Geant4 Monte Carlo simulations for size-specific organ dose estimates in CT based on patient silhouette and voxelized phantoms.

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IV Geant4 International User Conference at the physics-medicine-biology frontier, 24-26 October, Napoli (Italy)

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Sezione di Napoli

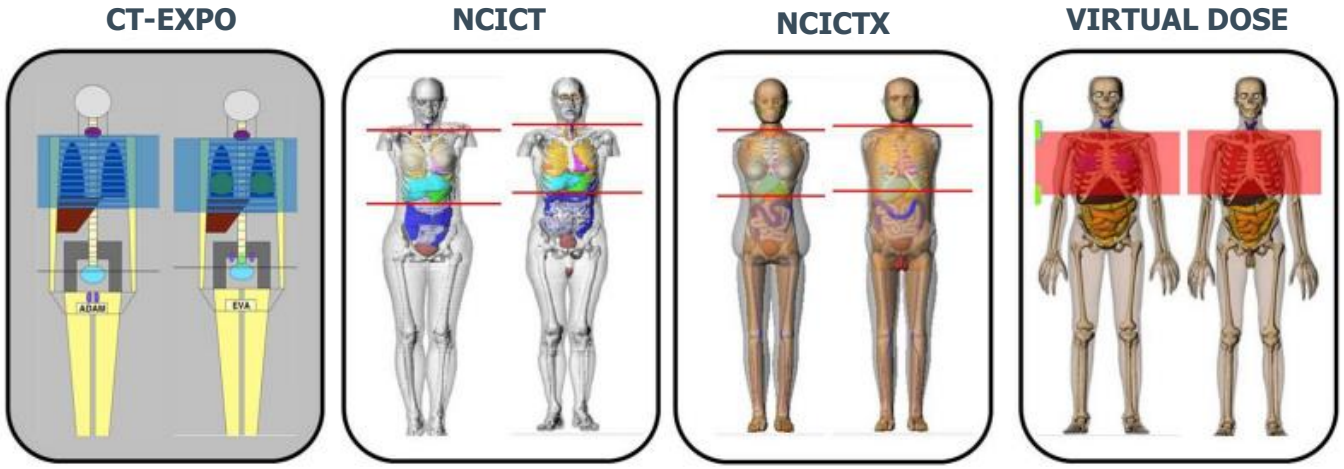
Whole body CT dosimetry: state of the art

Monte Carlo simulations represent now the *gold-standard technique* for dose quantification in CT

- Digital voxelized phantoms are put in input into the MC code to *simulate the patient*;
- The dataset used in this work was provided by the National Cancer Institute (**NCI**);
- The phantoms were obtained from the segmentation of 1000+ CT real images and range *from newborns to adults*.

Voxelized phantoms developed by the National Cancer Institute (USA)

Some MC softwares for CT dosimetry



C. De Mattia et al. Patient organ and effective dose estimation in CT: comparison of four software applications. Eur. Radiol. Exp. (February 2020)

