Effect of subcutaneous fat on organ dose in radiography and computed tomography: A Monte Carlo calculational study

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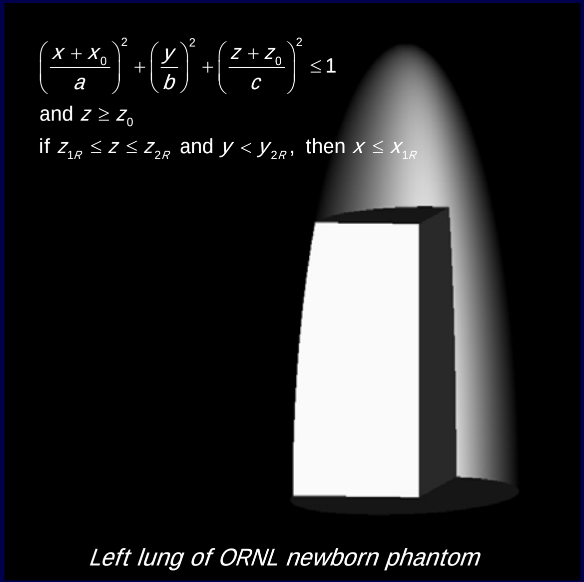
GATOR Engineering

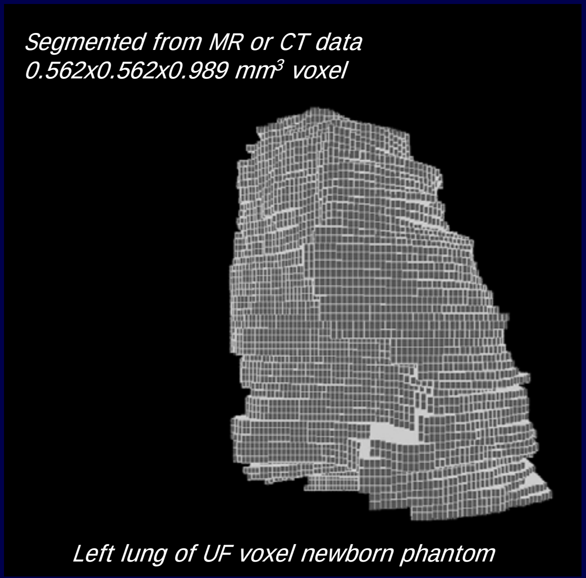
Background

- Radiation dose distributions within the human body from internally deposited radiation source have been calculated by the Monte Carlo method coupled with anthropomorphic computational phantoms.



Left lung of ORNL newborn phantom

Stylized (mathematical) phantom
Since 1960s



Left lung of UF voxel newborn phantom

Voxel (tomographic) phantom
Since 1980s

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Background

Paper

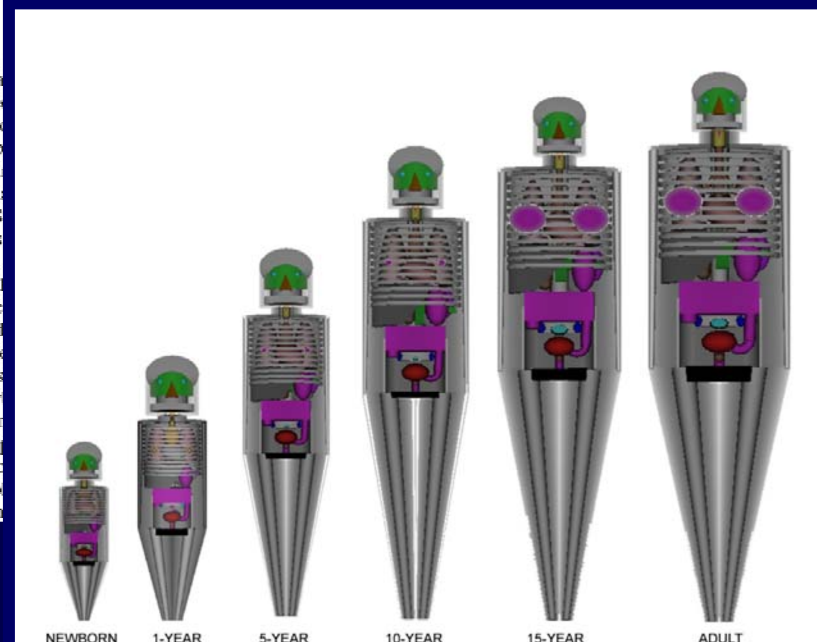
REVISIONS TO THE ORNL SERIES OF ADULT AND PEDIATRIC COMPUTATIONAL PHANTOMS FOR USE WITH THE MIRD SCHEMA

Eun Young Han,* Wesley E. Bolch,*† and Keith F. Eckerman‡

Abstract—The age-dependent series of stylized computational phantoms developed at the Oak Ridge National Laboratory in the late 1970's to early 1980's has found wide applicability in dosimetry studies ranging from dose coefficient compilations for external and internal photon emitters, simulations of patient radiological exams, and dose reconstruction activities. In the present study, we report on a series of revisions to the Oak Ridge National Laboratory series for their intended use within the MIRD schema of medical internal dosimetry. These revisions were made to (1) incorporate recent developments in stylized models of the head, brain, kidneys, rectosigmoid colon, and extra-pulmonary airways; (2) incorporate new models of the salivary glands and the mucosa layer of the urinary bladder, alimentary tract organs, and respiratory airways; (3) adopt reference values of elemental tissue compositions and mass densities from ICRP Publication 89 and ICRU Report 46; (4) provide for explicit treatment of left and right organs within organ pairs; (5) provide for a systematic tabulation of electron absorbed fractions as a function of energy and subject age for all internal organs; and (6) provide for methods of deriving patient-specific values of the specific absorbed fraction for both electrons and photons through interpolation/extrapolation of their phantom-derived values. While tomographic computational phantoms provide improved anatomic realism given the CT or MR image sets used in their construction, there does not yet exist a comprehensive series of reference pediatric tomographic phantoms, nor the ability to sim-

INTRODUCTION

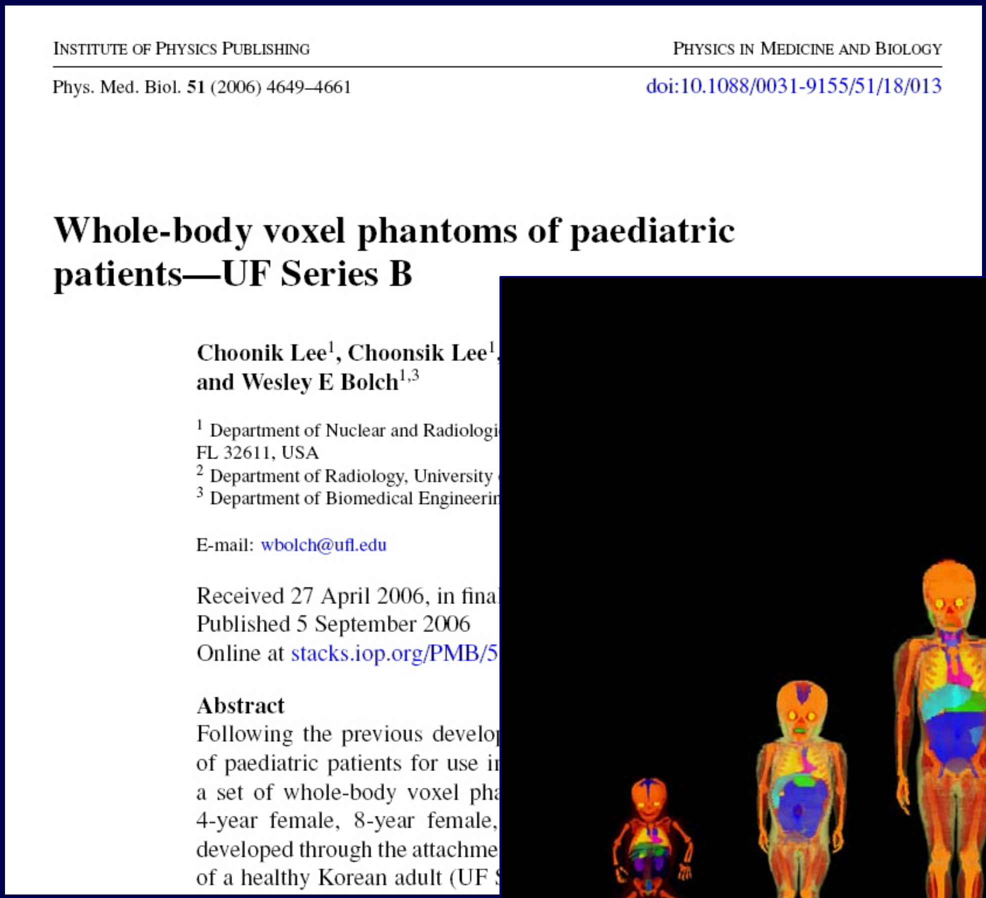
THE SERIES of stylized (or mathematical) phantoms developed at the Oak Ridge Na tory (ORNL) in the early 1980's have be sively in the study of organ doses in nu (Stabin and Sparks 2003; Stabin 1996), p ography (Jones and Wall 1985; Rosenstei et al. 2003), diagnostic and intervention (Bolch et al. 2003; Stern et al. 1995; S 1991), environmental radiation exposures al. 1999; Eckerman and Ryman 1993), protection (ICRP 1989, 1993, 1994, 2001). These phantoms utilize 3D surfac represent both internal organ structure and shape. The ORNL series are hermaphrodit both male and female organs and tissues mathematical representations of a new 5-y-old, 10-y-old, 15-y-old, and an adult model was originally considered to be re the adult female until the publication 12907 (Stabin et al. 1995) in which p absorbed fractions from the 15-y phantom



- Revised organ models (brain, kidneys, recto-sigmoid colon, salivary glands, mucosa layers) incorporated
- Organ-specific reference elemental compositions (ICRU46)

Revised ORNL adult and pediatric stylized phantoms (Han et al. 2006)

Background



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Whole-body voxel phantoms of paediatric patients—UF Series B

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Abstract
Following the previous develo
of paediatric patients for use i
a set of whole-body voxel pha
4-year female, 8-year female,
developed through the attachme
of a healthy Korean adult (UF

- Evolved from UF Series A torso phantoms (Lee et al. 2005)
- Arms and legs from Korean adult CT
- Match to ICRP89 reference data

UF Series B Voxel Phantoms (Lee et al. 2006)

Background

- Two classes of computational phantoms have both advantages and disadvantages.

