Feasibility of Intra-Operative BNCT Using Accelerator-Based Near-Threshold $^{7}Li(p,n)^{7}Be$ Direct Neutrons

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ABSTRACT

The dosage of intra-operative BNCT using near-threshold $^{7}Li(p,n)^{7}Be$ direct neutrons was evaluated with the calculation method validated with the phantom experiment. The production of both neutrons by near-threshold $^{7}Li(p,n)^{7}Be$ and gamma rays by $^{7}Li(p,p'gamma)^{7}Li$ in a Li target was calculated using Lee's method and their transport in the phantom was calculated with MCNP-4B. As a result, the region satisfying the requirements of the protocol in intra-operative BNCT for brain tumors in Japan was acknowledged to be comparable to present BNCT, for the proton energy of 1.900 MeV for example. A boron-dose enhancer (BDE) introduced in this study to increase $^{10}B(n,\alpha)^{7}Li$ dose in a living body was effective. The void used to increase doses in deep regions was also valid with the BDE. It was found that intra-operative BNCT using near-threshold $^{7}Li(p,n)^{7}Be$ direct neutrons is feasible.

Keywords: intra-operative BNCT, near-threshold $^{7}Li(p,n)^{7}Be$, direct neutrons, boron-dose enhancer, treatable region.

1. INTRODUCTION

The $^{7}Li(p,n)^{7}Be$ reaction (threshold: 1.881 MeV) is one of the most well researched neutron production reactions for accelerator-based boron neutron capture therapy (BNCT)[1]. The application of near-threshold $^{7}Li(p,n)^{7}Be$ neutrons to BNCT has actively been investigated recently due to the possibility of down-sizing or removing the moderator based on the production of less energetic neutrons[2], e.g. with 30 keV to around 90 keV for 1.900 MeV protons. Although fewer neutrons are produced at the near-threshold energy compared to 2.5 MeV mainly studied before, the $^{7}Li(p,n)^{7}Be$ reaction with resonance at 1.92 MeV is expected to render the irradiation field practical. BNCT in intra-operative irradiation "intra-operative BNCT" has the advantage of delivering a high dose to deep regions. If the accelerator-based neutron irradiation systems installed at hospitals are utilized, the treatment would be possibly completed in one operation by performing BNCT together with the operation to debulk the tumor. Thus it might become standard of BNCT in the future. Among the accelerator-based neutron irradiation systems, due to the compactness, those using near-threshold $^{7}Li(p,n)^{7}Be$ are particularly suitable for intra-operative BNCT, which needs the flexibility of the position and direction of irradiation. Based on this, we have been investigating the application of near-threshold $^{7}Li(p,n)^{7}Be$ direct neutrons to intra-operative BNCT[3]. In this report, the feasibility of the usage of the direct neutrons is studied from its dosage.

2. MATERIALS AND METHODS

The dosage was evaluated with a calculation method for the production of both neutrons by near-threshold $^{7}Li(p,n)^{7}Be$ and gamma rays by $^{7}Li(p,p'gamma)^{7}Li$ in a Li target using Lee's method[4] and their transport in a phantom by MCNP-4B. This calculation method has been validated through experiments with variable distance between the Li target and the phantom, focusing on large angular dependence[3]. Figure 1 shows the cross sectional configuration of the calculation geometry for the dosage. The thickness of the Li target was assumed to be just thick enough to slow 1.900 MeV protons past 1.881 MeV, i.e. 2.3 micro meter in order to reduce the gamma rays from $^{7}Li(p,p'gamma)^{7}Be$ (threshold: 550 keV) in the Li target. The Li target diameter, T-P distance, and proton energy were chosen to be 10 cm, 38 mm, and 1.900 MeV, respectively, as an example, based on parametric survey considering the ratio of the dose (D_n) by (n,n) reactions of H, C, N, O, to that by $^{10}B(n,alpha)^{7}Li$ reaction (D_B), and the ratio of gamma rays dose, and the intensity of D_B. The physical absorbed doses of heavy charged particles and gamma rays were calculated using the conversion factors given by Caswell and Coyne (1980), and Hubbel (1995), respectively. In order to investigate the feasibility of intra-operative BNCT using near-threshold ^{7}Li(p,n)^{7}Be direct neutrons, the "treatable region" satisfying the requirements for the protocol[5] in present BNCT for brain tumors in Japan was checked. In this protocol, the treatable dose is 15 Gy only for heavy charged particles and the tolerance doses are 15 Gy for heavy charged particles and 10 Gy for gamma rays independently. All are defined in physical absorbed dose. The ^{10}B concentration was assumed to be 30 ppm for the tumor and 10 ppm for the normal tissue. In order to reduce D_n/D_B, boron-dose enhancer (BDE) made of polyethylene was introduced on the phantom surface. The effect of the void to increase the dose in deep regions was also checked in case of the cylinder shape of 4 cm in diameter and 3 cm in length.

