Comparative dosimetric evaluation of three-dimensional conformal and stereotactic radiotherapy for treatment of intracranial tumors

Manoj Gupta a,*, M. Babaiah a, M. Dinesh Kumar a, Pushpendra H. Hirapara b, Arvind K. Patidar b, Rahul V. Walke b

a Radiation Oncology, Yashoda Hospital, Hyderabad, India
b Radiation Oncology, Acharya Tulsi Regional Cancer Treatment and Research Hospital (ATRCTRI), Bikaner, Rajasthan, India

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Conformity index; Dosimetric comparison; Heterogeneity index; Stereotactic radiotherapy; Target coverage; Three-dimensional conformal radiotherapy

Abstract
Aims: To evaluate the dosimetric profile among three-dimensional conformal radiotherapy (3D-CRT) and stereotactic radiotherapy (SRT) for the treatment of intracranial tumors.

Materials and methods: Seventeen patients with intracranial tumors of benign nature or low malignant potential were enrolled and planned for SRT as well as 3D-CRT. Dosimetric comparison between these two plans was done considering the following parameters: Target coverage, conformity index, and heterogeneity index.

Results: The dosimetric parameters of the 3D-CRT plans were a little inferior compared with those for the SRT plans. The difference between mean target coverage, mean conformity index and mean heterogeneity index for 3D-CRT and SRT plans was highly significant at P < 0.001 (t = 7.74), P < 0.001 (t = 5.52), and P < 0.01 (t = 3.15) respectively.

Conclusion: SRT is a very efficient treatment option for intracranial tumors, in view of better target coverage and conformality compared with 3D-CRT.

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Introduction

External-beam radiation therapy (EBRT) is a component of treatment for most primary intracerebral malignancies after a maximal safe surgical resection. In addition to dose considerations, the volume of brain irradiated to high dose must be minimized.

The appropriate volume to encompass within the radiation treatment portal varies with the specific histopathologic tumor type. Benign tumors that typically do not infiltrate beyond the...
lesional borders are seen by MRI. Certain tumors, such as benign meningiomas, pituitary adenomas, craniopharyngiomas, and acoustic neuromas, may be treated with narrow margins of surrounding normal tissues. In contrast, most common brain tumors, such as low-grade and malignant astrocytomas, are infiltrative into surrounding normal brain tissues many centimeters. Thus, a substantial amount of “normal” brain is included in the full-dose volume. Newer technologies have been developed to minimize the acute and long-term toxicities of RT when this modality is indicated. Stereotactic radiation therapy (SRT) uses highly focal, precise, fractionated radiation therapy. This form of treatment is made possible with head fixation devices and modifications to standard linear accelerators. SRT was developed using principles from stereotactic radiosurgery, which uses a single large fraction of radiation with an invasive head frame for immobilization. SRT combines the advantages of focused precision RT with biologic advantages of fractionation [1–4].

Stereotactic radiotherapy for intracranial tumors is of valuable importance over conventional radiotherapy in patients who have a relatively high probability of long term survival, that is patients with low-grade histology, localized tumor, young age and benign histopathology. The long term sequelae of irradiation of the brain in young children include neurocognitive, endocrinologic, carcinogenic and vascular events. These vary in severity, depending considerably on the age of the child, the radiation dose, and the size of the radiation field. The goal of SRT is to minimize the amount of normal tissues irradiated without compromising tumor control. The accuracy and precision of SRT allows for smaller margin of normal tissues to receive the prescription dose [4].

Given the potential advantages of the precise limited-field RT for intracranial tumors, we initiated a prospective study to evaluate the dosimetric profile among three-dimensional conformal radiotherapy (3D-CRT) and SRT for treatment of intracranial tumors.

Materials and methods

From March-05 to June-07, biopsy proved 17 patients (except patients with typical clinical and MRI findings suggestive of a brain stem glioma or optic nerve meningioma) with localized intracranial tumor of low-grade histopathology and malignant potential were selected for the study. Detailed history and thorough physical examination, including neurologic examination, and radiologic or any other investigation was done at the time of registration.

Fractionated SRT was performed using a Clinac-DMX 2300-CD linear accelerator (Varian, Palo Alto, CA) and a m3-micromultileaf collimator (Brain LAB) fixed on the gantry of the linear accelerator, each leaf width 3-mm.

