Evaluation of the dose calculation in a commercial planning system for a breast cancer brachytherapy technology using Monte Carlo simulation

Tissue uniformity is an important issue in brachytherapy considering current planning protocols. This is especially true for the SAVI device, which unlike other breast brachytherapy devices, has a cavity filled with air rather than water. Even small air bubbles in balloon brachytherapy can increase dose by up to 6\% within the first centimeter outside the surface of the balloon [1]. For the SAVI device itself it has been shown that for a single source in the center of the device dose can be up to 9\% higher at 1 cm away from the air-water boundary [2]. This presentation will detail our work on comparing the results of the MC simulation with those of the TPS with special emphasis on setting up and validating the simulation.

This study compares the dose distribution calculated by the BrachyVision treatment planning system (TPS) using the AAPM TG-43 protocol with the dose calculated by the PENELOPE Monte Carlo (MC) code [3] using heterogeneous materials (tissue, air, bone and Nitinol) as opposed to water as the medium for dose calculation. It is especially useful for analyzing effect of inhomogeneity on treatment planning.

Data from TPS plans for 21 patients were used including CT images, structures and source information. CT images were imported into the PENELOPE code as voxel files where the density was determined by calibrated Hounsfield units and the material was determined by the contoured structures from the treatment plan. Materials used include tissue, air, bone and Nitinol which were the materials distinguishable by the given range of energies. The source used was the VariSource 192Ir with gamma and fluorescence x-rays from the NuDat [4] database. Photons with intensity less than 0.1\% and x-rays with energies below 10 keV were omitted as transmission of these through the 0.0125 cm Nitinol capsule would be negligible. The source model was created as a quadric structure consisting of a 10 mm long cylindrical capsule with semispherical ends and a diameter of 0.34 mm encased in wire 0.59 mm diameter also with a semispherical end. The wire extends 1 mm beyond the active core and 150 cm in the other direction (although only 1 cm is used in the simulation). Source positions with orientations were extracted from the original plan and each was treated as a separate simulation. These simulations were run on the Trestles cluster at the San Diego Super Computer center with each source position run simultaneously on its own processors and then summed up weighted according to the dwell time.

In order to validate the accuracy of the simulation, a MC simulation of single source in water was compared to both to a TPS simulation of a single source in water and to results from a prior publication [2] of a single source in both water and water with an air cavity both using MC and ion chamber data. For comparison of the single source in water done via MC and TPS, a 30x30x30 cm water phantom was used with voxel size was 0.6x0.6x0.6 mm. 2.3x10^9 histories were run and the results were compared with corresponding TPS results as seen in figure 1. For comparison with MC and ion chamber data a phantom was created to simulate a ten-strut device containing an air cavity in a cylindrical water phantom 40 cm tall with a radius of 20 cm. Voxel size was 2x2x2 mm and approximately 1.7x10^9 histories were run for each simulation. The simulation was run with and without the air cavity, and results can be seen in figure 2.
Dose from the Monte Carlo plan was compared with dose from the original plan using isodose lines at 50, 100, 150 and 200% of the prescription dose of 34 Gy as seen in figure 3. Dosimetric coverage of the target was also compared by evaluating the V150 and V200 (volume of the target covered by 150 and 200% of the dose respectively) and the V100 (percent of the target covered by 100% of the dose). The V150 and V200 had an average increase (and standard deviation) of 3.8% (1.4%) and 9.1% (3.2%) respectively, while the average change in V100 was 1.2% (1.0%). Although on average 2*10^10 histories were run for each full simulation in relatively small voxels, the variance was 0.9% which, while acceptable for most MC, introduces relatively large variations when comparisons, ratios or absolute differences are computed.

References: