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Dosimetric evaluation of proton stereotactic radiosurgery

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Introduction

Surgical excision, conventional external radiotherapy, and chemotherapy could prolong survival in patients with small intracranial tumors. However, surgical excision for meningiomas located in the region of the base of skull or re-resection is often difficult. Moreover, treatment is needed for patients with recurrent tumors or post-operative residual tumors. Conventional external radiotherapy is popular and has significantly increased for treating brain tumors. Stereotactic radiosurgery is an effective alternative treatment technique to microsurgical resection such as benign brain tumor or vestibular schwannomas.

Proton irradiation offers superior dose conformality compare to photon irradiation. This advantage more apparent as the tumor volume increases. Proton-based SRS have been employed in various types of lesions such as arteriovenous malformation, vestibular schwannomas, and pituitary adenomas. These radiosurgery should be both highly conformal and homogeneous because radiation is delivered near the brainstem and multiple cranial nerves. The treatment using proton radiosurgery was used to control the tumor growth and to minimize the risk of neuropathy. Although, proton therapy is promising treatment and its interest is steadily grown at this time, it is needed to be considered for various uncertainties such as proton range, dose calculation error caused by inhomogeneities, mis-registration of tissue compensators, or patient immobilization.

The purpose of this study is to compare the proton planning results with fixed and arc beams based on dose-volume histograms (DVH) analysis for small incranial tumors. The dose quality factor (DQF) was employed to evaluate plan quality based on acceptable dose for planed target volume.

Materials and methods

Ten patients treated with fractionated stereotactic radiotherapy using noncoplanar dynamic conformal arc therapy were selected for this study. Four patients were men, six patients were women, and the median age was 59 years. Three of these patients had previously received whole-brain radiotherapy (WBRT) and others had undergone surgery previously. The prescribed dose varied from 14 Gy to 20 Gy was individually assessed dependent on tumor volume and involved critical structures. The median PTV was 2.65 cm^3 presented with small brain lesions.

Target volumes and organs at risks were delineated on the CT data fused with magnetic resonance imaging (MRI) by the use of image fusion software. The gross tumor volume (GTV) was defined as the contrast-enhancing tumor. Planning target volumes (PTV) included a 1 mm margin around the gross tumor volumes. Treatment planning system was used an Varian

Eclipse (v8.1) treatment planning system (Varian Medical System, Palo Alto, CA, USA) using the pencil beam algorithm for dose calculation. Proton dose calculation was performed by selecting the beam energies of 230 MeV. Dose calculations were performed on a grid of 25 x 25 x 25 mm^3. The doeswere normalized such that 95% volume of the PTV was covered by the stated prescribed dose.

All the proton treatment plans were conducted in passive scattering mode. The conformal arc and dynamic conformal arc plan were employed single scattering mode. The proximal, distal, and transverse margins were 2, 2, and 10 mm, respectively. In proton 3 field mode, compensator thickness was automatically optimized according to the target extension in each slice. The border smoothing and smearing margin were set at 5 mm and 3 mm, respectively. Treatment planning for dynamic conformal arcs requires the multileaf collimator for beam shaping. Since the multileaf collimator (MLC) was not installed in our planning system, the brass block instead of MLC was fitted to the PTV structure for dynamic conformal arc therapy at every 10 degree.

Treatment plan was evaluated by dose quality factor (DQF) based on clinical requirements of the doses for target and OARs. The dose quality factor for physical dose was defined as below:

$$DQF = DQF_{target} \times DQF_{OAR}$$

$$DQF_{target} = \sum W_i((D/D_{acc})^n)_i$$

$$DQF_{OAR} = \sum W_j((D_{acc}/D)^n)_j$$

where i and j were target and organ at risk structures.

Results

Mean volume, minimum volume, and maximum volume of PGTV were 33 cm^3, 23 cm^3, and 43 cm^3, respectively. The worst result focused on the minimum point dose was given by 3D conformal proton therapy with a minimum of 86.16%. All proton plans were covers over 99.6% of prescribed dose at V98. The dose quality factor calculation for tumor demonstrated that arc beam therapy uniformly delivered higher doses compared to fixed beam therapy.

In general, the dose to OAR of 3D conformal plan is lower than that of conformal arc and dynamic conformal arc plans. However, any of OARs was not reached to tolerance dose. Although mean dose of the healthy brain tissue for 3D conformal plan was slightly higher than that of arc plans, the doses of the healthy brain tissue at V10 and V20 were significantly low for dynamic conformal arc plan. The dosimetric differences were the greatest at lower doses. In contrast, 3D conformal plan was better spare at higher doses.

Conclusions

In this study, a dosimetric evaluation of proton stereotactic radiosurgery for brain lesion tumors was using fixed and arc beams. A brass block fitted to the PTV structure was modeled for dynamic conformal collimator. Although all treatment plans offer a very good coverage of the PTV, we found that proton arc plans had significantly better conformity to the PTV than static 3D conformal plan. The V20 dose of normal brain for dynamic conformal arc therapy is dramatically reduced compare to those for other therapy techniques.