Basic study of dose calculation error caused by internal heterogeneity for proton beam therapy

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1. Introduction

Pencil beam algorithms (PB) are adopted in the treatment planning system (TPS) for proton spot scanning to enable performing dose calculation in short time and with reasonable accuracy. Dose distributions are obtained by the superposition of Gaussian distributions which mean proton spot fluence. The accuracy of PB may deteriorate in the downstream area of heterogeneous regions[1], so that we evaluate the difference between the result from PB and that of Monte Carlo simulation (MC).

2. Materials and Methods

First, we compared characteristics of the dose irradiated by single spot calculated by using PB and MC. We used in-house program with PB in which the proton spot fluence is approximated by double Gaussian distribution and Geant4-based MC, PTSim[2], tuned with our measurement data. Figure 1 (a) shows a geometry Ⅰ which consists of a high or low density slab in water. The proton beam passes through the surface of the slab placed between 20 mm and 30 mm depth. Proton beam energy is assumed as 70 MeV, 140 MeV and 220 MeV.

Secondly, we compared cubic dose distribution 30 mm on each side formed by multiple spots calculated by using PB and MC. In this case, dose calculation by using PB was performed with TPS, VQA (HITACHI). In comparison the isocenter depth dose for the cubic target between VQA and PTSim in homogeneous geometry, the agreement was within 2%. Here, two cases of geometry are assumed. One case is geometry Ⅰ which consists of high density slab and the cubic target whose proximal depth is 40 mm. Another case is geometry Ⅱ which consists of a high density slab between 40 mm and 140 mm depth and the cubic target whose proximal depth is 190 mm. The thickness and position of the slab in Fig. 1 (b) are decided using pelvis phantom CT images as reference. The slab density is assumed to be 1.5 times as much as water. Spot parameters such as beam energy, spot position and spot beam amount to form cubic dose distribution are optimized by VQA.

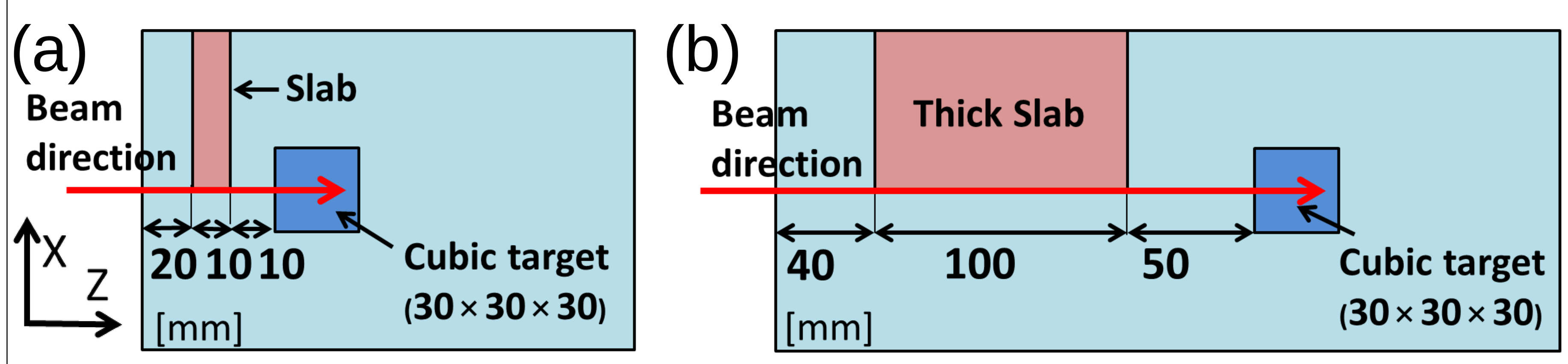

Fig.1 Schematic diagram of the calculation: (a) geometry Ⅰ with high or low density slab for single spot case, with high density slab for cubic target case and (b) geometry Ⅱ with high density slab with reference to pelvis phantom for cubic target case.

3. Results and Discussion

In the single spot case, calculated dose difference between PB and MC for geometry Ⅰ with high density slab is larger than with low density one and increases in inverse proportion to beam energy. In the case of incident proton with energy of 70 MeV, the largest difference occurred (Fig.2).

