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Contents

Anatomical Location

Convexity

Stereotactic radiosurgery for convexity meningiomas.

J Neurosurg. 2009;111(3):458–463.
DOI: 10.3171/2008.8.JNS17650

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Objective
Meningiomas of the cerebral convexity are often surgically curable because both the mass and involved dura mater can be removed. Stereotactic radiosurgery has become an important primary or adjuvant treatment for patients with intracranial meningiomas. The authors evaluated clinical and imaging outcomes in patients with convexity meningiomas after radiosurgery.

Methods
The patient cohort consisted of 125 patients with convexity meningiomas managed using radiosurgery at some point during an 18-year period. The patient series included 76 women, 55 patients who had undergone prior resection, and 6 patients with neurofibromatosis Type 2. Tumors were located in frontal (80 patients), parietal (24 patients), temporal (12 patients), and occipital (9 patients) areas. The WHO tumor grades in patients with prior resections were Grade I in 34 patients, Grade II in 15 patients, and Grade III in 6 patients. Seventy patients underwent primary radiosurgery and therefore had no prior histological tumor diagnosis. The mean tumor volume was 7.6 ml. Radiosurgery was performed using the Leksell Gamma Knife with a mean tumor margin dose of 14.2 Gy.

Results
Serial imaging was evaluated in 115 patients (92%). After primary radiosurgery, the tumor control rate was 92%. After adjuvant radiosurgery, the control rate was 97% for Grade I tumors. The actuarial tumor control rates at 3 and 5 years for the entire series were 86.1+/-3.8% and 71.6+/-8.6%, respectively. For patients with benign tumors (Grade I) and those without prior surgery, the actuarial tumor control rate was 95.3+/-2.3% and 85.8+/-9.3%, respectively. Delayed resection after radiosurgery was performed in 9 patients (7%) at an average of 35 months. No patient developed a subsequent radiation-induced tumor. The overall morbidity rate was 9.6%. Symptomatic peritumoral imaging changes compatible with edema or adverse radiation effects developed in 5%, at a mean of 8 months.

Conclusions
Stereotactic radiosurgery provides satisfactory control rates either after resection or as an alternate to resection, particularly for histologically benign meningiomas. Its role is most valuable for patients whose tumors affect critical neurological regions and who are poor candidates for resection. Both temporary and permanent morbidity are related to brain location and tumor volume.

Gamma knife surgery of superficially located meningioma.

J Neurosurg. 2005;102(suppl):255–258.
PMID: 15662820 DOI: 10.3171/jns.2005.102.s_supplement.0255

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Objective
The authors analyzed tumor control rates and complications in patients with superficially located meningiomas after gamma knife surgery (GKS).

Method
Between 1998 and 2003, GKS was performed in 23 patients with 26 lesions in whom follow-up imaging for 1 year or more was available. The male/female ratio was 1:22. The mean age was 59 years. The median tumor volume was 4.7 cm3, and the mean margin dose was 16 Gy at the 50% isodose line. Peritumoral edema was revealed on magnetic resonance (MR) imaging in four patients before GKS. Magnetic resonance imaging and clinical examinations were performed every 6 months after GKS. The mean follow-up duration was 32 months. The tumor shrank in eight cases, was stable in 17, and enlarged in one; thus 25 (95%) of 26 tumors were controlled. A peritumoral high signal on T2-weighted MR images was found in eight lesions and preexisting edema was aggravated in three lesions after GKS. Ten of these 11 patients complained of severe headache, and three patients experienced neurological deficits at the same time after a mean latency of 3 months; however, high signal was not demonstrated on imaging before 6 months on average. Steroid agents, when required, gave relief to all patients. The complication rate was 43% (10 of 23 cases). High signal disappeared in nine patients and decreased in the remaining two. High signal was associated with a high integral dose and a large tumor volume. Tumor shrinkage at the last follow-up examination was more prominent in the patients with symptomatic high signal ($p = 0.03$).

Conclusions
There was a good tumor control rate with a high complication rate. Longer follow up of more patients is needed. Adjusting the dose-volume relationship should be considered to reduce complications.

Intraventricular meningiomas

Gamma knife radiosurgery for intraventricular meningiomas.

Acta Neurochir (Wien). 2009;151(5):447–452.
PMID: 19337685 DOI: 10.1007/s00701-009-0273-x

Kim IY[1], Kondziolka D, Niranjan A, Flickinger JC, Lunsford LD.
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Objective
Intraventricular meningiomas are relatively rare tumors that may benefit from stereotactic radiosurgery as a minimally invasive treatment strategy. We report our experience using gamma knife radiosurgery (GKR) for intraventricular meningiomas.

Method
Over a 16-year period, we identified 9 patients with intraventricular meningiomas who were eligible for GKR out of a total management experience of 1,045 patients. The mean patient age was 51 years (range, 14 to 81). Three had radiosurgery for recurrent tumors after prior resection, and GKR was used as an adjunctive after subtotal resection in 1 patient. In the other 5 patients, GKR was used as primary management. Two had a diagnosis of meningioma confirmed by biopsy. The median tumor volume at GKR was 3.9 cc (range, 0.8–11.8). A median margin dose of 16.0 Gy (range, 14.0–22.5) was delivered to the tumor margin.

Results
The average follow-up was 64 months. None of the patients developed hydrocephalus or treatment-related morbidity. The progression-free periods after radiosurgery varied from 7 to 160 months (mean, 60). Four tumors regressed and 2 remained unchanged. Three patients showed delayed tumor progression. Meningioma growth control was obtained in 7 out of 9 patients, but 1 patient required two radiosurgical procedures.

Conclusions
Gamma knife radiosurgery may be an additional minimally invasive management option for small intraventricular meningiomas in patients who either fail or are unsuitable for resection.

Presumed intraventricular meningioma treated by embolisation and the gamma knife.

Neuroradiology. 1999;41(5):334–337.
PMID: 10379589 DOI: 10.1007/s002340050759

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A 58-year-old woman with a presumed incidentally discovered meningioma in the left lateral ventricle was treated by superselective embolisation and gamma knife therapy. The diameter of the tumour was 40 mm, and its main feeding artery was the left lateral posterior choroidal artery. This vessel was embolised with microcoils. At 8 months following embolisation, the diameter of the tumour had decreased and was stable. The gamma knife was chosen as an adjuvant therapy for the further control 13 months after embolisation. Embolisation and gamma knife therapy may be an alternative treatment for meningiomas where surgical resection appears difficult.

Olfactory groove

Gamma knife radiosurgery of olfactory groove meningiomas provides a method to preserve subjective olfactory function.

J Neurooncol. 2014;116(3):577–583.
PMID: 24398616 DOI: 10.1007/s11060-013-1335-8
Gande A[1], Kano H, Bowden G, Mousavi SH, Niranjan A, Flickinger JC, Lunsford LD.
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Anosmia is a common outcome after resection of olfactory groove meningioma(s) (OGM) and for some patients represents a significant disability. To evaluate long term tumor control rates and preservation of subjective olfaction after Gamma Knife (GK) stereotactic radiosurgery (SRS) of OGM. We performed a retrospective chart review and telephone assessments of 41 patients who underwent GK SRS between 1987 and 2008. Clinical outcomes were stratified by full, partial or no subjective olfaction, whereas tumor control was assessed by changes in volume greater or lesser than 25%. The median clinical and imaging follow-up were 76 and 65 months, respectively. Prior to SRS, 19 (46%) patients had surgical resections and two (5%) had received fractionated radiation therapy. Twenty four patients (59%) reported a normal sense of smell, 12 (29%) reported a reduced sense of smell and five (12%) had complete anosmia. The median tumor volume was 8.5 cm(3) (range 0.6–56.1), the mean radiation dose at the tumor margin was 13 Gy (range 10–20) and the median estimated dose to the olfactory nerve was 5.1 Gy (range 1.1–18.1). At follow-up, 27 patients (66%) reported intact olfaction (three (7%) described return to a normal sense of smell), nine (22%) described partial anosmia, and five (12%) had complete anosmia. No patient reported deterioration in olfaction after SRS. Thirteen patients (32%) showed significant tumor regression, 26 (63%) had no further growth and two (5%) had progressed. The progression free tumor control rates were 97% at 1 year and 95% at 2, 10 and 20 years. Symptomatic adverse radiation effects occurred in three (7%) patients. Stereotactic radiosurgery provided both long term tumor control and preservation of olfaction.

Parasagittal

Edema following gamma knife radiosurgery for parasagittal and parafalcine meningiomas.

J Neurosurg. 2015; 123(4):1287–1293.
PMID: 26115473 DOI: 10.3171/2014.12.JNS142159

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Objective
Stereotactic radiosurgery (SRS) has been shown to offer a high probability of tumor control for Grade I meningiomas. However, SRS can sometimes incite edema or exacerbate preexisting edema around the targeted meningioma. The current study evaluates the incidence, timing, and degree of edema around parasagittal or parafalcine meningiomas following SRS.

Method
A retrospective review was undertaken of a prospectively maintained database of patients treated with Gamma Knife radiosurgery at the University of Virginia Health System. All patients with WHO Grade I parafalcine or parasagittal meningiomas with at least 6 months of clinical follow-up were identified, resulting in 61 patients included in the study. The median radiographic follow-up was 28 months (range 6–158 months). Rates of new or worsening edema were quantitatively assessed using volumetric analysis; edema indices were computed as a function of time following radiosurgery. Statistical methods were used to identify favorable and unfavorable prognostic factors for new or worsening edema.

Results
Progression-free survival at 2 and 5 years was 98% and 90%, respectively, according to Kaplan-Meier analysis. After SRS, new peritumoral edema occurred or preexisting edema worsened in 40% of treated meningiomas. The median time to onset of peak edema was 36 months post-SRS. Persistent and progressive edema was associated with 11 tumors, and resection was undertaken for these lesions. However, 20 patients showed initial edema progression followed by regression at a median of 18 months after radiosurgery (range 6–24 months). Initial tumor volume greater than 10 cm3, absence of prior resection, and higher margin dose were significantly ($p<0.05$) associated with increased risk of new or progressive edema after SRS.

Conclusions
Stereotactic radiosurgery offers a high rate of tumor control in patients with parasagittal or parafalcine meningiomas. However, it can lead to worsening peritumoral edema in a minority of patients. Following radiosurgery, transient edema occurs earlier than persistent and progressive edema. Longitudinal follow-up of meningioma patients after SRS is required to detect and appropriately treat transient as well as progressive edema.

Histopathology of radiation necrosis with severe peritumoral edema after gamma knife radiosurgery for parasagittal meningioma. A report of two cases.

Stereotact Funct Neurosurg. 2007;85(6):292-295.
PMID: 17709982 DOI: 10.1159/000107362

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Background
Gamma knife radiosurgery (GKS) has been an effective treatment for meningiomas. Nevertheless, it still has certain risks. We present 2 cases of parasagittal meningioma after GKS complicated with radiation necrosis and peritumoral edema. The results of histologic examination are discussed.

Case description
Two cases of parasagittal meningioma received GKS. Symptomatic peritumoral edema developed 3-4 months after GKS. Both of them underwent surgical resection of their tumor afterwards. Histologic examination showed necrotic change inside the tumor and infiltration of inflammatory cells in both cases. Hyalinization of blood vessels was seen in the 2nd case. The patients had improvement of neurologic function after surgical resection. Imaging performed 3 months after surgical resection showed alleviation of brain edema.

Conclusions
After radiosurgery peritumoral edema tends to occur in meningiomas with a parasagittal position. Radiation necrosis, infiltration of inflammatory cells, and radiation injury to the vasculature causing hyalinization of blood vessels are suggested as the underlying histopathology.

Multimodal treatment of parasagittal meningiomas: a single-center experience.

J Neurosurg. 2017;127(6):1249-1256
PMID: 28156245 DOI: 10.3171/2016.9.JNS161859.