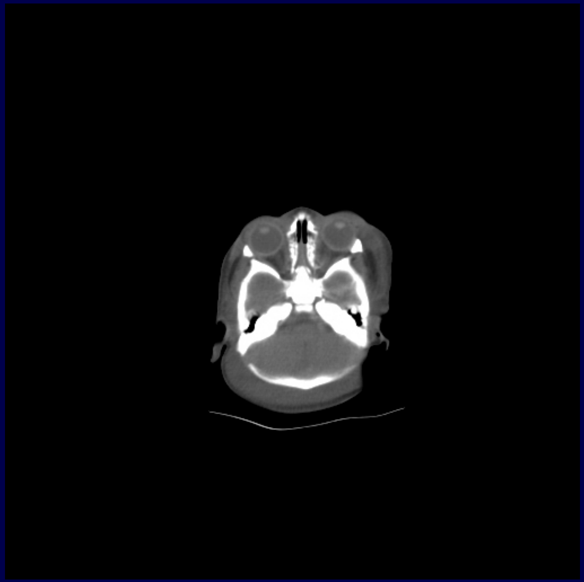
	Stylized Phantoms	Voxel Phantoms
Anatomic realism	Smooth organ surfaces	Cubically-shaped organ surfaces
	Equation-based organ descriptions	Manual image segmentation required
	Unrealistic organ depth, position, shape	Realistic organ depth, position, and shape
Flexibility	Parameter-based modification	Pixel-based modification
	Non-uniform scaling – difficult but possible	Uniform scaling is achievable
	Posture change – difficult but possible	Difficult to change posture

Background

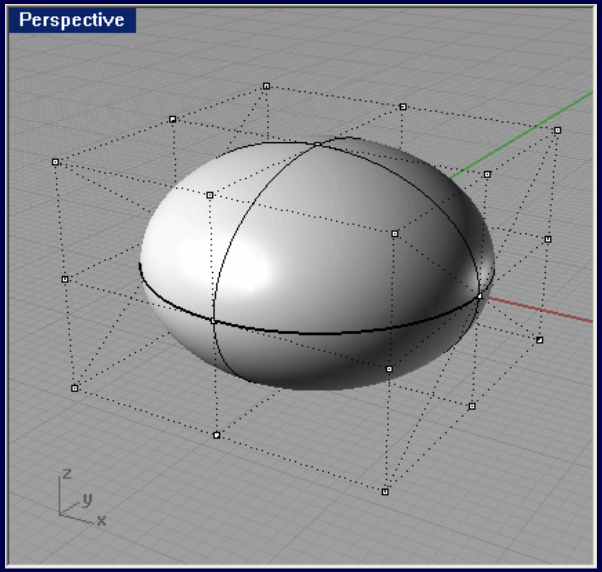
- Current stylized/voxel phantoms are based on reference human, but there are few 'reference-like' individuals in the world!
  - Weight and height variability
  - Body shape variability (fat distribution)
- How to estimate 'individual-specific' organ dose?
  - Approach 1: Make a library of voxel phantoms from lots of individuals
  - Approach 2: Do CT scan and automatic segmentation
  - Approach 3: Make flexible template phantoms and deform to individual

Background

- Hybrid approach taking advantages of stylized and voxel phantoms
  - Based on realistic CT data (anatomic realism of voxel phantoms)
  - Employ flexible Non-uniform rational B-spline (NURBS) surface



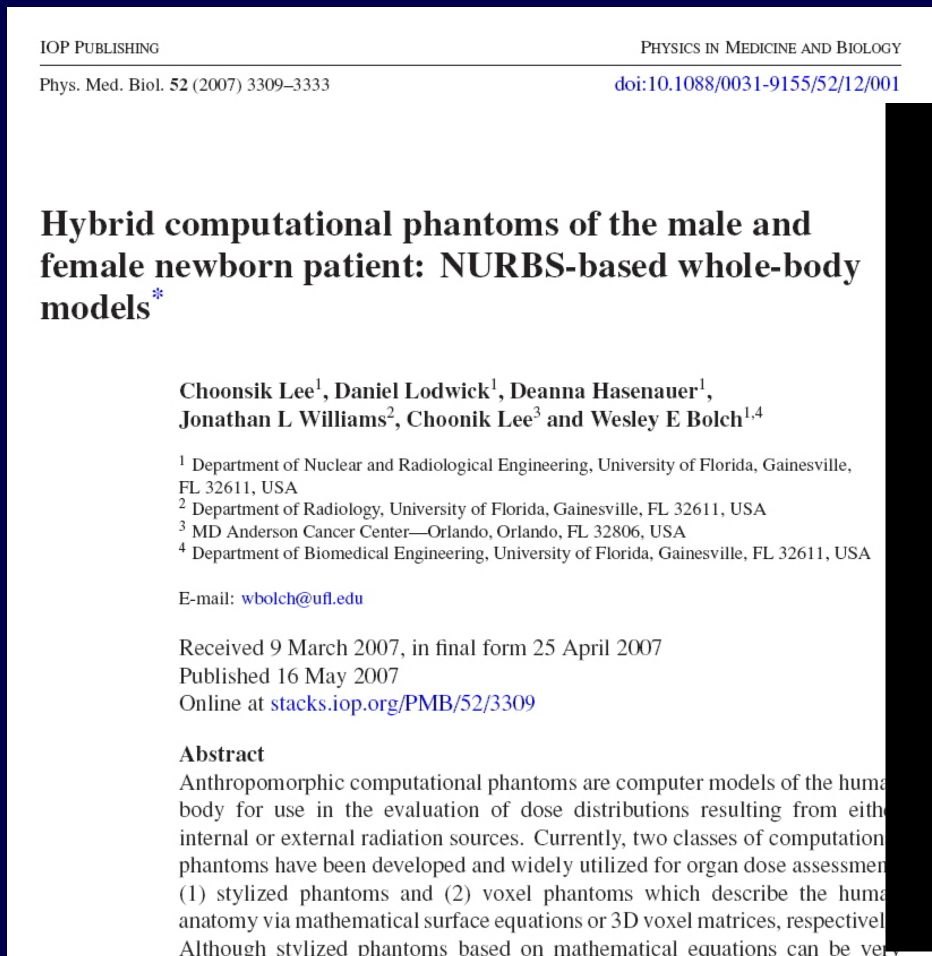
Anatomical Realism
(CT images of patient)



Flexibility
(NURBS surface)

Materials and Methods

Methodology for hybrid phantom established (Lee et al. 2007)



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Hybrid computational phantoms of the male and female newborn patient: NURBS-based whole-body models*

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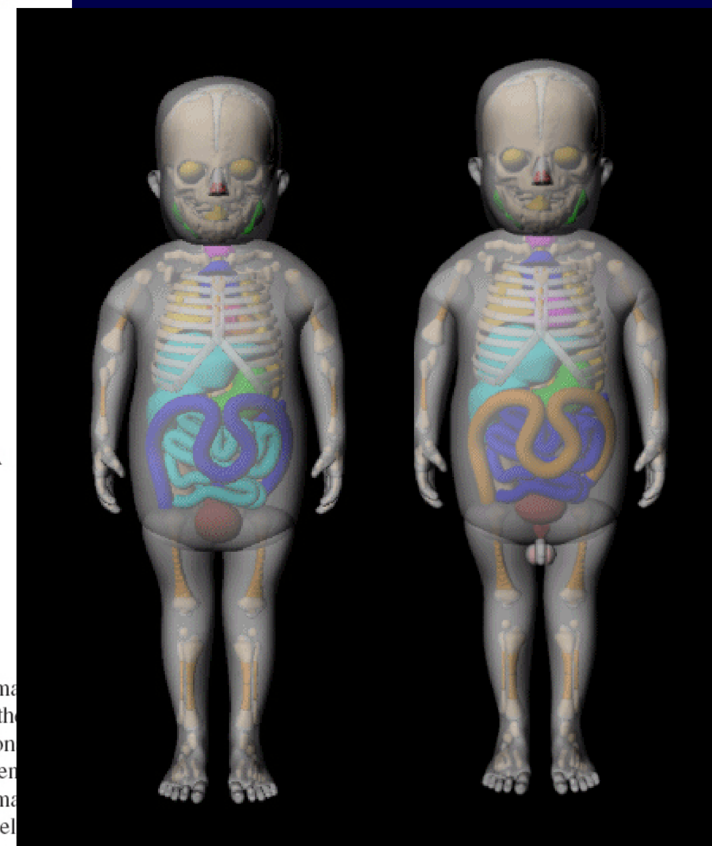
Abstract