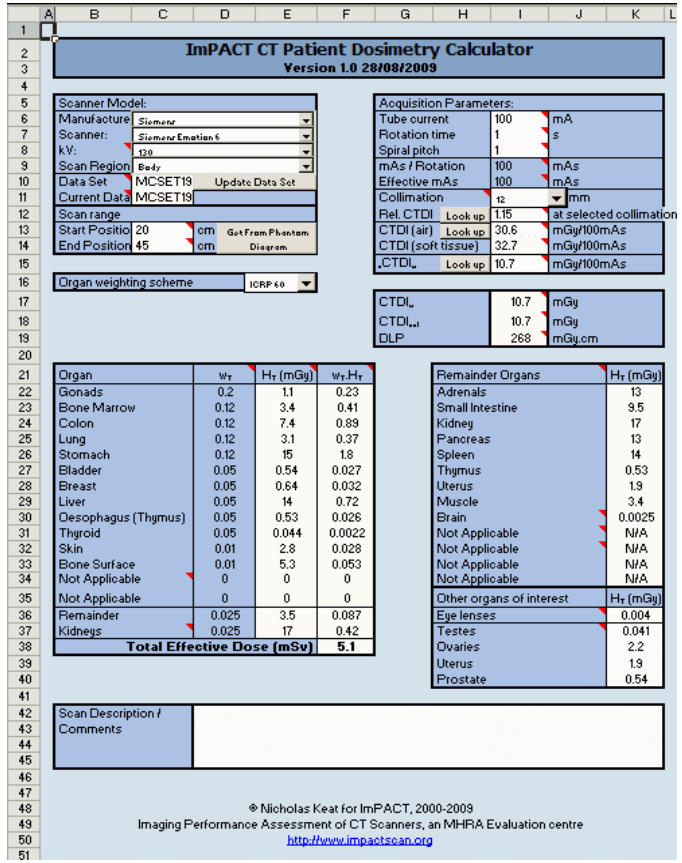
CTRAD

Personalized Computed Tomography Organ Dose Estimation

MEDIRAD

IMPLICATIONS OF MEDICAL LOW DOSE RADIATION EXPOSURE

J. Damilakis. CT Dosimetry: what has been achieved and what remains to be done. Invest. Radiol. 2021;56(1):62-68



ImPACT CT Patient Dosimetry Calculator
Version 1.0 28/08/2009

Scanner Model:		Acquisition Parameters:		
Manufacture	Siemens	Tube current	100	mA
Scanner:	Siemens Emotion 6	Rotation time	1	s
kV:	130	Spiral pitch	1	
Scan Region	Body	mAs / Rotation	100	mAs
Data Set	MCSET19 Update Data Set	Effective mAs	100	mAs
Current Data	MCSET19	Collimation	12	mm
Scan range		Rel. CTDI Look up	1.15	at selected collimation
Start Positio	20 cm Get From Phantom	CTDI (air) Look up	30.6	mGy/100mAs
End Position	45 cm Diagram	CTDI (soft tissue)	32.7	mGy/100mAs
Organ weighting scheme	ICRP 60	CTDI Look up	10.7	mGy/100mAs

$CTDI_{air}$	10.7	mGy
$CTDI_{w}$	10.7	mGy
DLP	268	mGy.cm

Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.2	1.1	0.23
Bone Marrow	0.12	3.4	0.41
Colon	0.12	7.4	0.89
Lung	0.12	3.1	0.37
Stomach	0.12	15	1.8
Bladder	0.05	0.54	0.027
Breast	0.05	0.64	0.032
Liver	0.05	14	0.72
Oesophagus (Thymus)	0.05	0.53	0.026
Thyroid	0.05	0.044	0.0022
Skin	0.01	2.8	0.028
Bone Surface	0.01	5.3	0.053
Not Applicable	0	0	0
Not Applicable	0	0	0
Remainder	0.025	3.5	0.087
Kidneys	0.025	17	0.42
Total Effective Dose (mSv)			5.1

Remainder Organs	H_T (mGy)
Adrenals	13
Small Intestine	9.5
Kidney	17
Pancreas	13
Spleen	14
Thymus	0.53
Uterus	1.9
Muscle	3.4
Brain	0.0025
Not Applicable	N/A
Not Applicable	N/A
Not Applicable	N/A
Not Applicable	N/A

Other organs of interest	H_T (mGy)
Eye lenses	0.004
Testes	0.041
Ovaries	2.2
Uterus	1.9
Prostate	0.54

Scan Description / Comments

Imaging Performance Assessment of CT Scanners, an MHRA Evaluation centre
http://www.impactscan.org

http://www.impactscan.org/ctdosimetry.htm

Purpose of this work

1. Standardized voxelized phantoms

2. Implementation of a **Monte Carlo code** for simulating CT exams and organ dose estimates

Purpose of this work

2

Implementation of a **Monte Carlo code** for simulating CT exams and organ dose estimates

3

Validation through measurements on a clinical CT scanner

Purpose of this work

3

Validation through measurements on a clinical CT scanner

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3D optical body scanning of anatomical districts

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Purpose of this work

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3D optical body scanning of anatomical districts

