Hybrid Phantom Applications to Nuclear Medicine

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Abstract

Annually, many people are irradiated for diagnostic and therapeutic purposes. Assessment of radiation dose and its related risks to patients are important issues in radiation protection dosimetry. The complex mathematical calculations of the absorbed and effective doses are now done with computers. The calculations are performed with the help of anthropomorphic computational models of human body called phantoms and Monte Carlo codes (MCNP). There are various types of phantoms, yet the latest type is hybrid phantom which has been introduced to the scientific community in recent years. Hybrid phantom is the connection between mathematical and voxel phantoms. They retain both the anatomic realism of voxel phantoms and the flexibility of mathematical phantoms. Using hybrid phantoms, the absorbed doses can be determined for any patients before they are exposed to radiation. Then, the energy of the emitted particles and irradiation geometry can be determined for any special purposes. A hybrid phantom is under construction for Iranian patients to be used in different applications such as testing new radiopharmaceuticals or cancer treatments with high LET radiation. Herein, we report on our findings.

Keywords

Computational phantoms; Hybrid phantoms; Dosimetry; Nuclear medicine

Introduction

Anthropomorphic computational phantoms are computer models of the human body. These phantoms are extensively used in the evaluation of dose distributions resulting from either internal or external radiation sources. Currently, two classes of computational phantoms are widely used for the organ dose assessments: mathematical phantoms, which describe the human anatomy via mathematical surface equations such as ORNL models, and voxel phantoms that are based on segmented images such as those from MR and CT images. The advantage of mathematical phantoms is their flexibility in size, shape and position of organs. Voxel phantoms, on the other hand, provide much better anatomical realism in comparison with simpler stylized phantoms. However, they are limited in defining organs presented with low contrast in MR or CT images (Fig. 1). Researcher have reported clear differences in dosimetry results directly attributed to the differences in body shape as well as the organ size, depth and position [1, 2]. So, voxel phantoms with much better anatomical realism are superior to stylized phantoms for dosimetry calculations. Nonetheless, voxel phantoms have the following limitations: surface contours of organs and tissues in voxel phantoms are primarily dependent on manual image segmenta-

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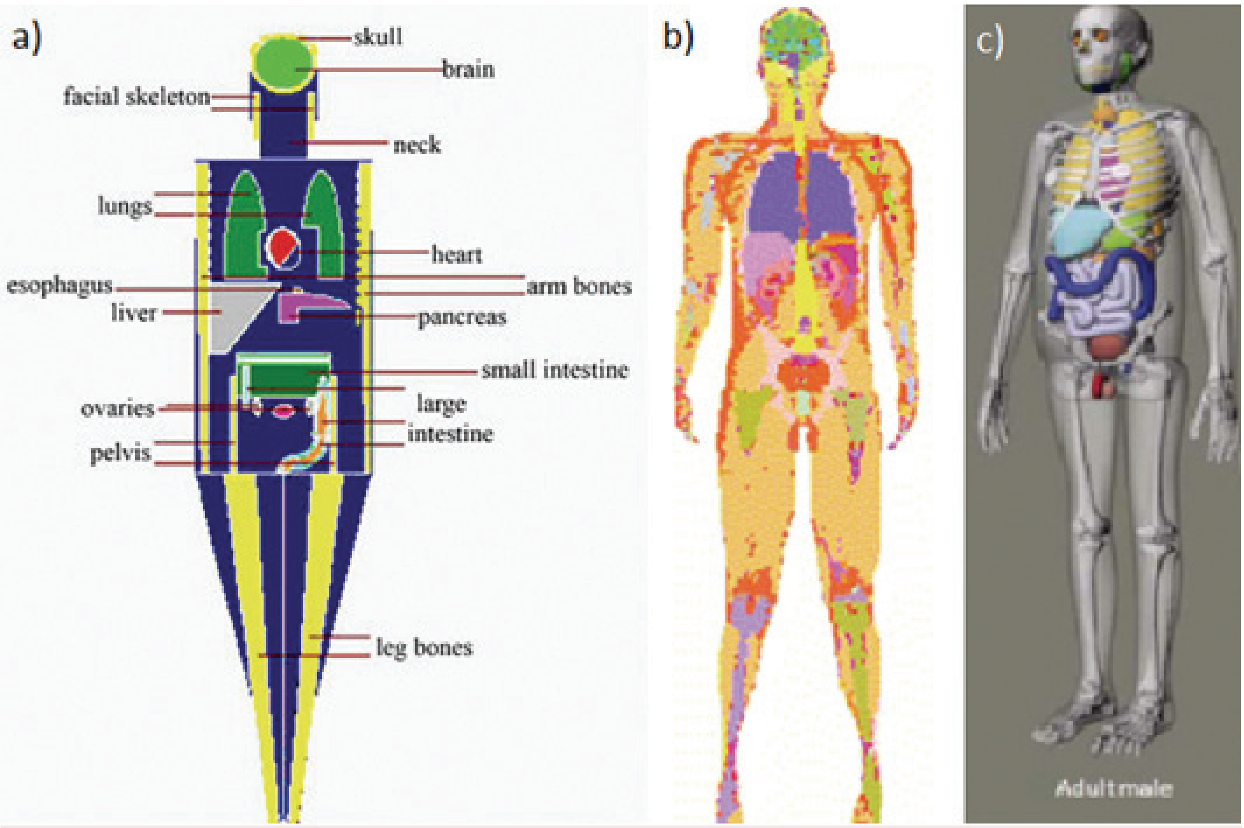