Gatterbauer B[1], Gevsek S[1], Höftberger R[2], Lütgendorf-Caucig C[3], Ertl A[1], Mallouhi A[4], Kitz K[1], Knosp E[1], Frischer JM[1].
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Objective
Treatment of parasagittal meningiomas is still considered a challenge in modern microsurgery. The use of microsurgical resection, radiosurgery, or a microsurgery-radiosurgery combination treatment strategy is often debated. The aim of this study was to evaluate the treatment of parasagittal meningioma and provide evidence that a multimodal approach reduces complication rates and achieves good tumor control rates.

Method
The authors retrospectively reviewed long-term follow-up data on 117 patients who had been treated for parasagittal meningiomas at their institution between 1993 and 2013. Treatment included microsurgery, Gamma Knife radiosurgery (GKRS), and radiotherapy.

Results
The median tumor volume prior to the first microsurgical resection was largest in the microsurgery-radiosurgery combination treatment group. Invasion of the superior sagittal sinus was significantly associated with a Simpson Grade IV resection and subsequent radiosurgery treatment. The Simpson resection grade did not influence time to progression or recurrence in benign meningioma cases. Complete sinus occlusion was followed by microsurgical resection of the occluded sinus, by tumor resection without resection of the sinus, or by GKRS. Histopathology revealed WHO Grade I tumors in most patients. However, a high percentage (33%) of atypical or malignant meningiomas were diagnosed after the last microsurgical resection. The time to recurrence or progression after microsurgery was significantly longer in patients with WHO Grade I meningiomas than in those with Grade II or III meningiomas. At follow-up, tumor control rates after GKRS were 91% for presumed meningioma, 85% for benign meningioma, 71% for atypical meningioma, and 38% for malignant meningioma.

Conclusions
A multimodal treatment approach to parasagittal meningiomas reduces the rate of complications. Thus, microsurgery, radiotherapy, and radiosurgery are complementary treatment options. Gamma Knife radiosurgery is safe and effective in patients with meningiomas invading the superior sagittal sinus. The procedure can be part of a multimodal treatment plan or administered as a single treatment in well-selected patients.

Post-radiosurgical edema associated with parasagittal and parafalcine meningiomas: a multicenter study.

J Neurooncol. 2015;125(2):317–324.

PMID: 26329323 DOI: 10.1007/s11060-015-1911-1

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Stereotactic radiosurgery (SRS) offers a high degree of tumor control for benign meningiomas. However, radiosurgery can occasionally incite edema or exacerbate pre-existing peri-tumoral edema. The current study investigates the incidence, timing, and extent of edema around parasagittal or parafalcine meningiomas following SRS. A retrospective multicenter review was undertaken through participating centers in the International Gamma Knife Research Foundation (previously the North American Gamma Knife Consortium or NAGKC). All included patients had a parafalcine or parasagittal meningioma and a minimum of 6 months follow-up. The median follow-up was 19.6 months (6–158 months). Extent of new or worsening edema was quantitatively analyzed using volumetric analysis; edema indices were longitudinally computed following radiosurgery. Analysis was performed to identify prognostic factors for new or worsening edema. A cohort of 212 patients comprised of 51.9% (n = 110) females, 40.1% upfront SRS and 59.9% underwent adjuvant SRS for post-surgical residual tumor. The median tumor volume at SRS was 5.2 ml. Venous sinus compression or invasion was demonstrated in 25% (n = 53). The median marginal dose was 14 Gy (8–20 Gy). Tumor volume control was determined in 77.4% (n = 164 out of 212 patients). Tumor edema progressed and then regressed in 33% (n = 70), was stable or regressed in 52.8% (n = 112), and progressively worsened in 5.2% (n = 11). Tumor location, tumor volume, venous sinus invasion, margin, and maximal dose were found to be significantly related to post-SRS edema in multivariate analysis. SRS affords a high degree of tumor control for patients with parasagittal or parafalcine meningiomas. Nevertheless, SRS can lead to worsening peritumoral edema in a subset of patients such as those with larger tumors (>10 cc) and venous sinus invasion/compression. Long-term follow-up is required to detect and appropriately manage post-SRS edema.

Posterior fossa

Gamma knife radiosurgery for posterior fossa meningiomas: a multicenter study.

J Neurosurg. 2015;122(6):1479–1489.
PMID: 25829812 DOI: 10.3171/2014.10.JNS14139

Sheehan JP[1], Starke RM[1], Kano H[2], Barnett GH[3], Mathieu D[4], Chiang V[5], Yu JB[5], Hess J[5], McBride HL[6], Honea N[6], Nakaji P[6], Lee JY[7], Rahmathulla G[3], Evanoff WA[3], Alonso-Basanta M[7], Lunsford LD[2]
[1]University of Virginia, Charlottesville, Virginia, USA; [2]University of Pittsburgh, Pittsburgh, Pennsylvania, USA; [3]Cleveland Clinic, Cleveland, Ohio, USA; [4]University of Sherbrooke, Quebec, Canada; [5]Yale University, New Haven, Connecticut, USA; [6]Barrow Neurological Institute, Phoenix, Arizona, USA; [7]University of Pennsylvania, Philadelphia, Pennsylvania, USA.

Objective
Posterior fossa meningiomas represent a common yet challenging clinical entity. They are often associated with neurovascular structures and adjacent to the brainstem. Resection can be undertaken for posterior fossa meningiomas, but residual or recurrent tumor is frequent. Stereotactic radiosurgery (SRS) has been used to treat meningiomas, and this study evaluates the outcome of this approach for those located in the posterior fossa.

Method
At 7 medical centers participating in the North American Gamma Knife Consortium, 675 patients undergoing SRS for a posterior fossa meningioma were identified, and clinical and radiological data were obtained for these cases. Females outnumbered males at a ratio of 3.8 to 1, and the median patient age was 57.6 years (range 12–89 years). Prior resection was performed in 43.3% of the patient sample. The mean tumor volume was 6.5 cm(3), and a median margin dose of 13.6 Gy (range 8–40 Gy) was delivered to the tumor.

Results
At a mean follow-up of 60.1 months, tumor control was achieved in 91.2% of cases. Actuarial tumor control was 95%, 92%, and 81% at 3, 5, and 10 years after radiosurgery. Factors predictive of tumor progression included age greater than 65 years (hazard ratio [HR] 2.36, 95% CI 1.30–4.29, p = 0.005), prior history of radiotherapy (HR 5.19, 95% CI 1.69–15.94, p = 0.004), and increasing tumor volume (HR 1.05, 95% CI 1.01–1.08, p = 0.005). Clinical stability or improvement was achieved in 92.3% of patients. Increasing tumor volume (odds ratio [OR] 1.06, 95% CI 1.01–1.10, p = 0.009) and clival, petrous, or cerebellopontine angle location as compared with petroclival, tentorial, and foramen magnum location (OR 1.95, 95% CI 1.05–3.65, p = 0.036) were predictive of neurological decline after radiosurgery. After radiosurgery, ventriculoperitoneal shunt placement, resection, and radiation therapy were performed in 1.6%, 3.6%, and 1.5%, respectively.

Conclusions
Stereotactic radiosurgery affords a high rate of tumor control and neurological preservation for patients with posterior fossa meningiomas. Those with a smaller tumor volume and no prior radiation therapy were more likely to have a favorable response after radiosurgery. Rarely, additional procedures may be required for hydrocephalus or tumor progression.

Gamma knife surgery of meningiomas located in the posterior fossa: factors predictive of outcome and remission.
J Neurosurg. 2011;114(5):1399–1409.
PMID: 21214335 DOI: 10.3171/2010.11.JNS101193
Starke RM,[1] Nguyen JH, Rainey J, Williams BJ, Sherman JH, Savage J, Yen CP, Sheehan JP.
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Objective
Although numerous studies have analyzed the role of stereotactic radiosurgery for intracranial meningiomas, few studies have assessed outcomes of posterior fossa meningiomas after stereotactic radiosurgery. In this study, the authors evaluate the outcomes of posterior fossa meningiomas treated with Gamma Knife surgery (GKS). The authors also assess factors predictive of new postoperative neurological deficits and tumor progression.

Method
A retrospective review was performed of a prospectively compiled database documenting the outcomes of 152 patients with posterior fossa meningiomas treated at the University of Virginia from 1990 to 2006. All patients had a minimum follow-up of 24 months. There were 30 males and 122 females, with a median age of 58 years (range 12–82 years). Seventy-five patients were treated with radiosurgery initially, and 77 patients were treated with GKS after resection. Patients were assessed clinically and radiographically at routine intervals following GKS. Factors predictive of new neurological deficit following GKS were assessed via univariate and multivariate analysis, and Kaplan-Meier analysis and Cox multivariate regression analysis were used to assess factors predictive of tumor progression.

Results
Patients had meningiomas centered over the tentorium (35 patients, 23%), cerebellopontine angle (43 patients, 28%), petroclival region (28 patients, 18%), petrous region (6 patients, 4%), and clivus (40 patients, 26%). The median follow-up was 7 years (range 2–16 years). The mean preradiosurgical tumor volume was 5.7 cm(3) (range 0.3–33 cm(3)), and mean postradiosurgical tumor volume was 4.9 cm(3) (range 0.1–33 cm(3)). At last follow-up, 55 patients (36%) displayed no change in tumor volume, 78 (51%) displayed a decrease in volume, and 19 (13%) displayed an increase in volume. Kaplan-Meier analysis demonstrated radiographic progression-free survival at 3, 5, and 10 years to be 98%, 96%, and 78%, respectively. In Cox multivariable analysis, pre-GKS covariates associated with tumor progression included age greater than 65 years (hazard ratio [HR] 3.24, 95% CI 1.12–9.37; p = 0.03) and a low dose to the tumor margin (HR 0.76, 95% CI 0.60–0.97; p = 0.03), and post-GKS covariates included shunt-dependent hydrocephalus (HR 25.0, 95% CI 3.72–100.0; p = 0.001). At last clinical follow-up, 139 patients (91%) demonstrated no change or improvement in their neurological condition, and 13 patients showed symptom deterioration (9%). In multivariate analysis, the only factors predictive of new or worsening symptoms were clival or petrous location (OR 4.0, 95% CI 1.1–13.7; p = 0.03).

Conclusions
Gamma Knife surgery offers an acceptable rate of tumor control for posterior fossa meningiomas and accomplishes this with a low incidence of neurological deficits. In patients selected for GKS, tumor progression is associated with age greater than 65 years and decreasing dose to the tumor margin. Clival- or petrous-based locations are predictive of an increased risk of new or worsening neurological deficit following GKS.

Gamma knife radiosurgery in meningiomas of the posterior fossa. Experience with 62 treated lesions.
Minim Invasive Neurosurg. 2001;44(4):211–217.
PMID: 11830780 DOI: 10.1055/2-2001-19934
Nicolato A,[1] Foroni R, Pellegrino M, Ferraresi P, Alessandrini F, Gerosa M, Bricolo A.
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Objective
This study was undertaken to assess the role of the gamma knife (GK) in the treatment of meningiomas of the posterior cranial fossa (PCF) and to statistically analyze the predictability of arbitrarily-selected prognostic factors in such treatment.

Method
From February 1993 to November 1998, 57 patients underwent GK treatment for 62 meningiomas of the PCF (19 M/38 F; average age, 57.5 years, ranging from 25–82 years). Tumor sites included: foramen jugular-petrous bone (26/62), petroclival (23/62), cerebellar convexity (6/62), tentorium (6/62), and foramen magnum (1/62). Single lesions were treated in 44/62 cases while meningiomatosis was treated in the remaining 18. Post-operative residual or recurrent tumor was found in 27/62 patients and, in 7/27, histology documented characteristics of biological aggressiveness (GII/III). Indications for radiosurgery included: advanced age, high operative risk, tumor volume <20 ml, inoperable or refused for additional surgery. The prognostic factors statistically analyzed included: meningiomatosis (yes/no), radiosurgery as primary or adjuvant treatment, GI vs. GII/III histology, and tumor volume (< or = 5 ml vs. >5 ml).

