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Effect of target volume on treatment planning parameters of skull base lesions and functional disorders in cyber knife

Abstract

Background: Benign and malignant tumoral growth can be controlled by several ways of which one is by irradiating the target by ionizing radiation (X-rays or gamma rays). Initially it was done by conventional radiation therapy offering fewer field orientations, thus increasing the dose to surrounding normal tissue and inability to achieve the required dose to the target, which was overcome by applying converging beams from different angles focused at a single spot (target), thus achieving higher doses with adequate normal tissue sparing.

Method: A retrospective review of 270 patients treated with Cyber knife in Cyber knife stereotactic Radiosurgery department JPMC Karachi was carried out and 88 patients with skull base lesions of anterior middle and posterior cranial fossa were included. The study data included treatment planning parameters and diagnosis of the patients.

Results: Data was statistically analyzed on SPSS V.22 software. Treatment planning parameters were compared with volume of the lesions as defined in the treatment planning data. On statistical analysis significant 2-tailed value at 95% confidence interval $p<0.001$ was obtained on correlating target volume with the homogeneity and new conformity indices.

Conclusion: In this study we have appreciated that tumors with greater volumes and treated with larger and multiple collimators were subjected to increased homogeneity and new conformity indices as comparable to those lesions with lesser volumes and were treated with smaller collimator sizes. Thus we have noted a significant impact of tumor volume on homogeneity and new conformity indices.

Keywords: irradiation, radio surgery, cyber knife, radio biology

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Abbreviations: DVHs, dose volume histograms; PTV, prescribed target volume; HI, homogeneity index; NCI, new conformity index; DRRs, digitally reconstructed radiographs

Introduction

Benign and malignant tumoral growth can be controlled by several ways of which one is by irradiating the target by ionizing radiation (X-rays or gamma rays). Initially it was done by conventional radiation therapy offering fewer field orientations, thus increasing the dose to surrounding normal tissue and inability to achieve the required dose to the target. To overcome these consequences a precise and accurate way of dose delivery was introduced termed Radiosurgery. It is quite different from conventional radiotherapy in terms of applying converging beams from different angles focused at a single spot (target), thus enabling to attain higher doses at the target by adequately sparing the normal tissue. Early systems dedicated for the above purpose were Gamma Knife and X- knife, able to deliver dose in a single fraction due application of frame and were meant regionally for intracranial lesions. Then was introduced Cyber Knife an image guided frameless radiosurgical equipment. Treatment is delivered by a linear accelerator mounted on a flexible robotic arm. Several-hundred treatment beams are chosen out of a repertoire of greater than one thousand possible beam directions using inverse treatment planning. These beams are delivered in a non-isocentric manner via circular collimators of varying size without intensity modulation. Non-isocentric treatment allows for simultaneous irradiation of multiple lesions. The lack of a requirement for the use of a head-frame allows for staged treatment. Since the planning system has access to a large number of potential non-isocentric beams, the Cyber Knife® should theoretically be able to deliver a highly conformal, uniform dose with steep dose gradients.[1] Therefore, treatment with the Cyber Knife® radiosurgical system should minimize toxicity to surrounding structure.[2]

Skull base tumors arise from the cranial base or reach it, either from an intracranial or extracranial origin. The tumors with their locations as well as their pathologies are classified as (Table 1). Meningioma are the most common skull base tumors and arise from anterior middle or posterior cranial fossa, sphenoid wing meningiomas are the most common of all meningiomas.[3] Contribution of pituitary adenomas is 15% they may attain giant size and invade paranasal sinuses and skull base. Others include schwannomas contributing approximately 5 to 8% all intracranial neoplasms including, trigeminal, acoustic and vestibular schwannomas. Chondrosarcoma is a tumor of cartilaginous origin with non-uniform biologic behavior.[4] It represents 0.15% of all cranial space-occupying lesions, whereas chordoma are locally aggressive malignant tumors and constitute 0.1 to 0.2% of all primary intracranial tumors. Chordomas are located in posterior fossa although typically considered as midline tumors of clivus. Paragangliomas are slow-growing tumors that extend along anatomic planes of least resistance and are the most common tumors of middle ear.