Figure 1: a) ORNL modified mathematical adult phantom [3], b) MAX-voxel phantom [4], and c) perspective view of the reference hybrid phantom [5].

tion. Some organs and tissues cannot easily be recognized even by experienced radiologists due to the limitations in image contrast. The walls and lumen of the alimentary tract are especially difficult to segment in typical CT images [6]. Furthermore, high resolution medical images are generally difficult to obtain [7]. In order to improve the resolution of images, long time scanning should be applied that is difficult for imaging of moving organs.

Investigators have sought new methods for anatomical modeling that provide and preserve both of these important features—the hybrid phantoms. They retain both the anatomic realism of voxel phantoms and the flexibility of stylized phantoms.

A hybrid phantom is under construction for Iranian patients to be used in different applications such as testing new radiopharmaceuticals or cancer treatments with high LET radiation. Herein, we report on our findings.

Construction of Phantoms

Construction of a hybrid phantom is performed in four steps: transforming 2D images of human body to 3D polygon mesh model of exterior body and internal organs; creating NURBS surfaces; voxelization of NURBS surfaces; and preparing the MCNP input file to simulate the creation and transportation of emitting particles through these boundary representation (BREP) structures. 3D-DOCTOR™ (Able Software Corp., Lexington, MA, USA) provides 3D-Models from CT, MR, and other types of images (Fig. 2). The software extracts object boundaries and creating both 3D surface and volume rendering for visualization. Surface rendering tool creates polygon-based 3D surface models from defined object boundaries. Rhinoceros™ (McNeel North America, Seattle, WA, USA) is a NURBS modeling software which can be used for 3D-modeling (Fig. 3). It uses non-uniform rational B-spline (NURBS) surface to construct 3D