Anthropomorphic computational phantoms are computer models of the huma body for use in the evaluation of dose distributions resulting from eith internal or external radiation sources. Currently, two classes of computation phantoms have been developed and widely utilized for organ dose assessmen (1) stylized phantoms and (2) voxel phantoms which describe the huma anatomy via mathematical surface equations or 3D voxel matrices, respectivel Although stylized phantoms based on mathematical equations can be ve

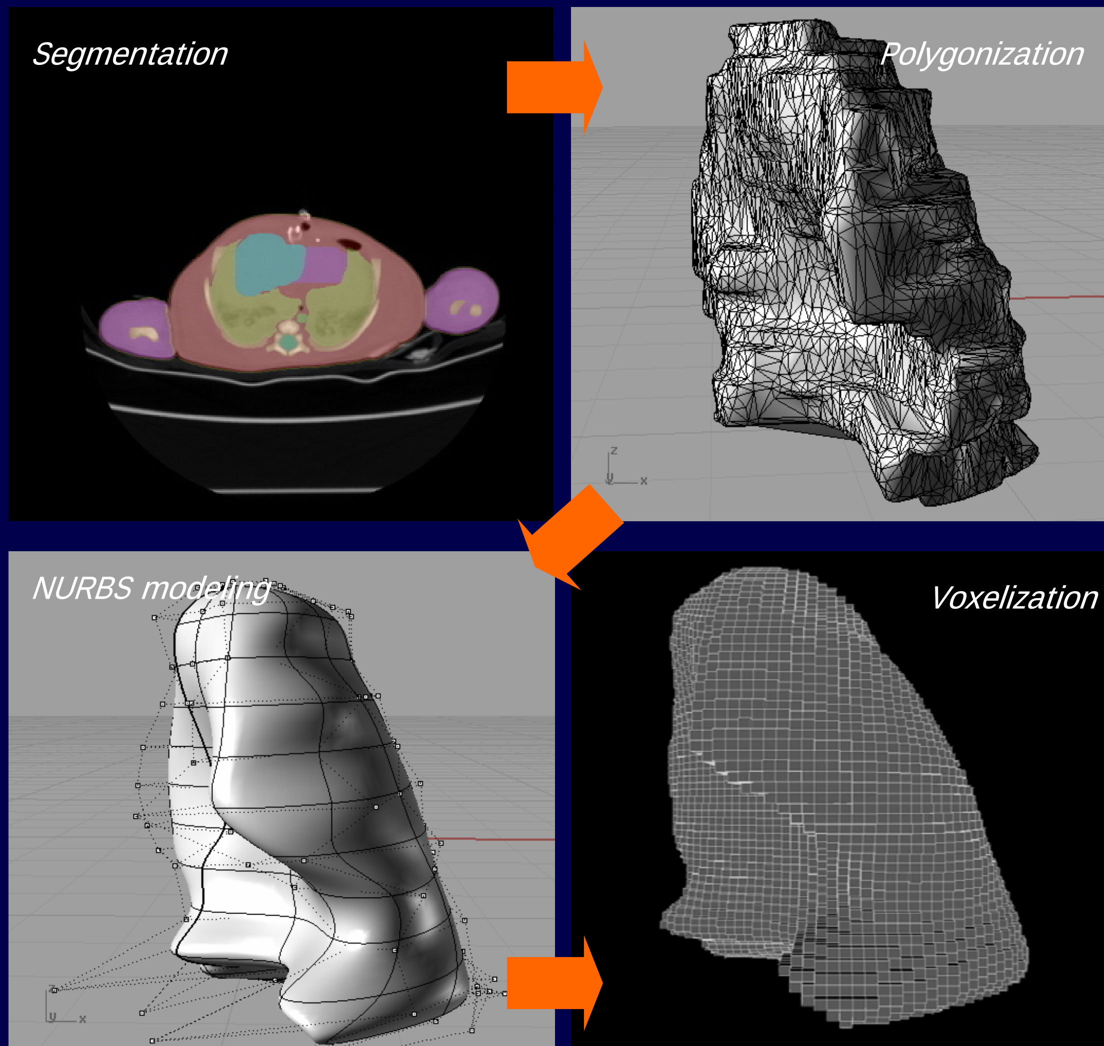


UF hybrid female (left) and male (right) newborns

Materials and Methods

Segment CT slices using 3D-DOCTOR, 3D segmenting and rendering software

Convert segmented model into polygon mesh using built-in function of 3D-DOCTOR



Make NURBS model from polygon mesh model using Rhinoceros, 3D NURBS modeling software, and

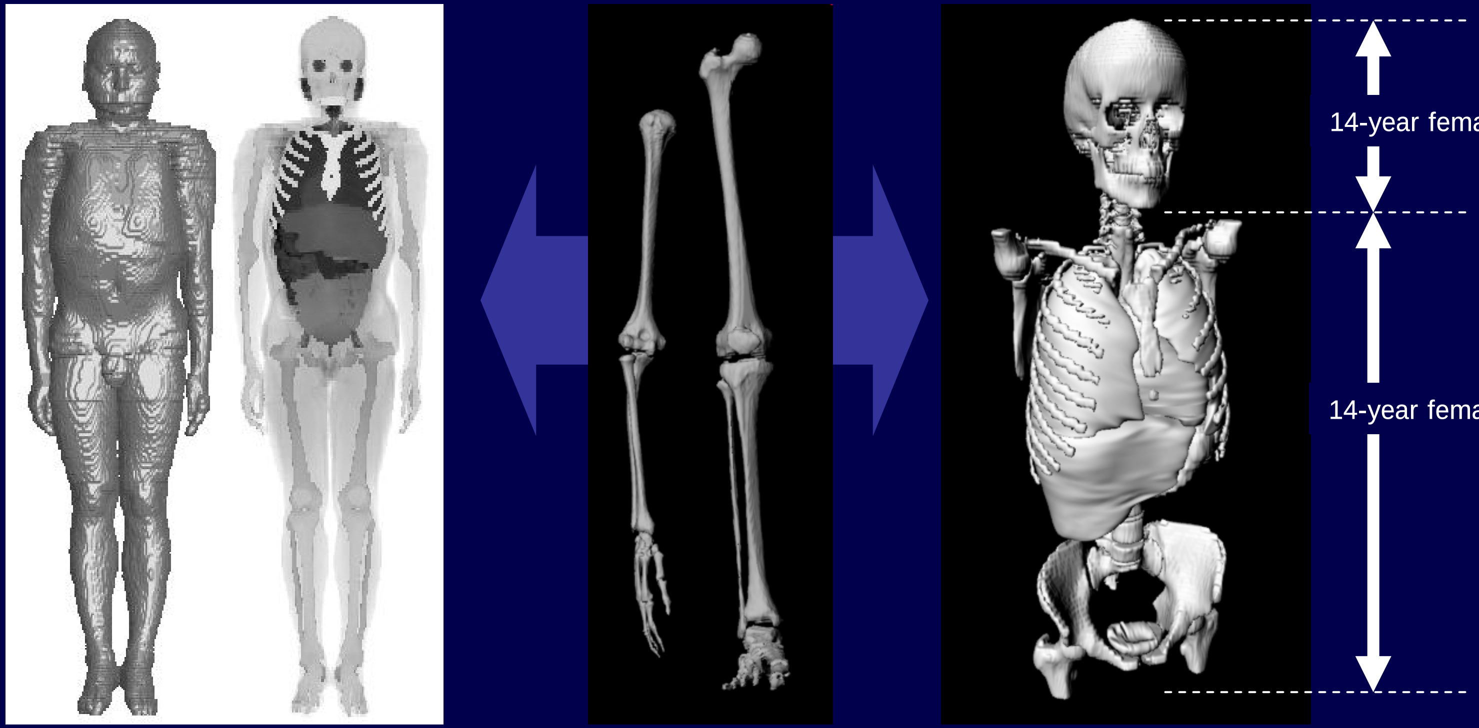
Match to ICRP89 reference organ mass

Convert NURBS model into voxel model using Voxelizer, in-house MATLAB code

Materials and Methods – source anatomy

15-year hybrid male phantom

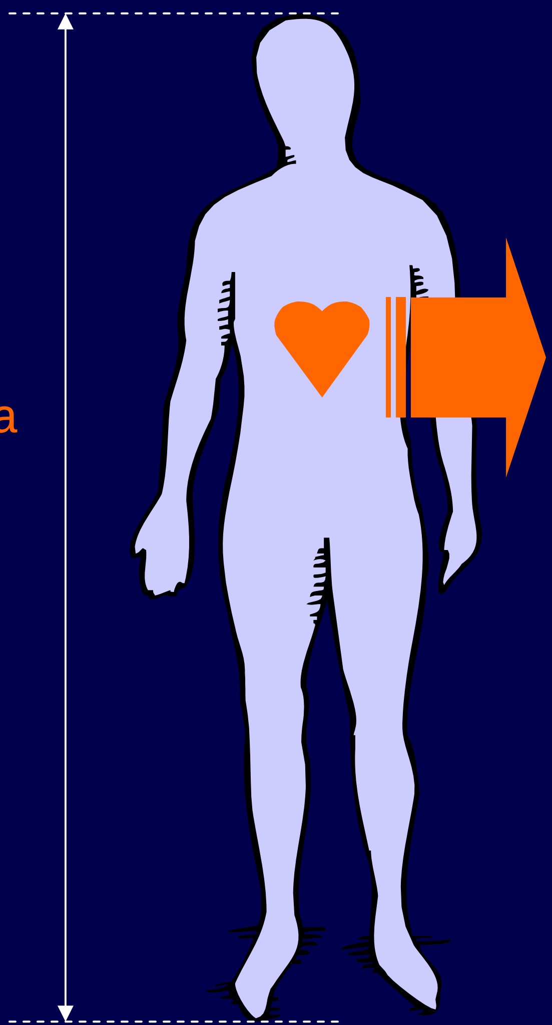
15-year hybrid female phantom



UF 14-year male voxel phantom

18-year male arm and leg CT

Materials and Methods – standardization



NHANES reference anthropometric data

- Standing height
- Sitting height
- Arm length
- Circumference
  - Head
  - Neck
  - Waist
  - Buttock
- Biacromial breadth

