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Comparative study of dose calculations with SERA and JCDS treatment planning systems

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ABSTRACT

Three treatment planning systems developed for clinical boron neutron capture therapy (BNCT) use are SERA developed by INL/Montana State University, NCTPlan developed by the Harvard–MIT and the CNEA group and JAEA computational dosimetry system (JCDS) developed by Japan Atomic Energy Agency (JAEA) in Japan. Previously, performance of the SERA and NCTPlan has been compared in various studies. In this preliminary study, the dose calculations performed with SERA and JCDS systems were compared in single brain cancer patient case with the FiR 1 epithermal neutron beam. A two-field brain cancer treatment plan was performed with the both codes. The dose components to normal brain, tumor and planning target volume (PTV) were calculated and compared in case of one radiation field and combined two fields. The depth dose distributions and the maximum doses in regions of interest were compared. Calculations with the treatment planning systems for the thermal neutron induced (^{10}B and nitrogen) dose components and photon dose were in good agreement. Higher discrepancy in the fast neutron dose calculations was found. In case of combined two-field treatment plan, overall discrepancy of the maximum weighted dose was ~3% for normal brain and PTV and ~4% for tumor dose.

1. Introduction

The performance of MacNCTPlan (Zamenhof et al., 1996) and BNCT_rtpe treatment planning systems (Nigg et al., 1997) have been compared in a phantom study by Goorley et al. (2002) and Wojnecki and Green (2002) performed a comparison between MacNCTPlan and SERA systems (Nigg et al., 1999, Nigg, 2003) (recent version of the BNCT_rtpe) in the phantom geometries. Most recently, Casal et al. (2004) compared the calculations performed with the updated version of MacNCTPlan, NCTPlan (González et al., 2005), and SERA to the measurements in a phantom at the RA-6 reactor facility. Boron neutron capture therapy (BNCT) treatment planning system JAEA computational dosimetry system (JCDS) is developed and have been in clinical use at Japan Atomic Energy Agency (JAEA) (Kumada et al., 2004). The calculations with JCDS have been compared to measurements and to the calculations with a general Monte Carlo *n*-particle code MCNP (Briesmeister, 2000). To date JCDS has not been compared to other BNCT treatment planning systems.

The JCDS and NCTPlan systems use MCNP code as a computational tool. MCNP uses pointwise continuous-energy cross-section libraries, whereas SERA system uses multigroup neutron and photon cross-sections. Another notable difference between the codes is that SERA produces a patient model using pixel-by-pixel uniform volume element ('univel') reconstruction method, while JCDS and NCTPlan use the voxel reconstruction method for patient modelling. In the latest version of JCDS, MCNP5 is used with the mesh tally option, which has enabled more accurate calculations, since the voxel size in a patient model can be scaled down without increasing the simulation time dramatically (Kumada et al., 2006). In this study, the treatment planning calculations with SERA and JCDS programs are compared in a clinical BCNT case using the FiR 1 epithermal beam.

2. Materials and methods

The dose calculations with JCDS and SERA treatment planning systems were performed for one brain cancer patient using the FiR

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1 epithermal neutron beam following the Finnish treatment planning protocol of BPA-mediated BNCT for the recurrent brain tumors (Protocol FIN-BNCT-03, www.clinicaltrials.gov) (Joensuu et al., 2003). The 3D patient model in SERA was created using 48 T1 weighted MR image slices of the patient imaged from the top of the head to the neck, with pixel size of 1 mm and slice thickness of 5 mm. The skin, brain, cranium, sinuses, tumor, edema and planning target volume ('PTV', including tumor, edema and marginal of about 2 cm) were segmented in the patient model and the tissue material compositions were defined according to ICRU Report 46 (ICRU, 1992). The 'univel' patient model created by SERA was converted into grayscale images in order to reconstruct the same model with JCDS. In SERA calculations, the default size ($1\,cm^3$) voxel was used in the simulation edit mesh. The JCDS patient model was created with the $2\,mm \times 2\,mm \times 2\,mm$ voxels and the element size of $5\,mm \times 5\,mm \times 5\,mm$ was applied in the edit mesh.

Two circular (∅14 cm) (anterior and posterior to the patient) neutron fields were used in the treatment planning (Fig. 1). In the dose calculations, the weighting factors were obtained from the Brookhaven clinical trials (Chanana et al., 1999): 3.2 for hydrogen and nitrogen dose of Brook's brain material composition (corresponding to 3.16 for hydrogen and 2.68 for nitrogen in the ICRU brain material), 1.3 for ^{10}B in brain and 3.8 for ^{10}B in tumor. The ^{10}B concentration of 19 μg/g in brain and 66.5 μg/g in tumor was used. "Exactly the same FiR1 neutron beam model (Seren et al., 1999; Seppala, 2002) derived from DORT (Rhoades and Childs, 1988) discrete ordinates calculations was used in both SERA and JCDS calculations. Only proton recoil reaction induced 'hydrogen dose' was included in the fast neutron dose calculations with the both codes. In SERA calculations, a neutron calculation of 50 million simulation particles was performed following by a biased fast neutron calculation and gamma calculation (including beam photons and neutron induced gammas). About 100 million simulation particles were used in the JCDS calculations. All the results are normalized by the Au reaction rate measurement at the thermal neutron flux maximum (2 cm) depth in PMMA phantom. Slightly different normalization factors were obtained for SERA and JCDS (0.94 and 0.96, respectively). For optimal treatment plan of the combined fields, irradiation time of the left anterior oblique (LAO) and left posterior oblique (LPO) field was weighted 65:35, respectively. The calculation results were compared in case of one single radiation field (the LAO field, 'field 1') and combined fields.

