CT-Dose: a graphical user interface for dose calculation using MC-GPU Monte Carlo code

Council on Ionizing Radiation Measurements & Standards

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Outline

1. Introduction
2. Methods
3. Experimental Validation
4. Patient Application
5. Conclusions

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1. Introduction

Computed Tomography (CT)

Benefits

Benefits of CT scans are well known.

Concerns

About the imaging dose received by patients due to the increased usage of CT scanners in last decades.

Children

- More sensitive to radiation.
- Longer life expectancy.

New Directives

- 5 December 2013 in the directive of the constitutive Treaty of the European Atomic Energy Community.
- Since 6 February 2018, every CT scan must be able to calculate absorbed doses.

1. Introduction

Objective

Automatic: The method should require minimal user intervention.

Fast: The use of several calculation hours is not acceptable for production purposes.

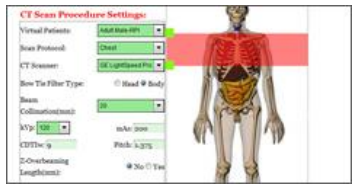
Organ dose: should be provided by the method.

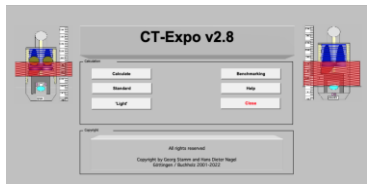
Personalized: Patient anatomy.

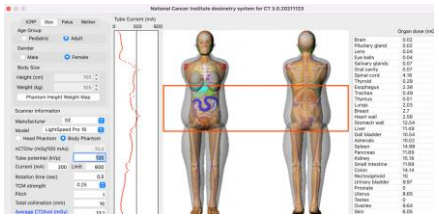
1. Introduction

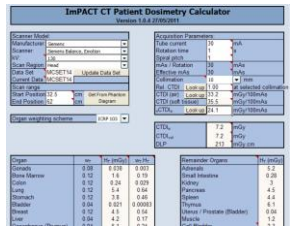
Before → **CT Scan** → **After**

- Dose calculation.
- Phantoms.
- Optimize Scan







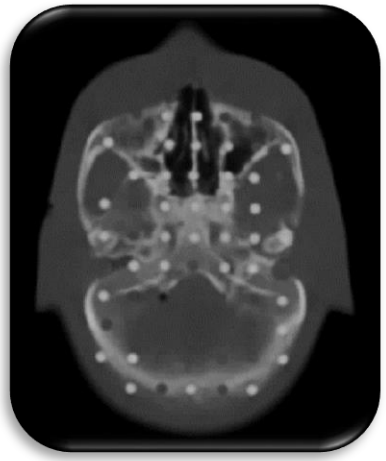


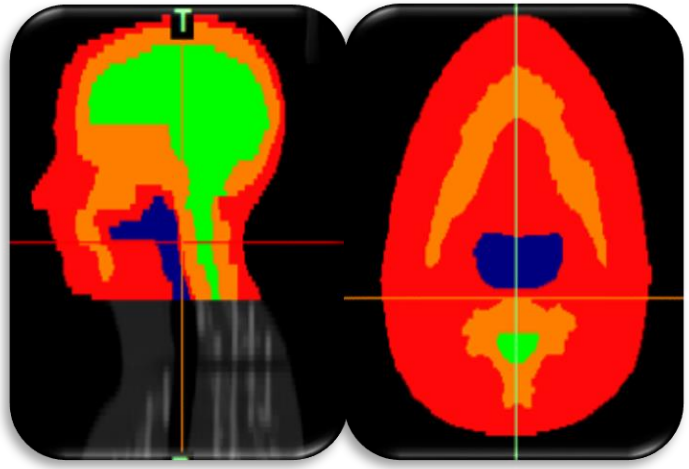
- CTDI
- Auto segmentation.
- Accelerated MC
- Personalized dose.
- APE

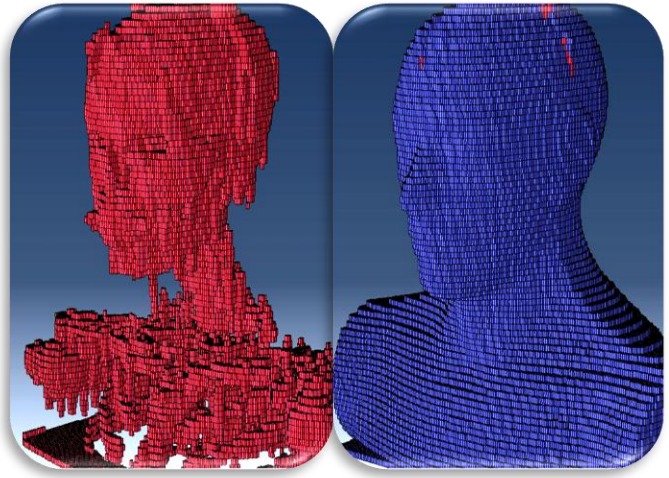
1. Introduction

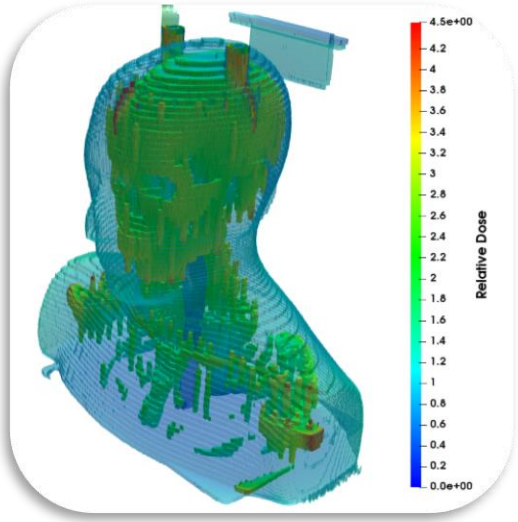
Proposal

Image acquisition → **Auto Segmentation** → **Voxelization** → **MC Simulation**









Automatic

Fast

Organ

Personalized

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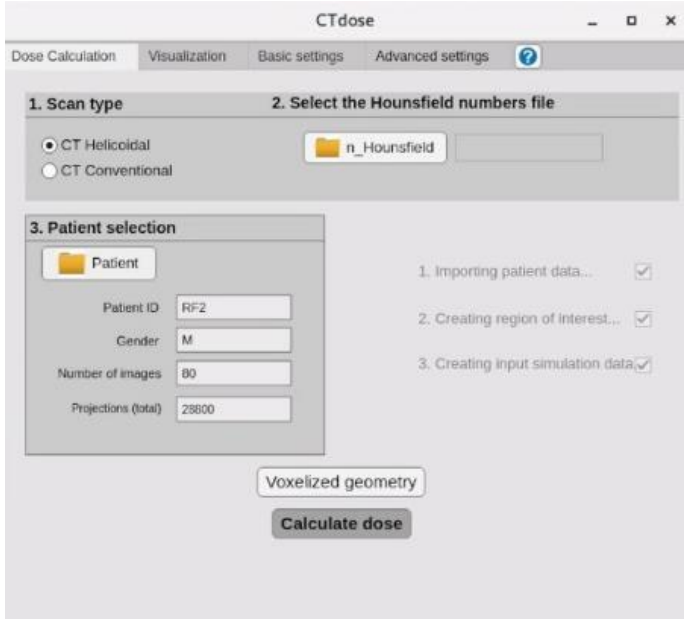
2. Methods