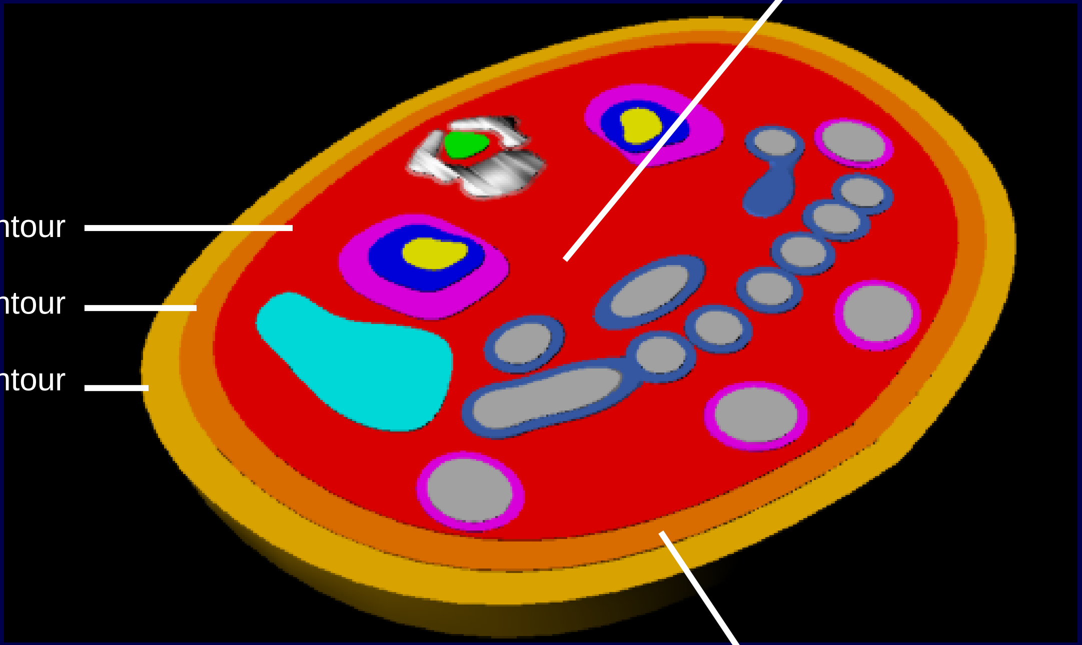
ICRP89 reference organ data

- 60 organs and tissues
- 38 bone sites

Materials and Methods – different body shape

- “Adiposity for male and female children is predominantly subcutaneous fat.”
- “In males, fat typically accumulates in the upper segment of the body, both subcutaneously and intra-abdominally. This is appar ent visually as a bulging abdomen in an apple-shaped distributio n. In females, adipose tissue accumulates subcutaneously, parti cularly over the thighs in a pear-shaped gluteal distribution.”

(Arnold H. Slyper, Pediatrics Vol. 102, No. 1, 1998)

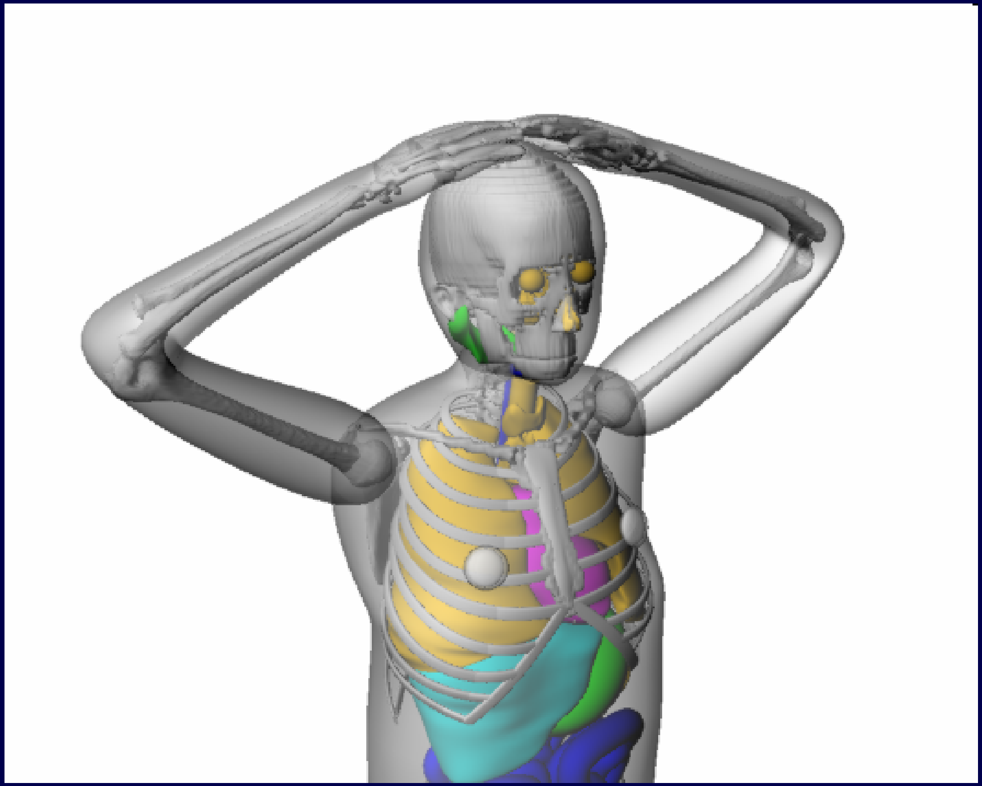


Materials and Methods – applications

- Calculate dose conversion coefficients for projection radiographs
  - 66 kVp tube potential, 1.05 mm of Al filtration, and 12 degree of anode angle
  - Simulate chest PA and abdomen AP examinations (MCNPX2.5)
  - Calculate organ absorbed doses per entrance and exit air kerma

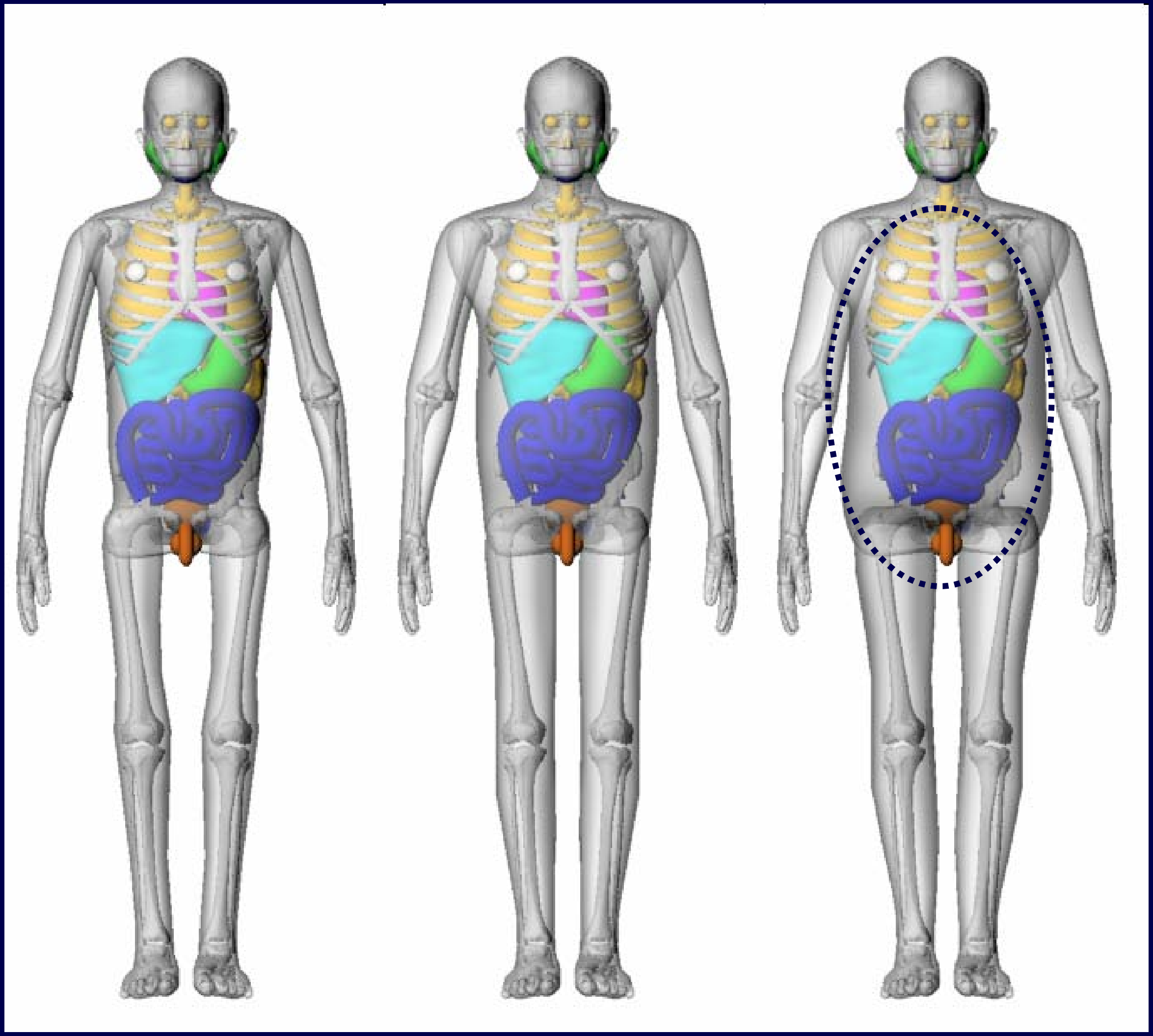
- Calculate organ absorbed dose for CT scans
  - Simulate SOMATOM Sensation 16 helical multi-slice CT scanner
  - MCNPX2.5 source routine was recompiled to incorporate helical CT beams
  - 100 kVp tube potential and 1.2 mm collimator width
  - Simulate chest and abdomen CT scans
  - Calculate organ absorbed doses normalized to 100 mAs