Table 1 Origin and pathology based classification of intracranial tumors

Site of tumor origin	Tumor pathology
Basal neuro vascular structures and meninges	Meningioma
	Schwannoma
	Pituitary adenoma
	Craniopharyngioma
	paraganglioma
	Hemangiopericytoma
Cranial base	Chondroma
	Chondrosarcoma
	Osteosarcoma
	plasmacytoma
	Metastasis
Subcranial with upward extension	Sinonasal carcinomas
	Olfactory neuroblastoma
	Juvenile angiofibroma
	Nasopharyngeal carcinoma
	Adenoid cystic carcinoma
	Primary sarcomas

Although surgical resection may be the treatment "gold-standard" but in many patients complete resection of skull base tumors is often not possible without a high risk of neurologic deficits and morbidity. Therefore, highly precise radiation techniques are required. Radiosurgery is an appropriate treatment option. It is a non-invasive treatment modality and can be offered to inoperable patients due to several comorbidities, after subtotal resection or to patients with poor prognosis as an alternative treatment to surgical intervention. Single fraction Radiosurgery is difficult as these tumors are potentially large in size and irregular in shapes. Their proximity to critical structures also leads to a risk of radiation-induced, long-term, neurological complication. For small tumor volumes Radiosurgery is often used, for lager tumor volumes fractionated stereotactic radiation therapy combines the advantage of spatial precision of Radiosurgery and the radiobiologic advantage of fractionation with better sparing of normal tissue.[5,6]

Radiosurgical plans are usually compared by means of Dose Volume Histograms (DVHs) but larger data volumes stand limitation for simple differentiation between multiple plans. But there are certain treatment planning parameters which determine the level of optimization of a treatment plan, chosen treatment planning parameters are homogeneity index and new conformity index. A conformity index is a single measure of how well the treatment dose distribution of a specific radiation treatment plan conforms to the size and shape of the target volume.[7,8] For LINAC based radiosurgical plans the homogeneity indices of 1.0 to 1.2 have been reported whereas for Gamma knife the same parameter has been reported as 2.0 to 3.0.[9]

Materials and methodolgy

We performed a retrospective review of 270 patients treated with Cyber knife in Cyber knife stereotactic Radiosurgery department JPMC Karachi; out of above defined counts we included 88 patients with skull base lesions of anterior middle and posterior cranial fossa. The study data included treatment planning parameters and diagnosis of the patients. The aim of study is to compare the volume of lesions with the treatment planning parameters to define the degree of optimism of a treatment plan with variable volumes as the tumors with greater volume were in close approximation to the critical organs like, brain stem optic chiasm pituitary gland and spinal cord. Whereas the treatment planning parameters homogeneity index and new conformity indices are considered to be the entities which can define the extent of justification and optimization of a treatment plan.[7,8]

The included 88 patients include benign malignant metastatic lesions and functional disorders (trigeminal neuralgia). These patients include acoustic neuroma, 20 pituitary adenoma, 15 meningioma (para sellar, supra sellar, cerebellopontine angle, orbital, cereberovertebral junction, and tentorial), 2 craniopharyngioma, 4 schwannoma (trigeminal, and cavernous sinus), an oligodendroglioma, 1 patient with posterior cranial fossa metastatic lesions, 1 patient was with chordoma, 4 patients were presenting brainstem glioma, 1 patient with giant cell skull base tumor, one with sphenoidal wing Chondrosarcoma, 7 trigeminal neuralgia, 1 adenoid cystic carcinoma, 7 patients were diagnosed of glomusjugulare, 2 patients were included of astrocytoma, one of paraganglioma and ependymoma each (Figure 1). In accordance to location the tumors were residing in anterior middle and posterior cranial fossa. In anterior cranial fossa the tumors were of orbital, sellar, sphenoidal wing, clival and cavernous sinus origin. Middle cranial fossa lesions were of CP angle jugular formenae, and foramen magnum. Whereas posterior cranial fossa lesions were usually cerebellar.