Results
The observation periods varied from 6 to 64.3 months (median 28.7 months). At the end of the study, 53/57 patients were alive and reported to be in stable or improved neurological condition. The cause of death for the remaining 4 patients included: 2 deaths associated with tumor progression, while 2 died due to causes unrelated to the disease. Neuroradiological evaluation documented the disappearance or reduction of the meningioma mass in 34/62 (55%) cases, a stable imaging picture in 25/62 (40%), and a progression only in 3/62 (5%). To date, there have been no reported cases of post-GK permanent morbidity or mortality. Side effects observed were of a transient nature due to post-radiosurgical edema (6.5%). With regard to statistical analysis, the only factor to appear to significantly influence efficacy of radiosurgery for tumor growth control (TGC) was the biological nature of the meningioma (chi(2) = 2.708). The presence of meningiomatosis, SR as a primary or adjuvant treatment nor tumor volume were shown to statistically influence tumor behavior after GK.

Conclusions
The excellent results obtained for TGC with minimal associated side effects suggest that GK is an effective therapeutic tool also for treatment of PCF meningiomas.

Foramen magnum

Gamma Knife surgery in the treatment paradigm for foramen magnum meningiomas.

J Neurosurg. 2012;117(5):864–873.
PMID: 22978541 DOI: 10.3171/2012.8.JNS111554

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Objective
Microsurgical management of foramen magnum meningiomas (FMMs) can be associated with significant morbidity and mortality. Stereotactic radiosurgery may be an efficient and safe alternative treatment modality for such tumors. The object of this study was to increase the documented experience with Gamma Knife surgery (GKS) for FMMs and to delineate its role in an overall management paradigm.

Method
Methods The authors report on their experience with 24 patients harboring FMMs managed with GKS. Twelve patients had primary symptomatic tumors, 5 had asymptomatic but enlarging primary tumors, and 7 had recurrent or residual tumors after a prior surgery.

Results
Follow-up clinical and imaging data were available in 21 patients at a median follow-up of 47 months (range 3–128 months). Ten patients had measurable tumor regression, which was defined as an overall volume reduction >25%. Eleven patients had no further tumor growth. Two patients died as a result of advanced comorbidities before follow-up imaging. One patient was living 8 years after GKS but had no clinical evaluation. Ten of 17 symptomatic patients with at least 6 months of follow-up had symptom improvement, and 7 remained clinically stable. Smaller tumors were more likely to regress. No patient suffered an adverse radiation effect after radiosurgery.

Conclusions
Gamma Knife surgery was a safe management strategy for small, minimally symptomatic, or growing FMMs as well as for residual tumors following conservative microsurgical removal.

Gamma knife radiosurgery of meningiomas involving the foramen magnum.

J Craniovertebr Junction Spine. 2010;1(1):23–28.
PMID: 20890411 DOI: 10.4103/097-8237.65478

Starke RM,[1] Nguyen JH, Reames DL, Rainey J, Sheehan JP.
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Background
Foramen magnum meningiomas represent a challenging clinical entity. Although resection is performed for those with a mass effect, complete resection is not always feasible. For some patients, stereotactic radiosurgery may be used as the primary treatment modality. We evaluatedthe long-term outcome of Gamma Knife radiosurgery (GKRS) for the treatment of patientswith a foramen magnum meningioma.

Materials and methods
Between 1991 and 2005, 222 patients with a meningioma in the posterior fossa were treated with GKRS at the University of Virginia. Of these patients, 5 had meningiomas involving the foramen magnum. At the time of GKRS, the median age of the patients was 60 years (range, 51–78). Three patients were treated with radiosurgery following an initial resection and 2 were treated with upfront radiosurgery. The patients were assessed clinically and radiologically at routine intervals following GKRS.

Results
The median tumor volume was 6.8 cc (range 1.9–17 cc). The GKRS tumor received a marginal dose of 12 Gy (range 10–15), and the median number of isocenters was 5 (range 3–19). The mean follow-up was 6 years (range 4–13). One lesion increased in size following GKRS requiring a second treatment, resulting in size stabilization. At the time of the last follow-up, all meningiomas had either demonstrated no growth (n = 4) or reduction in size (n = 1). No patients experienced post-radiotherapy complications.

Conclusions
GKRS affords a high rate of tumor control and preservation of neurologic function for patients with foramen magnum meningiomas. Further study of its role in the neurosurgical management of such patients seems warranted.

Stereotactic radiosurgery for anterior foramen magnum meningiomas.

Surg Neurol. 1999;51(3):268–273.
PMID:10086490 DOI: 10.1016/S0090-3019(98)00099-8

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Background
Total microsurgical resection is the procedure of choice for growing and symptomatic foramen magnum meningiomas. We hypothesized that for patients with advanced age, complicating medical conditions, or residual or recurrent meningiomas at the foramen magnum, stereotactic radiosurgery would be a useful adjunctive (n = 2) or alternative (n = 3) treatment.

Methods
We report our experience in five elderly patients (73–84 years) who underwent gamma knife radiosurgery. The median tumor volume was 10.5 ml and the tumor margin dose varied from 10 to 16 Gy. Because of the irregular tumor volumes along the inferior clivus, multiple isocenters of irradiation were required (range, 2–8; mean 4.4).

Results
During the follow-up interval of 1–5 years (median, 3 years), one patient died of an intercurrent illness, and all remaining patients were stable without any further deterioration in their clinical condition. Follow-up imaging studies revealed a reduction in tumor volume in one patient and no further growth in the remaining four.

Conclusion
We believe that stereotactic radiosurgery provides safe and effective management for patients who are poor candidates for resection of their foramen magnum meningiomas

Mirror meningioma at foramen magnum: a management challenge.

World Neurosurg. 2016;85:364.
PMID: 26282489 DOI: 10.1016/j.wneu.2015.08.006

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Background
Meningiomas of the foramen magnum are among the most challenging of all skull base lesions. Controversies continue regarding the most appropriate approach to this critical anatomic region. The authors report a first case in English literature about twin meningiomas arising from both sides of the ventrolateral dura at the foramen magnum.

Case description
Preoperative imaging showed a solitary mass engulfing the lower medulla. However, intraoperatively a twin mass was discovered. It encased the right side vertebral artery (VA) and abutted the left side. The unilateral far lateral transcondylar approach is not enough to resect both tumors at the same time. However, the far lateral transcondylar approach in both sides may compromise the stability and increase the risk of injury to either side of the neurovascular structures.

Conclusions
We suggest that resection can be safely achieved via the unilateral far lateral transcondylar approach followed by Gamma Knife radiosurgery (GKRS) or a staged bilateral approach.

Skull base

Outcomes and complications of gamma knife radiosurgery for skull base meningiomas.

J Neurol Surg B Skull Base. 2014;75(6):397–401.
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Objective
To review the outcomes and complications of meningiomas treated with gamma knife radiosurgery (GKRS) as a primary treatment as well as an adjunct therapy.

Materials and method
We performed a retrospective review (2000–2013) of 136 patients with meningiomas who received GKRS. Of 136 patients, 68 patients had recurrent or residual tumors after microsurgical resection, and the other 68 patients received GKRS alone. The study population was evaluated clinically and radiographically after GKRS treatment.

Results
GKRS in meningiomas showed significant variations in tumor growth control (decreased in 69 patients [50.7%], arrested growth in 47 patients [34.6%], and increased tumor size in 20 patients [14.7%]). Progression-free survival rates after GKRS at 3, 5, and 10 years were 98%, 95% and 85%, respectively. Overall improvement of signs and symptoms after GKRS was 30% (71% versus 41%) compared with pretreated sign and symptoms ($p = 0.0001$). The Karnofsky performance scale was significantly improved after GKRS compared with the pretreated status (92 versus 80). Twenty patients (14.7%) required resection after initial GKRS.

Conclusion
These study findings revealed that GKRS offers a high rate of tumor control, preservation of multiple nerve functions, and a good quality of life in both new and recurrent patients with meningiomas.

Gamma knife surgery for skull base meningiomas.

J Neurosurg. 2011;116(3):588–597.
PMID: 22175723 DOI: 10.3171/2011.11.JNS11530

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Objective
Skull base meningiomas are challenging tumors owing in part to their close proximity to important neurovascular structures. Complete microsurgical resection can be associated with significant morbidity, and recurrence rates are not inconsequential. In this study, the authors evaluate the outcomes of skull base meningiomas treated with Gamma Knife surgery (GKS) both as an adjunct to microsurgery and as a primary treatment modality.

Method
The authors performed a retrospective review of a prospectively compiled database detailing the outcomes in 255 patients with skull base meningiomas treated at the University of Virginia from 1989 to 2006. All patients had a minimum follow-up of 24 months. The group comprised 54 male and 201 female patients, with a median age of 55 years (range 19–85 years). One hundred nine patients were treated with upfront radiosurgery, and 146 patients were treated with GKS following resection. Patients were assessed clinically and radiographically at routine intervals following GKS. Factors predictive of new neurological deficit following GKS were assessed via univariate and multivariate analysis, and Kaplan-Meier analysis and Cox multivariate regression analysis were used to assess factors predictive of tumor progression.

Results
Meningiomas were centered over the cerebellopontine angle in 43 patients (17%), the clivus in 40 (16%), the petroclival region in 28 (11%), the petrous region in 6 (2%), and the parasellar region in 138 (54%). The median duration of follow-up was 6.5 years (range 2–18 years). The mean preradiosurgery tumor volume was 5.0 cm(3) (range 0.3–54.8 cm(3)). At most recent follow-up, 220 patients (86%) displayed either no change or a decrease in tumor volume, and 35 (14%) displayed an increase in volume. Actuarial progression-free survival at 3, 5, and 10 years was 99%, 96%, and 79%, respectively. In Cox multivariate analysis, pre-GKS covariates associated with tumor progression included age greater then 65 years (HR 3.41, 95% CI 1.63–7.13, p = 0.001) and decreasing dose to tumor margin (HR 0.90, 95% CI 0.80–1.00, p = 0.05). At most recent clinical follow-up, 230 patients (90%) demonstrated no change or improvement in their neurological condition and the condition of 25 patients had deteriorated (10%). In multivariate analysis, the factors predictive of new or worsening symptoms were increasing duration of follow-up (OR 1.01, 95% CI 1.00–1.02, p = 0.015), tumor progression (OR 2.91, 95% CI 1.60–5.31, p <0.001), decreasing maximum dose (OR 0.90, 95% CI 0.84–0.97, p = 0.007), and petrous or clival location versus parasellar, petroclival, and cerebellopontine angle location (OR 3.47, 95% CI 1.23–9.74, p = 0.018).

Conclusions
Stereotactic radiosurgery offers a high rate of tumor control and neurological preservation in patients with skull base meningiomas. After radiosurgery, better outcomes were observed for those receiving an optimal radiosurgery dose and harboring tumors located in a cerebellopontine angle, parasellar, or petroclival location.

Stereotactic radiosurgery for skull base meningioma.

Neurol Med Chir (Tokyo). 2009;49(10):456–61.
PMID: 19855141

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Stereotactic radiosurgery is now a treatment option for meningiomas, especially for high-risk patients such as those with skull base lesions. The clinical outcomes were retrospectively analyzed of stereotactic radiosurgery using the Leksell Gamma Knife((R)) performed for 98 patients with 106 skull base meningiomas at the University of Tokyo Hospital between June 1990 and April 2006 and followed up for more than a year. After a median follow-up period of 53.2 months (range 12.2–204.4 months), local tumor control rates were 86.9% and 78.9% at 5 years and 10 years, respectively. Tumors with volume of 4 cm(3) or smaller (97.5% vs. 76.1% at 5 years, p = 0.001) and tumors completely included within the isodose line of 14 Gy or more (97.5% vs. 67.2% at 5 years, p = 0.0006) had higher local control rates. Postoperative residual tumors treated by stereotactic radiosurgery were controlled in all 25 cases. Cranial nerve deficits were improved, stable, and deteriorated in 12, 64, and 3 patients, respectively, after stereotactic radiosurgery. Stereotactic radiosurgery was effective treatment method for local control of skull base meningiomas, especially for small or postoperative residual tumors. Correct combination of microsurgery and radiosurgery leads to excellent local control.

Gamma knife radiosurgery for skull base meningioma: long-term results of low-dose treatment.

J Neurosurg. 2008;109(5):804–810.
PMID: 18976068 DOI: 10.3171/JNS/2008/109/11/0804

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Objective
In this study, the authors evaluate the long-term results after Gamma Knife radiosurgery of cranial base meningiomas. This study is a follow-up to their previously published report on the early results.

