

SRS-1. Spatial Errors of Stereotactic MRIs: Clinical Consideration during Stereotactic Surgery

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Objective: The aim of this study is to identify the effects of frequency encoding direction during planning for gamma knife radiosurgery using 1.5-tesla MRI.

Methods: We retrospectively reviewed imaging data of 57 patients treated with gamma knife radiosurgery from September 2014 to December 2014. In all patients, two frequency encoding direction (right to left and anterior to posterior) images with gadolinium-enhanced T1-weighted MRIs were obtained. Spatial errors were evaluated by comparing the difference of marginal radiation dose for lesion between right to left and anterior to posterior frequency encoding direction images in each patient.

Results: Among 57 patients, two patients were treated with AVMs, 28 patients with meningioma, 26 with metastatic brain tumor, and one with vestibular schwannoma. The mean distances from center of the frame to center of lesion were as follows; 24.2 mm (± 16.1) for x-axis, 32.1 mm (± 18.2) for y-axis, 38.4 mm (± 25.9) for z-axis, and 62.1 mm (± 22.0) for actual. The mean difference of minimum marginal radiation dose for lesions was 0.56 Gy (± 0.79) and the mean difference of maximum marginal dose to normal brain was 1.37 Gy (± 1.41) between each frequency encoding direction images. The z-axis and actual distances from center of frame to center of lesion had statistical significance for mean difference of minimum marginal radiation dose for lesions between each frequency encoding direction images.

Conclusion: This retrospective study showed spatial errors of stereotactic MRIs for gamma knife radiosurgery. Although there is no definitive way to eliminate these errors, we must consider that there could be spatial error during radiosurgery resulting in inadvertent treatment failure.

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SRS-2. Stereotactic Radiosurgery for Dural Carotid Cavernous Sinus Fistulas

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Objective: We reviewed our 7-year experience to assess the efficacy of stereotactic radiosurgery (SRS) for dural carotid cavernous fistulas (DCCFs). We analyzed the clinical outcome, complications, and angiographic results.

Methods: We performed a retrospective analysis of 18 consecutive patients with DCCF treated by SRS alone using Gamma Knife between 2009 and 2015. Median target volume was 2.6 cm³ (range, 0.6-11.6 cm³) and median radiation dose to the target was 17 Gy (range, 14-19 Gy). Median follow-up period was 30 months (range, 6-65 months).

Results: Fifteen patients (83%) achieved a total obliteration of the DCCF and a subtotal obliteration of the DCCF was achieved in three patients (17%). Total obliteration rates after SRS were 53% at 1 year, 90% at 2 years, and 100% at 5 years. Twelve patients (67%) showed complete recovery from symptoms or signs and six patients (33%) showed incomplete recovery. Improvement rates of neurological function after SRS were 56% at 1 month, 72% at 3 months, and 94% at 6 months. None of the patients experienced radiation-related complications. A multivariate analysis revealed that absence of cortical venous drainage (p=0.023, hazard ratio, 3.902, 95% confidence interval, 1.157-13.166) was significantly associated with symptom improvement.

Conclusion: SRS for DCCFs offered a high obliteration rate with low risk of radiation-induced complications. In patients with benign DCCFs that are not amenable to embolization or microsurgery, SRS is a safe and effective treatment for complete obliteration of the arteriovenous shunt and for improving the quality of life.

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SRS-3. The Modification in Penumbra of a Gamma Knife for Functional Radiosurgery

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Objective: This study is to make a special collimator for functional Gamma Knife radiosurgery in Gamma Knife model C, reducing the penumbra area which causes the complication after radiosurgery. We compared the dose distribution with normal collimator.

Methods: For functional radiosurgery using Gamma Knife, the maximum dose of 80-130 Gy is delivered to the target. Therefore, besides the area of 50% isodose, the penumbra area of 25% isodose is important because the 20-32.5 Gy is delivered to the area. The dose can cause the direct effect of necrosis and the indirect effect that the surrounding tissue will die from the vessel occlusion by radiation. The Gamma Knife model C has the hemispherical 5 ring distribution of 201 cobalt source, the first ring has 35 sources, the second ring has 39 sources, the third ring has 39 sources, the fourth ring has 44 sources and the fifth ring has 44 sources. All sources are focused at SAD (source axis distance) of 40 cm. The distribution of the sources makes a nonlinear ellipse of radiation in X, Y and Z direction. The FWHM (full width at half maximum) and 25% of isodose were 4.8 mm and 5.8 mm in Z direction but in X and Y direction the value was 5.9 mm and 8.8 mm which meant that the penumbra of X and Y direction was bigger than in Z. To reduce this effect, we made a special distribution of sources by plugging the 5th ring and the 5th and 4th ring. The special collimator was compared with normal collimator by analyzing the volume and size of 50% and 25% and treatment time.

