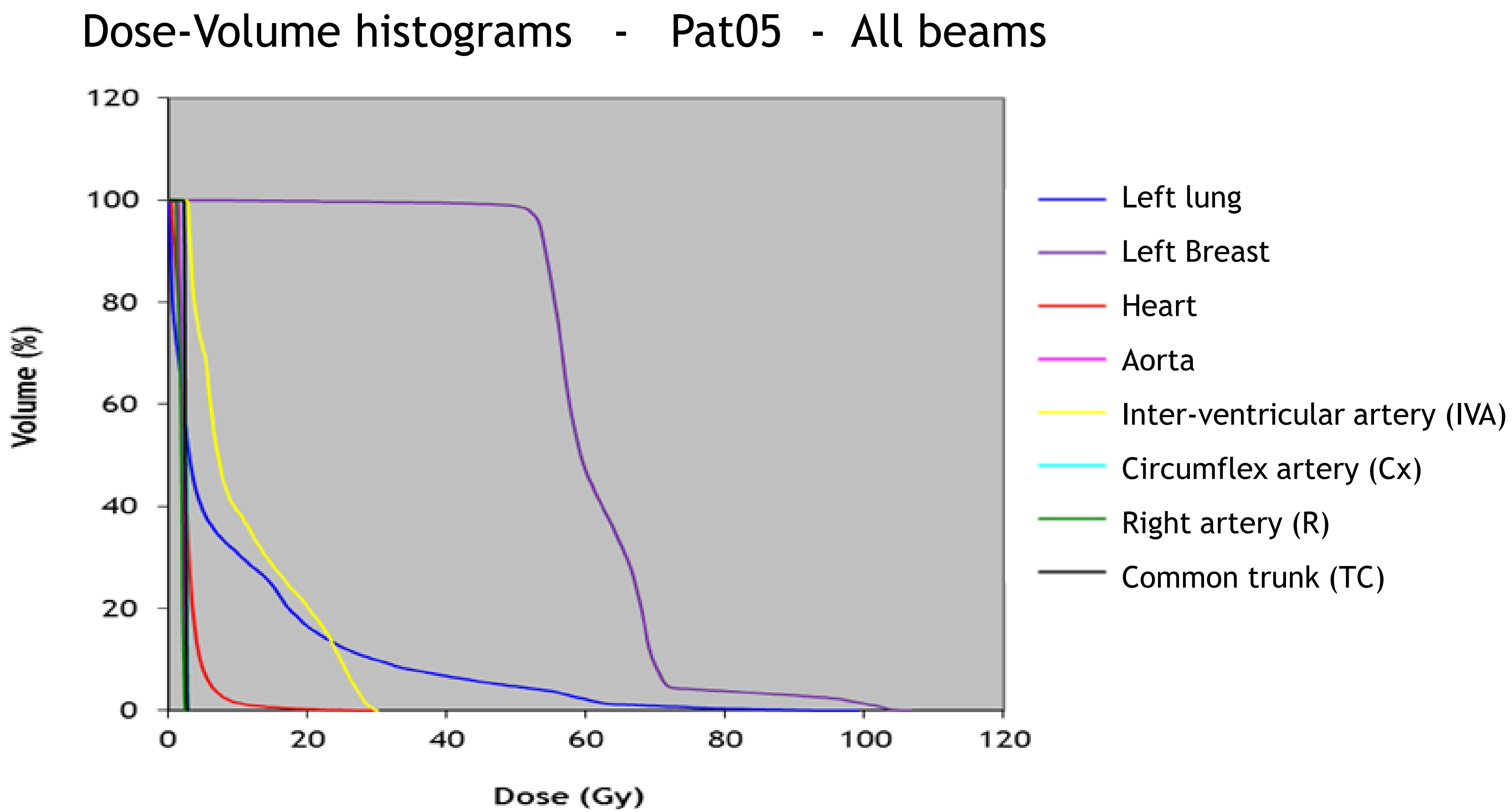
Classic current breast radiotherapy



Studied questions

1. What is the dose spread within each structure ?
2. Which structure receive high doses ?
3. Which beam is responsible for high doses ?
4. How is the dose distribution along the coronaries ?
5. Is the mean heart dose a good surrogate for IVA doses ?