Methods
Between January 1994 and December 2001, the authors treated benign cranial base meningiomas in 108 patients using low-dose Gamma Knife radiosurgery. The tumor volumes ranged from 1.7 to 55.3 cm3 (median 8.1 cm3), and the radiosurgery doses ranged from 8 to 12 Gy (median 12 Gy) to the tumor margin.

Results
The mean duration of follow-up was 86.1 months (range 20-144 months). Tumor volume decreased in 50 patients (46%), remained stable in 51 patients (47%), and increased (local failure) in 7 patients (6%). Eleven patients experienced tumor recurrence outside the treatment field. Among these patients, marginal failure was seen in 5 and distant recurrence was seen in 6. Seven patients were thought to have malignant transformation based on histological or radiological characteristics of the lesion. The actuarial progression-free survival rate, including malignant transformation and outside recurrence, was 93% at 5 years and 83% at 10 years. Neurological status improved in 16 patients (15%). Permanent radiation injury occurred in 7 patients (6%).

Conclusions
Gamma Knife radiosurgery is a safe and effective treatment for cranial base meningiomas as demonstrated with a long-term follow-up period of >7 years. Surgeons must be aware of the possibility of treatment failure, defined as local failure, marginal failure, and malignant transformation; however, this may be the natural course of meningiomas and not related to radiosurgery.

Gamma knife radiosurgery for skull-base meningiomas.

Prog Neurol Surg. 2009;22:96–111.
PMID: 18948722 DOI: 10.1159/000163385

Takanashi M,[1] Fukuoka S, Hojyo A., Sasaki T, Nakagawara J, Nakamura H.
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Objective
The primary purpose of this study was to evaluate the efficacy of gamma knife radiosurgery (GKRS) when used as a treatment modality for cavernous sinus or posterior fossa skull-base meningiomas (SBMs), with particular attention given to whether or not intentional partial resection followed by GKRS constitutes an appropriate combination treatment method for larger SBMs.

Patients and methods
Of the 101 SBM patients in this series, 38 were classified as having cavernous sinus meningiomas (CSMs), and 63 presented with posterior fossa meningiomas (PFMs). The patients with no history of prior surgery (19 CSMs, 57 PFMs) were treated according to a set protocol. Small to medium-sized SBMs were treated by GKRS only. To minimize the risk of functional deficits, larger tumors were treated with the combination of intentional partial resection followed by GKRS. Residual or recurrent tumors in patients who had undergone extirpations prior to GKRS (19 CSMs, 6 PFMs) are not eligible for this treatment method (due to the surgeries not being performed as part of a combination strategy designed to preserve neurological function as the first priority).

Results
The mean follow-up period was 51.9 months (range, 6–144 months). The overall tumor control rates were 95.5% in CSMs and 98.4% in PFMs. Nearly all tumors treated with GKRS alone were well controlled and the patients had no deficits. Furthermore, none of the patients who had undergone prior surgeries experienced new neurological deficits after GKRS. While new neurological deficits appeared far less often in those receiving the combination of partial resection with subsequent GKRS, extirpations tended to be associated with not only a higher incidence of new deficits but also a significant increase in the worsening of already-existing deficits.

Conclusions
Our results indicate that GKRS is a safe and effective primary treatment for SBMs with small to moderate tumor volumes. We also found that larger SBMs compressing the optic pathway or brain stem can be effectively treated, minimizing any possible functional damage, by a combination of partial resection with subsequent GKRS.

Gamma knife radiosurgery for skull base meningiomas: long-term radiologic and clinical outcome.

Int J Radiat Oncol Biol Phys. 2008;72(5):1324–1332.
PMID: 18922647 DOI: 10.1016/j.ijrobp.2008.03.028

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Purpose
To analyze the long-term outcomes in patients with skull base meningiomas (SBMNGs) treated with Gamma Knife radiosurgery (GKRS).

Materials and methods
Of the 98 consecutive patients with SBMNGs treated with GKRS between 1998 and 2002, 63 were followed up for more than 48 months. The mean (+/-SD) age of the patients was 50 +/- 12 years, the mean tumor volume was 6.5 cm(3) (range, 0.5–18.4 cm(3)), the mean marginal dose was 12.6 Gy (range, 7.0–20.0 Gy), and the mean follow-up duration was 77 +/- 18 months. The mean number of shots was 13.7 +/- 3.8. The tumor volume was decreased at the last follow-up in 28 patients (44.4%) and increased in 6 (9.6%). The actuarial tumor control rate was 90.2% at 5 years. No notable prognostic factor related to tumor control was identified. Ten patients (15.9%) with a cranial neuropathy showed unfavorable outcomes. The rate of improvement in patients with a cranial neuropathy was 45.1%. Age >70 years was likely correlated with an unfavorable outcome in patients with cranial neuropathy (odds ratio = 0.027; p = 0.025; 95% confidence interval 0.001–0.632). Cavernous sinus location was significantly associated with improvement of a cranial neuropathy (odds ratio = 7.314; p = 0.007; 95% confidence interval 1.707–31.34).

Conclusions
Gamma Knife radiosurgery is an effective modality for the treatment of SBMNGs and provides favorable outcomes in patients with cranial neuropathy, even in the long-term follow-up period. However, radiosurgery for patients with no or only mild symptoms should be performed cautiously because neither complication rate is low enough to be negligible, especially in elderly patients. A cranial neuropathy by MNGs involving the cavernous sinus seems to have a higher chance of improvement after radiosurgery than other SBMNGs.

The principles of skull base radiosurgery.

Neurosurg Focus. 2008;24(5):E11.
PMID: 18447740 DOI: 10.3171/FOC/2008/24/5/E11

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Stereotactic radiosurgery is commonly used for selected patients with benign cranial base tumors. The goal of radiosurgery is cessation of tumor growth and preservation of neurological function. Over the last 2 decades, the technique of radiosurgery has evolved due to improved imaging, better radiosurgical devices and software, and the continued analysis of results. In this report, the authors discuss technical concepts and dose selection in skull base radiosurgery.

Postoperative gamma knife surgery for benign meningiomas of the cranial base.

Neurosurg Focus. 2007;23(4):E6.
PMID: 17961043 DOI: 10.3171/FOC-07/10/E6

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Objective
The standard treatment for meningiomas is complete resection, but the proximity of skull base meningiomas to important neurovascular structures makes complete excision of the lesion difficult or impossible. The authors analyzed the mid- and long-term results obtained in patients treated with postresection Gamma Knife surgery (GKS) for residual or recurrent benign meningiomas of the cranial base.

Method
Thirty-six patients with residual or recurrent benign meningiomas of the skull base following one or more surgical procedures underwent GKS. There were 31 women and five men, ranging in age from 22 to 73 years. The median tumor volume was 4.1 ml (range 0.8–20 ml) and the median radiation dose to the tumor margin was 16 Gy (range 15–16 Gy).

Results
Patients were followed for a median of 81 months (range 30–141 months) after GKS. At the end of the follow-up period, overall neurological improvement was observed in 16 patients (44.4%), whereas the condition in 20 patients (55.6%) was unchanged. One patient suffered transient cerebral edema 6 months after GKS. Based on imaging documentation, a partial response was seen in five patients (13.9%), the disease remained stable in 30 patients (83.3%), and in one patient (2.8%) there was an increase in tumor size. The actuarial progression-free survival rate was 100% at 5 years and 94.7% at 10 years.

Conclusions
Gamma Knife surgery was shown to be an excellent adjunct to resection because of its durable rate of tumor control and low toxicity. It should be initially considered along with surgery for the treatment of complex skull base meningiomas.

Gamma-knife radiosurgery for cranial base meningiomas: experience of tumor control, clinical course, and morbidity in a follow-up of more than 8 years.

Neurosurgery. 2006;58(1):28–36.
PMID: 16385326 DOI: 10.1055/s-2009-1222316

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Objective
Surgical resection of cranial base meningiomas is often limited owing to involvement of crucial neural structures. Within the last 2 decades Gamma Knife radiosurgery (GKRS) has gained increasing importance as an adjunct treatment after incomplete resection and as an alternative treatment to open surgery. However, reports of long- term results are still sparse. We therefore performed this study to analyze the long-term results of GKRS treatment of cranial base meningiomas, following our previously published early follow-up experience.

Method
A retrospective analysis of the medical files for Gamma Knife and surgical treatments, clinicoradiological findings, and outcome was carried out focusing on tumor control, clinical course, and morbidity.

Results
Between 1992 and 1995, we treated 36 patients with cranial base meningiomas using GKRS (male:female ratio, 1:5; mean age, 59 yr; range, 44–89 yr). Twenty-five patients were treated with GKRS after open surgery, and 11 patients received GKRS alone. Tumor control, neurological outcomes, and adverse effects were analyzed after a long-term follow-up period (mean, 103 mo; range, 70–133 mo) and compared with our previous results after an early follow-up period (mean, 48 mo; range, 36–76 mo). Control of tumor growth was achieved in 94% of patients. Compared with the early follow-up period, the late neuroradiological effects of GKRS on cranial base meningiomas were continuing tumor shrinkage in 11 patients (33%), stable tumor size in 20 patients (64%) and tumor progression in two meningiomas (6%). The neurological status improved in 16 patients (44%), remained stable in 19 patients (52%), and deteriorated in one patient (4%). Adverse side effects of GKRS were found only during the early follow-up period.

Conclusions
Our data confirm that GKRS is not only a safe and effective treatment modality for cranial base meningiomas in short- term observation, but also in a mean long-term follow-up period of more than 8 years. Tumor shrinkage and clinical improvement also continued during the longer follow-up period.

Gamma-knife radiosurgery for cranial base meningiomas: experience of tumor control, clinical course, and morbidity in a follow-up of more than 8 years – Commentary.
Neurosurgery. 2006;58(1):36.
PMID: 16385326
Lunsford LD, Chang SD, Pollock BE.
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Gamma knife radiosurgery in skull base meningiomas: a possible relationship between somatostatin receptor decrease and early neurological improvement without tumour shrinkage at short-term imaging follow-up.
Acta Neurochir (Wien). 2005;147(4):367–375.
PMID: 15696264 DOI: 10.1007/s00701-005-0483-9
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Background
This study investigates a possible relationship between the effects of gamma knife (GK) on meningioma somatostatin receptors (SRs) and the high rate of early neurological improvement without tumour reduction at short-term imaging follow-up.

Methods
From December 1997 to December 2002, somatostatin receptor scintigraphy (SRS) using an (111)Indium-labelled somatostatin analogue, Octreotide, was performed both before and 7-12 months after radiosurgery in 20 patients with intracranial meningiomas. Semiquantitative data were calculated as an SRS index.

Results
The pre-GK SRS index was always >1, averaging 4.44+/-3.20. There were no statistically significant differences between the pre-GK average values of primary (4.80+/-3.65) and residual (3.75+/-1.93) meningiomas. At the first clinical/MRI follow-up, the neurological examination had improved in 15/20 (75%) and had not changed in 5/20 patients. A corresponding slight tumour shrinkage on high-resolution MRI was documented in 3/20 cases only. The post-GK average SRS index was lower than pre-GK values both in primary (3.87+/-3.19) and in adjuvant (2.52+/-1.14) treatments, but the differences were not significant. However, the subgroup of patients with early neurological improvement showed a higher pre-GK average SRS index (5.21+/-3.33) and a more substantial post-GK average SRS index decrease (3.86+/-3.00) than the patients whose clinical condition remained stable (2.10+/-0.59 and 1.99+/-0.55, respectively). The difference between the two subgroups of patients proved to be statistically significant ($P < 0.05$).

Conclusions
Our preliminary findings suggest a possible relationship between a decrease in the concentration of SRs on meningioma cells at short-term functional imaging follow-up after radiosurgery and early neurological improvement.

Long term experience of gamma knife radiosurgery for benign skull base meningiomas.