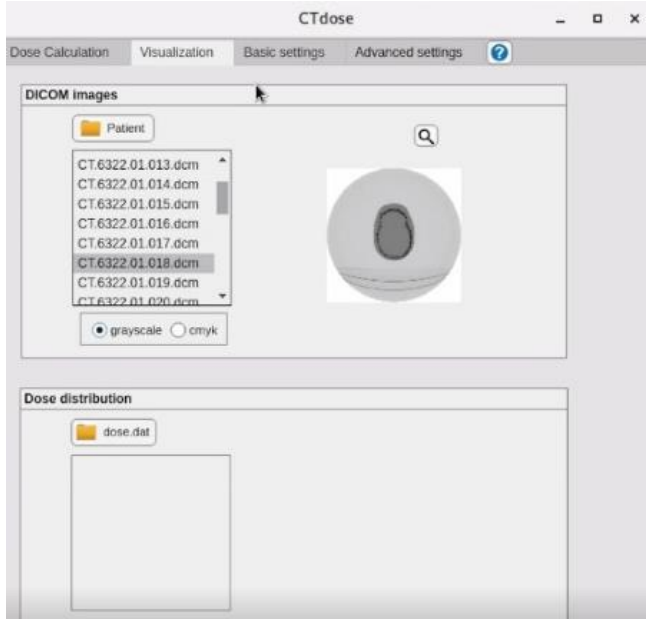
Software → **CT-Dose**

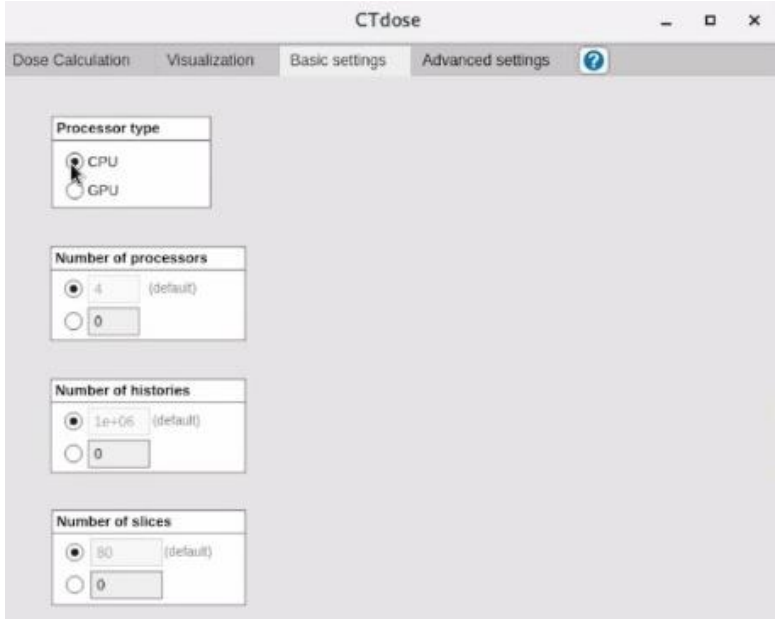
Guide User Interface.

Input: Patient CT Images or DICOM images.