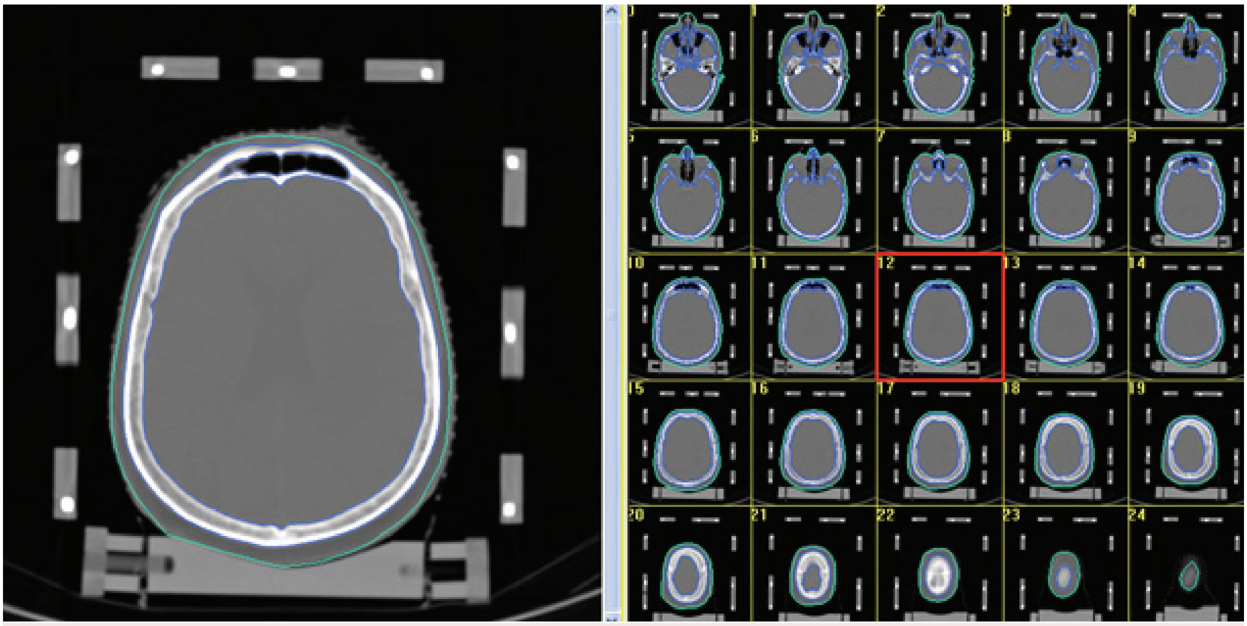

Figure 2: 3D-DOCTOR interface

surface models. Polygon mesh surfaces should be converting to NURBS surfaces. It could be done by extracting contours and then lofting them to make a surface. One may exports the final NURBS model with wavefront file format (*.Obj). This Obj file then voxelizes with special voxelization packages such as binvox software. The voxelized data will then be prepared as an MCNP input file with scanning to MCNP program.

Why Hybrid?

Like voxel phantoms, hybrid phantoms are based on CT or MR images. However, voxel phantoms, which are based originally on the unique anatomy of the subject imaged, are somewhat inflexible in regard to changing. In one approach to hybrid phantom construction, the 3D surface equations used to define organ boundaries are replaced with nonuniform rational B-spline (NURBS) [8]. This surface geometry with NURBS control points provides flexibility for the whole model and each organ individually. The flexibility, *i.e.*, the possibility of changing size, shape and position of organs, does have the following advantages: i) it makes the model flexible in regard to changing that anatomy represents a reference individually that differs substantially in body morphometry (such as ICRP reference MAN). Radiation dose estimates based on the hybrid model with ICRP reference MAN properties could then be compared with other calculations of the same type; ii) it is possible to es-

