Bi-material Bolus for Minimizing the Non-uniformity of Proton Dose Distribution

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ABSTRACT

Generally uniform dose distribution is assumed to be formed in a target region when a conventional dose formation method using a broad proton beam, a fixed modulation technique, a bolus and an aperture is employed. However, actual situations differ. We usually find non-uniformity in the target region. This is due to the insertion of a range-compensating bolus before the patient. Since the range-compensating bolus has an irregular shape, the scattering in the bolus depends on the lateral position. Dose distribution is overlapping results of dose distribution of pencil-proton beams traversing different lateral positions of the bolus. The lateral extent of dose distribution of each pencil beam traversing the different position differs each other at the same depth in the target object. This is a cause of the non-uniformity of the dose distribution. Therefore the same lateral extent of dose distribution should be attained for different pencil beams at the same depth to obtain a uniform dose distribution. For that purpose, we propose here a bi-material bolus. The bi-material bolus consists of a low-Z material determining mainly the range loss and a high-Z material defining mainly the scattering in the bolus. After passing through the bi-material bolus, protons traversing different lateral positions will have different residual range yet with the same lateral spread at a certain depth. Using the optimized bi-material bolus, we can obtain a more uniform dose distribution in the target region as expected.

Keywords: Bi-material, Bolus, proton, dose distribution, uniformity

1.INTRODUCTION

A fixed-modulation using a ridge filter or a rotating wheel and beam-spreading devices is a well-established method forming a uniform dose distribution in proton therapy. The method of dose formation uses a range-compensating bolus for conforming the distal edge of the dose distribution to the distal boundary of a tumor. Although it is usually assumed that dose distribution formed by the above-mentioned method is uniform in the target region, the actual dose distribution is not uniform due to the different lateral spread of the pencil beams traversing different thicknesses of the bolus.

2.MATERIALS AND METHODS

Net dose distribution is summation of dose distributions of pencil beams passing through the different positions of the bolus. Therefore the lateral beam spreads of such pencil beams should be the same at the same water-equivalent depth in order to obtain a uniform dose distribution. The lateral beam spread of a pencil beam is determined by the path length it traverses in the bolus, by the water-equivalent depth in the target, and by the incident beam energy. Since a bolus is a device for adjusting the residual ranges of the beam traversing the different positions, the range losses are fixed parameters. If the bolus is made from single material, scattering strength of a pencil beam passing through some portion of the bolus depends on the path length the beam traverse in the bolus. In order to obtain the same lateral spread of the pencil beams contributing to some position at some water-equivalent depth, scattering angles of the pencil beams traversing different positions should be adjusted while keeping the range losses in the bolus the same. A bi-material bolus can be used for that purpose. It consists of low-Z material like ABS resin, Lucite, Mixed-DP and high-Z material like hard-lead, brass. Since it has two degrees of freedom, thickness of the low-Z material and that of the high-Z material, the scattering strengths can be adjusted while keeping the range losses the design values so that the same lateral spread can be obtained at some depth.

3.RESULTS AND DISCUSSION

The dose distribution of a broad beam obtained by a usual bolus made from single material is calculated using the pencil beam algorithm and is shown in Fig. 1. The SOBP (Spread-Out Bragg Peak) width of the beam is 5 cm. The bolus is made of a chemical wood and in square shape. The thickness of the thin part is 1.0 cm and that of the thick part is 5.0 cm. The Bragg peak position of the incident beam is 20 cm. The figure is a contour plot of equi-dose lines in the x-z plane at y = 0, where x and y are lateral coordinates and z is the coordinate in the depth direction. As seen in the figure, hot and cold regions are observed at interface regions. The similar distribution is also observed in the measured results. Fig. 2 shows the calculation result in the case that a bi-material bolus made from chemical wood and hard lead is used. It is clear that the dose uniformity is improved in the interface region. The thickness of the chemical wood and that of the hard lead are 5 cm and 0 cm, respectively, at the thick part of the bolus. The thickness of the chemical wood and that of the hard lead are 0.430 cm and 0.113cm, respectively, at the thin part of the bolus.

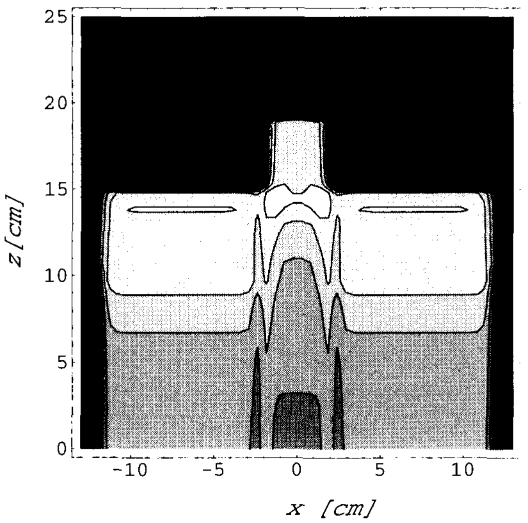

Fig. 1 Calculated iso-dose distribution for broad proton beam with a single-material bolus

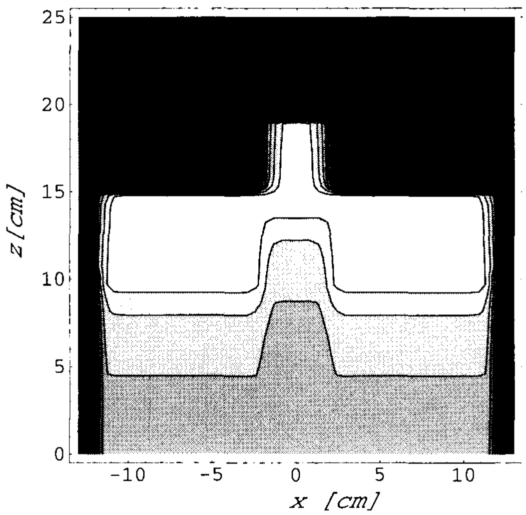

Fig. 2 Calculated iso-dose distribution for broad proton beam with a bi-material bolus

4.CONCLUSION

A bi-material bolus has been proposed to improve the dose uniformity in the target region where uniform dose distribution is expected. Since the non-uniformity arises from the different lateral spreads of pencil beams traversing different thicknesses of a single-material bolus at the same water-equivalent depth, a bi-material bolus is effective to adjust the lateral beam spread while keeping the range losses at the bolus the design values. It is verified that such an expected improvement of dose uniformity can be attained by calculation based on the pencil beam algorithm. Although the bi-material bolus is effective, production of the bi-material bolus requires more task of machining. Therefore efforts for efficient production should be made.