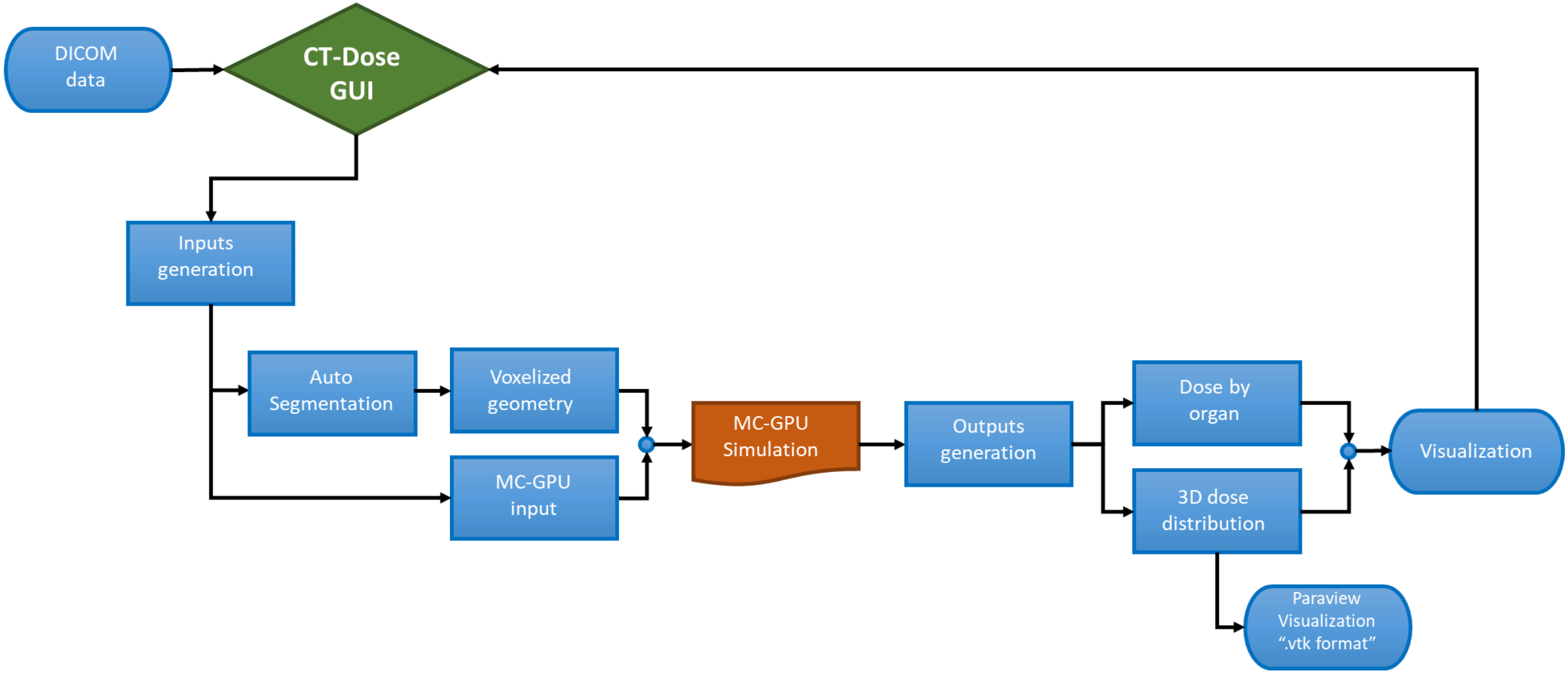
Output: 3D dose + Organ dose



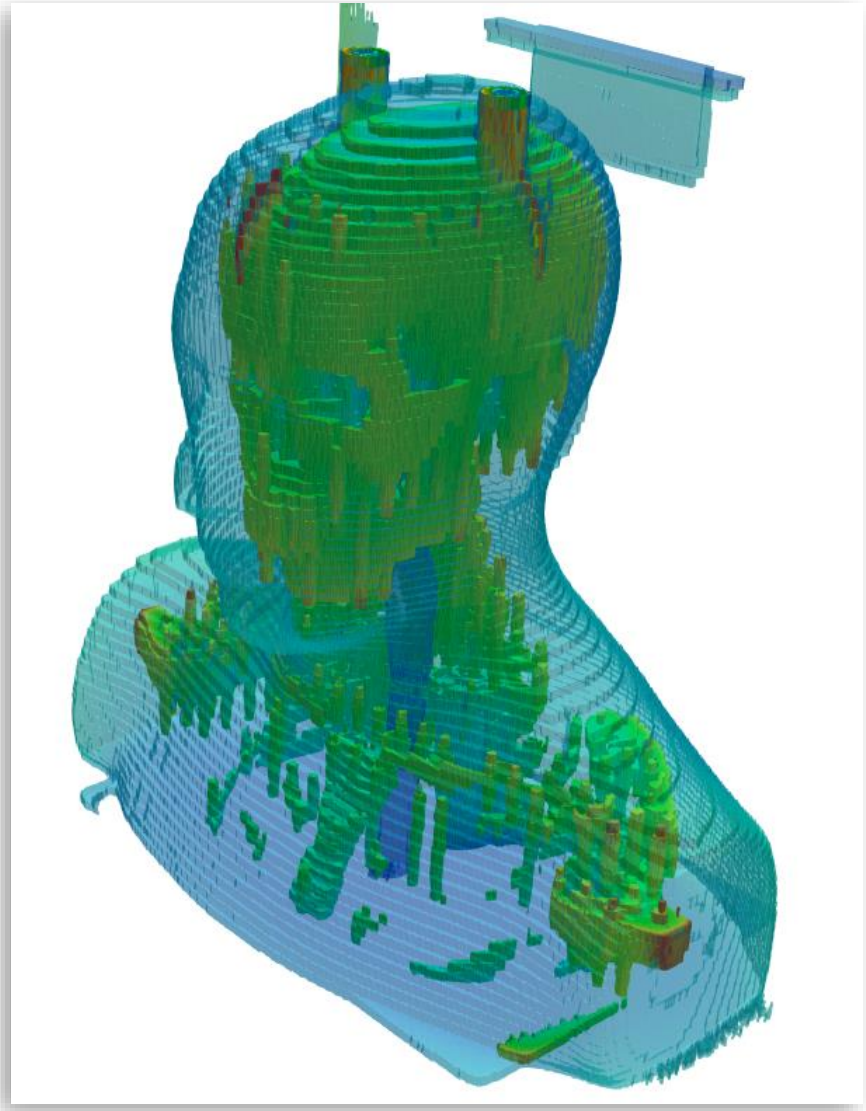




2. Methods


DICOM data
CT-Dose GUI
Inputs generation
Auto Segmentation
Voxelized geometry
MC-GPU input
MC-GPU Simulation
Outputs generation
Dose by organ
3D dose distribution
Paraview Visualization ".vtk format"
Visualization

2. Methods



[1] Andreu Badal and Aldo Badano, "Accelerating Monte Carlo simulations of photon transport in a voxelized geometry using a massively parallel Graphics Processing Unit", Medical Physics 36, pp. 4878-4880 (2009)

[1] FDA

Monte Carlo → MC-GPU v1.3

- Can generate synthetic radiographic images and computed tomography (CT) scans of realistic models of the human anatomy.
- Implements a massively multi-threaded Monte Carlo simulation algorithm for the transport of X rays in a voxelized geometry.
- The X ray interaction models and material properties have been adapted from PENELOPE 2006.
- CUDA programming model from NVIDIA.
- Can be also executed in a regular CPU.

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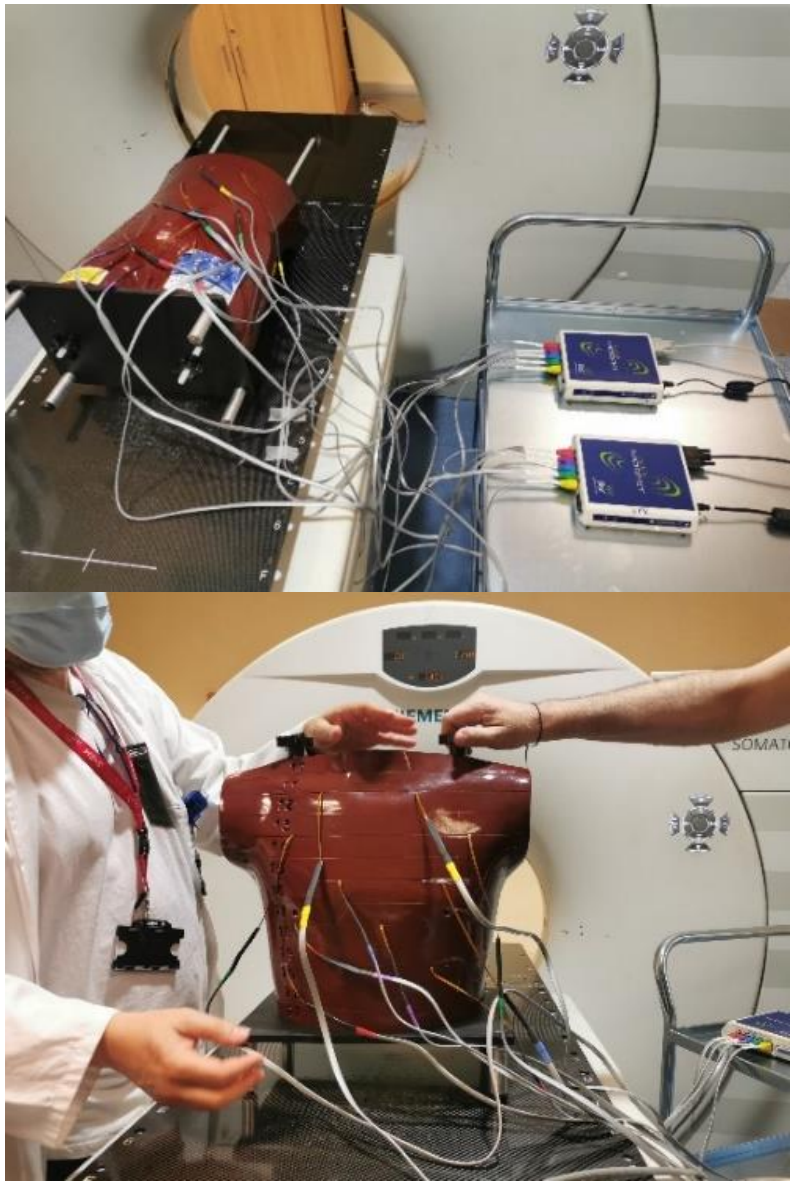
3. Experimental Validation

Rando Phantom [2]

- Experimental setup was conducted by the radiophysics service of the *Consorci Hospitalari Provincial de Castello*, *Spain*.
- female RANDO® phantom:
  - 163 cm, 54 kg, 49 slices 2.5 cm, real skeleton, plastic: soft tissue, lung material.
- CT-Scan → Siemens Somatom Emotion
- Detectors: MOSFET (Metal Oxide Semiconductor Field Effect Transistor)



[2] RANDO® Phantoms - http://www.rsdphantoms.com/rt_art.htm

3. Experimental Validation

$$Dose_{mat.} = \frac{\mu_{en,mat}(E)}{\mu_{en,air}(E)} \cdot Dose_{air}$$

Dosimeters

- Commonly used for dosimetry in vivo in the patient skin.
- Very small size → They can be introduced in the phantom holes.
- The calibration of the MOSFETS was previously carried out in the *Ionizing Radiation Metrology Laboratory of the National Dosimetry Center of Spain*
- MOSFETs cannot provide material dose → Air Kerma
- Material dose conversion factor.