J Neurol Neurosurg Psychiatry. 2005;76(10):1425–1430.
PMID: 16170090 DOI: 10.1136/jnnp.2004.049213

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Objective

As most reports on the gamma knife have related only to short or mid-term results, we decided to evaluate the effectiveness and toxicity of radiosurgical treatment for benign skull base meningiomas in 200 patients with a follow up of 5-12 years to define the role of gamma knife radiosurgery (GKRS) for basal meningiomas and to provide further data for comparison with other treatment options.

Method

In total, 99 patients were treated with a combination of microsurgical resection and GKRS. In 101 patients, GKRS was performed as the sole treatment option. Tumour volumes ranged from 0.38 to 89.8 cm3 (median 6.5 cm3), and doses of 7-25 Gy (median 12 Gy) were given to the tumour borders at covering isodose volume curves (range 20-80%, median 45%).

Results

The actuarial progression free survival rate was 98.5% at 5 years and 97.2% at 10 years. Passing radiation induced oedema occurred in two patients (1%). The neurological status improved in 83 cases (41.5%), remained unaltered in 108 (54%), and deteriorated in 9 (4.5%). Worsening was transient in seven patients (3.5%) and unrelated to tumour or treatment in one (0.5%). Repeated microsurgical resection was performed in five patients following GKRS (2.5%).

Conclusions

GKRS has proved to be an effective alternative to microsurgical resection, radiotherapy, and Linac based radiosurgery for adjunctive and primary treatment of selected patients with basal meningiomas. Because of the excellent long term tumour control rate and low morbidity associated with GKRS, this treatment option should be used more frequently in the therapeutic management of benign skull base meningiomas.

The evolving role of stereotactic radiosurgery for patients with skull base tumors.

J Neurooncol. 2004;69(1-3):199–207.
PMID: 15527091 DOI: 10.1023/B:NEON.0000041883.22235.15

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Tumors located at the base of the skull are among the most difficult problems that neurosurgeons encounter. Management of patients with skull base tumors must take into account that complete tumor removal is not possible with acceptable morbidity in many patients. Therefore, radiation therapy and stereotactic radiosurgery are commonly performed. The use of radiosurgery for patients with skull base tumors has increased significantly over the past three decades and we now possess a better understanding of the expectations of skull base radiosurgery. For properly selected patients with benign tumors (meningiomas, schwannomas, glomus tumors), tumor control rates between 90 and 100% have been reported. Local control rates for chordomas and chondrosarcomas have ranged from 50 to 70%, but tumor growth adjacent to the treated area (marginal failure) remains a significant problem. Radiosurgery is also commonly performed for patients with malignant skull base tumors as a palliative treatment and symptom relief is common, especially for patients with facial pain related to their tumor. Follow-up beyond 10 years is still needed to better define long-term results of radiosurgery and the incidence of radiation-induced neoplasms after radiosurgery.

Gamma knife radiosurgery of skull base meningiomas.

Acta Neurochir Suppl. 2004;91:65–74.
DOI: 10.1007/978-3-7091-0583-2_7

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Meningiomas are the most frequent benign tumors treated by gamma knife radiosurgery and the majority of them are located on the skull base. Between 1992 and 1999, 197 skull base-located meningiomas in 192 patients were treated by gamma knife in Prague. Contact with the chiasma or optic tract was not regarded as a contraindication for gamma knife radiosurgery and such contact was observed in 32% of the skull base meningiomas treated. 176 patients were monitored during a median of 36 months, of whom 73% showed a decrease in tumor volume; no change was observed in 25% and continued growth was observed in 2%. Neurodeficit improved in 63% of patients, temporary morbidity occurred in 11% and persistent morbidity remained in 4.5%. Radiosurgery induced edema in 11%. Significantly lower edema occurrence was observed after radiosurgery in patients with no history of edema prior to radiosurgery, where the tumor was located in the posterior skull base and where the dosage to the tumor margin was lower than or equal to 14 Gy. Radiosurgery of skull base meningiomas has been proven to be safe and efficient. We consider gamma knife treatment for skull base meningiomas to be the method of choice whenever tumors are within the volume limits and there is no need for an urgent decompressive effect from the open operation.

Long-term results of gamma radiosurgery for skull base meningiomas.

Japanese Journal of Neurosurgery. 2003;12(5):370–377.
DOI: 10.7887/jcns.12.370

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The effects of gamma radiosurgery on 106 out of 150 cases of skull base meningiomas which had been treated by gamma knife and followed-up for more than 3 years (mean of 48.2 months) have been evaluated. Overall results showed that partial resonse (PR) was found in 44 cases, minor response (MR) in 9, no change (NC) in 42 and progression (PG) in 11. Another words, response rate was 41.5%, control rate was 89.6% and progression rate was 10.4%. There found differences of the response among different locations; the response rate of C-P angle and CS-parasellar meningiomas showed higher than others, but control rate was higher in C-P angle and tentorial meningioma. Progression was found only in CS-parasellar and petroclival meningioma. The progression rate has changed from 0% at less than 3 years of follow-up, 10.4% at more than 3 years and 18.2% at more than 5 years. The factors related to the progression are the tumor size, the radiation dosis, the locations and the tumor pathology. Side effects were found in 4 cases (4.6%) -that is radiation induced edema in one, hearing deterioration in two and visual deterioration in one case within 2 years of treatment.

Preservation of cranial nerve function following gamma knife radiosurgery for benign skull base meningiomas: experience in 121 patients with follow-up of 5 to 9.8 years.

Acta Neurochir Suppl. 2002;84:71–76.
PMID: 12379007 DOI: 10.1007/978-3-7091-6117-3_8

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Introduction
Microsurgical excision with preservation of juxtaposed neurovascular structures is considered the treatment of choice for skull base meningiomas, but there exists a great controversy regarding surgical resectability, potential risk for subsequent postoperative Cranial Nerve Deficit (CND) and the role of adjuvant or adjunctive treatment options. In this study we evaluated the effect of Gamma Knife Radiosurgery (GKRS) in 121 patients with benign basal meningiomas after a follow-up of 5 to 9.8 years.

Methods
Sixty patients had undergone open resections prior to radiosurgical treatment and 61 patients were treated by GKRS alone. Tumour volumes of 0.5 to 89.9 ccm (median 6.8 ccm) received a median marginal dose of 13 Gy (range 7–25 Gy) at the covering 25% to 80% isodose volume curves (median 45%).

Results
Neuroradiological controls demonstrated decreased tumour size in 73 patients (60.3%), stable meningioma volume in 47 cases (38.9%) and tumour enlargement in one patient (0.8%). Clinically, 54 patients (44.6%) improved and 61 cases (50.4%) remained unchanged. Four patients (3.3%) showed temporary and two patients (1.7%) permanent neurological deterioration (unrelated to tumour or treatment in one patient). Two patients (1.7%) developed radiation induced new or aggravated pre-existent CND (1 transient, 1 permanent) and two patients (1.7%) required further surgical resection.

Conclusions
In our long-term experience, GKRS proved to be an attractive additional and save alternative primary treatment option in selected patients with basal meningiomas. The tumour control rate of 98.3% associated with excellent clinical outcome and low incidence for treatment related CND (1.7%) compares favourably with the reported microsurgical series.

Radiosurgery as alternative treatment for skull base meningiomas.

J Clin Neurosci. 2001;8(4):12–14.
PMID: 11386818 DOI: 10.1054/jocn.2001.0869

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The effect of radiosurgical treatment of skull base meningiomas in 197 patients with a follow-up of at least 2 years was evaluated. Ninety- two of these patients had combined surgical and radiosurgical treatment, while Gamma Knife Radiosurgery (GKRS) was performed as primary treatment in 105 patients. Follow-up was available in 164 patients with intervals of 25–97 months (median 55 months) after GKRS. The imaging controls revealed decreased tumour size in 84 patients (51%), stable tumour volume in 76 ca ses (47%) and increased tumour size in 4 cases (2%). Neurological examinations showed improved neurological status in 58 cases (35%), stable clinical status in 100 patients (61%) and slight worsening in 6 cases (4%). Due to excellent tumour control rate, good clinical outcome and a low complication rate GKRS represents not only an attractive additional treatment option for basal meningiomas, but may even replace microsurgery in selected cases.

Gamma knife radiosurgery for skull base meningiomas.

Neurosurg Clin N Am. 2000;11(4):659–666.
PMID: 11082176

Pollock BE[1], Stafford SL, Link MJ.
[1]Department of Neurological Surgery, Mayo Clinic and Foundation, Rochester, Minnesota, USA.

Radiosurgery has been proven to be a safe and effective management strategy for skull base meningiomas either primarily or for tumor recurrence or progression after prior microsurgical resection. With its steep radiation falloff, radiosurgery provides long-term tumor growth control without the complications associated with conventional fractionated radiation therapy. Stereotactic MR imaging has allowed better definition of the tumor margin for precise multiisocenter conformal dose planning, and our current radiation dose prescription has decreased the incidence of new cranial nerve deficits after radiosurgery to less than 10%. Tumor growth control after radiosurgery remains greater than 90%; patients with subsequent growth typically have tumor outside the irradiated volume or a histologic diagnosis of atypical or malignant meningioma. Still, longer follow-up is needed to ensure that tumor growth control remains permanent after radiosurgery. For patients with large tumors of the skull base, radiosurgery can be part of a staged approach with microsurgery. Initially, the tumor is debulked without an attempt at resection involving the cranial nerves or basal vessels. Radiosurgery can then be performed for the small remaining tumor volume with little risk of cranial nerve deficits. Such multimodality treatment should result in reduced patient morbidity, with long-term tumor control.

Risk of injury to cranial nerves after gamma knife radiosurgery for skull base meningiomas: experience in 88 patients.

J Neurosurg. 1999;90(1):42–49.
PMID: 10413154 DOI: 10.317/jns.1999.90.1.0042

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Introduction

In this study the authors sought to determine the neurological risks and potential clinical benefits of gamma knife radiosurgery for skull base meningiomas.

Methods

A consecutive series of 88 patients harboring skull base meningiomas were treated between 1990 and 1996 by using the Leksell gamma knife in a prospective clinical study that included a strict dose-volume protocol. Forty-nine patients had previously undergone surgery, and six had received external-beam radiotherapy. The median treatment volume was 10 cm3, and the median dose to the tumor margin was 16 Gy. The radiosurgical dosage to the optic nerve, the cavernous sinus, and Meckel's cave was calculated and correlated with clinical outcome. The median patient follow-up time was 35 months (range 12–83 months). Two tumors (2.3%) progressed after radiosurgery; the progression-free 5-year survival rate was 95%. At last follow-up review, 60 (68%) tumors were smaller and 26 (29.5%) remained unchanged. Clinical improvement (in vision, trigeminal pain, or other cranial nerve symptoms) occurred in 15 patients. Functioning optic nerves received a median dose of 10 Gy (range 1–16 Gy), and no treatment-induced visual loss occurred. Among nine patients with new trigeminal neuropathy, six received doses of more than 19 Gy to Meckel's cave.

Conclusions

Gamma knife radiosurgery appeared to be an effective method to control the growth of most skull base meningiomas in this intermediate-term study. The risk of trigeminal neuropathy seemed to be associated with doses of more than 19 Gy, and the optic apparatus appeared to tolerate doses greater than 10 Gy. Considering the risks to cranial nerves associated with open surgery for comparable tumors, the authors believe that gamma knife radiosurgery is a useful method for the management of properly selected recurrent, residual, or newly diagnosed skull base meningiomas.

Gamma knife surgery for skull base meningiomas. The effectiveness of low-dose treatment.

Surg Neurol. 1999;52(1):40–44.
PMID: 10390171 DOI: 10.1016/S0090-3019(99)00037-3

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Background
The surgical removal of skull base meningiomas has a high morbidity rate, even by modern microsurgical standards. We evaluated the results of gamma knife surgery for skull base meningiomas using a relatively low radiation dose for the tumor margins.

Method
We reviewed 24 cases of skull base meningiomas during a 30-month period. The locations of the tumors were the petroclival region in 11 cases, the cavernous sinus region in 9 cases, and the cerebellopontine angle region in 4 cases. Eight patients (33%) had been operated on previously and fourteen patients (67%) had been treated by neuroimaging. The marginal doses for the tumors were 8 Gy to 15 Gy (median, 10.6 Gy). A large petroclival tumor 58 mm in diameter was treated with a staged treatment protocol with a 6-month interval between treatments.