Materials and Methods – applications



Example of modified arm structure of $UFH15M_{50th}$ for CT calculation

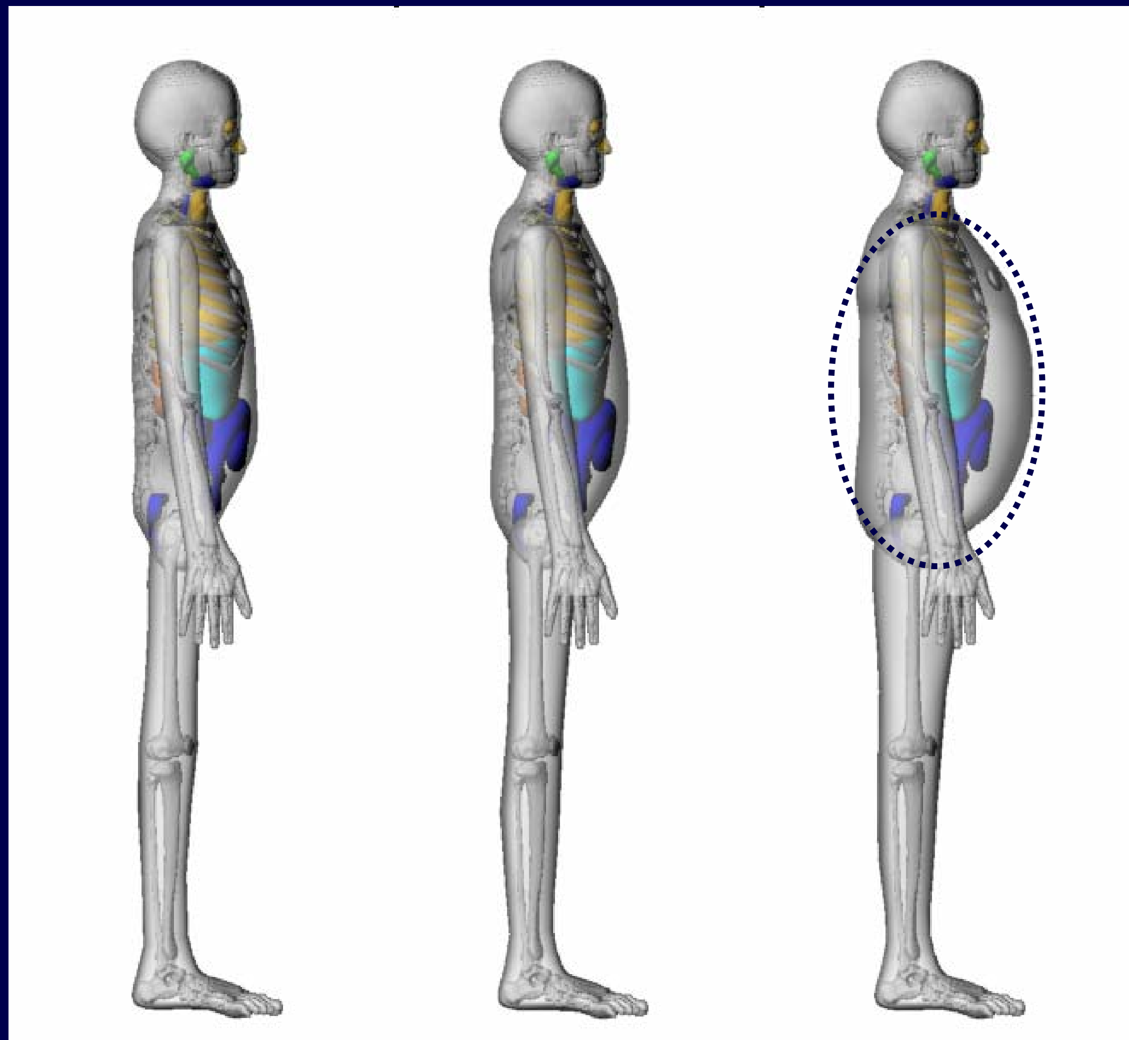
Results and Discussions



Apple shape

UFH15M$_{10th}$ UFH15M$_{50th}$ UFH15M$_{90th}$

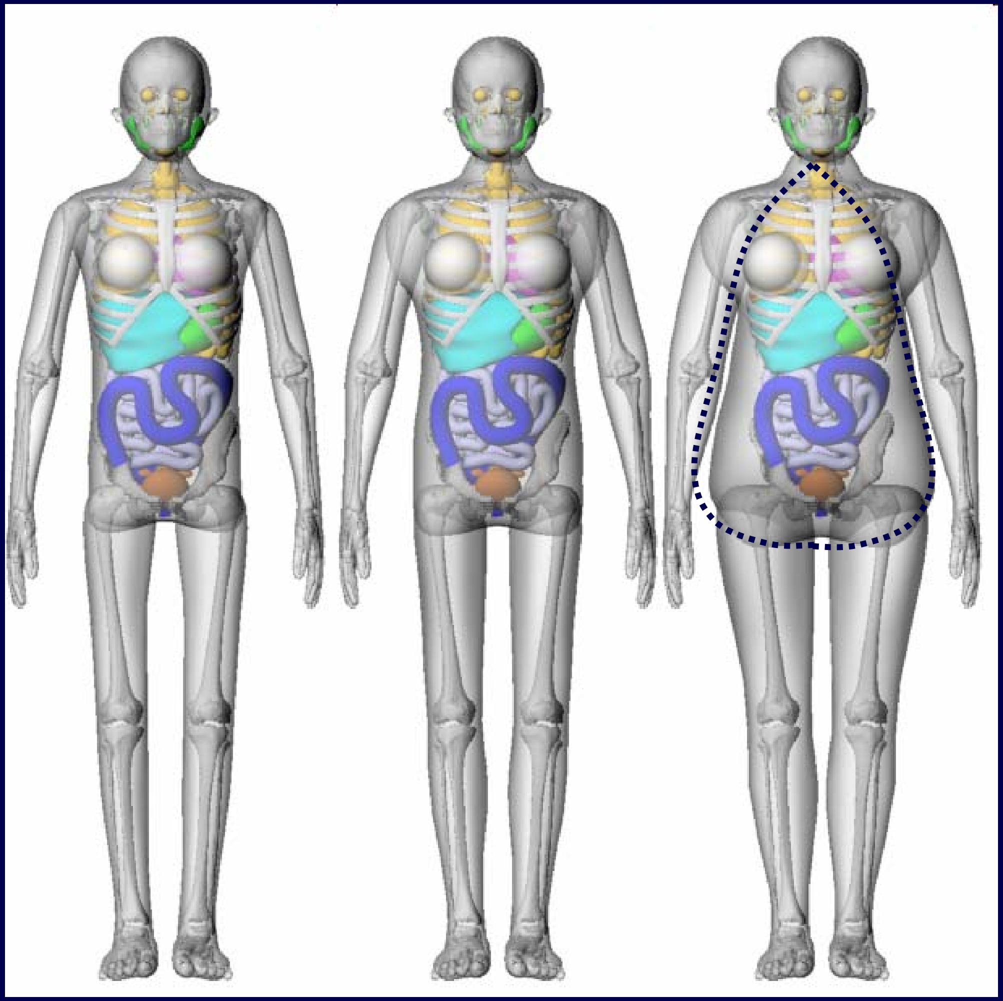
Results and Discussions



Apple shape

UFH15M$_{10th}$ UFH15M$_{50th}$ UFH15M$_{90th}$ UFH15M$_{90th}$