The peak of the lateral dose profile calculated by PB is lower than calculated by MC where large dose difference appeared at the depth of the Bragg peak and near the downstream surface of the slab. We found that dose distributions by single spot irradiation had similar tendency with that of multiple spots irradiation (Fig.3(a)). When beam pass through the surface of the thick slab, the dose difference was remarkable (Fig.3(b)).

As for MC, particles were transported in step-by-step processes. On the other hand, as for PB, a set of particles is approximated as Gaussian distribution. Therefore smaller target structure than the size of Gaussian distribution cannot be considered. These caused the dose difference between PB and MC.

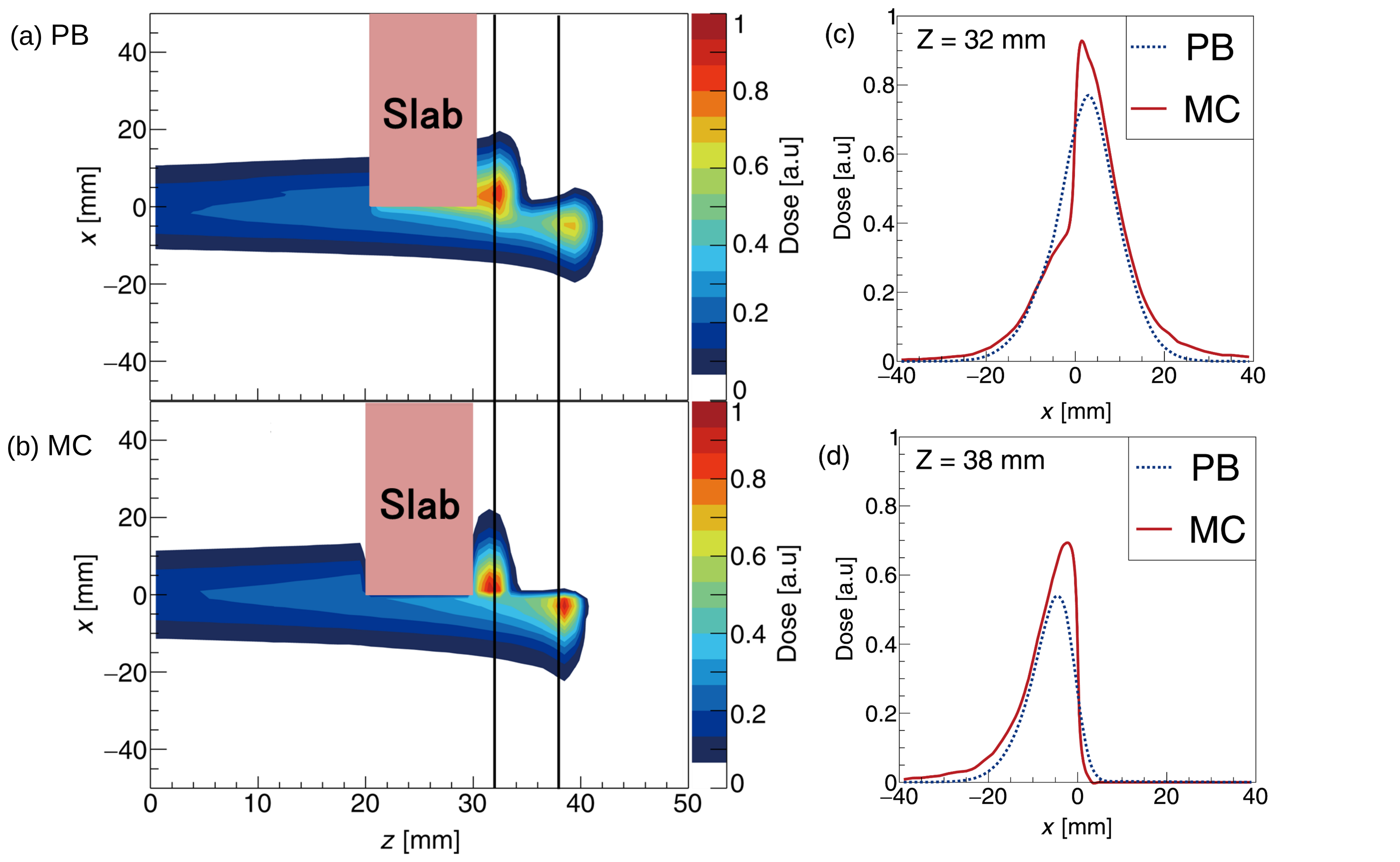

Fig. 2 The dose distributions of single spot irradiation with 70 MeV protons: (a) 2D dose image using PB, (b) 2D dose image using MC, (c) lateral dose profile at z = 32 mm and (d) lateral dose profile at z = 38 mm