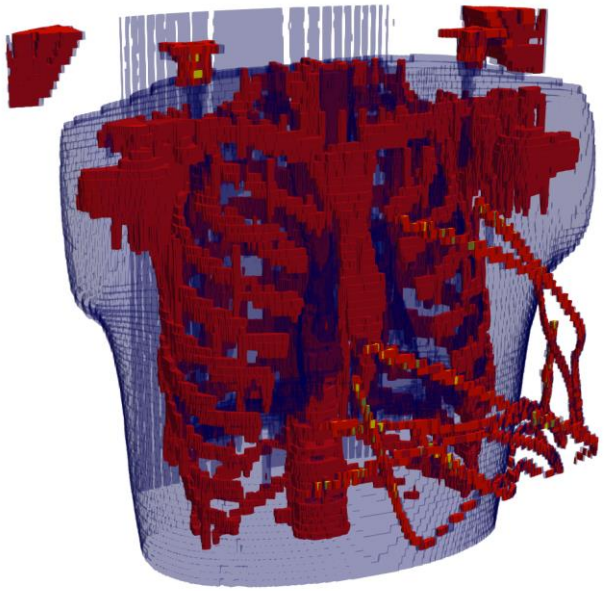
3. Experimental Validation

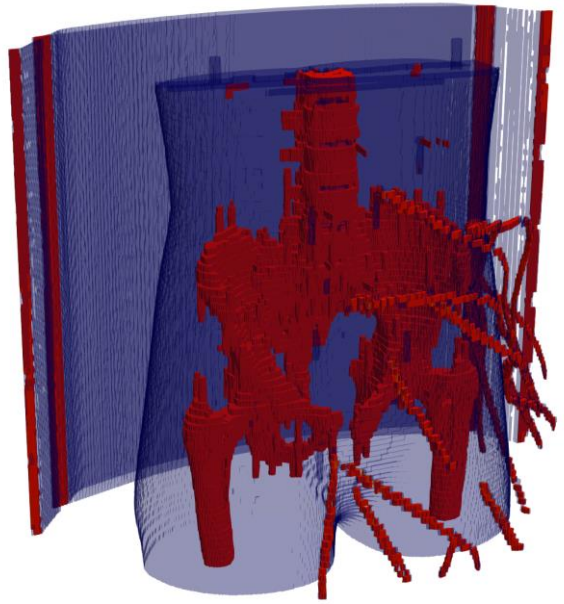
MC Simulation parameters

- Voxelized model (Hounsfield numbers)

- MC-GPU input with same parameters as the image acquisition (Information extracted from DICOM data)

  - 130 kV
  - Beam collimation: $\theta = 2\ deg, \alpha = 50\ deg.$
  - Source to Isocenter distance: 53.5 cm
  - Source to detector distance: 94 cm
  - Table speed: 19mm/s
  - Table feed per rotation: 19.2 mm/rev
  - Spiral Pitch Factor: 1
  - Exposure time: 1000 ms
  - Current: 243 mA

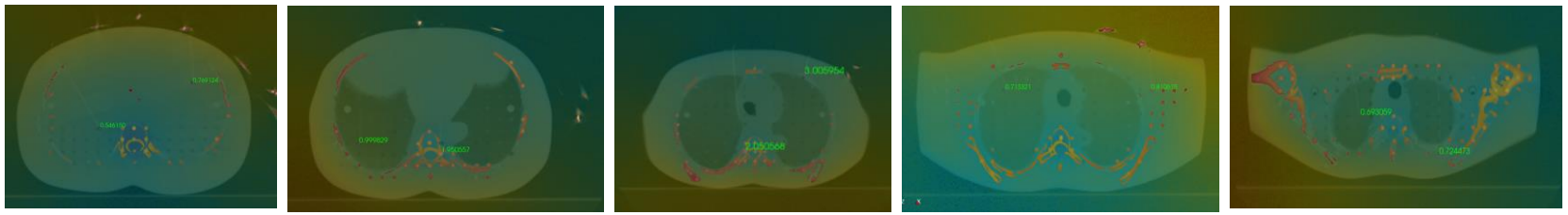


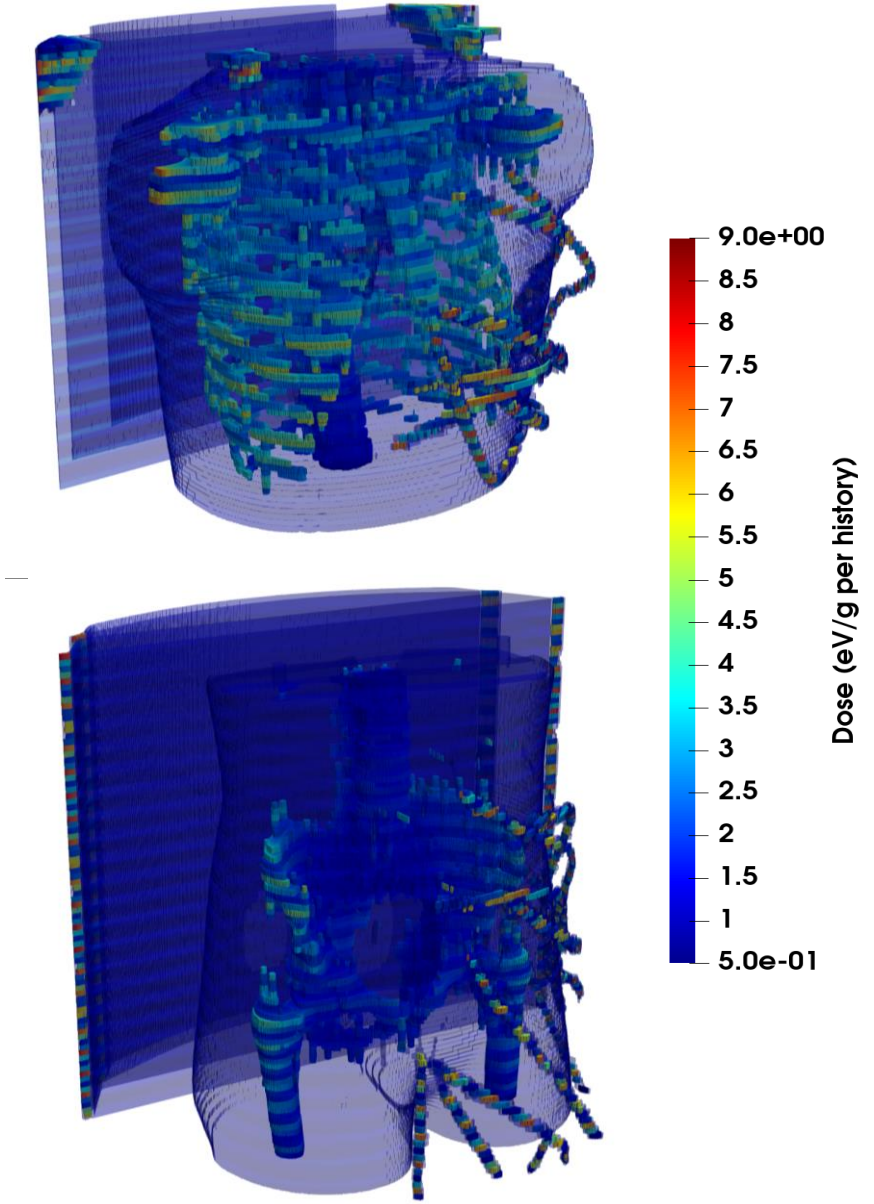


3. Experimental Validation

MC Simulation→ **MC-GPU**

- 10^8 particles
- 32 CPUs using *Quasar* cluster from *ISIRYM* group in the *UPV*.
- Simulation time: 27 h → pelvis
  22 h → thorax
- Outputs: 3D dose distribution (".vtk") → 10 dose points in each simulation.



