GSF Male and Female Adult Voxel Models Representing ICRP Reference Man

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Motivation

- Medical image data provides
  - Improved anatomical realism
  - Studies indicate dosimetric impact (photons)
    - Few tens percent external
    - Order magnitude on internal sources
- ICRP desires to adopt computational phantoms
  - Limitations of voxel models
    - Individual organ topology
    - Individual organ masses
- ICRP Reference computational phantoms
  - Needs to represent population average
  - Reference Man Publications 23 and 89
Methodology-1

- Strategy
  - Select CT image data set of persons close to Reference Man (height and weight)
  - Segmentation of the data set
  - Adjust body height to reference value (scaling voxels)
  - Adjust skeletal mass to reference value (in plane voxel dimensions)
  - Adjust individual organs to reference values by addition/subtraction of voxels
Methodology-2: Skeleton

- Proportion of bone marrow and bone mineral based on CT values in skeleton voxels
- Regional distribution of active marrow as in Publication 89
- Fraction of marrow that is active (red) is based on cellularity data in Pub 89
- Yellow marrow located in all other regions
- Structure of trabecular bone not modeled
- Response functions used to estimate active marrow and endosteal dose from fluence
Methodology-3

- Software package *VolumeChange* for modification of soft-tissue organs
  - Programming language IDL
  - Represent organ by its surface voxels (i.e., voxels that have at least one neighbor that does not belong to the same organ)
  - Modify organs by shifting surface voxels
Methodology-4

- **Advantage of software system**
  - Various platforms (Windows/Unix/Linux)
  - Direct manipulation of segmented data set
  - Possible to decide if voxel belonging to neighboring soft-tissue organ maybe overwritten (bone never overwritten)
  - Easy to modify to address new needs

- **Limitation**
  - Not a segmentation tool
  - *AnalyzeAVW* 3.0 used in segmentation
Modification to Golem-1

- Segmentation of additional organs
  - Blood (large vessels in trunk)
  - Breast (adipose and gland tissue)
  - Cartilage
  - Pituitary gland
  - Salivary gland
  - Tongue
  - Tonsils
  - Ureters
Modification to Golem-2

- Contents added to previous solid organs
  - Gall bladder
  - Heart
  - Small Intestine

- Subdivision of colon
  - Ascending colon
  - Transverse colon, right and left
  - Descending colon
  - Recto sigmoid colon

- Consistent with pending alimentary tract publication (ICRP Publication 99)
## Methodology - Adult Male

<table>
<thead>
<tr>
<th></th>
<th>Golem</th>
<th>Reference</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>176</td>
<td>176</td>
<td>ok</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>69.6</td>
<td>73.0</td>
<td>Adjust</td>
</tr>
<tr>
<td>Golem voxel size</td>
<td>0.208 x 0.208 x 0.8 cm</td>
<td></td>
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</tr>
</tbody>
</table>
Modification to Golem-3

- Reference Model in supine position
  - No attempt made to adjust organ positions
- Lungs are compressed: adjusted to reference mass by density (0.427 g cm$^{-3}$)
- Skeletal mass 10.45 vs. 10.5 kg reference value
- Voxel dimensions
  - Height 8 mm (not modified)
  - Pixel dimensions (2.08 mm → 2.085 mm)
Modification to Golem-4

- Adjustment to organs
- First difficulty: brain
  - Mass: Golem 1224 g Reference Man 1450 g
  - Brain surrounded by skull – can not add voxels
- Further organs in head
  - Salivary gland 64.7 g vs. 85 g
  - Teeth 39.1 g vs. 50 g
  - Tongue 36.3 g vs. 70 g
- Necessary to adjust pixel size in head
Modification to Golem-5

- Pixel size in head changed to 2.269 mm
- Volume re-sampled to accommodate voxel of original size (2.085 mm)
- Larger number of head voxels, constant voxel size for whole body
- Mass of skeleton: 10.58 kg vs. 10.5 kg reference value
Modifications to Golem-6

Did adjustment to skull distorted body propositions?

Left side: Golem with original proportions

Right side: pixel size in head changed to 2.269 mm

Judged acceptable.
Reference Male Phantom

- 220 cross-section images
  - 256 x 256 pixels (2.085 mm)
  - 8 mm in vertical
- Phantom
  - 2,021,500 tissue voxels
  - Voxel volume 0.0348 cm³ or ~ 35 mg
  - Each voxel assigned 1 byte ID
  - 85 tissues/contents identified
  - 14.1 Mbyte data file
Reference Male Phantom
**Methodology – Adult Female**

Reference Adult Female based on GFS’ Laura

<table>
<thead>
<tr>
<th>Comparison of Laura and Reference Female</th>
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</thead>
<tbody>
<tr>
<td>Laura</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Mass (kg)</td>
</tr>
<tr>
<td>Laura voxel size (0.1875 x 0.1875 x 0.5 cm)</td>
</tr>
</tbody>
</table>

Follow same adjustments as for male
Reference Female Phantom

- 346 cross-section images
  - 256 x 256 pixels (1.765 mm)
  - 4.84 mm in vertical
- Phantom
  - 3,911,611 tissue voxels
  - Voxel volume 0.0156 cm³ or ~ 16 mg
  - Each voxel assigned 1 byte ID
  - 89 tissues/contents identified
  - 22.1 Mbyte data file
Reference Female Phantom
Limitations of Methodology

- Some tissues not reference values
  - Extrathoracic airways
  - Skin
  - Gall bladder wall
  - Major blood vessels
  - Bronchi
  - Adipose tissue

- Limited by resolution
Development in Final Stages

- Add identification of left-right organ pairs
- Further work on skeleton
- ICRP Committee 1 tissues at risk
  - Tissues of remainder
- Input from ongoing reviewers
- Prepare ICRP Publication
  - Computational phantoms on CD
Reference Adult Male and Female