1. What is the dose spread within each structure ?



➚ IVA is an organ-at-risk not well spared in left-side breast RT because it receives high doses within a high volume

1. What is the dose spread within each structure ?

	Dose dispersion, σ/μ, per structure for each patient				
	Heart	IVA	Cx	R	TC
Pat01	64.5%	37.4%	14.6%	40.0%	9.3%
Pat02	66.7%	52.0%	11.5%	24.0%	3.4%
Pat03	72.8%	58.4%	6.2%	30.5%	3.2%
Pat04	69.8%	67.1%	30.1%	37.9%	7.3%
Pat05	83.1%	74.5%	7.8%	20.2%	5.3%
Pat06	84.1%	68.4%	7.7%	33.2%	9.4%
Pat07	81.8%	85.6%	13.1%	15.7%	3.9%
Pat08	74.4%	50.2%	11.9%	30.9%	3.9%
Pat09	97.1%	40.0%	5.0%	25.3%	4.3%
Pat10	78.7%	40.2%	41.6%	46.0%	4.5%
Mean	**77.3%**	**57.4%**	**15.0%**	**30.4%**	**5.4%**

IVA = Inter-Ventricular Artery
Cx = Circumflex artery
R = Right artery
TC = Common trunk

➚ High dose spread within the heart and the IVA

2. Which structure receives high doses ?

	Mean Dose (Gy)				
	Heart	IVA	Cx	R	TC
Pat01	2.8	7.1	2.3	1.7	2.6
Pat02	2.6	5.5	2.2	2.0	2.4
Pat03	2.5	6.1	2.4	1.6	2.2
Pat04	2.6	7.5	2.2	1.5	2.5
Pat05	2.7	10.9	2.5	1.7	2.5
Pat06	2.7	7.6	2.1	2.1	1.9
Pat07	2.6	8.6	2.3	2.3	2.3
Pat08	2.7	8.2	2.4	1.9	2.6
Pat09	2.7	7.3	2.6	1.9	2.5
Pat10	2.5	5.4	1.7	1.5	2.2

Mean μ	**2.6**	**7.4**	**2.3**	**1.8**	**2.4**
Standard deviation σ	**0.1**	**1.6**	**0.2**	**0.3**	**0.2**
Dispersion σ/μ	**4.1%**	**22.0%**	**5.5%**	**14.9%**	**8.8%**

➚ IVA with high mean dose and high inter-patient dose dispersion compared with the other structures

2. Which structure receives high doses ?

	Maximal Dose (Gy)				
	Heart	IVA	Cx	R	TC
Pat01	25.3	16.9	2.9	2.7	3.2
Pat02	25.9	12.6	2.5	2.7	2.6
Pat03	25.3	21.9	2.7	2.3	2.4
Pat04	25.3	24.1	2.8	2.3	2.9
Pat05	29.5	30.0	2.8	2.4	2.8
Pat06	28.7	27.2	2.6	3.1	2.3
Pat07	29.0	28.8	2.6	2.9	2.6
Pat08	26.0	22.4	2.8	2.8	2.9
Pat09	38.9	24.2	2.8	2.7	2.8
Pat10	26.9	11.5	2.5	2.5	2.5

μ	28.1	22.0	2.7	2.6	2.7
σ	4.1	6.4	0.2	0.3	0.3
σ/μ	14.7%	29.2%	5.5%	9.8%	9.3%

↗ Heart and IVA maximal doses with a highest order of magnitude than the maximal doses of the other stuctures