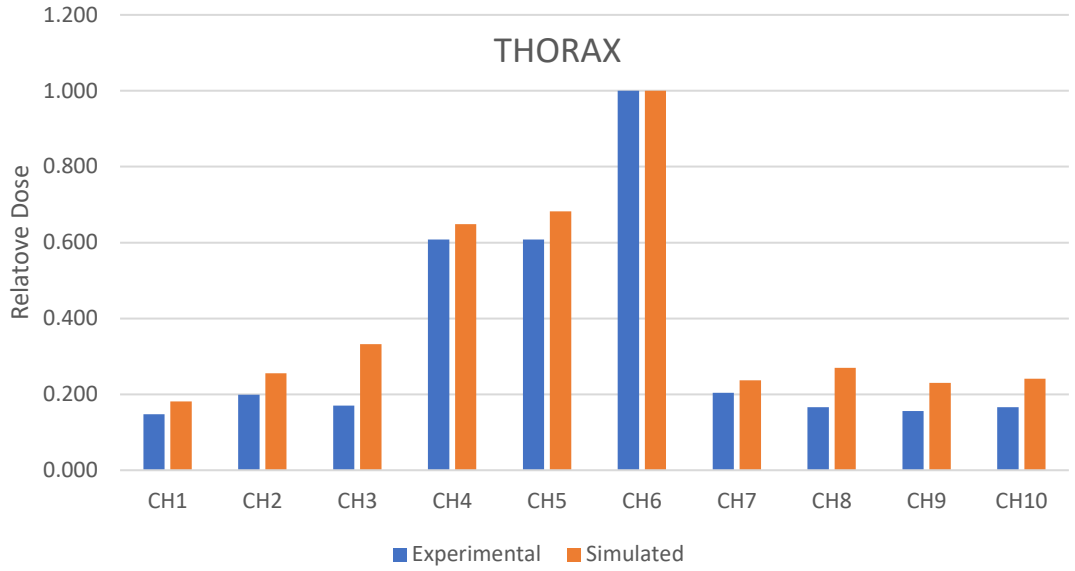


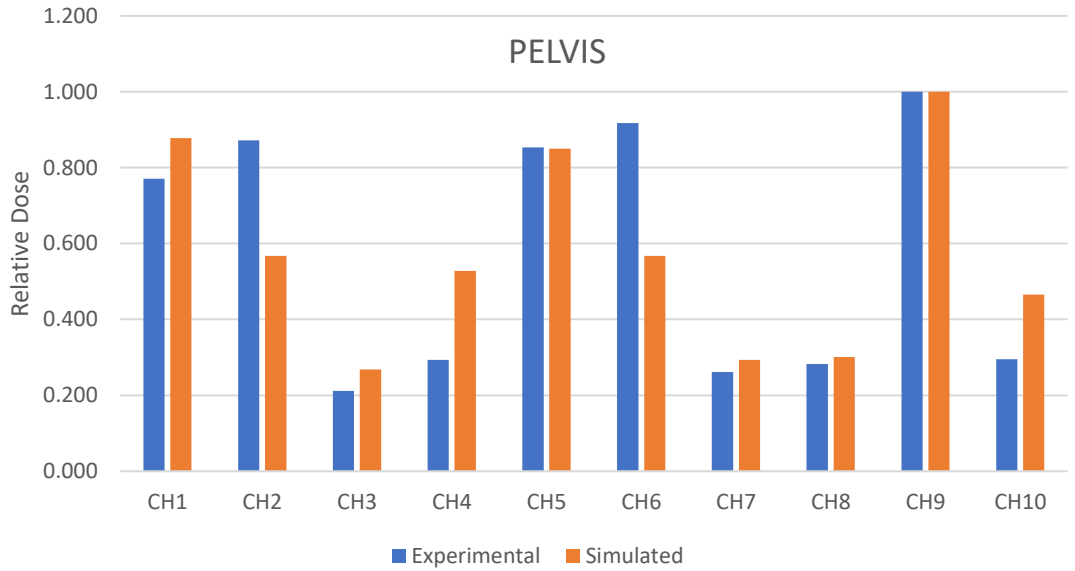
3. Experimental Validation

Comparison Results

Uncertainty sources

- Beam positioning.
- Material dose conversion factor.
- Initial beam spectrum.