Results
Tumor regression was observed in 46% of the patients imaged during the follow-up period (median, 17.1 months). No patients revealed tumor growth in the follow-up period (100% tumor control rate). Eleven patients (46%) had improved clinically by the time of the follow-up examinations. Preexisting cranial nerve deficit in one patient worsened because of radiation injury.

Conclusions
Although a longer follow-up period is required, the relatively low minimum tumor radiation dose treatment for skull base meningiomas using a gamma knife seems to be an effective treatment with low morbidity.

Stereotactic radiosurgery of skull base meningiomas.

Minim Invasive Neurosurg.1997;40(3):87–90.
DOI: 10.1055/s-2008-1053423

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Between April 1992 and February 1996, 97 patients with skull base meningiomas were treated at our department. The age of these patients ranged from 10 to 80 years. The male/female ratio was 1/2. Fifty-three of these patients had primary open surgery for partial removal or recurrent growth and subsequent radiosurgical treatment. Radiosurgery was performed as a primary treatment in 44 patients. The mean tumor volume was 13.7 cm3 (range: 0.8–82 cm3). These tumor volumes could be covered by mean isodose volumes of 45% (range: 20–70%) and were treated by a mean dose of 13.8 Gy (range: 7–25 Gy) at the tumor border. Six patients underwent radiosurgery with a staged treatment protocol with 4.6–6 months interval. In 78 patients, a total of 102 follow-up scans were available. The remaining 19 patients have not been included in the post-radiosurgical evaluation since the observation time was either too short or the patients were lost for follow-up. The mean interval between gamma knife treatment and last follow-up scan was 18.5 months, with a range from 6 to 46 months. Follow-up imaging (CT, MRI or both) revealed a decreased volume of the tumor in 31 cases (40%). In 44 cases (56%), tumor progression was stopped, and in 3 cases (4%) increased tumor volumes could be observed. In 8 cases marked central tumor necrosis was seen. Neurological follow-up examinations in 76 patients showed a stable neurological status in 71%, ameliorated status in 24% and worsening in 5% of the patients.

Growth control of cranial base meningiomas by stereotactic radiosurgery with a gamma knife unit.

Neurol Med Chir (Tokyo). 1996;36(1):7–10.
PMID: 8786836 DOI: 10.2176/nmc.36.7

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The effect of gamma knife radiosurgery for cranial base meningiomas was analyzed using magnetic resonance (MR) imaging in 33 patients followed up for a mean 26.5 months. There were 10 male and 23 female patients aged from 38 to 87 years (mean 54.5 yrs). Twenty-three patients had already had more than one open surgery before radiosurgery. The mean tumor volume was 16.8 cm3. The mean maximum dose was 29 Gy and the mean marginal dose was 15.1 Gy. Four patients were treated by two-stage treatment at 1– to 4–month intervals. Follow-up MR imaging revealed a decrease in tumor size in 10 patients, a small low intensity area in the tumor center in three, increase in tumor size in two, and no change in 18. After radiosurgery one patient had marked edema on MR imaging and showed cognitive deficits, and another three patients had neurological deterioration. All other patients were unchanged or improved. Growth control of cranial base meningiomas without severe neurological deficits can be achieved by radiosurgery.

Gamma knife radiosurgery in skull base meningiomas. Preliminary experience with 50 cases.

Stereotact Funct Neurosurg. 1996;66(1)(suppl):112–120.
PMID: 9032851 DOI: 10.1159/000099776

Nicolato A,[1] Ferraresi P, Foroni R, Pasqualin A, Piovan E, Severi F, Masotto B, Gerosa M.
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Gamma Knife radiosurgery was performed on 50 patients (10 males and 40 females) with skull base meningiomas (SBMs) between February 1993 and September 1995. The patients ranged in age from 25 to 78 years (mean age 56 years). The location of the tumors was anterior fossa (n = 4), sphenoorbital (n = 2), sellar region (n = 5), cavernous sinus (n = 26), petroclival (n = 12), and occipital foramen (n = 1). The tumor volume ranged from 0.6 to 20 cm3 (mean 8.6 cm3). The mean values for dose planning were edge isodose (EI) 46.7%, edge dose (ED) 18.0 Gy, maximum dose 39.8 Gy, average dose (AD) 25.4 Gy, and average number of isocentres 5.7. The patients were analyzed for five parameters: tumor volume (<7.5 vs. > or = 7.5 cm3); EI (<50 vs. > or = 50%); ED (<18 vs. > or = 18 Gy); AD (<25 vs. > or = 25 Gy), and primary versus residual or recurrent tumors. The overall frequency of tumor growth control (TGC) was 98%, with 1– and 2–year TGC rates of 97% and 100%, respectively. The most favorable neurological results were obtained with a tumor volume <7.5 cm3 ($p < 0.05$), EI > or = 50% (NS), ED > or = 18 Gy (NS) and with primary SBMs ($p < 0.01$). A favorable TGC was demonstrated at follow-up imaging examinations when the tumor volume was > or = 7.5 cm3 (100% TGC rate), EI <50% (100%), ED > or = 18 Gy (100%), AD >25 Gy (100%), in both primary SBMs (100%) and residual or recurrent SBMs (96.5%). To date, only 3 (6%) of the 50 patients have presented signs of neurological worsening related to the Gamma Knife radiosurgery. While no early complications were noted, neuroradiological follow-up did show delayed transient imaging complications (3 edema and 1 radionecrosis; 8% of all patients). In conclusion, our preliminary results seem to confirm that Gamma Knife radiosurgery is an effective and safe adjuvant or a feasible alternative primary treatment in controlling or preventing SBM progression.

Long-term results of stereotactic radiosurgery for skull base meningiomas.

Neurosurgery. 2016;79(1):58–68.
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Background
Gamma knife radiosurgery (GKRS) is well established in the management of inaccessible, recurrent, or residual benign skull base meningiomas. Most series report clinical outcome parameters and complications in the short intermediate period after radiosurgery. Reports of long-term tumor control and neurological status are still lacking.

Objective
To report the presentation, treatment, and long-term outcome of skull base meningiomas after GKRS.

Method
From a prospectively collected institutional review board-approved database, we selected patients with a World Health Organization grade I skull base meningioma treated with a single-session GKRS and a minimum of 60 months follow-up. One hundred thirty-five patients, 54.1% males (n = 73), form the cohort. Median age was 54 years (19–80). Median tumor volume was 4.7 cm (0.5–23). Median margin dose was 15 Gy (7.5–36). Median follow-up was 102.5 months (60.1–235.4). Patient and tumor characteristics were assessed to determine the predictors of neurological function and tumor progression.

Results
At last follow-up, tumor volume control was achieved in 88.1% (n = 119). Post-GKRS clinical improvement or stability was reported in 61.5%. The 5-, 10-, and 15-year actuarial progression-free survival rates were 100%, 95.4%, and 68.8%, respectively. Favorable outcome (both tumor control and clinical preservation/improvement) was attained in 60.8% (n = 79). Pre-GKRS performance status (Karnofsky Performance Scale) was shown to influence tumor progression (P = .001) and post-GKRS clinical improvement/preservation (P = .003).

Conclusions
GKRS offers a highly durable rate of tumor control for World Health Organization grade I skull base meningiomas, with an acceptably low incidence of neurological deficits. The Karnofsky Performance Scale at the time of radiosurgery serves as a reliable long-term predictor of overall outcome.

Cavernous sinus

Gamma knife surgery of meningiomas involving the cavernous sinus: long-term follow-up of 100 patients.
Neurosurg. 2010;66(4):661–668.

PMID: 20305491 DOI: 10.1227/01.NEU.0000366112.04015.E2

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Objective
Resection of meningiomas involving the cavernous sinus often is incomplete and associated with considerable morbidity. As a result, an increasing number of patients with such tumors have been treated with gamma knife surgery (GKS). However, few studies have investigated the long-term outcome for this group of patients.

Method
100 patients (23 male/77 female) with meningiomas involving the cavernous sinus received GKS at the Department of Neurosurgery at Haukeland University Hospital, Bergen, Norway, between November 1988 and July 2006. They were followed for a mean of 82.0 (range, 0–243) months. Only 2 patients were lost to long-term follow-up. Sixty patients underwent craniotomy before radiosurgery, whereas radiosurgery was the primary treatment for 40 patients.

Results
Tumor growth control was achieved in 84.0% of patients. Twelve patients required re-treatment: craniotomy (7), radiosurgery (1), or both (4). Three out of 5 patients with repeated radiosurgery demonstrated secondary tumor growth control. Excluding atypical meningiomas, the growth control rate was 90.4%. The 1–, 5–, and 10–year actuarial tumor growth control rates are 98.9%, 94.2%, and 91.6%, respectively. Treatment failure was preceded by clinical symptoms in 14 of 15 patients. Most tumor growths appeared within 2.5 years. Only one third grew later (range, 6–20 yr). The complication rate was 6.0%: optic neuropathy (2), pituitary dysfunction (3), worsening of diplopia (1), and radiation edema (1). Mortality was 0. At last follow-up, 88.0% were able to live independent lives.

Conclusions
GKS gives long-term growth control and has a low complication rate. Most tumor growths manifest within 3 years following treatment. However, some appear late, emphasizing the need for long-term follow-up.

Neuroophthalmological evaluation after gamma knife surgery for cavernous sinus meningiomas.

Neurosurg Focus. 2007;23(6):E10.
PMID: 18081487 DOI: 10.3171/FOC-07/12/E10

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Objective
Treatment options for patients with cavernous sinus meningiomas (CSMs) include microsurgical tumor resection, radiotherapy, and radiosurgery. Gamma Knife surgery (GKS) is increasingly being used because it is associated with lower mortality and morbidity rates than microsurgery. The purpose of this study was to assess the role of GKS in the treatment of CSM and to thoroughly analyze the clinical response to GKS.

Method
Between January 2001 and December 2005, 123 patients (25 men and 98 women; mean age 62.6 +/- 11 years, range 31–86 years) who underwent treatment for CSMs were included in this study. Of these, 41 patients underwent microsurgery before GKS, whereas the remaining 82 had GKS as a first-line therapy after a diagnosis was made based on magnetic resonance imaging findings. Dysfunction in cranial nerves (CNs) II, III, IV, V, and VI was noted in 74 patients at the time of GKS. The mean tumor volume was 7.99 cm(3) (0.7–30.5 cm(3)). The mean prescription dose to the tumor margin was 13.8 +/- 1.1 Gy (range 10–20 Gy).

Results
The overall tumor control rate was 98.4% with a median follow-up of 36 months. The actuarial tumor control rate at 5 years was 90.5%. A reduction in tumor volume was observed in 53 patients (43.1%), whereas in 68 patients (55.3%) no volumetric variation was recorded. Of the 74 patients who presented with CN deficits, improvement was noted in 23 (31.1%).

Conclusions
Gamma Knife surgery is a useful treatment for CSM both as a first- or second-line therapy. It is a safe and effective treatment for tumors located close to the optic pathways.

Long-term outcomes of gamma knife surgery for cavernous sinus meningioma.

J Neurosurg. 2007;107(4):745-751.
PMID: 17937218 DOI: 10.3171/JNS-07/10/0745

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Objective
The aim of this study was to evaluate long-term outcomes, including tumor control and neurological function, in patients with cavernous sinus meningiomas treated using Gamma Knife surgery (GKS).

Method
One hundred fifteen patients with cavernous sinus meningiomas, excluding atypical or malignant meningiomas, were treated with GKS between 1991 and 2003. Forty-nine patients (43%) underwent GKS as the initial treatment. The mean tumor volume was 14 cm3, and the mean maximum and margin doses applied to the tumor were 27 and 13 Gy, respectively. The median follow-up period was 62 months. During the follow-up, 111 patients were able to be evaluated with neuroimaging.