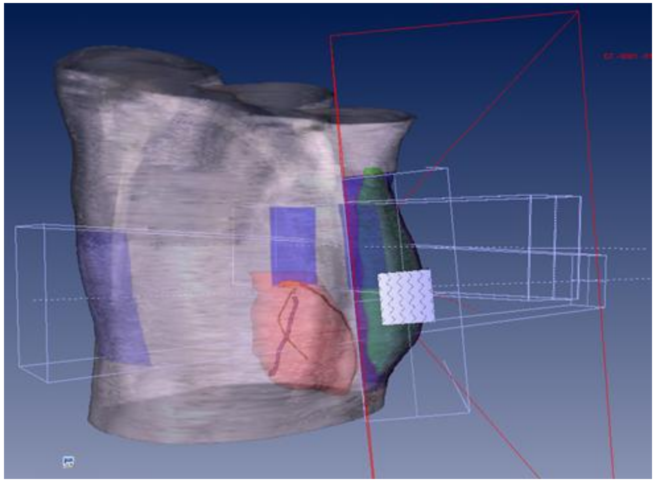
3. Which beam is responsible for high doses?

	Mean dose (Gy)				
	Heart	IVA	Cx	R	TC
All beams	2.6	7.4	2.3	1.8	2.4
Lit T	0.2	0.4	0.2	0.2	0.2
IMC p+e	0.6	3.1	0.4	0.3	0.5
TGs	1.9	3.9	1.7	1.4	1.7

Lit T = Tumoral bed
IMC = Internal mammary chain
p = photon beam
e = electron beam
TGs = tangentials

- TGs have the major contribution to the mean dose for each structure

- TGs and IMC contribute with similar proportions to the IVA mean dose



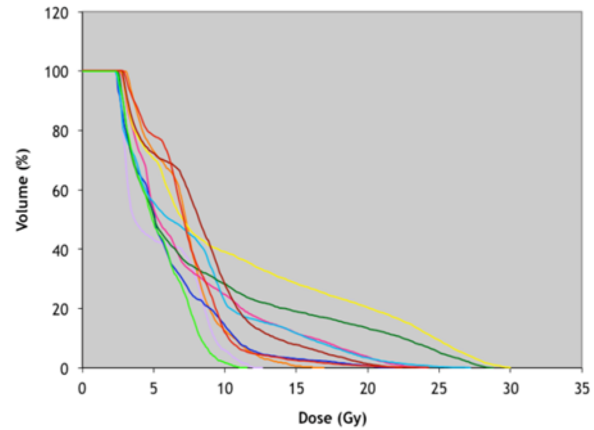
3. Which beam is responsible for high doses?

	Maximal dose (Gy)				
	Heart	IVA	Cx	R	TC
All beams	28.1	22.0	2.7	2.6	2.7
Lit T	2.3	1.0	0.3	0.3	0.3
IMC p+e	**22.4**	**14.0**	0.6	0.5	0.6
TGs	**17.7**	11.1	**1.9**	**1.9**	**1.9**

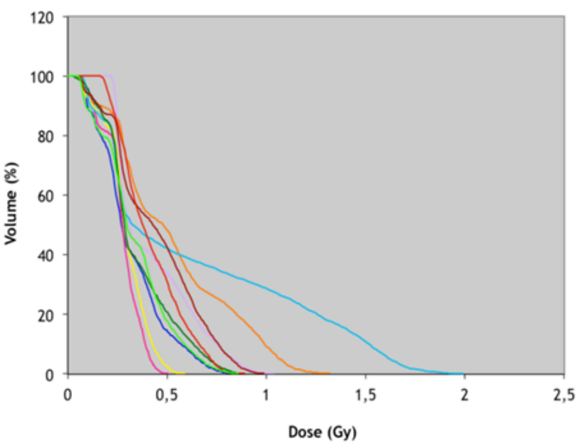
➚ IMC is responsible for the maximal dose to the heart and the IVA whereas it is the TGs for the other structures