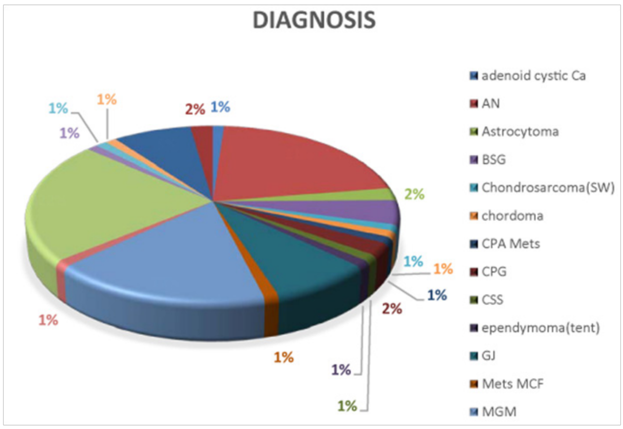

Figure 1 Percentages of patients with respect to diagnosis.

The radiosurgical treatment planning was done on computed tomographic images with square matrix and operating at 120 KVp and maximum achievable tube currents (up to 400mA). All the patients were injected non-ionic contrast media Iopamiro for greater vascular detail. The region included was from vertex up to C7. The accessory imaging modality considered was MRI, a contrast enhanced MRI was performed for each patient for greater definition of the lesion. The treating radiation oncologist determined the minimal tumor margin dose of the target volume and the treatment isodose. This discussion was influenced by various factors, including previous radiation to the area, tumor volume, and extent of contact and compression of critical neurological structures. In most cases, the dose was prescribed to the isodose surface that encompassed the margin of the tumor. Twelve collimator sizes are available with the Cyber Knife® radiosurgical system ranging from 5 mm to 60 mm. In general, a collimator size less than the maximum length of the prescribed target volume (PTV) was chosen for treatment planning.[10] An inverse planning method

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with non-isocenteric technique was used for all cases. The DVH and doses to the critical organs were evaluated for critical organs before accepting a plan.

Treatment planning parameters

The treatment planning parameters which were focused in this study are target volume, homogeneity index and new conformity index and percent target coverage. Target volume is the contoured lesion volume on the treatment plan on CT accompanied by MRI images by the treating radiation oncologist. The homogeneity index (HI) describes the uniformity of dose within a treated target volume, and is directly calculated from the prescription isodose line chosen to cover the margin of the tumor:

$$HI = \frac{Maximum\ Dose}{Prescription\ Dose}$$

Whereas the new conformity index (NCI) as formulated by Paddick, and modified by Nakamura describes the degree to which the prescribed isodose volume conforms to the shape and size of the target volume. It also takes into account avoidance of surrounding normal tissue:

$$NCI = \frac{\left[(treatment\ volume) \times (prescription\ isodose\ volume)\right]}{(volume\ of\ the\ target\ covered\ by\ the\ prescription\ isodose\ volume)^2}$$

Percent target coverage is the percentage of target volume covered by prescription isodose.

Results

Out of 270 patients treated at our center we considered 88 patients with skull base lesions and functional disorders in our study performed retrospectively. Included patients were, meningioma 15(17%) acoustic neuroma 19(21.6%) pituitary adenoma 20(22.7%) glomusjugulare 7(8%) schwannomas (trigeminal, and cavernous sinus) 4(4.5%) brainstem glioma 3(3.4%) craniopharyngioma 2(2.3%) astrocytoma 2(2.3%). Other patients with metastatic lesion, chordoma, ependymoma, oligodendroglioma, paraganglioma and skull base giant cell tumor contributed 9(9.7%) of the total included population of the study. Data was then subjected to statistical analysis performed on SPSS V.22 software. Treatment planning parameters were compared with volume of the lesions as defined in the treatment planning data.

