Contribution ID: **3**

Type: **ORAL**

Analysis of the bias induced by the voxel and unstructured mesh Monte Carlo models with the MCNP6 code

Tuesday 29 May 2018 17:15 (20 minutes)

The use of Monte Carlo methods for the set up of treatment planning systems (TPS) in radiotherapy applications is a current standard. The most advanced modeling techniques aim to directly link the output of CT scans to the patient specific model build up instead of standard phantoms and look up tables. This phase represents a critical step since even the most accurate segmentation and organ volume definition must be translated into a suitable input for the Monte Carlo code. During that step usually the segmented volume is mapped on a regular geometrical lattice (cubic voxels). A more sophisticated option appears to be a volume description based on unstructured mesh (UM) typical of current finite element codes. In this paper we compared the two approaches analyzing the bias induced by the different choices.
Starting from anonymous patient DICOM files coming from the CT scans, suitable segmentation and volume definition have been carried out and voxelized and UM based equivalent models for the Monte Carlo code MCNP6 have been built. The various computational phantoms, covering some significant portion of the human body (head, lower limb) have been used as a benchmark of the dose distribution obtained from X-Ray sources commonly used in radiotherapy applications. Experimental measurements on phantom slabs irradiated by an X-Ray tube were carried out preliminarily as validation of the simulated radiation source. As shown in the results, the UM computational phantoms (built through the Simpleware SCAN-IPTM tool) can reduce the bias induced by the regularity of the classical cubic voxel geometry, gives a more accurate description of the volume and complex surfaces and, thanks to an optimized discretization of the volumes, are also able to reduce the computational work.
For the same UM models, various comparisons with different voxel sizes have been produced to investigate the dose distributions and evaluate the relation between voxel effects and voxel edge lengths. The comparison shows a convergence pattern of the voxel model to the UM one. It is possible to see that the most significant bias occurs where the dose gradient is higher, along the beam borders and at tissue interfaces. These simulations showed that the UM can be used reliably to compute the dose distributions within computational anthropomorphous phantoms obtained from CT scans.
The comparison between voxel and UM models for the MCNP6 code has been performed with particular reference to the bias induced by the two approaches when building the patient's computational phantom. The results have shown how the voxel model highlights the border field effects with respect to the UM that can handle in a more refined way complex radiation fields and geometries. In conclusion the application of UM in Monte Carlo methods can provide models which represent accurately the complex surfaces of human structures, with significant benefits over voxel models.

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Session Classification: Scientific / Education

Track Classification: Scientific / Education