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4. Patient Application

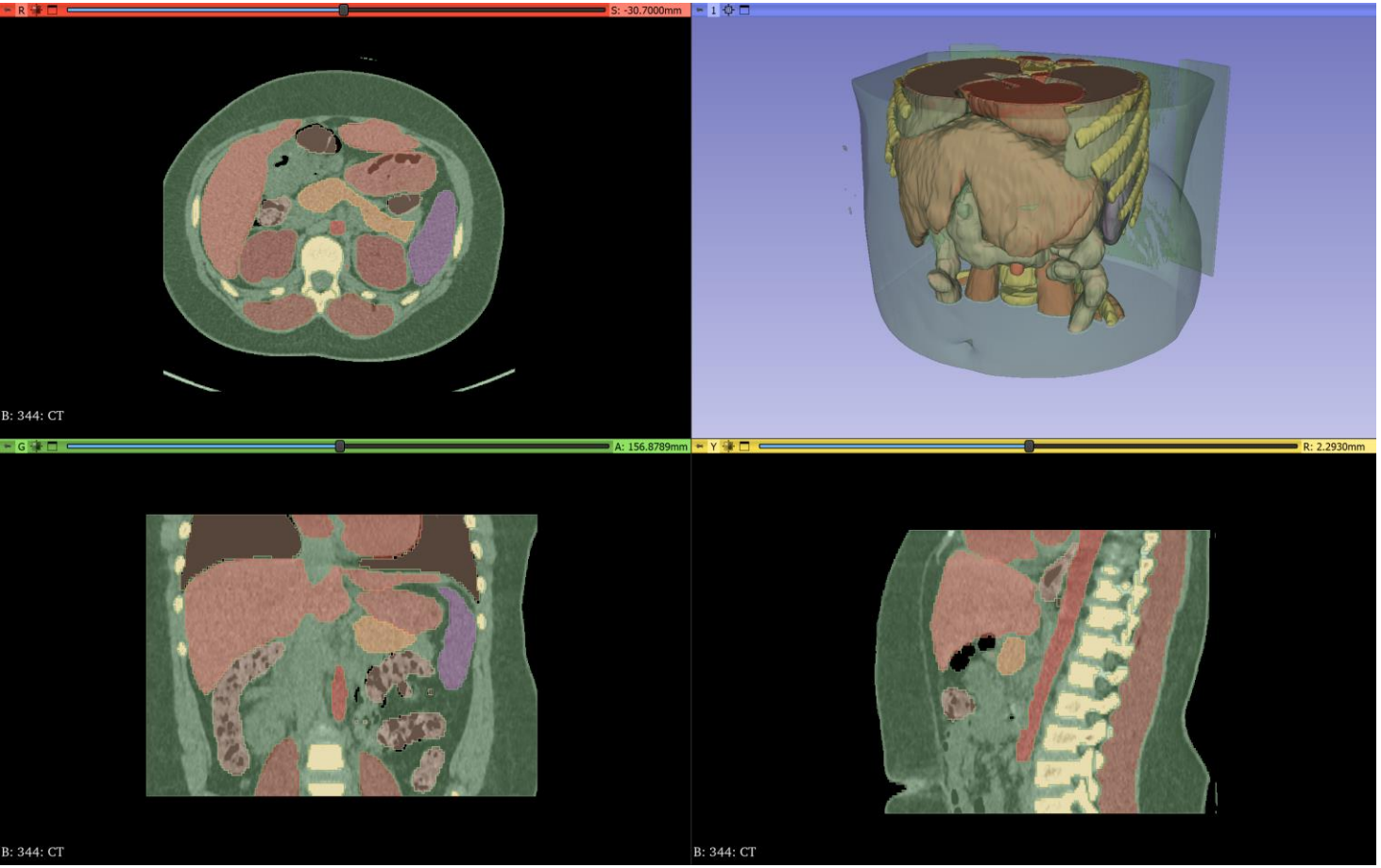
Real Patient

- 8 years old.
- 144 cm.
- 60 kg
- DICOM images from lower chest to upper hip.
- Slice thickness: 2mm
- 100 kV

4. Patient Application

[3] Wasserthal J., Meyer M., Breit H., Cyriac J., Yang S., Segeroth M. TotalSegmentator: robust segmentation of 104 anatomical structures in CT images, 2022. URL: https://arxiv.org/abs/2208.05868. arXiv: 2208.05868

Auto segmentation → **Total Segmentator**[3]

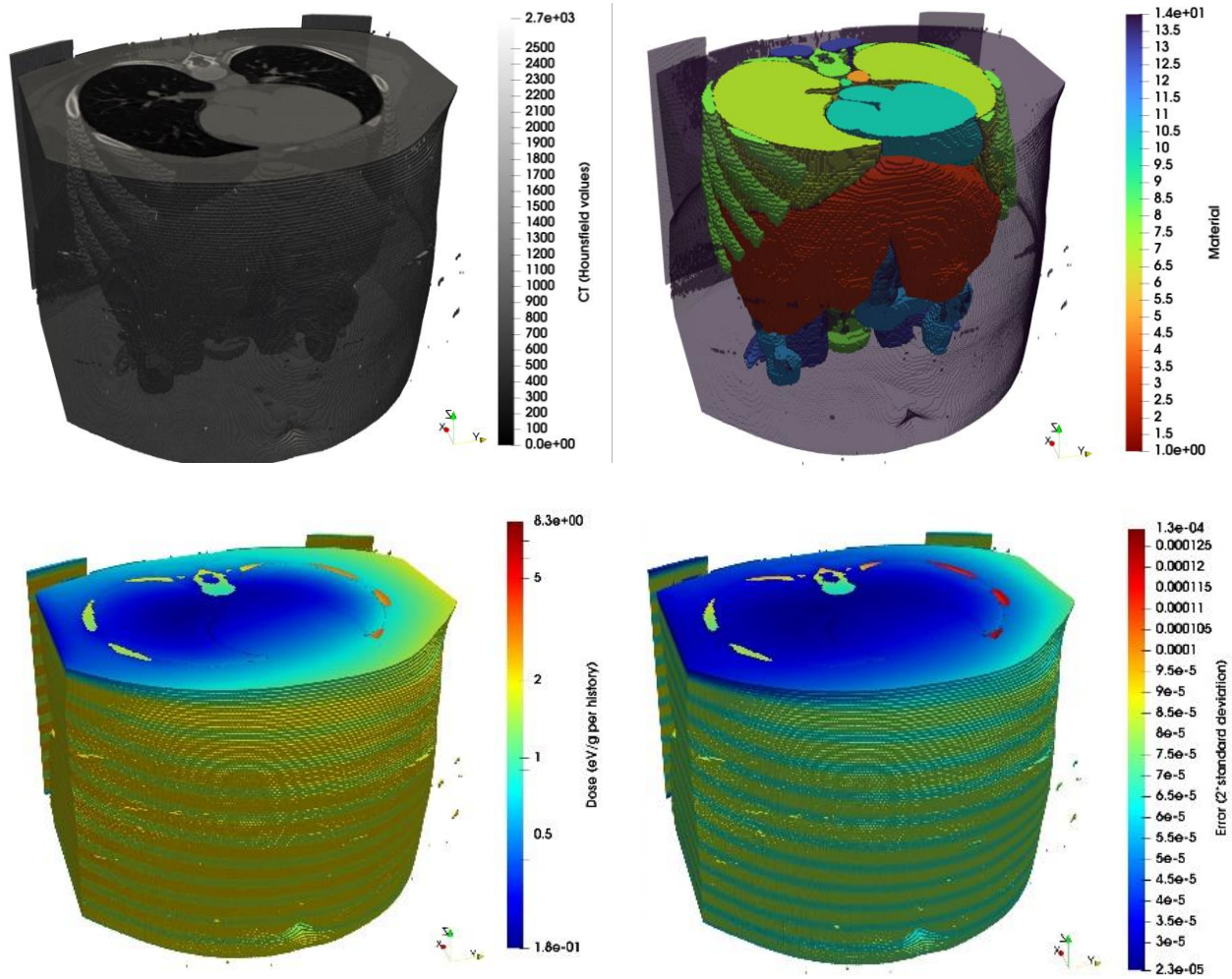


- High resolution auto segmentation
- CUDA parallelization using GPUs, or you can use common CPU.
- 2 min using V100-SXM2 NVIDIA in BIOWULF cluster from NIH.
- 104 anatomical structures.
- Standardized organ names.

4. Patient Application

MC Simulation→ **MC-GPU**

- 10^8 particles
- NVIDIA V100-SXM2 GPU card in BIOWULF cluster from NIH.
  (32 GB VRAM, 5120 cores, 640 Tensor cores)
- Simulation time: 50 min
- Outputs: 3D dose distribution
  + Organ dose.



4. Patient Application

- Organ Dose results → 10^8 particles

Organ	Dose (eV/g/hist)	Error (2·std. dev.)	Energy deposited (eV/hist)	Organ mass (g)	Number of voxels
Spleen	1.13967	0.00005	186.98	164.06779	225368
Kidneys	0.99722	0.00004	194.35	194.89519	270263
Liver	1.13375	0.00002	1283.02	1131.66305	1514478
Stomach	1.05968	0.00005	150.66	142.17969	207020
Aorta	0.61211	0.00008	18.61	30.3955	40715
Pancreas	0.94155	0.00012	19.77	20.99781	80036
Lungs	0.75927	0.00001	1553.33	2045.81166	1551455
Vertebras	3.58007	0.00007	1283.50	358.5118	501932
Esophagus	0.44806	0.00014	3.01	6.70927	9037
Heart	0.55655	0.00003	91.29	164.03066	238836
Colon	1.03266	0.00004	262.96	254.63865	340464
Hip	1.97283	0.00018	55.89	28.33099	21485
Muscles	1.04090	0.00002	686.05	659.09193	913969
Soft Tissue	1.36143	0.00001	12434.70	9133.57579	13298896
Air	1.91634	0.00028	14.43	7.52903	9097598

4. Patient Application

- Organ Dose results → 10^8, 10^7 and 10^6 particles

	10^8 Particles (50 min)		10^7 particles (8 min)		10^6 particles (4 min)	
Organ	**Dose (eV/g/hist)**	**Error (2·std. dev.)**	**Dose (eV/g/hist)**	**Error (2·std. dev.)**	**Dose (eV/g/hist)**	**Error (2·std. dev.)**
Spleen	1.06511	0.00004	1.06516	0.00014	1.06505	0.00044
Kidneys	0.91920	0.00004	0.91919	0.00012	0.91880	0.00038
Liver	1.06825	0.00002	1.06826	0.00005	1.06823	0.00017
Stomach	0.98562	0.00005	0.98557	0.00015	0.98608	0.00046
Aorta	0.54222	0.00007	0.54224	0.00024	0.54246	0.00074
Pancreas	0.86030	0.00011	0.86030	0.00036	0.85997	0.00112
Lungs	0.70066	0.00001	0.70067	0.00003	0.70069	0.00010
Vertebras	3.52620	0.00006	3.52618	0.00020	3.52630	0.00064
Esophagus	0.39241	0.00014	0.39214	0.00043	0.39185	0.00134
Heart	0.51127	0.00003	0.51122	0.00010	0.51096	0.00031
Colon	0.96524	0.00003	0.96523	0.00011	0.96493	0.00034
Hip	1.91539	0.00017	1.91513	0.00055	1.91579	0.00172
Muscles	0.98570	0.00002	0.98573	0.00007	0.98567	0.00021
Soft Tissue	1.32050	0.00001	1.32050	0.00002	1.32053	0.00005
Air	1.92182	0.00029	1.92263	0.00090	1.91965	0.00283

4. Patient Application

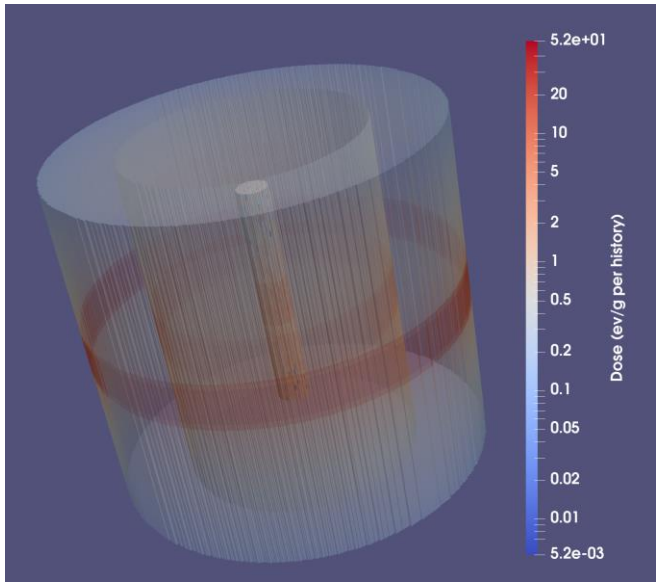
Absolute Dose conversion factors

- 2 MC-GPU simulations
- $CTDI_{centered}$, $CTDI_{periphery}$

$$CTDI_{vol\ MC-GPU}\left(\frac{eV}{g}\ per\ hist\right) = \frac{1}{3}CTDI_{centered} + \frac{2}{3}CTDI_{periphery}$$

$$Abs.DOSE = \frac{Dose_{MC-GPU}\left(\frac{eV}{g}\ per\ hist\right)}{CTDI_{vol\ MC-GPU}\left(\frac{eV}{g}\ per\ hist\right)} \cdot \mathrm{CTDI}_{vol}$$

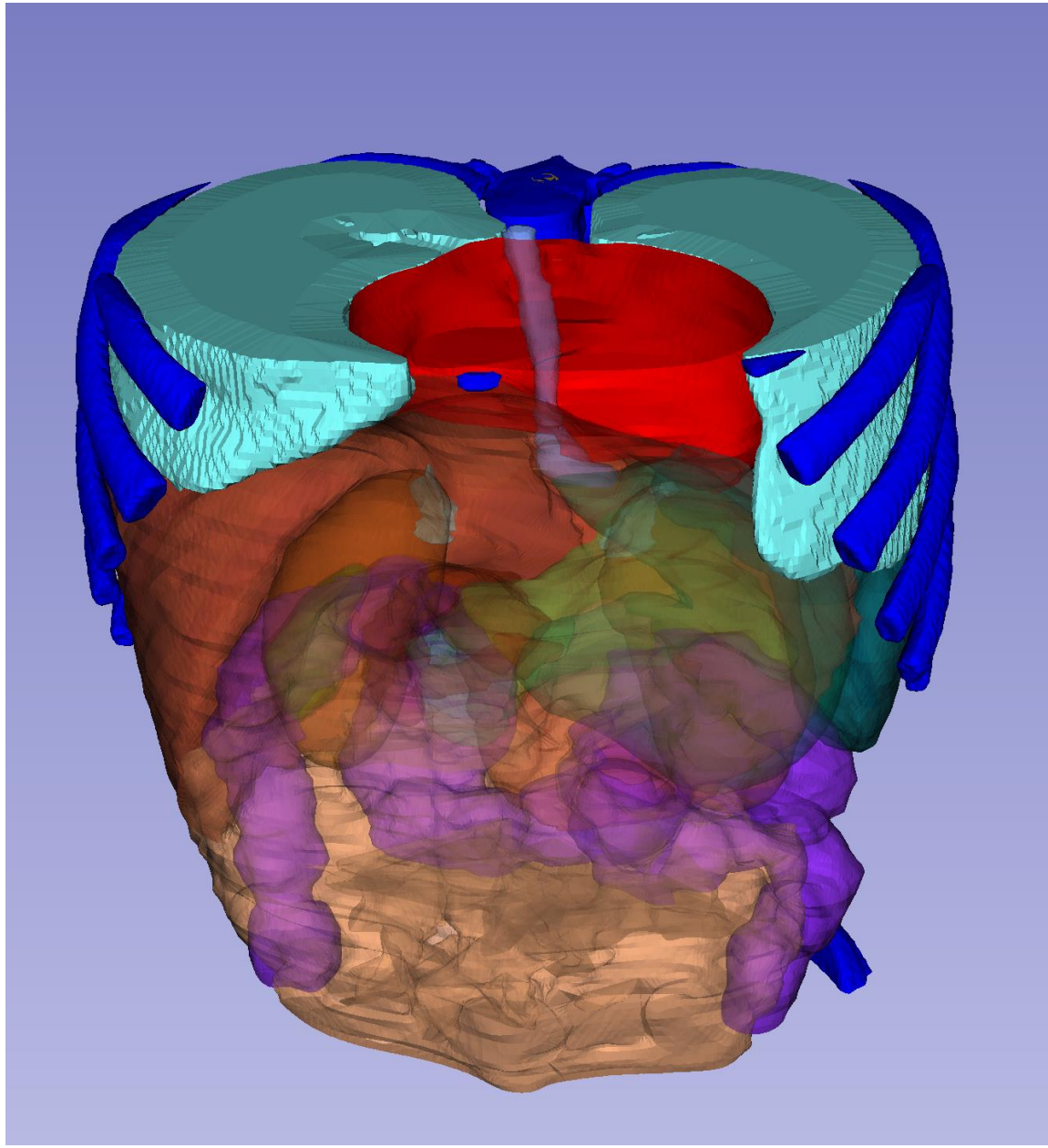
- CTDI_{vol}
  - DICOM data
  - Literature