5

Personalized voxellized phantoms from rigid adaptation

Purpose of this work

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Personalized voxellized phantoms from rigid adaptation

6

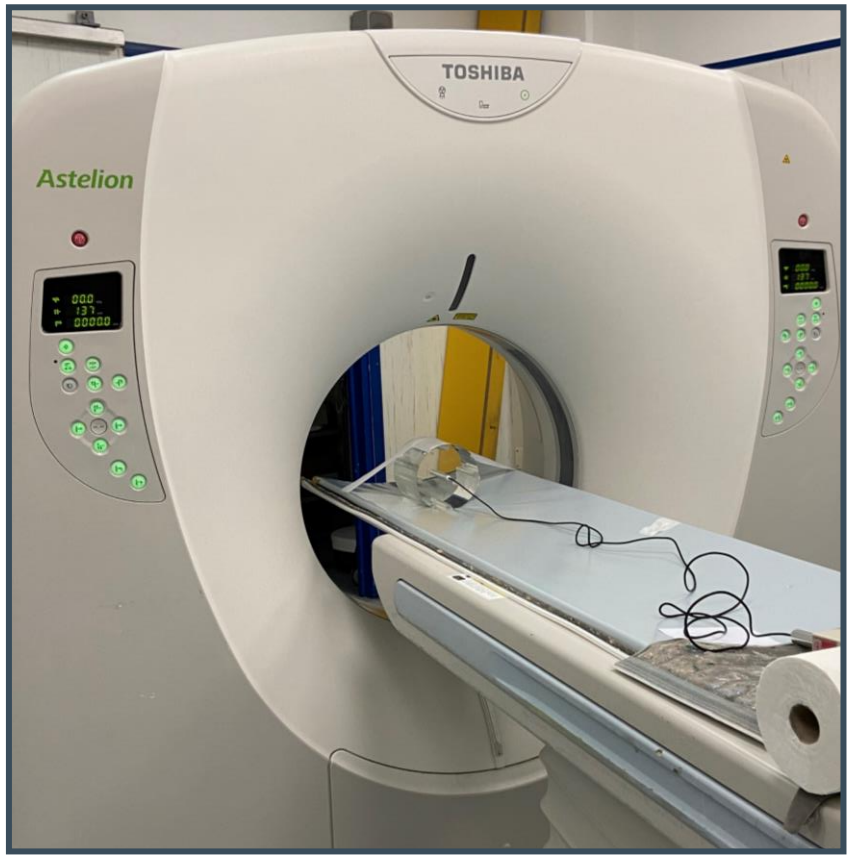
Personalized dose estimates

Purpose of this work

6

Personalized dose estimates

Geant4 *validation* and CT scanner *model description*



- Version **10.6**, low energy **standard Physics List Option 4**;
- The code reproduces the clinical CT scanner Astelion (Toshiba) available at the «Azienda Ospedaliera Universitaria Federico II»;
- Segmented voxelized phantoms, technical specifications, several tissue compositions, and the number of photons are put in input;
- The outputs are the **dose distributions** in several organs.

Experimental validation of the Monte Carlo code

- Half Value Layer (HVL);
- Bowtie beam profile;
- CTDI head and body;
- 3D printing validation;