On statistical analysis significant 2-tailed value at 95% confidence interval $p<0.001$ was obtained on correlating target volume with the homogeneity and new conformity indices. This significant p-value defines that there is always an impact of the target volume on HI and nCI being considered as the tools in defining degree of optimism of a treatment plan.

Discussion

Cyber knife was introduced to get rid of frame associated radio surgeries (gamma knife). Cyber knife is image guided radio surgical equipment which takes in contest bony landmarks to track the region of interest by means of DRRs (Digitally Reconstructed Radiographs) developed from high resolution computed tomographic images thus providing a precision of 0.1mm. Gamma knife has limited approach to skull base lesions as comparable to cyber knife. In patients with acoustic neuroma mean tumor volume was 10.83cc and all the population was treated in three fractions with a mean maximum dose of 24.02Gy and multiple collimator sizes were utilized with respect to tumor volume and contiguous normal structures ranging from 5-25mm. Meningioma with a mean tumor volume of 16.53cc were treated with a mean maximum dose of 32.50Gy in 3 to 5 fractions with collimator sizes ranging from 5-15mm. Brainstem glioma with mean volume of 30.71cc, mean maximum dose of 37.93Gy were treated in 5 fractions with collimator size ranging from 7.5 to 20mm (Figure 2A & 2B).

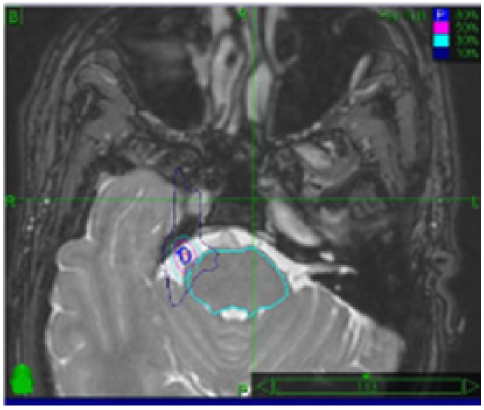

Figure 2a Patient with trigeminal neuralgia treated with 60Gy at 80% Isoline.

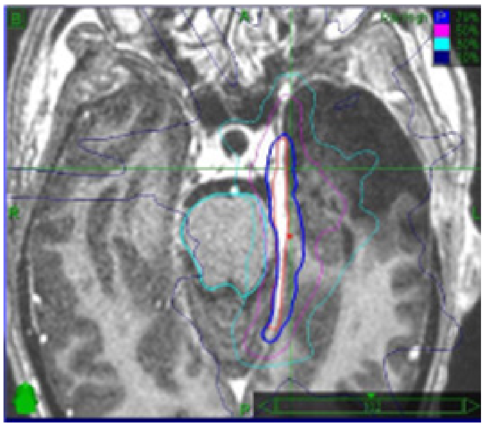

Figure 2b Patient with tentorial meningioma treated with 21Gy in three fractions.

Trigeminal neuralgia and pituitary adenoma were having mean volumes of .07cc and 8.0cc with mean maximum doses of 75 and 32.96Gy and collimator sizes ranging from 5mm and 5-20mm respectively. In all treated targets treatment volume coverage of 95% was not compromised with treatment planning parameters. Thus a trend was demonstrated in treatment planning parameters and tumor volume that with increasing tumor volume it stood difficult to maintain doses to the critical structures, and utilizing multiple collimators lead to increased homogeneity and new conformity indices, and treating the greater volumes with smaller collimators was compromising the target coverage. So tumors with smaller volumes and by applying smaller diameter collimators lead to sharper peripheral dose fall offs leading to decreased new conformity indices.

Conclusion

In this study we have appreciated that tumors with greater volumes and treated with larger and multiple collimators were subjected to increased homogeneity and new conformity indices as comparable to those lesions with lesser volumes and were treated with smaller collimator sizes. Thus we have noted a significant impact of tumor volume on homogeneity and new conformity indices.

Acknowledgments

None.

Conflicts of interest

Authors declare there are no conflicts of interest.

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