Results and Discussions



$UFH15F_{10th}$ $UFH15F_{50th}$ $UFH15F_{90th}$

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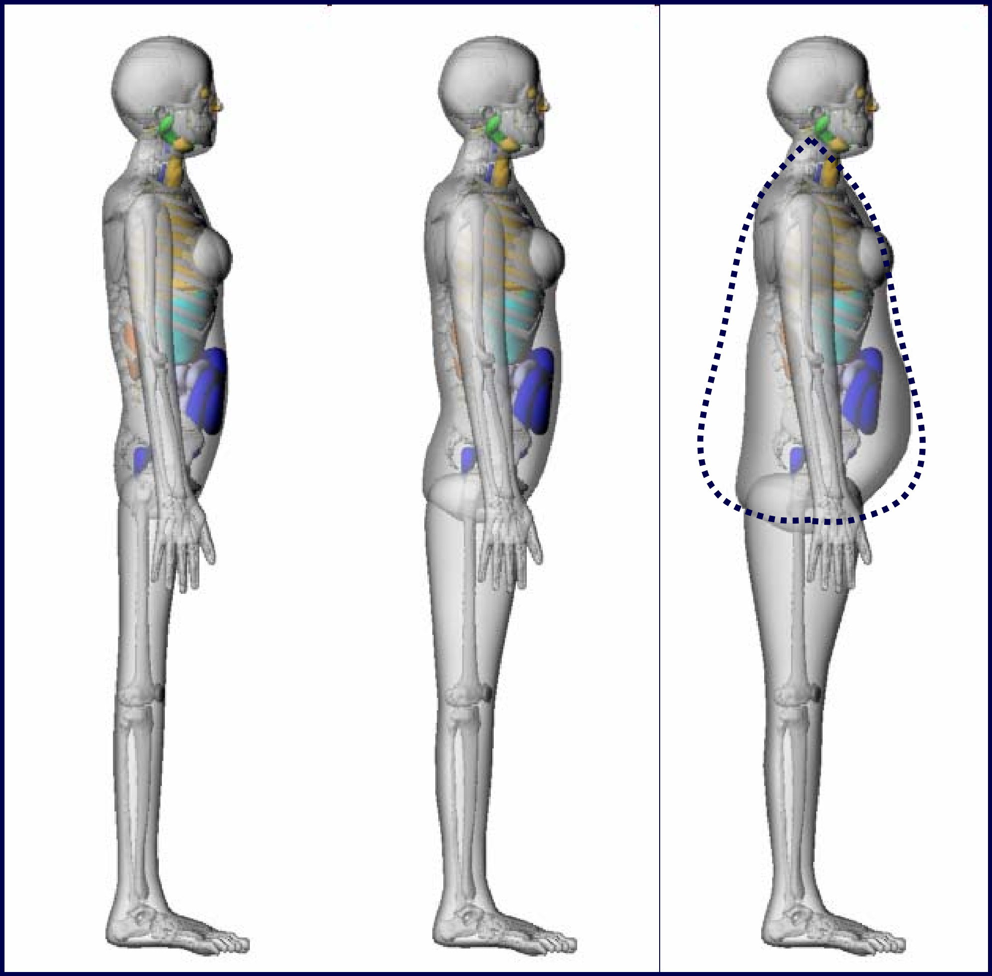
Results and Discussions



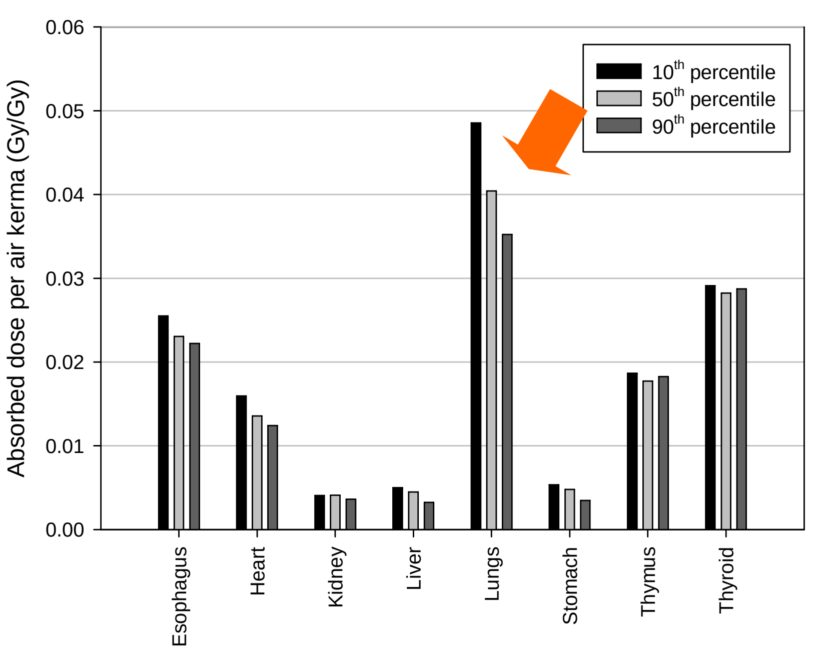
Pear shape

$UFH15F_{10th}$ $UFH15F_{50th}$ $UFH15F_{90th}$

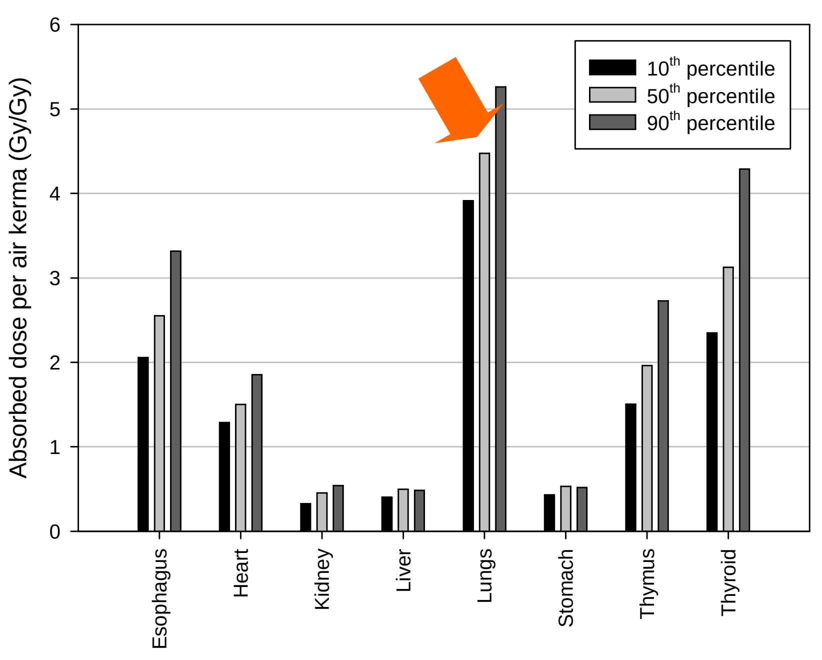
$UFH15F_{10th}$ $UFH15F_{50th}$ $UFH15F_{90th}$