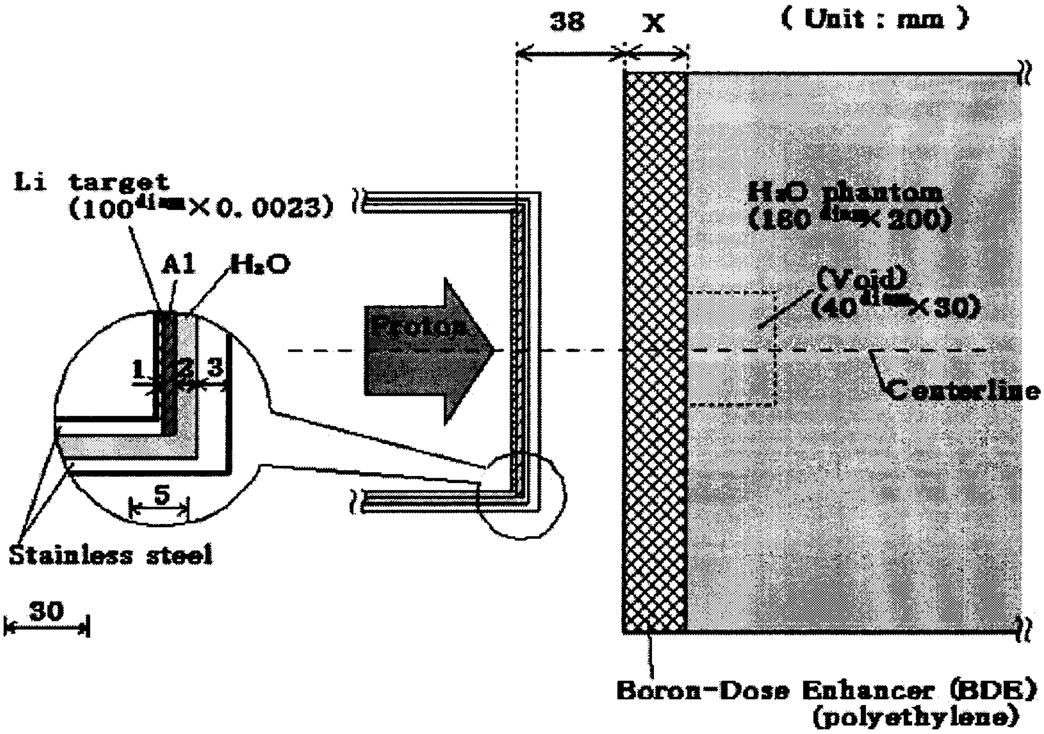

Fig. 1. Cross sectional geometry of a irradiation geometry

3. RESULTS AND DUSCUSSION

Figure 2 shows the treatable region dependent on the BDE thickness. Treatable region for the 1 cm thick BDE extends to a depth of 4.0 cm on the centerline of the phantom and up to 4.7 cm in radius on the surface. The void expands the treatable region to 5.4 cm on the centerline and 5.2 cm on the surface for the 1 cm-thick BDE. Figure 3 shows the relationship between BDE thickness and the depth of the treatable region (treatable depth) along the centerline of the phantom for each tolerance dose of heavy charged particles and gamma rays. From these data, treatable depth was decided by heavy charged particles for the BDEs with thickness up to around 1 cm and by gamma rays for the thicker BDEs. The optimum BDE thickness for large treatable region in this case is expected in the range between 1.0 and 1.5 cm. Figure 4 shows the comparison of the treatable region to those by the standard mix or epithermal neutron irradiation modes (OO-0000-F, CO-0000-F) of Kyoto university reactor heavy water neutron irradiation facility (KUR-HWNIF)[6], which are currently utilized for BNCT. These data indicates that BNCT using near-threshold ^{7}Li(p,n)^{7}Be direct neutrons can be comparable to present BNCT. Accordingly, intra-operative BNCT using near-threshold ^{7}Li(p,n)^{7}Be direct neutrons is found to be feasible. The proton current required for BNCT of this treatable region by 1 hour irradiation is expected to be 10.3 mA which would be obtainable using present technology.