4. Patient Application

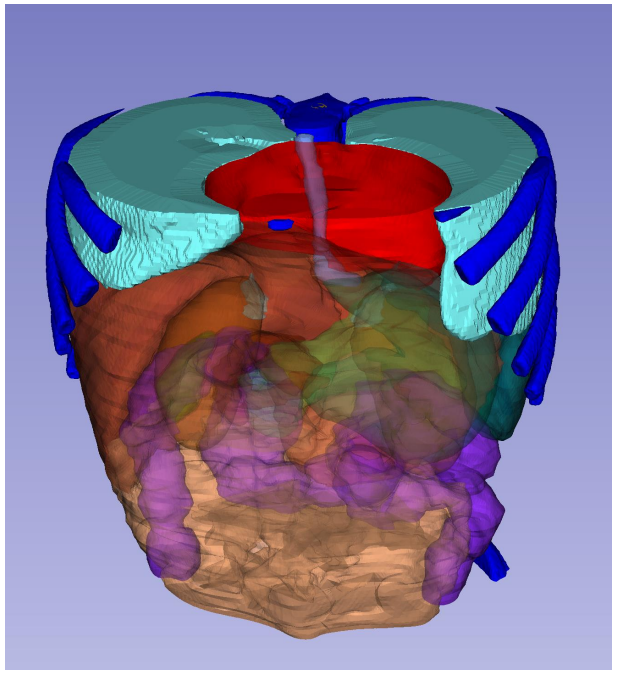
NCICT comparison

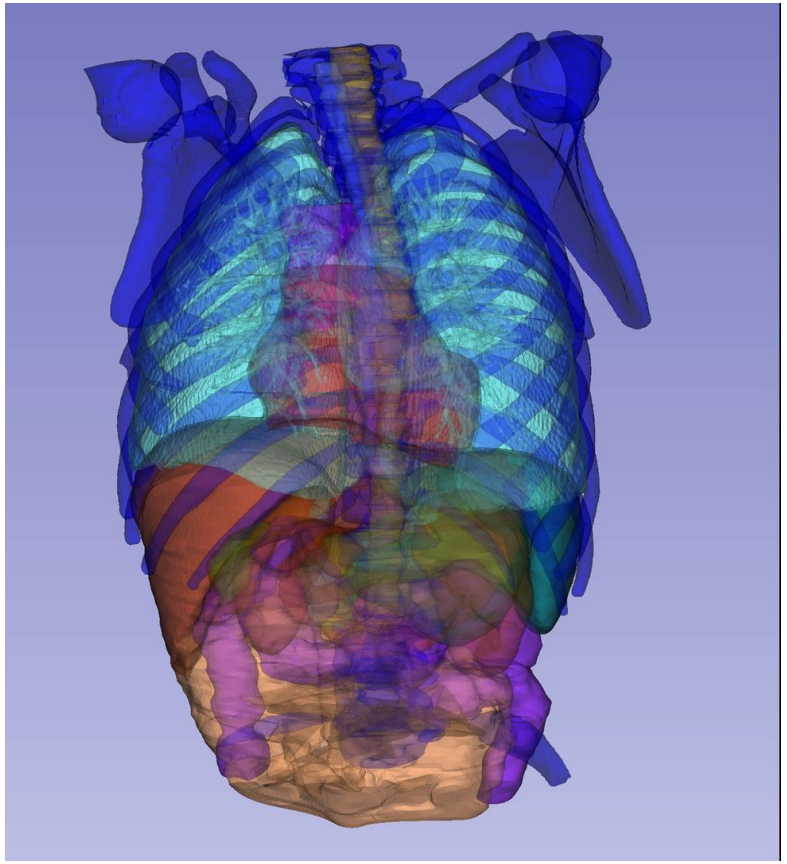
Organ	Dose_max (mGy)	NCICT (mGy)	MC-GPU Relative values	NCICT Relative Values
Spleen	1.1004	5.81	1.0000	1.0000
Kidneys	0.9496	6.11	0.8630	1.0516
Liver	1.1036	5.19	1.0029	0.8933
Stomach	1.0183	5.1	0.9254	0.8778
Aorta	0.5602		0.5091	
Pancreas	0.8888	4.73	0.8077	0.8141
Lungs	0.7239		0.6578	
Vertebras	3.6430		3.3106	
Esophagus	0.4054	1.84	0.3684	0.3167
Heart	0.5282		0.4800	
Colon	0.9972	4.94	0.9062	0.8503
Hip	1.9788		1.7983	
Muscles	1.0183		0.9254	
SoftTissue	1.3642		1.2398	
Air	1.9855		1.8043	

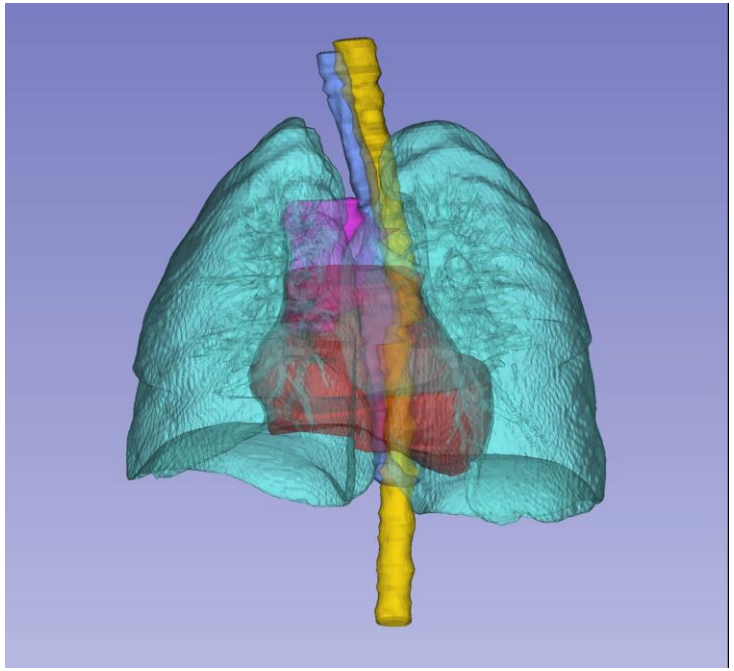


4. Patient Application

- Anatomically Predictive Extension (APE method)







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5. Conclusions

A new methodology has been developed to calculate dose delivered to a patient by a CT scan, which has several advantages.

Fast: the method calculation times are acceptable for production purposes thanks to the use of GPUs parallelization during MC calculations and auto-segmentation process.

3D distribution dose + Organ dose: the method can provide both types of data.

Personalized: the method uses the own patient images to generate the model, improving the accuracy of the method.

5. Conclusions

Anatomically Predictive Extension Method: a complete organ dose will be provided for those organs which have only partial structures in the CT scan.

Monte Carlo Simulation: personalized Monte Carlo Simulation.

Good candidate: the presented methodology seems a good approach to perform automatic dose calculations and to obtain a clinical dose record of the patients undergoing CT scan.

This **clinical dose record** would be interesting for clinical purposes and for future epidemiology studies.

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