Results and Discussions – projection radiographs

Absorbed dose per air kerma (Gy/Gy) for CHEST PA examination



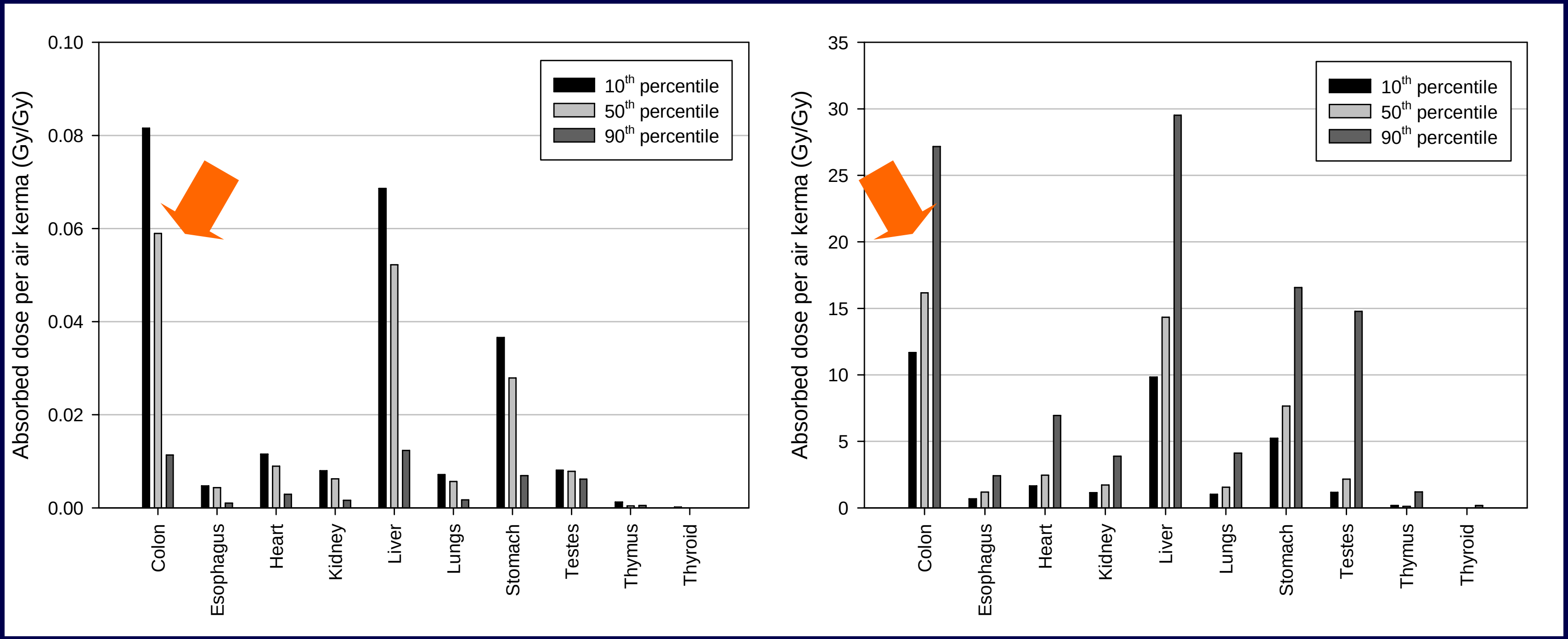
Organ dose per ENTRACE air kerma



Organ dose per EXIT air kerma

Results and Discussions – projection radiographs

Absorbed dose per air kerma (Gy/Gy) for ABDOMEN AP examination



Organ dose per ENTRACE air kerma

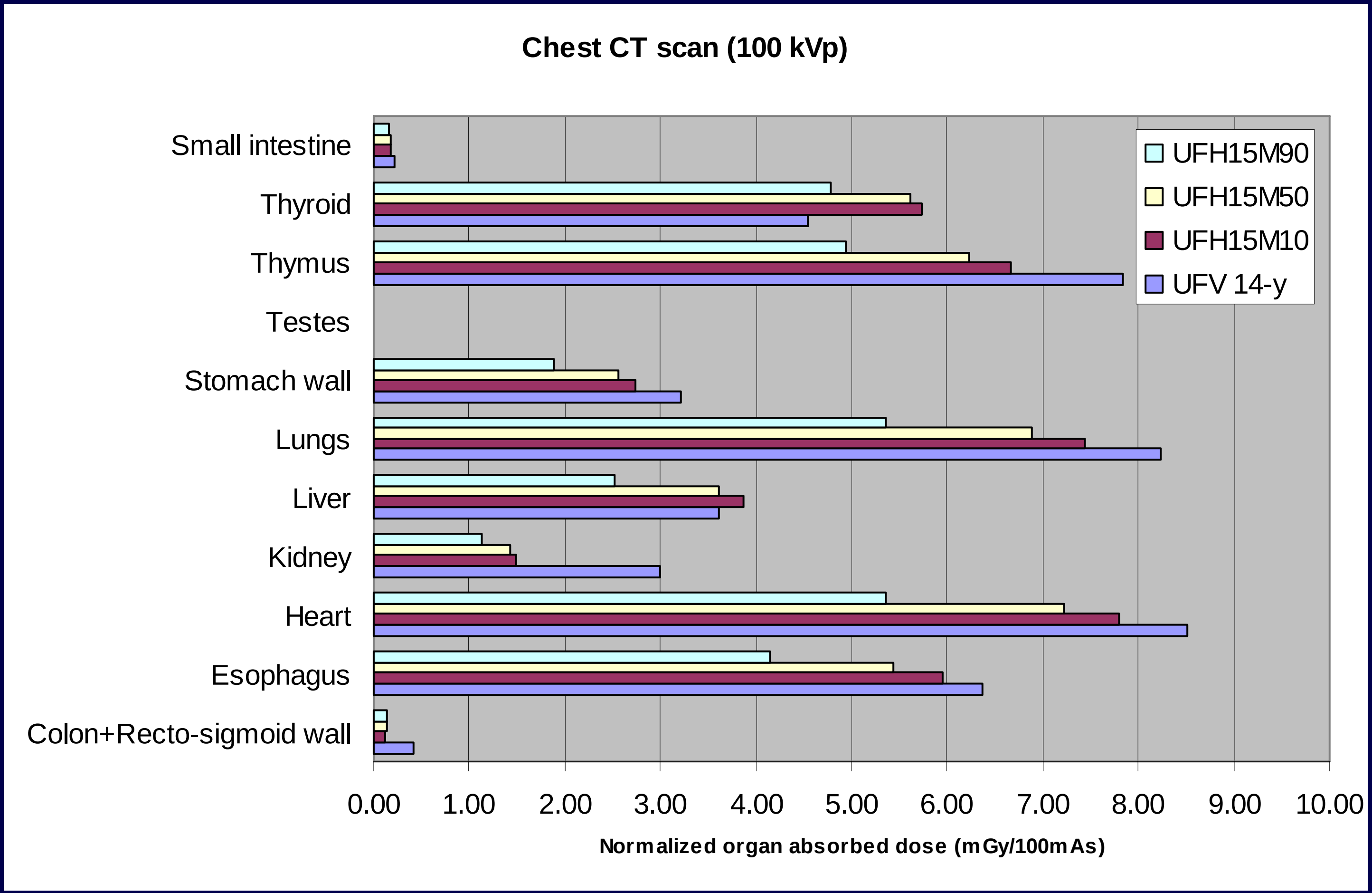
Organ dose per EXIT air kerma

Results and Discussions – projection radiographs

- Effect of subcutaneous fat on organ dose

		Dose per entrance air kerma			Dose per exit air kerma		
		10^{th}	90^{th}	$(10^{th} - 90^{th})/90^{th} \times 100$ (%)	10^{th}	90^{th}	$(90^{th} - 10^{th})/10^{th} \times 100$ (%)
Chest PA	Lungs	0.0485	0.0352	38	3.9125	5.2601	34
	Esophagus	0.0255	0.0222	15	2.0560	3.3161	61
Abdomen AP	Colon	0.0816	0.0113	622	11.6781	27.1642	133
	Liver	0.0686	0.0123	458	9.8259	29.5184	200

Results and Discussions – CT simulation



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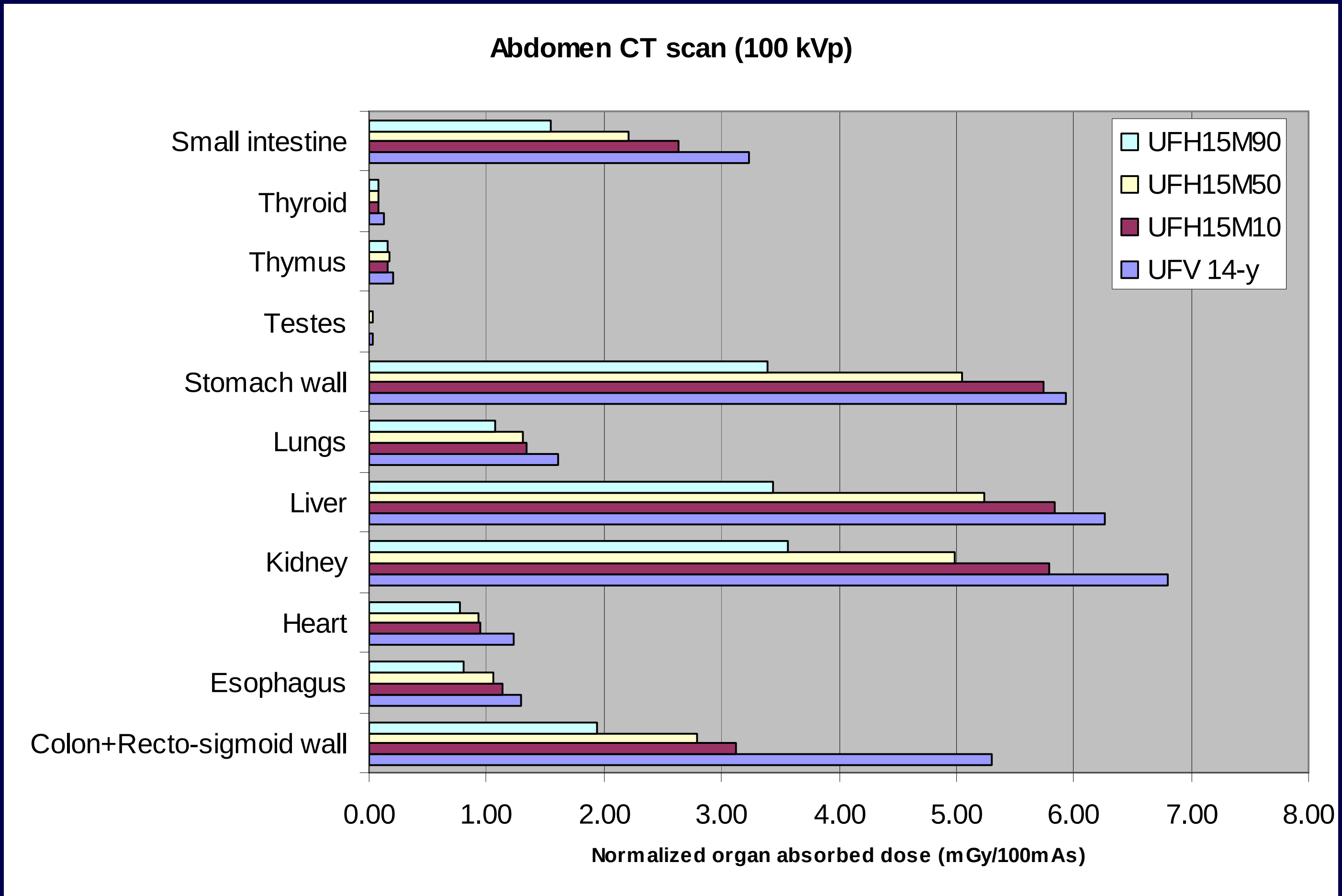
Results and Discussions – CT simulation