3. Which beam is responsible for high doses?

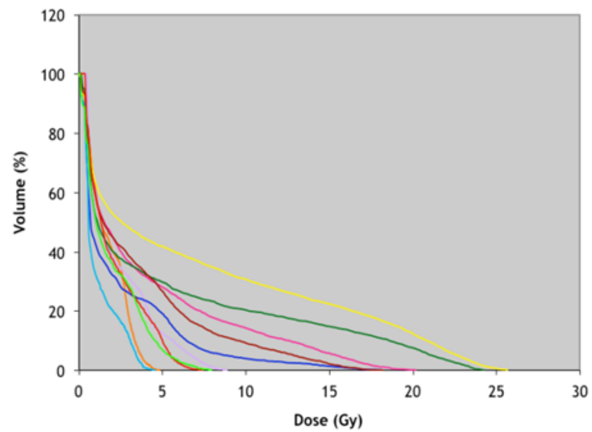
IVA – All beams



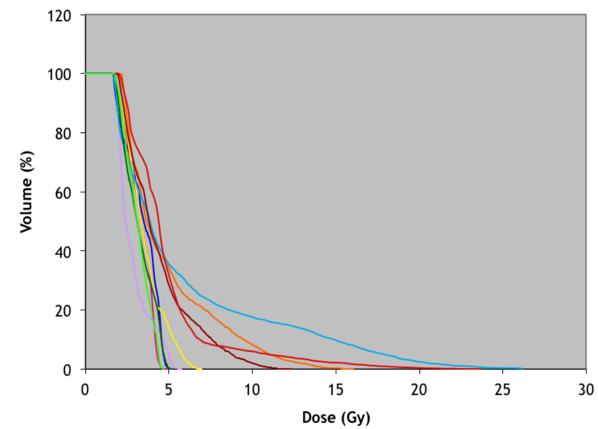
IVA – LitT



IVA – IMC photon-electron

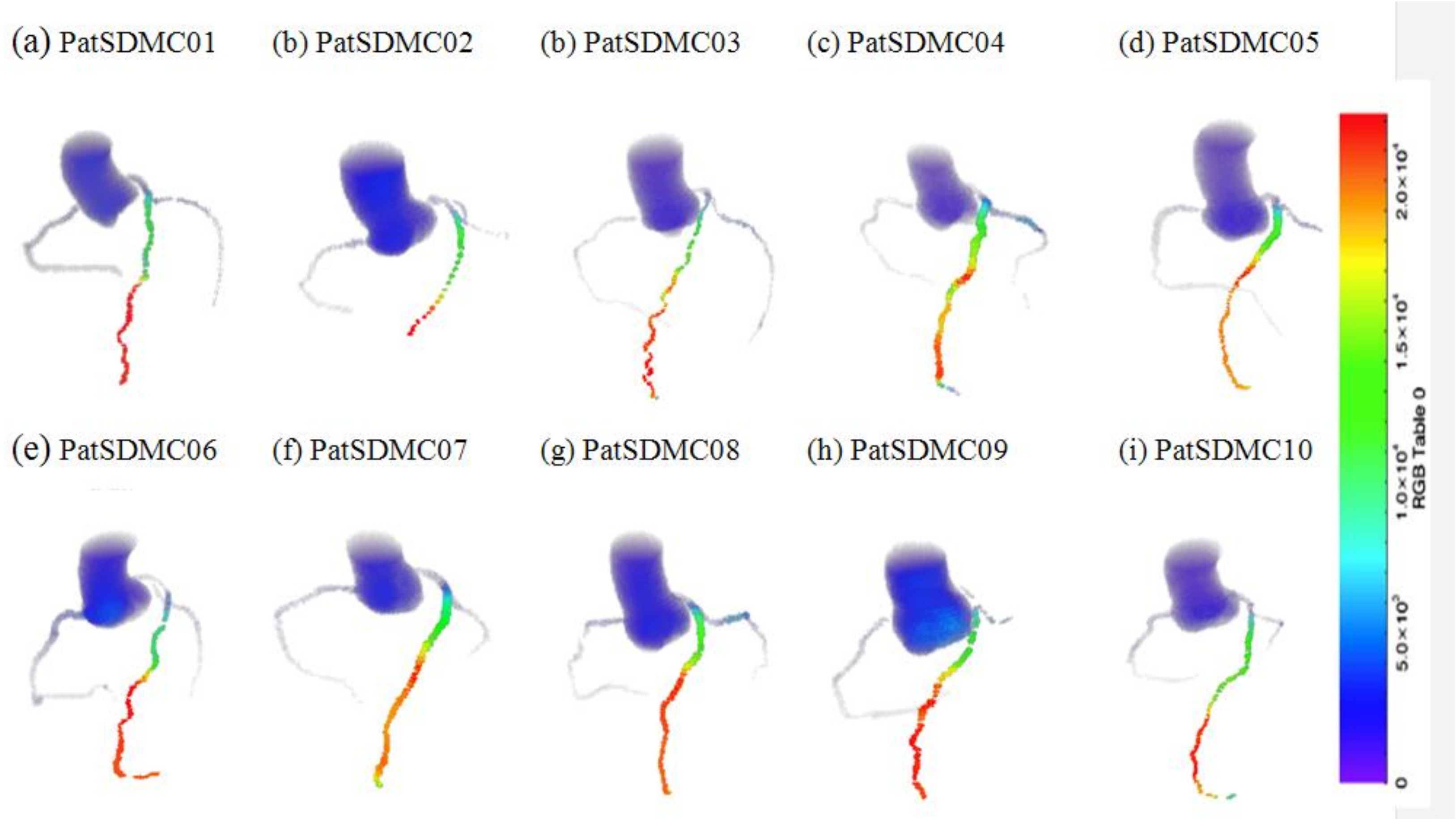


