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Original Article

Volume-staged gamma knife surgery for the treatment of large skull base meningioma surrounding the optical apparatus: A snowman-shape design

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Abstract

Background: In cases of meningioma surrounding the optical apparatus, this study sought to reduce the incidence of radiation-induced optical neuropathy resulting from gamma knife surgery (GKS) by dividing the treatment volume into 2 or 3 fractions.

Methods: Four patients with a large skull base meningioma (1 male and 3 females; median age: 42 years; range: 33−43 yrs) were treated using volume-staged GKS. In stage I, the large basal part of the tumor (13.2 mL; range: 3.9−54.7 mL) was treated with a marginal dose of 13.5 Gy (range: 12−15 Gy). In stage II, treatment focused on the smaller upper portion of the tumor located close to the optical apparatus (4.3 mL; range: 1.5−16.2 mL), and the marginal dose was 9 Gy (range: 8−10 Gy).

Results: All patients tolerated the treatments well, and tumors regressed over a median follow-up period of 100.5 months (range: 42−122 mos). Specifically, a 34−46% reduction in tumor volume was observed. All four patients presented improvements in the neurological deficits observed prior to GKS treatment, albeit to varying degrees. No adverse effects of radiation or new visual deterioration were observed during the follow-up period. Furthermore, no evidence of new endocrine dysfunction or new cranial nerve neuropathy was observed within a follow-up period of 100.5 months.

Conclusion: The application of volume-staged GKS using snowman-shape design appears to be an effective approach to control tumor growth when treating benign meningiomas surrounding the optical apparatus. This approach enables the application of higher radiation dosages to facilitate tumor control while still preserving optic nerve function.

Keywords: Gamma knife; Meningioma; Optical neuropathy; Stereotactic radiosurgery

1. Introduction

Despite recent advances in the surgical treatment of skull base meningioma, this disease is still associated with high rates of morbidity.[1−5] In contrast, radiosurgery is able to control the growth of tumors in 80−100% cases of skull base meningioma,[6−10] and GKS can reduce morbidity rates among meningioma patients. For example, Kondziolka et al. reported long-term tumor control in 91% of 290 consecutive patients who underwent GKS for a meningioma between 1987 and 1997.[11] However, in cases where the tumor is large and close to the optical apparatus, surgeons face a clinical dilemma as high-dose radiation exposure can lead to optic neuritis and irreversible deterioration in visual function.

Vision can be preserved by limiting the maximum radiation exposure of the optic pathway to 8−10 Gy per stereotactic radiosurgery (SRS) session[12−15]; unfortunately, the minimum effective dose for the treatment of benign skull base meningioma is 11−13 Gy. To address this dilemma, we developed a

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volume-staged SRS strategy, referred to as the snowman-shape design, that enables tumor control while also protecting the optical apparatus from radiation damage. Using the technique, the basal portion of the tumor (distal to the optical apparatus) is first treated with a regular (high) dose of radiation, and the upper portion of the tumor (proximal to the optical apparatus) is treated at intervals of 3 months or more. This paper reports on four cases in which the snowman-shape volume-stage treatment was implemented. We provide a detailed account of the techniques employed as well as resulting treatment outcomes.

2. Methods

2.1. Patient population

Four patients with a benign meningioma at the base of the skull were subjected to volume-staged GKS (Elekta Instruments, Inc., Stockholm, Sweden) using the snowman-shape design between Nov. 2005 and Sep. 2012. The Institutional Review Board of the Buddhist Tzu Chi Medical Center approved the research protocol. Three female patients and one male patient met the criteria for inclusion in the study. The age range of participants was 33–43 years (median: 42 years). The tumors were located in either the tuberculum sellae, the cavernous sinus, the suprasellar or retrosellar region, the petroclivus, or in all of the aforementioned locations. In all cases, the optical apparatus was compressed or encased by the tumors. Preoperative neurological deficits are presented in Table 1. All patients underwent microsurgery prior to GKS, and all of their histologies presented WHO grade I meningioma.

2.2. Radiosurgery technique

Each treatment session began by fixing a rigid Leksell frame (Model G, Elekta Instruments, Stockholm, Sweden) to the head of the patient after local anesthesia had been applied to the scalp (5% bupivacaine and 2% xylocaine). The frame was tilted anteriorly approximately 30°, which aligned the frame parallel to the plane of the optic nerves and chiasm, thereby ensuring that the optic nerve and chiasm were positioned along the same plane in axial MR images. MR stereotactic images acquired using a fiducial system attached to the stereotactic frame were transported through a fiber optic Ethernet cable to a GammaPlan (Elekta Instruments) computer, where images were checked for distortion/accuracy. Axial MR images using coronal and sagittal reconstruction with a slice thickness of 1 or 2 mm were required for the planning of treatment. After optimizing the plan, the marginal and maximum doses were determined for the target. Radiosurgery was performed using a 201-source, cobalt-60 gamma knife, and both the head of the patient and the stereotactic frame were immobilized within a collimator helmet. The automatic positioning system (APS) automatically moves the stereotactic frame until the target is fully irradiated.

Table 1
Demography of the 4 patients who underwent volume-staged GKS for skull base meningioma close to the optic apparatus.

Case/No.	Age (yrs)/sex	Tumor location	Neurological deficits	Total tumor vol (ml)	Stage	Treated target vol (ml)	Marginal dose/isodose	Fractional interval (mos)	Mean tumor dose (Gy)	Mean/max chiasm dose (Gy)	Tumor vol after treatment (ml)[b]	New endocrine dysfunction[c]	Follow-up period[a] (mos)
1	42/M	PC	Ataxia	69.4	I	54.7	15 Gy/50%	–	21.0	6.2/8.0	46.1 (−34%)	No	122
		C	R 2–5N Df		II	16.2	10 Gy/50%	6	13.6	5.0/9.5			
2	42/F	TS	L 2N Df	13.9	I	7.8	13 Gy/50%	–	16.8	4.0/5.1	8.4 (−40%)	No	105
		C + Orb			II	4.5	8 Gy/42%	4	12.0	2.2/7.0			
3	33/F	TS	Ataxia	21.5	I	18.5	14 Gy/50%	–	16.3	7.3/8.2	11.6 (−46%)	No	96
		PC + C	R 3–5N Df		II	4.0	8 Gy/50%	4	11.2	6.1/9.3			
4	43/F	TS	Bil 2N Df	5.3	I	3.9	12 Gy/50%	–	16.3	6.2/12.8	2.9 (−45%)	No	42
		C			II	0.38	10 Gy/50%	4	14.3	2.6/7.7			
					III	1.14	10 Gy/50%	8	13.8	2.1/11.3			

R = right, L = left, Bil = bilateral, N = cranial nerve, Pc = petroclival, C = cavernous sinus, Orb = orbit, TS = tuberculum sellae, Df = dysfunction.
[a] Follow up since the first GKS.
[b] The data also showed the percentage of tumor volume decrease.
[c] The basal endocrine function for adrenocorticotropic hormone, cortisol, thyroid-stimulation hormone, triiodothyronine (T3), tetraiodothyronine (T4), growth hormone, and prolactin.