

A MALE RADIATION WORKER MODEL DEVELOPED FROM TRANSVERSE COLOR IMAGES OF THE VISIBLE HUMAN PROJECT

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Simulation of human responses to environmental stimulus (such as ionizing radiation) must use well-defined whole-body anatomical models. The computational procedures involve careful specification of the human anatomy and the exposure scenarios. Radiation transport and energy deposition in organs of interest are taken care of by a Monte Carlo code. Early anatomical models for radiation protection purposes involved simple equations. Recently, 3D CT and MRI medical images, are used to develop models, although whole-body images are difficult to obtain.

We have developed an adult male whole-body model, called VIP-Man, using transverse color photographic images from National Library of Medicine's Visible Human Project (VHP) in the United States [1]. Figure 1 shows the original Visible Male data set consisting of MRI, CT and color anatomical photographs.

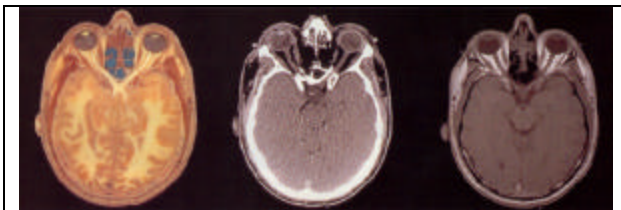


Fig. 1. Images from the Visible Human Project: (Left) Transverse color photography at 2048 x 1216 pixel resolution; (Middle) CT images at 512 x 512 pixel resolution; and (Right) Magnetic Resonance Imaging at 256 x 256 pixel resolution.

The transverse anatomical photographs for both male and female cadavers are 2048 pixels by 1216 pixels where each pixel is defined by 24 bits of color. The anatomical photographs are at 1-mm thick slices for the male cadaver and 0.33-mm for the female. These color photographic data set for whole-body has a voxel size of 0.33 mm x 0.33 mm x 1 mm for the male (0.33 mm x 0.33 mm x 0.33 mm for the female). Unlike earlier mathematical whole-body models, an image-based model contains a huge number of tiny cubes grouped to represent each

anatomical structure. This kind of new models is termed voxel or tomographic models.

There were three steps in constructing VIP-Man: 1) Identify and segment the organs or tissues from the original images; 2) Assign physical properties to organs or tissues; and 3) Implement the anatomical data into a Monte Carlo code (for ionizing radiation simulations).

1. The original color photographs for the Visible Man had been identified and segmented to yield up to more than 1400 structures [6]. Organs or tissues adopted to construct VIP-Man include adrenals, bladder, esophagus, gall bladder, stomach mucosa, heart muscle, kidneys, large intestine, liver, lungs, pancreas, prostate, skeletal components, skin, small intestine, spleen, stomach, testes, thymus, thyroid, etc. Automatic and manual imaging processing and segmentation were performed to obtain additional radiosensitive organs: gray matter, white matter, teeth, skull CSF, stomach mucosa, male breast, eye lenses, and red bone marrow. Figure 2 shows the segmented whole-body images and 3-D distribution of the red bone marrow.

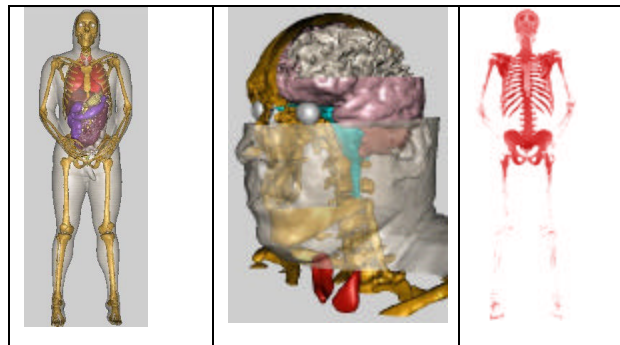


Fig. 2. VIP-Man in 3-d views showing: (Left) whole-body skin and skeletal structure, (Middle) details of the head and brain containing skull in gold, white matter in white, gray matter in gray, nerve in blue, spinal cord in gold, thyroid in red, and skin in white, and (Right) the red bone marrow distribution.

2. For biomedical engineering simulations, organs or tissues of interest have to be related to appropriate

physical properties. In radiation protection dosimetry, the average tissue compositions and densities recommended in ICRP 23 were used to tag each voxel in VIP-Man [4]. This step allows the radiation interaction cross section library in a Monte Carlo code to be linked to each voxel for radiation transport simulations.

1. Computers have limited amount of random accessible memory (RAM). Although today's technologies are much more advanced than a few year ago, the maximum "useable" RAM for a typical PC is often less than 2 GB, seemingly less than the size of VIP-Man containing a total of about 3.7 billion voxels and additional coding. A significant amount of effort was required to reduce the memory burden by using an innovative look-up table (LUT) algorithm. The LUT algorithm was successfully implemented in EGS4 code [9], allowing the computer to store only key anatomical and physical data; the details are unfolded from specific tables when needed. The memory saving with the LUT algorithm in VIP-Man/EGS4 is about a factor of 20. On a 450-MHz Pentium II PC of 512-MB RAM, VIP-Man/EGS4 can be run at the original 0.33 mm x 0.33 mm x 1 mm voxel size. This makes VIP-Man/EGS4 the finest model ever developed for Monte Carlo calculations. MCNP code and MCNPX code [2,3], on the other hand, were designed to be general-purpose codes, therefore, their default code options had to be changed to optimize memory. These improvements, however, were not enough, and as a result, the voxel size of VIP-Man/MCNP/X had to be compromised to 4 mm x 4 mm x 4 mm (or about 6-million voxels for the whole body) in order to run it on the same PC. VIP-Man has been applied extensively in health physics dosimetry [7-12].

In summary, an adult male whole-body model, VIP-Man, has been constructed from the VHP color photographic images. VIP-Man has been adopted into the state-of-the-art Monte Carlo codes, EGS4, MCNP, and MCNPX for radiation transport studies and organ dose calculations involving photons, electrons, neutron, and protons. To date, VIP-Man represents the world's finest and most complete human anatomical model, containing small tissues, such as skin, GI track mucosa, eye lenses, and red bone marrow, which were not (or not as realistically) represented in the MIRD-based mathematical models and other image-based models. This is also the first time that an image-based whole-body model was adopted for Monte Carlo calculations involving electrons, neutrons and protons. These advances are significant in that we now are able to investigate subtle dose variations in relatively small structures from various charged particles. The new capability in multiple particle transport not only provides needed health physics dosimetric data but also opens doors for applications in radiotherapy.

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