Detailed breast models for ICRP adult female mesh-type reference computational phantom

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1. Introduction

The International Commission on Radiological Protection (ICRP) recently released new mesh-type reference computational phantoms (MRCPs) for adult male and female [1] by converting the ICRP voxel-type reference computational phantoms (VRCPs) in ICRP *Publication 110* into the high-quality mesh format [2], overcoming the limitations of the VRCPs due to the limited voxel resolution. In the MRCPs, for example, the breast is fully covered by the skin, which is not the case for the VRCPs, thereby significantly improving the breast dosimetry for weakly penetrating radiations [3]. Despite the improvement, the current breast model of the MRCPs still defines the adipose and glandular tissues only macroscopically. In the present study, to improve the accuracy of breast dosimetry, voxel-based detailed breast models comprising adipose tissue, fibroglandular tissue, and Cooper's ligament were constructed and installed in the adult female MRCP. Then, the doses to glandular tissue were calculated and compared with those of the original breast of the female MRCP.

2. Materials and Methods

The detailed breast models were first constructed by using the OpenVCT program of University of Pennsylvania [4]. The constructed breast models were in voxel format with 200 μm isotropic spatial resolution, comprising adipose tissue, fibroglandular tissue, and Cooper's ligament. Then, the constructed models were modified to match the outer surfaces of the breasts of the breasts the adult female MRCP with the Shepard-based interpolation morphing algorithm [5].

The developed models were then installed in the mesh-based adult female MRCP by using the parallel geometry feature of the Geant4 Monte Carlo radiation transport code [6]. Note that due to the different geometries (i.e. stair-stepped organ surface of the voxel phantom vs. smooth surface of the mesh phantom), there are overlaps between the breast models and the adult female MRCP at the border. In Geant4, the geometries are generally defined in the mass geometry (= default world). In addition to the mass geometry, the geometries can be placed in the parallel geometry that can overlay the pre-defined geometries in the mass geometry. By using this feature, the detailed models and the adult female MRCP were implemented in the mass and parallel geometry, respectively, so that the smooth surface could be remained at the border between the voxel and mesh.

3. Results and Discussion

Figure 1 shows the detailed breast model constructed from the OpenVCT program, the original breast of the adult female MRCP, and the modified detailed breast model, for the right breast as an example. As shown in figure 1, after applying the Shepard-based interpolation morphing algorithm, the detailed breast model with two ellipsoid surfaces is naturally modified to match the outer surface of the breast model of the adult female MRCP.

Figure 2 shows the glandular tissue-averaged absorbed doses calculated using the detailed breast model and the original breast model of the adult female MRCP, for external exposure to broad parallel photon beams (0.01–10,000 MeV) in the antero-posterior (AP) irradiation geometry. At low energies (< 50 keV), the detailed breast model shows larger dose values than the original model. The differences increase as energy decreases, and the

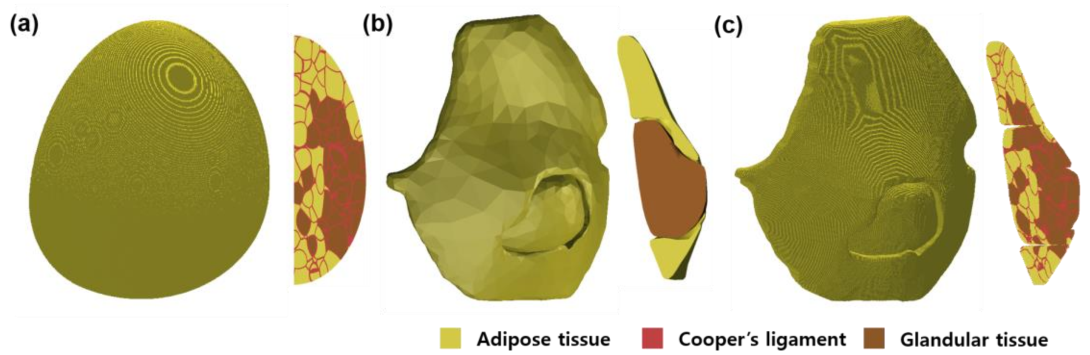

Figure 1. Outer surfaces of (a) detailed breast model constructed from OpenVCT program, (b) the original breast model of adult female MRCP, and (c) modified detailed breast model and their cross-section at the center.

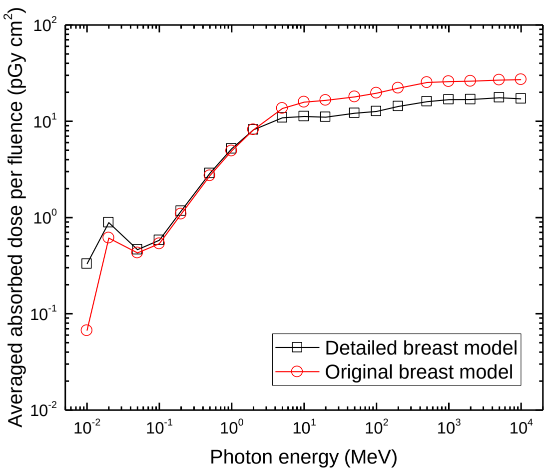

Figure 2. Glandular tissue averaged absorbed dose per fluence calculated by using detailed breast model and original breast model of adult female MRCP for external exposures to photons in antero-posterior geometry.

maximum difference is as large as a factor of ~5 at 0.01 MeV. This difference is mainly due to the fact that for the detailed breast model, compared to the original breast model, the glandular tissue is located near the nipple and the glandular tissue is widely distributed when viewed from the front. At the energies between 50 keV and 5 MeV, the doses between two models are in good agreement, differences being less than ~10%. At energies >5 MeV, on the other hand, the detailed breast model shows smaller dose values than the original model, the maximum difference being 60% at 10 GeV. This is due to the increased depth of the dose build-up region for high energy photons.

4. Conclusion

In the present study, the detailed breast models comprising adipose tissue, fibroglandular tissue, and Cooper's ligament were constructed and installed in the adult female MRCP. Then, the glandular tissue-averaged absorbed doses were calculated using the detailed model and then compared with those of the original breasts of the adult female MRCP. The results show that the detailed breast models produce significantly larger dose values (i.e., as large as a factor of ~5 at 0.01 MeV) than the original breast model. In the future, a set of detailed breast models representing different breast sizes and glandular tissue masses will be constructed for use in breast dosimetry.

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