Dosimetric Characterization of the Therapeutic Neutron Beams from Dual Beam Port Assembly for Accelerator-Based BNCT

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1. Introduction

The use of accelerator-based neutron source for boron neutron capture therapy (BNCT) has been treated as the subject of several research papers, since this approach offers a number of obvious advantages over the more traditional reactor sources. In particular, among various neutron sources based on accelerator, ^{7}Li(p,n)^{7}Be reaction is the most efficient method for adopting BNCT due to its high neutron yield with relatively low energy ranges[1].

To reduce the treatment time of BNCT, sufficient epithermal neutrons should be obtained by using the beam shaping assembly. Most of current studies of accelerator-based BNCT beams have been focused on a forward facing assembly in which the direction of extracted epithermal neutrons is parallel with the incoming proton beam. However, the forward facing assembly is only effective for proton beam with near threshold energy ($1.89 < E < 2$ MeV), since generated neutrons in the near threshold region are emitted into the solid angle range from 20 to 40^o with reference to the direction of incident proton beam[2].

In the previous study, a feasibility of dual beam port assembly has been researched with the focus on producing epithermal neutron beams and enhancing neutron economics[3]. On the basis of the feasibility study, performance of the assembly designed in this study has been estimated by MCNPX[4] simulation. In particular, dosimetric properties of beams generated from each side beam port have been evaluated by using a mathematical head phantom.

2. Materials and Methods

The neutron source was assumed to be produced from a 2.5 MeV proton beam with a 100 μm lithium target. By examining the characteristics of neutron source, it was found that the relatively low energy neutrons were emitted into the solid angle range between 50^o and 150^o to the direction of proton beam. Therefore, beam port was positioned perpendicularly to the direction of incident proton beam such that epithermal neutrons could be extracted efficiently. This assembly was composed of two moderators with a surrounding reflector as shown in Figure 1. Two moderator regions are respectively filled with Fluental^{TM} (ρ=2.9 g/cm^3) and heavy water (ρ=1.1056 g/cm^3), and reflector is made of graphite (ρ=1.85 g/cm^3).

The calculations of the dose distributions in tumor and normal tissues are required to evaluate the clinical efficiency of epithermal neutron beams for BNCT. Therefore, the mathematical head phantom proposed by Deutsch and Murray[5] was employed to represent the human brain as shown in Figure 2, and was positioned with epithermal neutrons entering from the sagittal direction. The phantom was also divided into the small cells (5×0.3×5 cm^3) along the central axis of neutron beam to analyze the contribution of various dose components (boron, neutron, and photon dose) as a function of depth. The ratio of ^{10}B concentration between tumor and normal tissue was assumed to be 4:1. In this study, ^{10}B was assumed to be concentrated in tumor of 40 ppm. RBE values of 3.8, 3.2, and 1.0 were applied to the ^{10}B reaction products, neutrons, and photons, respectively.

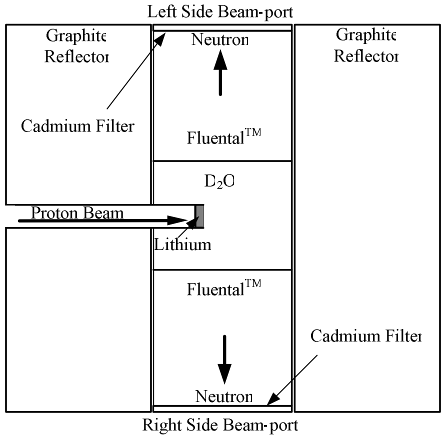

Fig. 1. Configuration of a Dual Beam Port Assembly to Produce Epithermal Neutrons

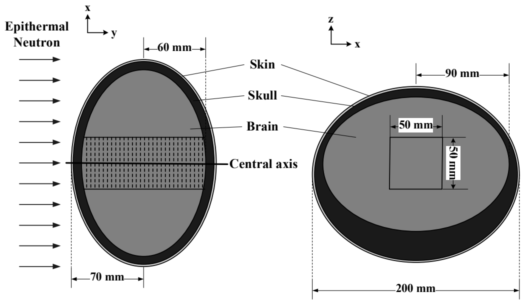

Fig. 2. Schematic Illustration of the Skin-Skull-Brain Mathematical Head Phantom

3. Results and Discussions

Simulated neutron flux distributions along the central axis of the ellipsoidal head phantom are shown in Figure 3 for the beams produced at each side beam port. It is found that epithermal and fast neutron fluxes are decreased sharply with increasing the penetration length, while maximum thermal neutron flux is occurred at the depth of 3 cm.

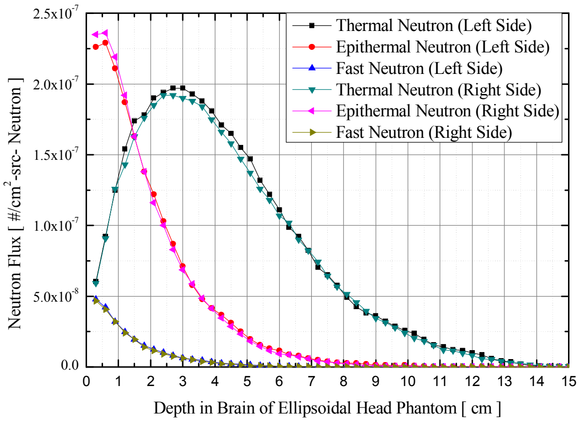

Fig. 3. Distributions of Neutron Fluxes in Small Cells along the Brain Central Line of the Ellipsoidal Head Phantom

The advantage depth (AD), one of the important dosimetric properties used to evaluate the ability of neutron beam to treat deep-seated tumors[6], was calculated in Figure 4. It was recognized that the tumor positioned at the maximum depth of 7 cm from head skin could be treated by using the beam from the dual beam port assembly.

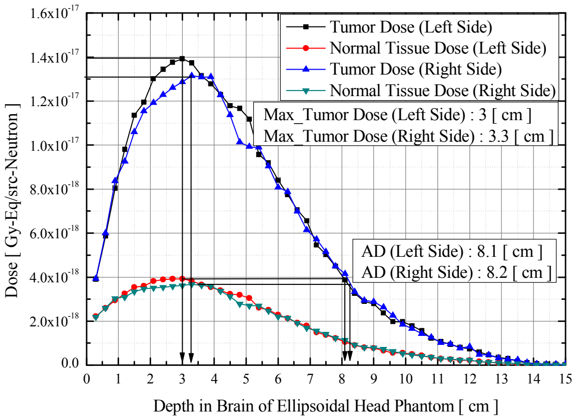

Fig. 4. Comparison of Depth Dose Profile between Tumor and Normal Tissue

4. Conclusions

This study has produced a distinct conclusion regarding the design of therapeutic neutron beam for accelerator–based BNCT. Sufficient epithermal neutron beams could be obtained from perpendicular beam extracted from the direction of 90° to the incident proton beam more easily than the forward facing assembly. In this case, therapeutic beams generated from the dual beam port assembly can treat more effectively the deep-seated tumors in brain, and furthermore, two patients could be treated in the same time.

It is also expected that the installation of a small-sized beam shaping assembly be possible into the hospitals for the practical use.

Acknowledgement

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