Results
The actuarial 5- and 10-year progression-free survival rates were 87 and 73%, respectively. Similarly, the actuarial 5- and 10-year focal tumor control rates were 94 and 92%, respectively. Regarding functional outcomes, 43 patients (46%) experienced some degree of improvement, 40 (43%) remained stable, and 11 (12%) had worse preexisting or newly developed symptoms. Patients who underwent GKS as the initial treatment experienced significant improvement of their symptoms ($p = 0.006$).

Conclusions
Gamma Knife surgery is a safe and effective treatment over the long term in selected patients with cavernous sinus meningiomas. Tumor progression is more likely to occur from the lesion margin outside the treatment volume. In small to medium-sized tumors, GKS is an excellent alternative to resection, preserving good neurological function. For relatively large-sized tumors, low-dose radiosurgery (< or = 12 Gy) is acceptable for the prevention of tumor progression.

Internal carotid occlusion following gamma knife radiosurgery for cavernous sinus meningioma.

Stereotact Funct Neurosurg. 2007;85(6):303–306.
PMID: 17709985 DOI: 10.1159/000107365

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Gamma knife radiosurgery is a safe and effective treatment for cavernous sinus meningioma, associated with a very low morbidity. However, a high dose of radiation could lead to modifications of the vascular wall such as in radiosurgical treatment of arteriovenous malformations. We present a patient treated by gamma knife radiosurgery for a left cavernous sinus meningioma using a margin dose of 13 Gy at the 50% isodose. A complete occlusion of the intracavernous segment of the ICA occurred during the follow-up, in combination with a regression of the meningioma volume. The patient sustained no neurological deficit. We found that a hot spot of dose was administered to the intracavernous segment of the internal carotid artery, with a maximum dose of 22.3 Gy. Dose heterogeneity inside the target volume can produce hot spots of dose inside the internal carotid artery that can lead to a vascular occlusion. Therefore, we recommend shifting the hot spot during the dosimetry planning in order to reduce the incidence of such vascular injury.

Results of stereotactic radiosurgery for patients with imaging defined cavernous sinus meningiomas.

Int J Radiat Oncol Biol Phys. 2005;62(5):1427–1431.
PMID: 16029803 DOI: 10-1016/j.ijrobp.2004.12.067

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Introduction
The purpose of this study was to evaluate the efficacy and safety of stereotactic radiosurgery as primary management for patients with imaging defined cavernous sinus meningiomas.

Method
Between 1992 and 2001, 49 patients had radiosurgery for dural-based masses of the cavernous sinus presumed to be meningiomas. The mean patient age was 55.5 years. The mean tumor volume was 10.2 mL; the mean tumor margin dose was 15.9 Gy. The mean follow-up was 58 months (range, 16–144 months).

Results
No tumor enlarged after radiosurgery. Twelve of 38 patients (26%) with preexisting diplopia or facial numbness/pain had improvement in cranial nerve function. Five patients (10%) had new (n = 3) or worsened (n = 2) trigeminal dysfunction; 2 of these patients (4%) underwent surgery at 20 and 25 months after radiosurgery despite no evidence of tumor progression. Neither patient improved after partial tumor resection. One patient (2%) developed an oculomotor nerve injury. One patient (2%) had an ischemic stroke related to occlusion of the cavernous segment of the internal carotid artery. Event-free survival was 98%, 85%, and 80% at 1, 3, and 7 years after radiosurgery, respectively. Univariate analysis of patient and dosimetric factors found no analyzed factor correlated with postradiosurgical morbidity.

Conclusions
Radiosurgery was an effective primary management strategy for patients with an imaging defined cavernous sinus meningioma. Except in situations of symptomatic mass effect, unusual clinical presentation, or atypical imaging features, surgery to confirm the histologic diagnosis is unlikely to provide clinical benefit.

Changing treatment strategy of cavernous sinus meningiomas: experience of a single institution.

Surg Neurol. 2005;64(Suppl):S58–66.
PMID: 1626845 DOI: 10.1016/j.sumeu.2005.07.053

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Background
Oncological treatment of a neoplasm is more than surgical removal of the tumor. Probably, this truth is the reason for the ongoing discussion on cavernous sinus meningiomas in the last decade. Debate on optimal management of cavernous sinus meningiomas aims to compare the different treatment strategies: (a) radical surgical resection and (b) conservative surgical resection complemented with radiosurgical treatment.

Materials and methods
Natural history of the change in the management strategy of cavernous sinus meningiomas in our department before and after GK facility became available in 1997 allowed us to compare the 2 aforementioned strategies. Before installation of a Leksell GK unit at the hospital in 1997, the neurosurgical team at Marmara University Institute of Neurological Sciences and Faculty of Medicine (Istanbul, Turkey) treated patients with cavernous sinus meningioma using radical resection (radical strategy, group A, 10 patients). After 1997, the same neurosurgical team used understanding of surgical removal of the extracavernous sinus tumor component with GK irradiation of the intracavernous part (conservative strategy, group B, 12 patients). Another group of patients, who were treated with GK as a first-step treatment, was analyzed (GK group, group C, 26 patients).

Results
At the end of the third year, more stable tumor volume control was achieved in groups B and C; after the second year, an incline in the tumor volume-time graph was detected. Group B resulted in less cranial nerve-related complications; a certain degree of improvement in cranial nerve deficits was observed.

Conclusions
Comparing 2 different management strategies for cavernous sinus meningiomas in the same hospital setting using the same neurosurgical group, we conclude that extracavernous resection followed by GK is as effective as radical surgery. Considering cranial nerve complications and third-year tumor volume control achievement, conservative approach yielded better results. Longer follow-up with larger series is necessary.

Evaluation of fractionated radiotherapy and gamma knife radiosurgery in cavernous sinus meningiomas: treatment strategy.

Neurosurg. 2005;57(5):873–886.
PMID: 16284558 DOI: 10.1227/01.NEU.0000179924.76551.cd

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Objective
To investigate the respective role of fractionated radiotherapy (FR) and gamma knife stereotactic (GKS) radiosurgery in cavernous sinus meningioma (CSM) treatment.

Method
The authors report the long-term follow-up of two populations of patients harboring CSMs treated either by FR (Group I, 38 patients) or GKS radiosurgery (Group II, 36 patients). There were 31 females with a mean age of 53 years in Group I and 29 females with a mean age of 51.2 years in Group II. In 20 patients (Group I) and 13 patients (Group II), FR and GKS radiosurgery were performed as an adjuvant treatment. In 18 patients (Group I) and in 23 patients (Group II), FR and GKS radiosurgery were performed as first line treatment. In our early experience with GKS radiosurgery (1992, date of gamma knife availability in the department), patients with tumors greater than 3 cm, showing close relationship with the optic apparatus (<3 mm) or skull base dural spreading, were treated by FR. Secondarily, with the advent of new devices and our growing experience, these criteria have evolved.

Results
The median follow-up period was 88.6 months (range, 42–168 mo) for Group I and 63.6 months (range, 48–92 mo) for Group II. According to Sekhar's classification, 26 (68.4%) patients were Grade III to IV in Group I and 10 (27.8%) patients in Group II ($P < 0.05$); 23 (60.5%) patients had extensive lesions in Group I and 7 (19.4%) patients in Group II ($P < 0.05$). Mean tumor volume was 13.5 cm in Group I and 5.2 cm in Group II ($P < 0.05$). Actuarial progression-free survival was 94.7% and 94.4% in Group I and II, respectively. Clinically, improvement was seen for 24 (63.2%) patients in Group I and for 21 (53.8%) patients in Group II ($P > 0.05$). Radiologically, 11 (29%, Group I) patients and 19 (Group II, 52.7%) patients showed tumor shrinkage ($P = 0.04$). Transient morbidity was 10.5% in Group I and 2.8% in Group II. Permanent morbidity was 2.6% in Group I and 0% in Group II.

Conclusions
FR and GKS radiosurgery are safe and efficient techniques in treatment of CSMs, affording comparable satisfactory long-term tumor control. However, GKS radiosurgery provides better radiological response, is far more convenient, and fits into most patients lives much better than FR. Therefore, in the authors' opinion, GKS radiosurgery should be advocated in first intention for patients with CSMs, whereas conventional radiotherapy should be reserved for cases that are not amenable to this technique, thus making these two therapeutic modalities not alternative but complementary tools in CS meningioma treatment strategy.

Proposed treatment strategy for cavernous sinus meningiomas: a prospective study.

Neurosurg. 2004;55(5):1068–1075.
PMID: 15509313 DOI: 10.1227/01.NEU.0000140839.47922.5A

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Objective
To establish a safe and effective treatment strategy for cavernous sinus (CS) meningiomas, we prospectively analyzed the outcome of a treatment protocol combining surgery and radiosurgery during the past 7 years.

Method
Tumors confined to the CS and distant from the optic apparatus and the brainstem were treated with radiosurgery alone. Tumors attached to or compressing the optic apparatus and brainstem and that were larger than 3 cm in mean diameter, extended into the multiple cranial fossae, and were suspected of being malignant were treated with combined nonradical microsurgery and radiosurgery.

Results
In accordance with this treatment protocol, 40 patients aged 26 to 72 years (median, 51 yr) with primary (n = 27) or recurrent (n = 13) CS meningiomas (volume range, 0.9–39.3 cm(3); median volume, 5.4 cm(3)) were treated with combined surgery and radiosurgery (n = 23) or radiosurgery alone (n = 17). During radiosurgery, 12 to 18 Gy (median, 16 Gy) was delivered to the tumor margin. The follow-up period ranged from 14 to 79 months (median, 47 mo). The actuarial tumor control rate was 94.1% at 5 years. The improvement of cranial nerve function was significantly frequent in patients with primary CS meningiomas (P <0.05). Permanent cranial nerve dysfunction was significantly frequent in patients with tumors compressing the brainstem or smaller than 10 cm(3) (P <0.05). All 36 patients with a pretreatment Karnofsky Performance Scale score of 90 or more maintained the same range after treatment.

Conclusions
Proper combination of microsurgery and radiosurgery for CS meningiomas provides excellent growth control with favorable functional state. Outcomes were better when this protocol was adopted at the initial diagnosis for patients with smaller tumors that did not compress the brainstem.

Gamma knife radiosurgery for benign cavernous sinus tumors: quantitative analysis of treatment outcomes.

Neurosurg. 2004;54(6):1385–1393.
PMID: 15157295 DOI: 10.1227/01.NEU.0000124750.13721.94

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Objective
We review our 8-year experience with gamma knife radiosurgery (GKRS) for the treatment of patients with benign cavernous sinus tumors and present a quantitative analysis of factors relevant to treatment outcomes.

Method
From 1994 to 2002, a total of 139 patients with benign cavernous sinus tumors were treated in 145 sessions. Their median age was 53 years, and the median follow-up was 3.5 years. The tumors included 57 meningiomas, 76 pituitary tumors (49 nonfunctional adenomas, 15 prolactinomas, 5 adrenocorticotropic hormone-secreting tumors, 6 growth hormone-secreting tumors, and 1 plurihormone-secreting tumor), 4 schwannomas, 1 hemangioma, and 1 paraganglioma. Sekhar tumor grades were as follows: I, n = 28 (20%); II, n = 42 (30%); III, n = 42 (30%); IV, n = 19 (14%); and V, n = 8 (6%). The median tumor volume was 3.4 cm(3), and the median prescribed dose was 15 Gy defined to the 50% isodose line.

Results
IA total of 136 treated tumors (97.8%) were well controlled by GKRS, with low morbidity. For meningiomas, 29 tumors (51%) were unchanged and 26 (46%) were smaller at a median of 15.2 months. For pituitary tumors, 50 (66%) were unchanged and 25 (33%) were smaller at a median of 20.6 months. Improvement in cranial nerve (CN) function was seen in 19 (36.5%) of 52 patients with pre-GKRS deficits, and 3 patients (2.2%) developed new stable CN deficits after GKRS: 1 patient developed IVth.

Radiosurgical treatment of cavernous sinus neoplasms: indications and results.