For treatment planning and delivery, patients were immobilized in a relocatable stereotactic head frame (Brain LAB, Heimstetten, Germany) with associated bite-block, occipital impression, and facial aquaplast assuring an overall positioning accuracy of 1–2 mm. The planning CT scan with contrast, with a Brain LAB CT localizer was attached to their head frame using a 3-mm slice thickness. A contrast-enhanced MRI was performed in the treatment position. CT and MRI images and configuration data were transmitted to a Brain Scan apparatus for SRT planning. For treatment planning, the position of the nine localizer rods on the CT slices were used to map each voxel of the CT scan into the coordinate space. The CT scan was fused to an axial MRI series using Object pair matching for better definition of the target volume. The T1-weighted post-contrast and T2-weighted images were used to ensure adequate identification of the tumor. After image fusion, the target volume and organs at risk (OAR) were delineated in each slice using the three dimension treatment planning Brain Scan software (version 5.3, Brain LAB AG). The gross target volume (GTV) was defined as the area with contrast enhancement on T1-weighted MRI and the planning target volume (PTV) included a 2–3 mm safety margin to allow possible patient misalignment. Dose–volume histograms were constructed. The prescription dose was chosen after evaluation of the DVH, taking into account the location of the intracranial tumor.

At the time of treatment, a Brain LAB laser localizer was attached to the patient’s head frame and used to align the patient to the planned isocenter. A single isocenter was used in all cases, with five to seven fields.

3D-CRT plan was created for each patient undergoing stereotactic irradiation treatment, in ECLIPSE three dimensional treatment planning system, using multileaf collimator (each leaf width 1-cm), and CT scan and MRI images (used for SRT planning).

For a fair comparison, the PTV margin was defined as 3-mm, and the specific prescription dose was set at 95% for all the plans.

The target coverage, conformity index (CI), and heterogeneity index (HI) were used to compare the different plans in this study. The target coverage was defined as the percentage of the PTV at the prescription dose. Conformity index (CI), represents an attempt to measure objectively how well the distribution of radiation follows the shape of target. It was expressed as, $CI = V_a/V_t$ (where $V_a$ and $V_t$ are the volume of the normal tissues and target receiving the prescription dose, respectively).

### Table 1 Patients’ characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Median</th>
<th>Range</th>
<th>No. of patients</th>
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<tr>
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<td>27 year</td>
<td>7–75 year</td>
<td>17</td>
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<tr>
<td>Gender</td>
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<td>Female</td>
<td>12</td>
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<tr>
<td>Age</td>
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<tr>
<td>KPS</td>
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</table>
Heterogeneity index, is expressed as: $HI = \frac{D_{5\%}}{D_{95\%}}$ (where $D_{5\%}$ and $D_{95\%}$ correspond to the dose delivered to 5% and 95% of the PTV, respectively).

Statistical analysis was done using SPSS, version 8.0.0, statistical software package. For quantitative data, ‘$t$’ test was applied to calculate the difference between two means.

Results

Patient characteristics are shown in Table 1.

Tumours were: acoustic schwannoma; meningioma involving right cavernous sinus, sellar and suprasellar region; astrocytic tumor involving optic chiasma; pineal gland tumor; arterio-venous malformation involving right parietal lobe and left temporo-parietal area and other histologic types, including pituitary adenoma, oligodendroglioma involving left fronto-parietal region, chordoma involving right petrous apex, craniopharyngioma, hemangioma involving pons (imaging based diagnosis) (see Table 2).

Mean target coverage for 3D-CRT plan is 83.46% and for SRT 95.74%. This difference in the mean was highly significant at $P < 0.001$ ($t = 7.74$). Mean of conformity index for 3D-CRT is 1.46 and for SRT is 1.07. This difference in the mean was highly significant at $P < 0.001$ ($t = 5.52$). Mean of heterogeneity index for 3D-CRT plan is 1.103 and for SRT plan 1.105. This difference in the mean was highly significant at $P < 0.01$ ($t = 3.15$) (see Figs. 1–3).

Discussion

Fractionated stereotactic radiotherapy (FSRT) is a potent, noninvasive method of precise high-dose RT for localized benign and malignant intracranial tumors [5]. Using a relocatable stereotactic head frame for accurate immobilization and localization, image fusion for accurate target delineation, and treatment planning with multiple, static, conformal noncoplanar beams, treatment plans with SRT are of high precision and conformality [6]. Radical radiotherapy using innovative techniques is undoubtedly effective for the treatment of inoperable or recurrent intracranial tumors.

The natural evolution of these radiotherapy planning techniques is to now consider intensity modulated stereotactic

<table>
<thead>
<tr>
<th>S. No.</th>
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<th>SRT</th>
<th>$t$-Value</th>
<th>$P$-value</th>
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<td>4.38</td>
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<td>Conformity Index</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
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<td>1.07</td>
<td>5.52</td>
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<tr>
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<td>SD</td>
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<td>0.028</td>
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<td>3</td>
<td>Heterogeneity Index</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
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<td>1.105</td>
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<td></td>
<td>SD</td>
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<td>0.0343</td>
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radiotherapy utilizing the localization/immobilization benefits of the stereotactic frame and the potential conformation benefit of IMRT, for example with dynamic micromultileaf collimation [7]. In a replanning study of 10 patients with skull base meningiomas, Baumert et al. [7] described improved PTV coverage and a decrease in the dose to organs at risk with intensity modulated stereotactic radiotherapy. Whether this has a therapeutic gain for patients is yet to be demonstrated.