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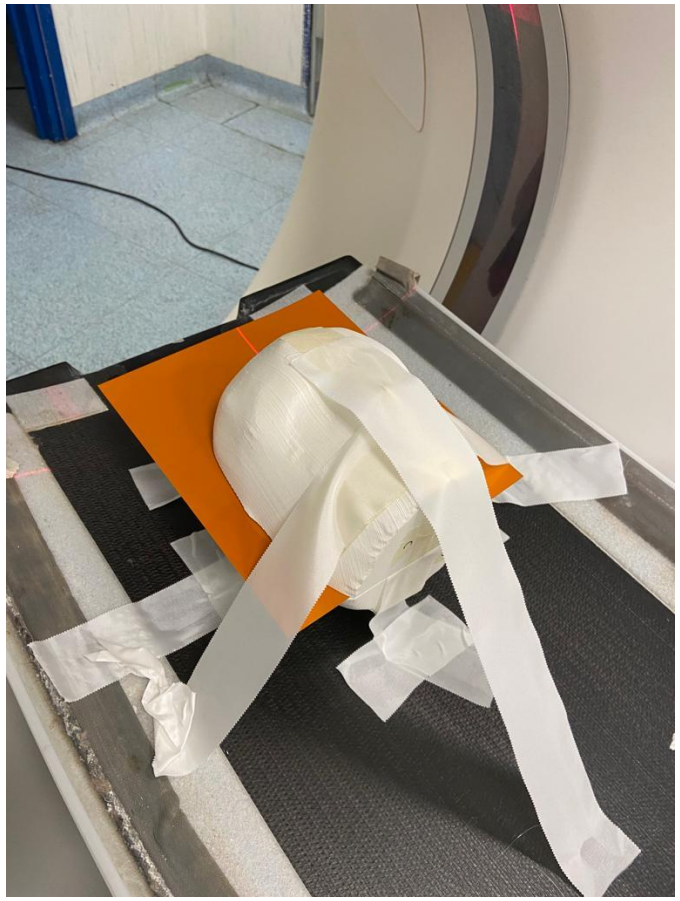