Results: As the treatment time in using all 5 rings is unit of 1, the time of plugging of 5th ring and of plugging of 5th ring and 4th ring were 1.28 and 1.79 respectively. The size of 50% in X and Y slightly decreased to 5.8 mm and 5.7 mm with plugging but in Z the size slightly increased to 4.9 mm and 5.0 mm. For the penumbra area of 25%, the size in X and Y much decreased to 8.3 mm and 7.8 mm but in Z, the size increased to 6 mm and 6.2 mm. These results showed the reduction of nonlinear ellipse in dose distribution. The comparison of 25% volume and 50% volume was calculated with GI (gradient index). The GI was first a 2.73 in using all 5 rings and changed to 2.69 with plugging 5th ring and changed to 2.7 with plugging 5th ring and 4th ring.

Conclusion: The nonlinearly increases in the penumbra of 25% in X and Y direction can cause complication of direct and indirect effect on normal tissue in high dose radiosurgery. This study showed the much reduction of penumbra and the increase of 50% size in Z direction with ring plugging. This technique will be applied to the functional Gamma Knife radiosurgery such as trigeminal neuralgia, thalamotomy and pallidotomy.



SRS-4. Gamma-Knife Surgery for the Multiple Brain Tumors and Arterio-Venous Malformations

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이기창, 정용태, 정영균, 표세영, 팽성화, 이근수, 김성태, 이원희, 김호수, 이영서, 김무성

Objective: The effectiveness of GammaKnife radiosurgery as primary treatment for small to medium sized brain tumors, AVM has been reported. But, the treatment of the multiple brain tumors and AVM, several times surgery is needed and we assessed the Gamma Knife Radiosurgery for multiple brain lesions.

Methods: Between October, 1994 and December 2014, 12 patients with multiple brain lesions were treated with Gamma Knife radiosurgery (GKS). 2 patients (16.7%) had AVM, 2 patients (16.7%) had germinomas, 6 patients (500%) had multiple meningiomas, 1 patients (8.4%) had meningiomas and pituitary adenoma, 1 patient (8.4%) had meningioma and schwannoma. The mean radiosurgical tumor volume was 5.6 mL (range 0.5-36 mL). The mean dose delivered to the lesion center was 25.2 Gy (range 20-45) and to the margin was 14.1 Gy (10-22.5 Gy).

Results: All patients underwent serial MRI scanning with a mean duration of imaging follow-up 45 months (range 5-110). Among the 2 AVM patients, two lesions were treated with GammaKnife Surgery. In 1 patient the AVM was disappeared, 1 patient showed partial obliteration and retreated with Gamma-Knife Surgery after 84 months. Pre Gamma Knife surgery, 2 germinoma patients (44%) underwent biopsies. And they received treated with GammaKnife surgery and booster radiotherapy. Imaging in 2 patient (32.3%) demonstrated complete response during mean 56.5 months (range 55-58 months). Among the multiple meningioma patients, all 6 patients the tumor were stationary. Of 1 patient with meningioma and pituitary tumor, initial she treated meningioma with GammaKnife surgery, but 4 years later, pituitary tumor was developed and retreated with GammaKnife surgery, which showed partial response through follow-up MRI image. In 1 pituitary tumor and low cranial nerve schwannoma patient, partial response after GammaKnife surgery.

Conclusion: Gamma-Knife radiosurgery is safe and effective treatment of multiple brain tumors and AVMs. Especially in cases of multiple AVM or meningioma, pituitary tumor, schwannomas, simultaneously treatment showed better results than the surgery. GK provides one time treated an advantage for all multiple brain tumors or AVMs.