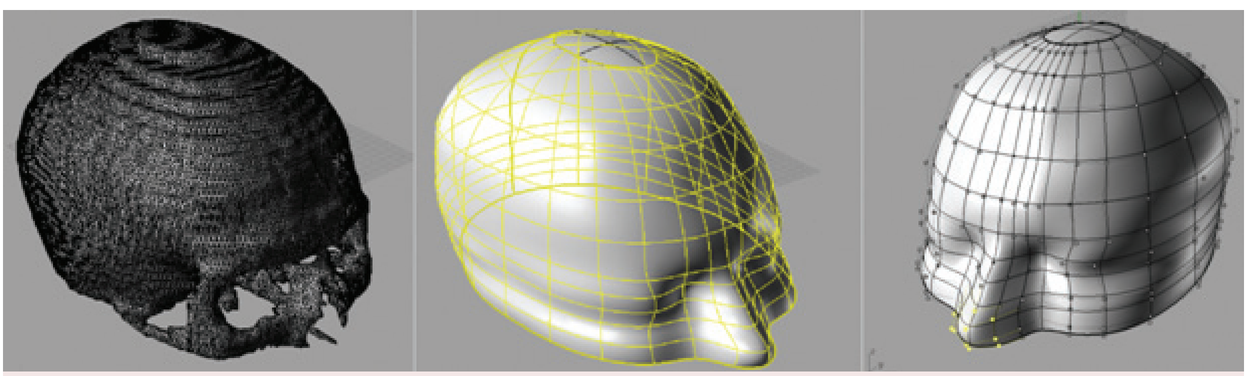

Figure 3: Mesh model of the skull and NURBS model of head constructed from CT images

tablish a virtual population in different weight and height percentile as a consequence of mentioned flexibility. This approach is called "patient-dependent" in dosimetry terminology; iii) NURBS control points make it conceivable to simulate the organ motions such as heart, lungs and intestines. This excellence is utilized in constructing NCAT and XCAT. So, heart and respiratory motions can be simulated with this technique in 4D phantoms.

Nuclear Medicine Applications

Internal dose calculations for diagnostic and therapeutic applications in nuclear medicine are currently based on standardized computational phantoms for reference adults, children, and pregnant women [9]. These phantoms may be used to develop more truly patient-dependent dosimetry. Absorbed dose—the amount of energy from ionizing radiation that is absorbed per unit of mass of any material—is usually calculated to evaluate the benefits and risks of a new radiopharmaceutical.

External dose calculations for therapeutic purposes could be done for a patient-individualized computational phantom for each patient. The absorbed dose can be evaluated for any specific patient before the individual subjected to radiation exposure by using hybrid phantoms. Then, the energy of the emitted particles and irradiation geometry can be determined for any special purposes.

Currently, the interest in studying nonionizing radiation effects is steadily increasing due to abundant uses of various nonionizing radiation emitting devices [9]. The hybrid model geometry with electromagnetic and thermal properties of tissues can be used for nonionizing radiation dosimetry for radiofrequency-based devices that are usually placed in the vicinity of the body.

Results

NURBS is a mathematical modeling technique, widely used in 3D computer graphics. When CT scans are obtained for voxel phantom, the subject is in a supine position with arms at the side. In some occupational exposure cases, it is necessary to evaluate the dose with the arms and legs in different positions. It will be very difficult and inefficient to simulate these exposure geometries. This ability exists in hybrid models.

By using a hybrid model, the number of voxels will be reduced by 40% of the original number (reduced by a factor of two or more) subsequently, and the computational time and memory will be reduced by almost 50% [10]. By constructing hybrid phantoms, we took advantages of both mathematical and voxel phantoms. The advantage of hybrid phantoms is their flexibility with respect to alterations in body contour shape and thickness. We should transform this phantom to voxel for applying Monte Carlo codes (MCNP).

Conclusion

Hybrid phantom can be used for any size of human body because the size of organs is changeable. This pliability is the effect of NURBS control points, which is the most important advantage of hybrid phantoms. Internal and external dose calculations for diagnostic and therapeutic applications could be performed for each patient using these patient-dependent hybrid phantoms, in which the base hybrid phantom may be modified using the patient values of body parameters and mass. The absorbed dose is usually calculated to evaluate the benefits and risks of a new radiopharmaceutical. When we acquire knowledge about the amount of received doses by the body, we will be able to find the new methods for decreasing of the absorbed dose. By using hybrid phantoms, the absorbed dose can be evaluated for any specific patients before they are exposed to radiation. Then, the energy of the emitted particles and irradiation geometry can be determined for any special purposes. Along with other countries, we are constructing hybrid phantoms for Iranian patients to be used in different applications such as testing new radiopharmaceuticals or cancer treatments with high LET radiation.

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