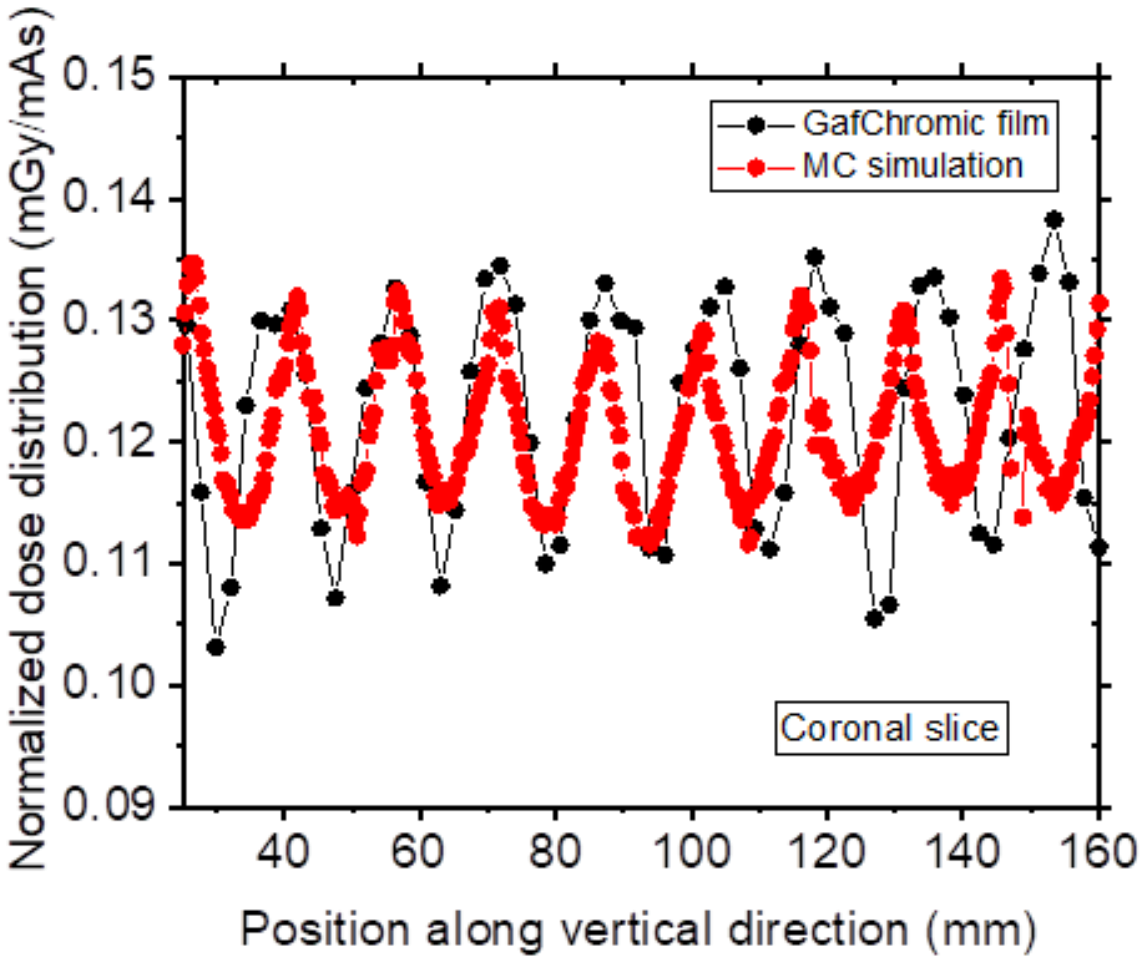
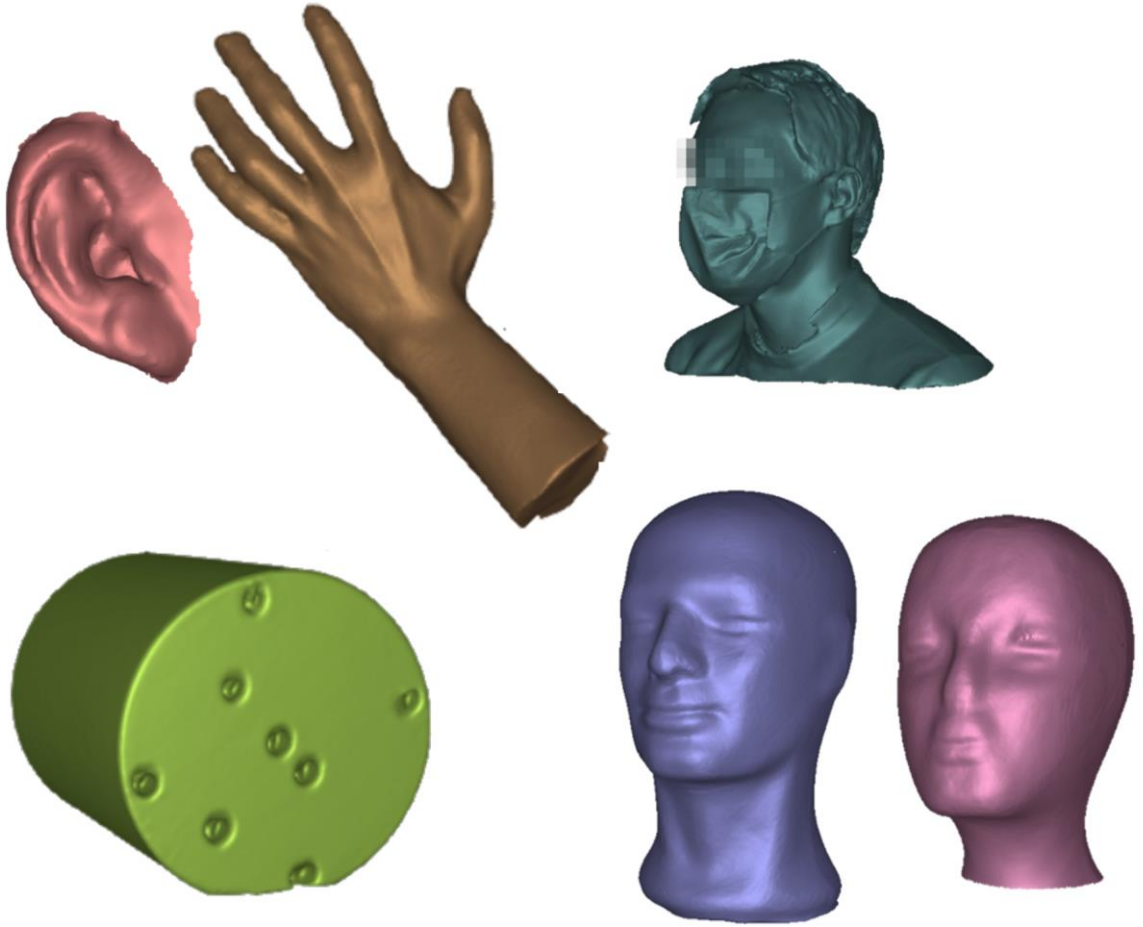