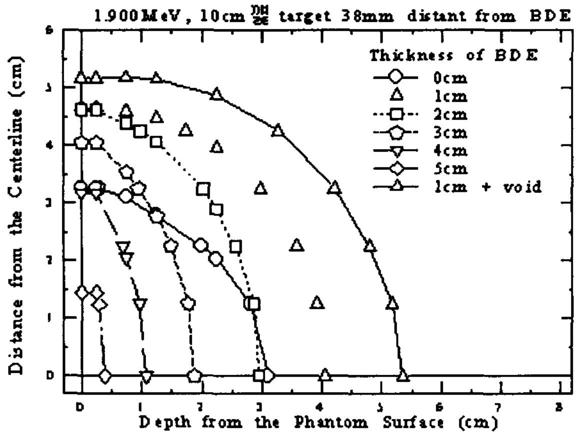

Fig. 2.Treatable region dependent on BDE thickness

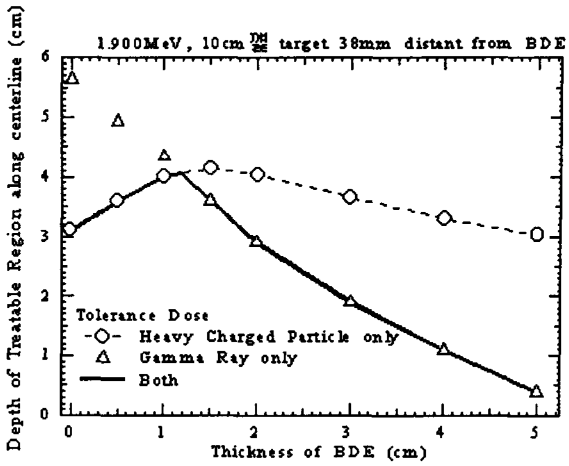

Fig. 3. Relationship between BDE thickness and reatable depth at centerline dependent on tolerance dose component

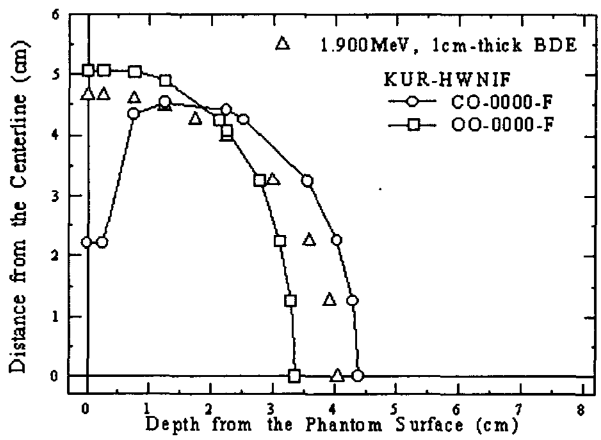

Fig. 4.Treatable region for direct neutrons and KUR-HWNIF without void

4. CONCLUSION

The treatable region for the protocol of present intra-operative BNCT for brain tumors in Japan was found to extend to a depth of 4.0 cm on the centerline of the human head and to 4.7 cm in radius from the center on the surface for an irradiation field using near-threshold $^{7}Li(p,n)^{7}Be$ by 1.900 MeV protons, a Li target of 10 cm in diameter and 2.3 micro meter in thickness, a 1 cm-thick polyethylene BDE on the human head surface, and a distance of 38 mm between the Li target and the BDE. Accordingly, BNCT using the near-threshold $^{7}Li(p,n)^{7}Be$ direct neutrons can be comparable to present BNCT using standard mix and epithermal neutron irradiation modes at KUR-HWNIF. BDE introduced in this study to increase $^{10}B(n,alpha)^{7}Li$ dose contribution in a living body was confirmed to be effective. Void utilized in intra-operative BNCT to increase doses in deep regions was also valid with the BDE. The optimization of the irradiation method is expected to be performed by combining the void and the BDE according to the position, shape and size of the tumor. This study indicates the feasibility of inra-operative BNCT using accelerator-based neutron irradiation systems installed at hospitals, in utilization of near-threshold $^{7}Li(p,n)^{7}Be$ direct neutrons for brain tumors. Accordingly, it will become a standard modality of BNCT in the future.

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