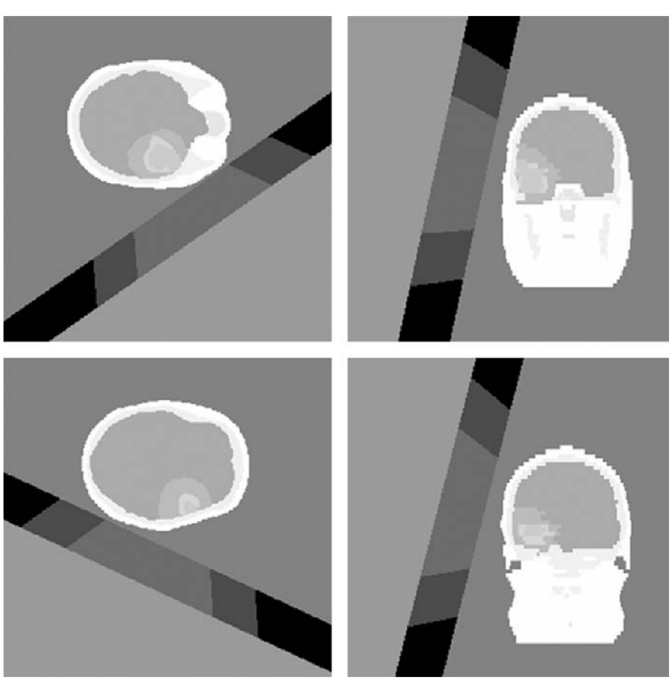

Fig. 1. The beam orientations used in the treatment planning calculations: for field 1 upper and for field 2 lower axial and coronal image slices.

3. Results and discussion

The depth profile along the beam centerline in the patient calculated with the both codes for the AOL field 1 are shown in Fig. 2 for nitrogen dose, Fig. 3 for fast neutron dose, Fig. 4 for photon dose and Fig. 5 for thermal neutron fluence. The peak evident in the depth dose curve at depths of about 1–2 cm in Figs. 2 and 3 is due to fact that the dose is calculated for ICRU skeleton cranium (5.0 wt% hydrogen and 4 wt% of nitrogen) at the location of skull in the patient model. Elsewhere the dose is calculated for ICRU brain (10.7 wt% of hydrogen and 2.2 wt% of nitrogen) at every point, also in the skin region, regardless of the real material in the patient model.

Difference between the JCDS and SERA calculation results for two combined neutron fields in regions of interest (brain, PTV and

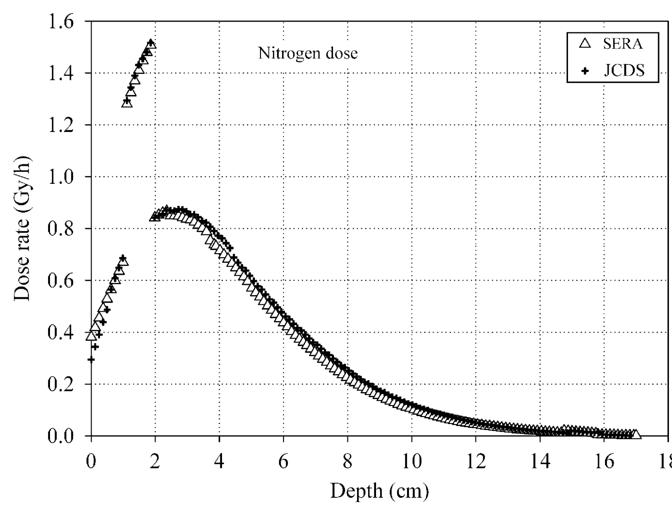

Fig. 2. Weighted nitrogen dose rate for anterior field 1 in the patient along the neutron beam (∅ 14 cm) axis calculated with SERA and JCDS.

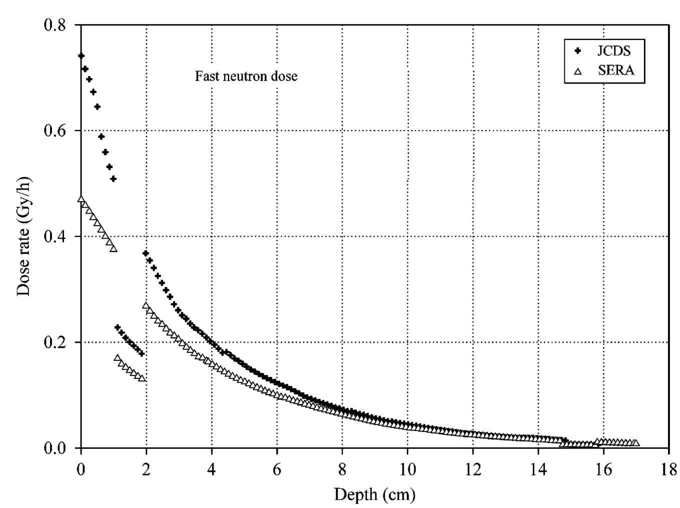

Fig. 3. Weighted fast neutron (proton recoil) dose rate for anterior field 1 in the patient along the neutron beam (∅ 14 cm) axis calculated with SERA and JCDS.