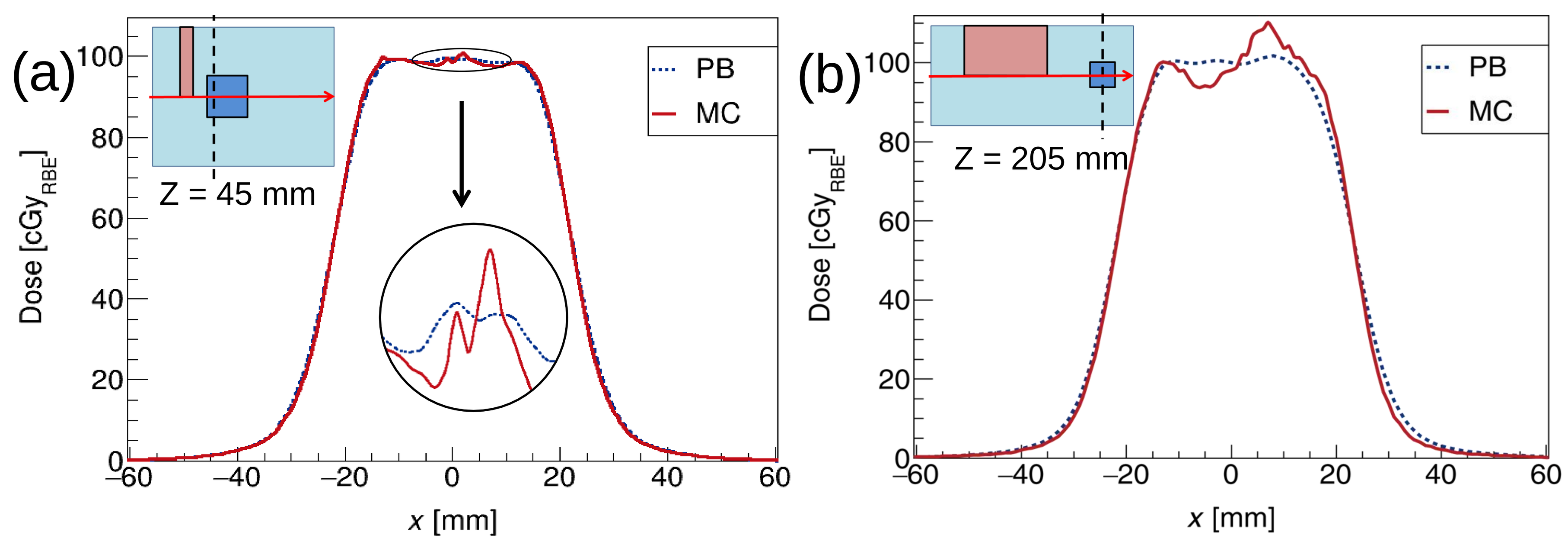

Fig. 3 The dose distributions of multiple spot irradiation using MC and PB: (a) lateral dose profile at z = 45 mm of geometry Ⅰ and (b) lateral dose profile at z = 205 mm of geometry Ⅱ.

4. Conclusions

We have investigated the dose difference between PB and MC in two cases of heterogeneous geometry. We found the dose differences tend to be large in downstream area of the boundary between two materials. Next step, we plan to make clear these effects of calculation algorithm in clinical case.

5. References

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[2] T. Akagi, et al.: The PTSim and TOPAS Projects, Bringing Geant4 to the Particle Therapy Clinic, Progress in NUCL SCI TECHNOL, Vol. 2, pp.912-917, Oct 2011.

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