Ding et al. [8] investigated the dosimetric differences among three-dimensional conformal radiotherapy (3D-CRT), dynamic conformal arc therapy (DCAT), and intensity-modulated radiotherapy (IMRT) for brain tumor treatment. The IMRT plans had a greater CI, better target coverage at the prescription dose, and a better heterogeneity index. For large tumors (PTV > 100 cm³), the IMRT plan had good target coverage at the prescription dose, and heterogeneity index and approximate CI values as those in the 3D-CRT and DCAT plans. The results of their study have shown that DCAT is suitable for most cases in the treatment of brain tumors. For a small target, 3D-CRT is useful, and IMRT is not recommended. For larger tumors, IMRT is superior to 3D-CRT and very competitive in sparing critical structures, especially for big tumors.

Grzadziel et al. [9] presented a comparison of the dose distribution of conformal three-dimensional radiotherapy plans with IMRT plans for cranial lesions in stereotactic radiotherapy. Results revealed that greatest homogeneity was reached in the conformal plans and IMRT plans with high planning target volume priority in the optimization process. This consequently led to a better probability of tumor control. Better protection of organs at risk and thereby lower normal tissue complication probabilities were achieved in the IMRT plans with increased weighting of the organs at risk. These results show the efficiency, as well as some limitations of the IMRT techniques.

Zwicker et al. [10] demonstrated that the use of an MLC with a leaf width of 5 mm (MLC-5) has significant advantages over an MLC with a leaf width of 10 mm (MLC-10) with respect to target coverage and protection of normal tissues in step-and-shoot IMRT of head and neck cancer. The use of MLC-5 led to a significantly higher conformity index and an improvement of the 90% coverage of PTV1 (planning target volume) and PTV2 compared with MLC-10.

Wang et al. [11] compared the impacts of multileaf collimator (MLC) widths (standard MLC width of 10 mm [SMLC] and micro-MLC width of 4 mm [MMLC]) on intensity-modulated radiotherapy (IMRT) planning for nasopharyngeal carcinoma (NPC). Ten patients with NPC were recruited in this study. The average conformity index (CI) and homogeneous index (HI) for the planning gross target volume in IMRT plans with MMLC were 0.790 ± 0.036 and 1.062 ± 0.011, respectively. Data in plans with SMLC were 0.754 ± 0.038 and 1.070 ± 0.010, respectively. The differences were statistically significant (P < 0.05). Compared with CI and HI for planning target volume in paired plans, data with MMLC obviously were better than those with SMLC (CI: 0.858 ± 0.026 vs. 0.850 ± 0.021, P < 0.05; and HI: 1.185 ± 0.011 vs. 1.195 ± 0.011, P < 0.05). According to these two kinds of Elekta MLC devices, IMRT plans with the MMLC have significant advantages in dose coverage for the targets, with more efficiency in treatment for NPC.

Fujimoto et al. [12] evaluated the dosimetric impact of treatment planning for three-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiotherapy (IMRT) of prostate cancer using Varian/BrainLAB 120-leaf high-definition multileaf collimator (HD120 MLC) with 2.5-mm leaf width and Varian 120-leaf millennium multileaf collimator (M120 MLC) with 5 mm leaf width. The results of this work demonstrated that the dose conformity of PTV improved and the dose of bladder and rectum decreased for 3DCRT and IMRT of prostate cancer using HD120 MLC compared to M120 MLC, because of the reduction of leaf width, leaf transmission, and rounded leaf end transmission.

In our study, the dosimetric impact of treatment planning for three-dimensional conformal radiotherapy (3DCRT) and stereotactic radiotherapy (SRT) of intracranial tumors using Varian/BrainLAB micromultileaf collimator with 3 mm leaf width and Varian multileaf collimator with 10 mm leaf width, demonstrated that the dosimetric parameters of the 3D-CRT plans were a little inferior compared with those for the SRT plans. The difference between mean target coverage, mean conformity index and mean Heterogeneity index for 3D-CRT and SRT plans was highly significant at P < 0.001 (t = 7.74), P < 0.001 (t = 5.52), P < 0.01 (t = 3.15), respectively.

**Conclusion**

In view of better target coverage, conformity index and heterogeneity index, SRT for the treatment of benign intracranial tumors is practical, safe and effective. SRT is a very efficient treatment option for asymptomatic and high-risk patients with benign intracranial tumor (tumor volume > 4 cc, distance to adjacent critical structures less than 2 mm, and recurrences), especially in cases of cavernous sinus – invading meningiomas and those that compress the optical pathways.

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