IVA – TGs



PatSDMC01 PatSDMC02 PatSDMC03 PatSDMC04 PatSDMC05
PatSDMC06 PatSDMC07 PatSDMC08 PatSDMC09 PatSDMC10

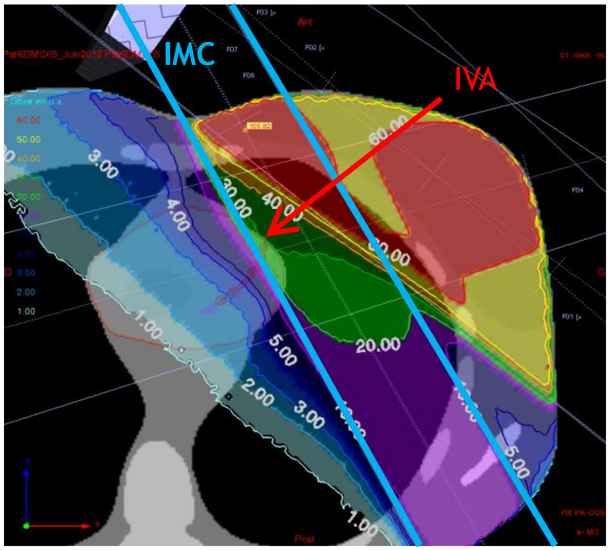
4. How is the dose distribution along the coronaries ?