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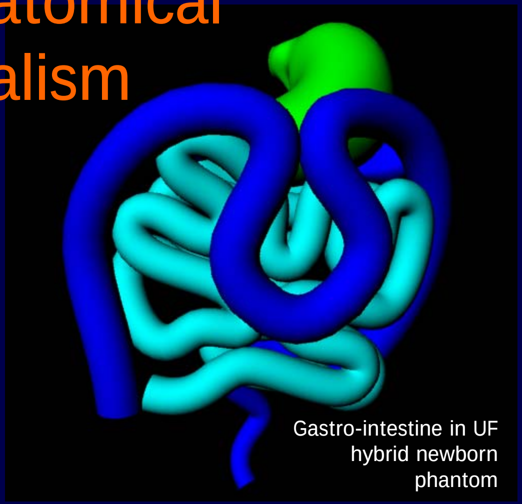
Results and Discussions – CT simulation

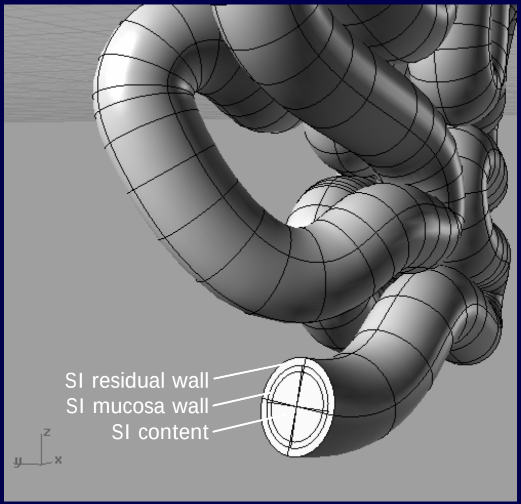
Percent difference between 10th and 90th phantoms

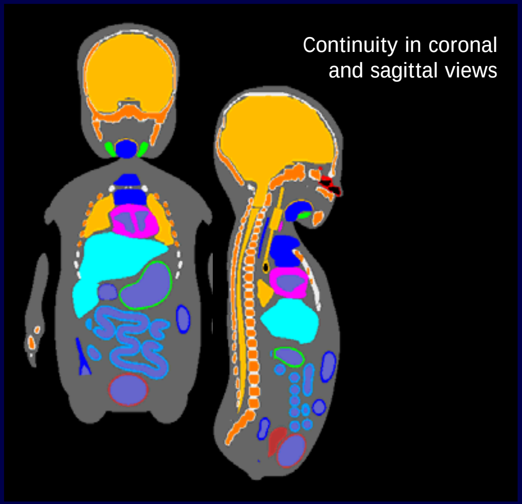
	UFH15M		UFH15F	
	UFH15M Chest CT	UFH15M Abdomen CT	UFH15F Chest CT	UFH15F Abdomen CT
Colon	-20.66%	55.67%	-22.57%	39.08%
Esophagus	42.05%	37.97%	18.18%	14.02%
Heart	42.28%	18.23%	19.87%	1.43%
Kidney	29.36%	58.42%	-1.15%	50.62%
Liver	48.56%	63.79%	13.91%	22.64%
Lungs	35.85%	23.10%	19.30%	4.55%
Stomach wall	40.38%	63.36%	13.04%	24.28%
Testes	4.88%	-0.35%	7.21%	-6.67%
Thymus	31.90%	-6.84%	12.48%	-7.29%
Thyroid	17.37%	1.28%	5.47%	-7.06%
Small intestine	6.56%	64.65%	-2.44%	53.44%

Conclusions

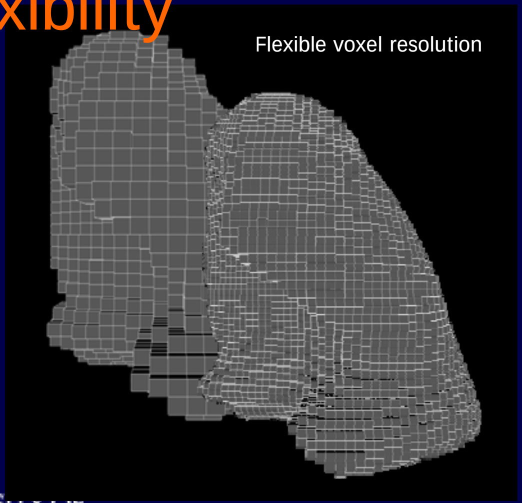
Anatomical Realism

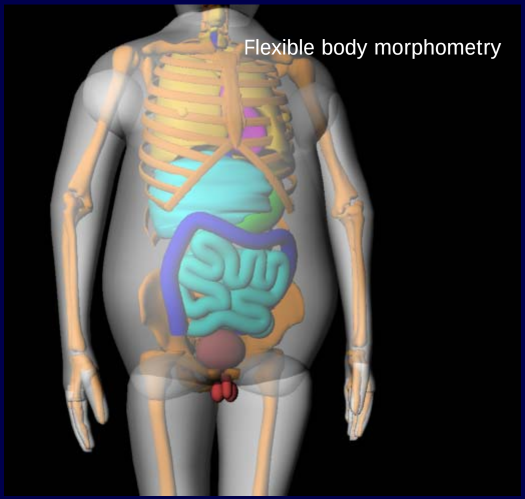


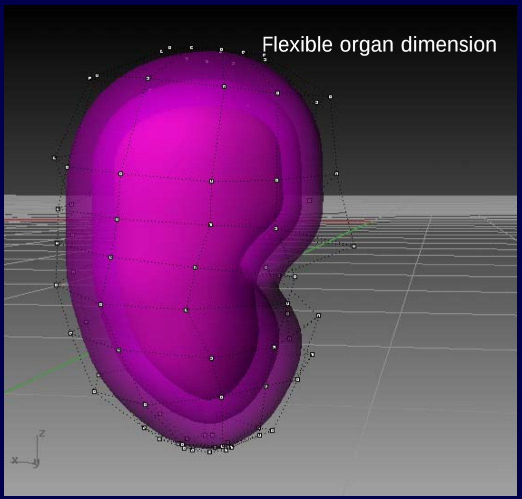




Flexibility

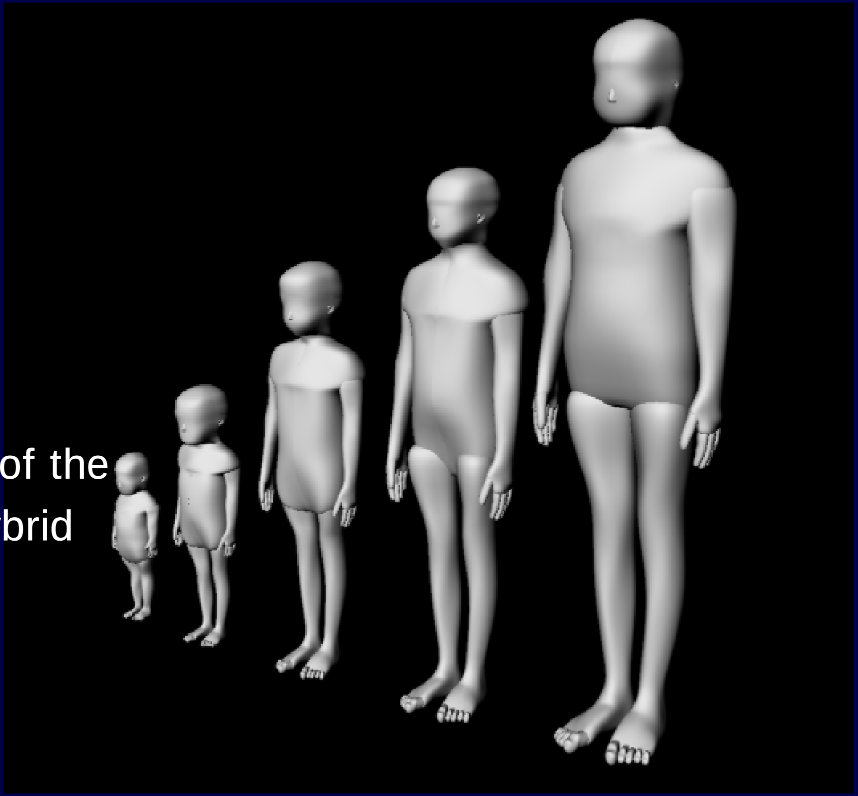






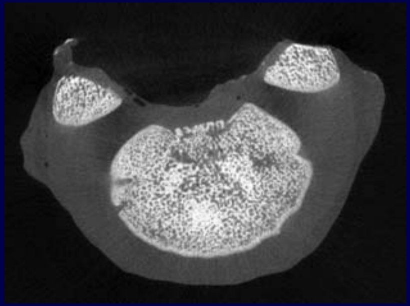
Future work

- UF hybrid pediatric series
  - 1, 5, 10, and adult male and female
  - Based on live CT images
  - Match ICRP 89 reference data



- Pediatric skeletal models
  - CT and microCT-based pediatric models of the skeleton to accompany each pediatric hybrid phantom of the UF series

microCT of newborn LV



Thank you for your attention!
Any questions or comments appreciated