SRS-5. Initial MRI Features Predictable Tumor Control after Stereotactic Radiosurgery for Metastatic Brain Tumors

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Objective: Metastatic brain tumors are the most common mass lesions in the brain. MRI is the most important imaging modality to evaluate intracranial metastases. The purpose of this study is which MRI features at stereotactic radiosurgery (SRS) could be related to further tumor control.

Methods: A retrospective review of 453 patients of lung and breast cancer with 1,843 intracranial metastases who underwent SRS between June 2004 and December 2013 was conducted. Among the tumors, 290 tumors in 188 patients were included in this study. Both the existence of pre-SRS diffusion-weighted images (DWI) and more than 1 cm of tumor diameter were selection criteria. We evaluated pre-SRS MR images of the patients, and, first, the tumors were grouped according to the diameter of the tumors. The investigated MRI features were (1) the enhancement pattern, (2) intensity in DWI, and (3) existence of intratumoral hemorrhage or (4) peritumoral edema of the tumors.

Results: The median progression-free survival (PFS) of metastases after SRS was 143 days (range, 11-1,478 days). Decreased DWI intensity were related to the favorable PFS ($p < 0.0001$). The tumor control was achieved in 188 tumors (65%). One hundred fifty (51.7%) lesions were classified with hyper-intensity on DWI and decreased ADC intensity. The tumor control was achieved in 83 tumors (55%) in hyper-intensity on DWI group. One hundred forty (48.3%) lesions were classified with hypo-intensity on DWI and increased ADC intensity. The tumor control was achieved in 100 tumors (72%) in hypo-intensity on DWI group. Patients with low intensity in DWI appear to be had longer PFS ($p < 0.0001$). Other features such as enhancement pattern, intratumoral hemorrhage, peritumoral edema did not reach to statistical significance in univariate analysis.

Conclusion: A decreased signal on DWI could be a favorable radiologic prognostic factor of tumor control and reflects the positive response after SRS. The DWI might be one as the practical methods to predict the treatment success after SRS for metastatic brain tumors.



SRS-6. Gamma Knife Radiosurgery for Vestibular Schwannoma: Clinical Results Focusing on Adverse Radiation Effects

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Objective: Radiosurgery for the treatment of vestibular schwannoma (VS) introduces risks to the facial nerve and hearing, as well as posttreatment complications such as pseudoprogession, hydrocephalus, balance disturbances, tinnitus, and other cranial neuropathies (Transient increase in tumor volume on MRI due to radiation can mimic tumor progression but are related to radiation treatment effects known as “pseudoprogession”). The purpose of this retrospective study was to investigate the results focusing on adverse radiation effects in patients with VS who underwent Gamma Knife radiosurgery (GKS).

Methods: A retrospective review of database of all VS patients treated between November 2007 and October 2010 at our institution using the Perfexion Leksell Gamma Knife. Patients who had a minimum of 12-months clinical and radiological assessment before and after GKS were included in this study. Tumor volume measurements were performed using axial T1 magnetic resonance imaging (MRI) with gadolinium, using GammaPlan software. Events were defined as volume change $\geq 20\%$. Pseudoprogession and hydrocephalus were documented and possible prognostic factors were analyzed. Concurrently, neurological deterioration involving trigeminal, facial, vestibular, and cochlear nerve functions were also assessed.

Results: The mean follow-up period was 39.3 months. There were 102 men and 141 women, whose mean age was 52.9 years. The mean target volume was 3.78 cm^3 , and the mean tumor margin dose was 12.5 Gy. Following GKS, 50 (20.58%) patients showed a pseudoprogession and 15 (6.17%) hydrocephalus. Mean tumor margin dose were 12.36 Gy for patients with pseudoprogession and 12.78 Gy for patient had no pseudoprogession, and there was significant differences ($p=0.012$). Mean target volume was 3.569 cm^3 for hydrocephalus and 6.965 cm^3 for no hydrocephalus ($p=0.003$). On multivariate analysis, solid-type tumor and prior surgical resection were significantly associated with pseudoprogre-



ssion. Also male gender and no prior surgical resection were significantly associated with newly developed or aggravated cochlear neuropathy. None of the following factors was associated with hydrocephalus, new facial weakness, or other cranial neuropathies: patient gender, tumor type (solid vs. cystic) and prior surgical resection.

Conclusion: The data indicated that psuedoprogession are associated with a significantly higher margin dose. Also, we found the tumor volume increase played a contributory role in the development of hydrocephalus.

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