Dose distribution comparisons between MC and GafChromic films



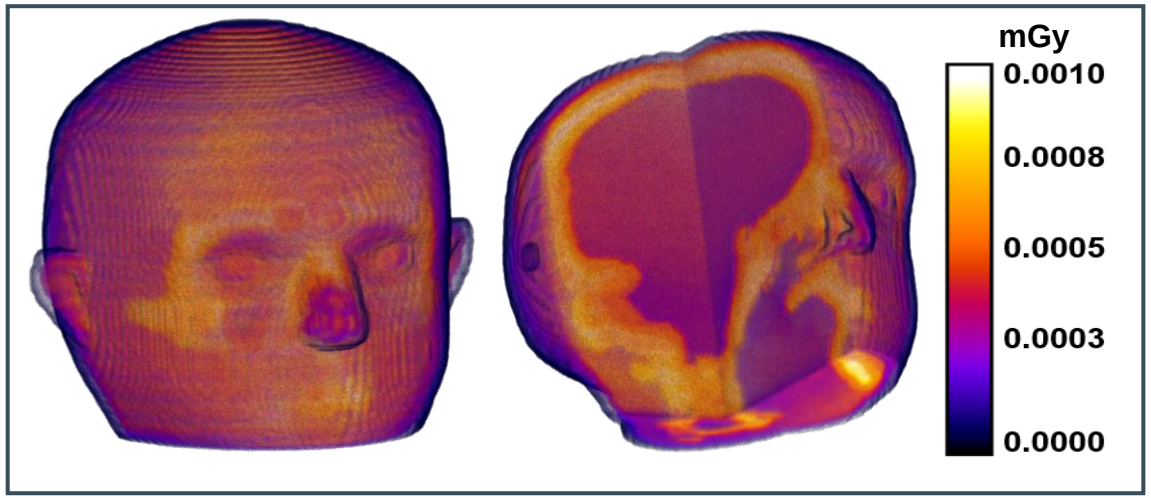
3D optical body scanner: the silhouette of the patient

https://www.artec3d.com/it/portable-3d-scanners/artec-eva



Dose distributions from the MC software: standard phantoms

MC irradiated phantom, 3D dose map



Organ	MC dose (mGy/mAs)	NCI dose (mGy/mAs)	Discrepancies (%)
Brain	0.107±0.004	0.0967	-10.9%
Eye balls	0.118±0.005	0.1114	-5.9%
Lens	0.126±0.005	0.1169	-7.8%
Pituitary gland	0.097±0.004	0.0933	-3.7%

These were calculated as:

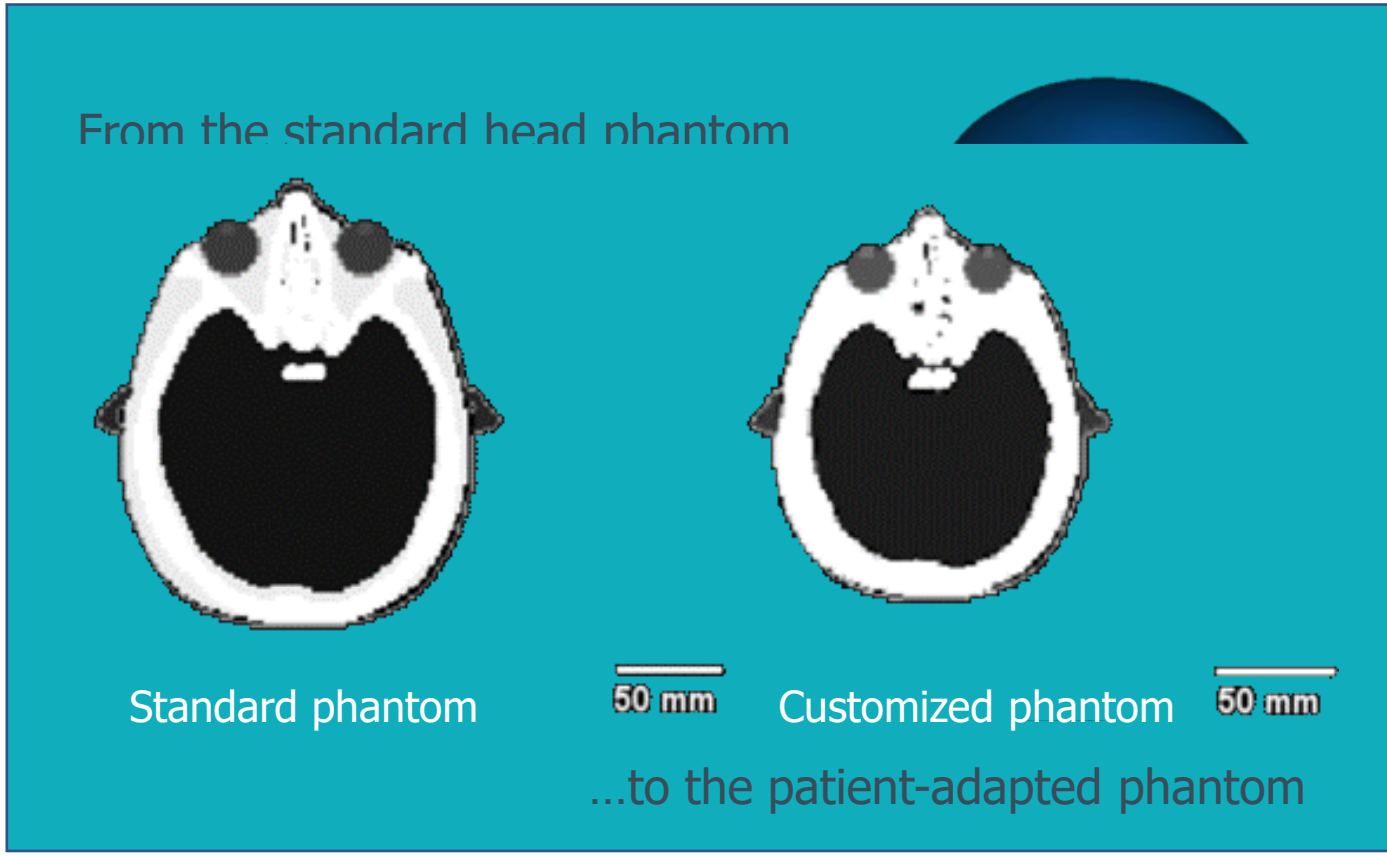
$$\frac{\mathrm{NCICT}_{\mathrm{dose}} - \mathrm{MC}_{\mathrm{dose}}}{\mathrm{NCICT}_{\mathrm{dose}}} \cdot 100$$

Parameters of the scan:

- Tube potential: **120kV**;
- **10^9 histories**;
- Pitch: **1**;
- Beam collimation: **10 mm**;
- Scan range: **20 cm**;
- 2.5×10^4 **photons/s** (2 × AMD EPYC7281, 2.2 GHz, 64 threads)

Rigid adaptation of the NCI head phantoms

The voxel size of the phantom was adapted according to the mannequins' dimensions (**rigid deformation**)!



First results from adaptation

The discrepancies in organ dose estimates between standard phantoms and customized ones:

Male adult

Tube potential (kV)	Brain	Eyeballs	Lens	Pituitary gland
80	+0.8	-7.4	-10.2	+4.9
100	-2.7	-9.2	-13.1	-0.7
120	-4.5	-10.0	-12.2	-4.1
135	-5.1	-9.9	-13.7	-4.9

Discrepancies go from -15% to 5%

Female adult

Tube potential (kV)	Brain	Eyeballs	Lens	Pituitary gland
80	+17.9	+8.9	+4.7	+20.4
100	+36.3	+30.8	+28.2	+38.0
120	+22.2	+17.6	+14.9	+23.3
135	+24.4	+16.8	+3.0	+6.6

Discrepancies go from +3% to +38%

Future persp

https://www.artec3d.com/it/portable-3d-scanners/artec-eva

scanning was proposed for

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med on **GPU platforms**.