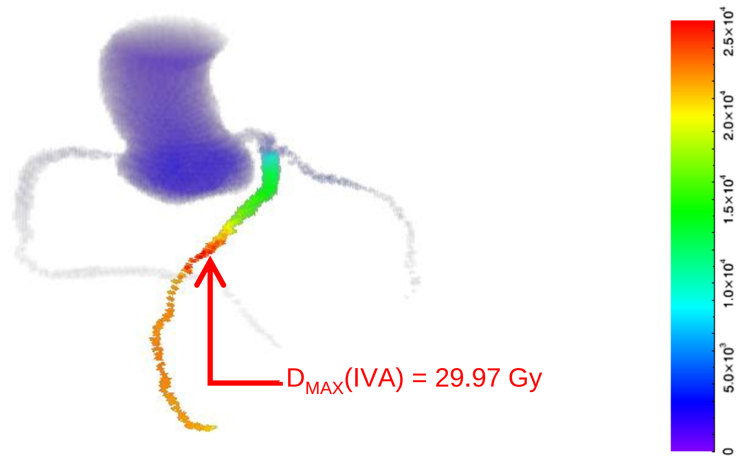


→ **These 3D maps were technically developped at our lab.**

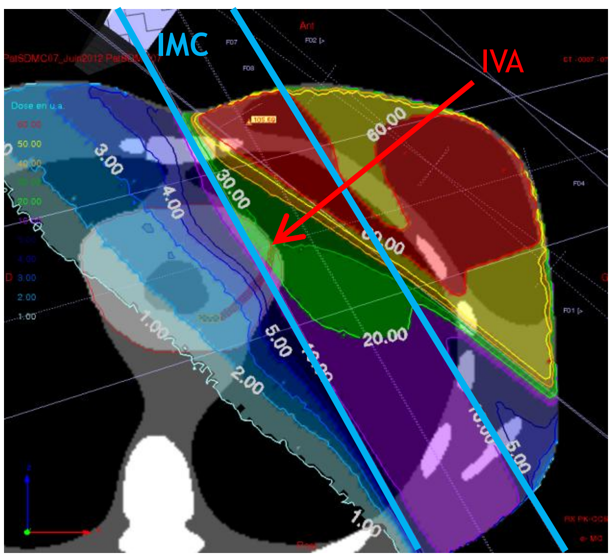
Hot spot location relative to the beams

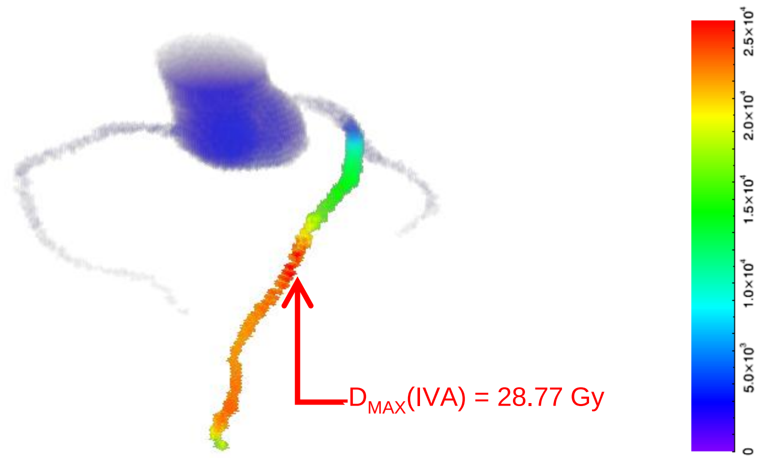
Pat05





Pat07





5. Is the mean heart dose a good surrogate for IVA doses?

	PatAnatomium	Pat01	Pat02	Pat03	Pat04	Pat05	Pat06	Pat07	Pat08	Pat09	Pat10
D_{IVA} (Gy)	17.1	7.1	5.5	6.1	7.5	10.9	7.6	8.6	8.2	7.3	5.4
D_{Heart} (Gy)	2.8	2.8	2.6	2.5	2.6	2.7	2.7	2.6	2.7	2.7	2.5
$\frac{D_{IVA}}{D_{HEART}}$	**6.2**	**2.6**	**2.1**	**2.5**	**2.9**	**4.0**	**2.8**	**3.2**	**3.1**	**2.7**	**2.2**

μ	σ	σ/μ
2.8	**0.6**	**21.0%**

- The ratio has a mean of 2.8 and a dispersion of 21%

Conclusion

- Hybrid computational phantoms allow to imagine a lot of interesting dose studies with their flexibility
- The IVA receives high dose compared with the other main coronaries in left-side breast RT
- Interesting analysis of the coronary doses using a dose map
- It appears that the hot spot is generally located on the middle of the IVA. It's a coronary location not seen in the RT CT images.
- The IVA mean dose is ~3 fold the heart mean dose. With only differences in terms of coronary topology, there is 21% of dose dispersion on the IVA mean dose from a model to another

Perspectives

- Now, we have to study the dose sensitivity to the thoracic morphology

- With these studies of sensitivity, we will have an idea of the coronary dose uncertainties in the retrospective studies due to the anatomical approximation

- Another part of our research will be to create model with the thoracic CT and the heart CT of a same patient

- We expect to give some elements to improve the treatment planning of the breast cancer and the dose-effect relationship establishment


Heart shape, Antelope canyon (USA)

Thanks

ありがとう

Merci