Techniques in Neurosurgery. 2003;8(4):251–260.
DOI: 10.1097/00127927-200308040-00009
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Although most pathologic tumors that involve the cavernous sinus are benign, the intimate association of these tumors to critical neurovascular structures makes their surgical resection difficult. Stereotactic radiosurgery provides effective tumor control with minimal morbidity. Its success with respect to meningiomas of the cavernous sinus is measured by its long-term tumor control rate and safety, and its success with respect to pituitary adenomas is measured by both endocrinologic control in addition to arrest of tumor growth. In a recent series of 186 patients with cavernous sinus meningiomas treated at the University of Pittsburgh, the authors observed a 5-year tumor control rate of 93% for typical meningiomas. Using marginal tumor doses of 13 Gy, the authors achieved long-term growth control and preserved neurologic function in most patients. By keeping the optic nerve dose less than 8 Gy and by using a marginal tumor dose of 13 Gy, they kept the risk of adverse radiation effects to 6.7%. The role of radiosurgery for pituitary adenomas requires careful analysis of the patient's visual, hormonal, and medical condition. The authors currently consider radiosurgery a viable alternative to microsurgery for patients with nonhormone-producing pituitary adenomas with cavernous sinus extension as long as they do not suffer from visual compromise from tumor compression of the optic apparatus. For patients with hormone-producing pituitary adenomas extending into the cavernous sinus, the authors favor microsurgery as the primary management modality and use radiosurgery for persistent/recurrent tumors or for patients who are not considered good candidates for surgical resection.

Gamma knife radiosurgery for the treatment of cavernous sinus meningiomas.

Neurosurg. 2003;52(3):517–524.
PMID: 12590675
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Objective
We report on the efficacy of gamma knife radiosurgery for cavernous sinus meningiomas.

Method
Between January 1994 and December 1999, we used gamma knife radiosurgery for the treatment of 43 patients with cavernous sinus meningiomas. Forty-two patients were followed up for a mean of 49.4 months (range, 18–84 mo). The patients' average age was 55 years (range, 18–81 yr). Twenty-two patients (52%) underwent operations before radiosurgery, and 20 patients (48%) underwent radiosurgery after the diagnosis was made by magnetic resonance imaging. The tumor volumes ranged from 1.2 to 101.5 cm(3) (mean, 14.7 cm(3)). The tumors either compressed or were attached to the optic apparatus in 17 patients (40.5%). The marginal radiation dose was 8 to 15 Gy (mean, 11 Gy), and the optic apparatus was irradiated with 2 to 12 Gy (mean, 6.2 Gy). Three patients with a mean tumor diameter greater than 4 cm were treated by two-stage radiosurgery.

Results
Thirty-eight patients (90.5%) demonstrated tumor growth control during the follow-up period after radiosurgery. Tumor regression was observed in 25 patients (59.5%), and growth was unchanged in 13 patients (31%). Regrowth or recurrence occurred in four patients (9.5%). The actual tumor growth control rate at 5 years was 92%. Only one patient (2.4%) experienced regrowth within the treatment field; in other patients, regrowth occurred at sites peripheral to or outside the treatment field. Twelve patients (28.6%) had improved clinically by the time of the follow-up examination. None of the patients experienced optic neuropathy caused by radiation injury or any new neurological deficits after radiosurgery.

Conclusion
Gamma knife radiosurgery may be a useful option for the treatment of cavernous sinus meningiomas not only as an adjuvant to surgery but also as an alternative to surgical removal. We have shown it to be safe and effective even in tumors that adhere to or are in close proximity to the optic apparatus.

The role of Gamma Knife radiosurgery in the management of cavernous sinus meningiomas.

Int J Radiat Oncol Biol Phys. 2002;53(4):992–1000.

DOI: 10.1016/S0360-3016(02)02802-X

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Purpose

To evaluate the efficacy of Gamma Knife (GK) radiosurgery in terms of neurologic improvement and tumor growth control (TGC) in a large series of patients with cavernous sinus meningioma (CSM).

Materials and methods

One hundred thirty-eight patients with CSM (28 males, 110 females; mean age: 56.2 years) were treated with GK between February 1993 and February 2001. GK was used as a first-choice treatment in 68/138 patients and as postoperative adjuvant therapy in 70/138. In 32 patients, it was possible to compare the size of the planned treatment volume to tumor volume using the conformity index (CI); optimal CI values were taken to be < or =1.5 (range: 0.94–2.24).

Results

A follow-up (FU) period of at least 12 months was available for 111 patients (median: 48.2 months, range: 12.1–84.5 months). Clinical conditions were improved or stable in 107/111 patients (96.5%). Neurologic recovery was observed in 76% of cases treated by GK alone and in 56.5% of adjuvant treatments ($p < 0.03$). Adequate TGC was documented in 108/111 tumors (97%), with shrinkage/disappearance in 70/111 (63%) and no variation in volume in 38/111 (34%); the overall actuarial progression-free survival rate at 5 years was 96%. Tumor size regression was observed in 79.5% of patients with FU >30 months, compared with 47.5% of patients with FU <30 months ($p < 0.001$). One hundred percent TGC was shown in treated patients with a CI < or =1.5 (20/32), compared with 92% TGC in cases with a CI >1.5 ($p < 0.15$, NS). Radiosurgical sequelae were transient in 4/111 cases (3.5%) and permanent in one case (1%).

Conclusions

For the FU period of our series (median: >4 years), GK radiosurgery seems to be both safe (permanent morbidity 1%) and effective (96% neurologic improvement/stability, 97% overall TGC, 96% actuarial TGC at 5 years) and might be considered as a first-choice treatment for selected patients with CSM.

Radiosurgical treatment of cavernous sinus meningiomas: experience with 122 treated patients.
Neurosurg. 2002;51(5):1153–1159.
PMID: 12383360 DOI: 10/1097/00006123-200211000
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Objective
To evaluate the efficacy of gamma knife (GK) radiosurgery, in terms of neurological improvement and tumor growth control (TGC), for a large series of patients with cavernous sinus meningiomas.

Materials and methods
Between February 1993 and January 2002, 156 patients with cavernous sinus meningiomas (35 male and 121 female patients; mean age, 56.1 yr) were treated with GK radiosurgery in our department. GK radiosurgery was used as a first-choice treatment for 75 of 156 patients and as postoperative adjuvant therapy for 81 of 156 patients (all with Grade I meningiomas). Eligibility criteria for radiosurgery were as follows: symptomatic meningiomas and/or documented tumor progression on magnetic resonance imaging scans, conditions of high operative risk, patient refusal of microsurgery or reoperation, tumor volume of <20 cm(3), and location no less than 2 mm from the optic pathways.

Results
Follow-up data for at least 12 months were available for 122 patients (median follow-up period, 48.9 mo). Clinical conditions were improved or stable for 118 of 122 patients (97%). Neurological recovery was observed for 78.5% of patients treated with GK radiosurgery alone and for 60.5% of patients treated with adjuvant therapy ($P < 0.05$). Adequate TGC was documented for 119 of 122 tumors (97.5%), with shrinkage/disappearance in 75 of 122 cases (61.5%) and no variation in volume in 44 of 122 cases (36%); the overall actuarial progression-free survival rate at 5 years was 96.5%. Tumor size regression was observed for 80% of patients with follow-up periods of more than 30 months, compared with 43.5% of patients with follow-up periods of less than 30 months ($P < 0.0002$). Radiosurgical sequelae were transient in 4 of 122 cases (3.0%) and permanent in 1 case (1%).

Conclusions
For the follow-up periods in our series (median, >4 yr), GK radiosurgery seems to be both safe (permanent morbidity rate, 1%) and effective (97% neurological improvement/stability, 97.5% overall TGC, and 96.5% actuarial TGC at 5 yr). GK radiosurgery might be considered a first-choice treatment for selected patients with cavernous sinus meningiomas.

Stereotactic radiosurgery providing long-term tumor control of cavernous sinus meningiomas.

J Neurosurg. 2002;97(1):65–72.
PMID: 12134934 DOI: 10.317/jns.2002.97.1.0065

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Objective
To evaluate long-term outcomes of patients who have undergone stereotactic radiosurgery for cavernous sinus meningiomas, the authors retrospectively reviewed their 14-year experience with these cases.

Method
One hundred seventy-six patients harbored meningiomas centered within the cavernous sinus. Seventeen patients were lost to follow-up review, leaving 159 analyzable patients, in whom 164 procedures were performed. Seventy-six patients (48%) underwent adjuvant radiosurgery after one or more attempts at surgical resection. Eighty-three patients (52%) underwent primary radiosurgery. Two patients (1%) had previously received fractionated external-beam radiation therapy. Four patients (2%) harbored histologically verified atypical or malignant meningiomas. Conformal multiple isocenter gamma knife surgery was performed. The median dose applied to the tumor margin was 13 Gy. Neurological status improved in 46 patients (29%), remained stable in 99 (62%), and eventually worsened in 14 (9%). Adverse effects of radiation occurred after 11 procedures (6.7%). Tumor volumes decreased in 54 patients (34%), remained stable in 96 (60%), and increased in nine (6%). The actuarial tumor control rate for patients with typical meningiomas was 93.1 +/- 3.3% at both 5 and 10 years. For the 83 patients who underwent radiosurgery as their sole treatment, the actuarial tumor control rate at 5 years was 96.9 +/- 3%.

Conclusions
Stereotactic radiosurgery provided safe and effective management of cavernous sinus meningiomas. We believe it is the preferred management strategy for tumors of suitable volume (average tumor diameter < or = 3 cm or volume < or = 15 cm3).

Analysis of treatment outcome after stereotactic radiosurgery for cavernous sinus meningiomas.

J Neurosurg. 2001;95(3):435–439.
PMID: 11565865 DOI: 10.3171/jns.2001.95.3.0435

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Objective
The long-term outcome of stereotactic radiosurgery for cavernous sinus (CS) meningiomas is not fully understood. The authors retrospectively reviewed their experience with 40 CS meningiomas treated with gamma knife radiosurgery.

Method
Follow-up periods for the 40 patients ranged from 12 to 123 months (median 42 months), and the overall tumor control rates were 86.4% at 3 years and 82.3% at 10 years. Factors associated with tumor recurrence in univariate analysis were histological malignancy ($p < 0.0001$), partial treatment ($p < 0.0001$), suprasellar tumor extension ($p = 0.0201$), or extension in more than three directions outside the CS ($p = 0.0345$). When the tumor was completely covered with a dose to the margin that was higher than 14 Gy (Group A, 22 patients), no patient showed recurrence within the median follow-up period of 37 months. On the other hand, when a part of the tumor was treated with 10 to 12 Gy (Group B, 15 patients) or did not receive radiation therapy (Group C, three patients), the recurrence rates were 20% and 100%, respectively. Neurological deterioration was seen in nine patients, but all symptoms were transient or very mild.

Conclusions
The data indicate that stereotactic radiosurgery can control tumor growth if the whole mass can be irradiated by dosages of more than 14 Gy. When optimal radiosurgical planning is not feasible because of a tumor's large size, irregular shape, or proximity to visual pathways, use of limited surgical resection before radiosurgery is the best option and should provide sufficient long-term tumor control with minimal complications.

Radiosurgical management of benign cavernous sinus tumors: dose profiles and acute complications.

Neurosurg. 2001;48(5):1022–1030.

PMID: 11334268 DOI: 10.1097/00006123-200105000-00011

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Objective

Radiosurgery has emerged as an alternative treatment modality for cranial base tumors in patients deemed not suited for primary surgical extirpation, patients with recurrent or residual tumor after open surgery, or patients who refuse surgical treatment. We review our short-term experience with radiosurgical management of cavernous sinus region tumors with the Leksell gamma knife.

Method

From August 1994 to February 1999, 69 patients with cavernous sinus lesions were treated in 72 separate treatment sessions. The tumor type distribution was 29 pituitary adenomas, 35 meningiomas, 4 schwannomas, and 1 paraganglioma. The median follow-up was 122 weeks. Lesions were stratified according to a five-level surgical grade. The grade distribution of the tumors was as follows: Grade I, 13; Grade II, 21; Grade III, 19; Grade IV, 12; Grade V, 4. Median tumor volume was 4.7 cm3. The median radiation dose was 15 Gy to the 50% isodose line. Median maximal radiation dose was 30 Gy.

Results

Analysis of tumor characteristics and radiation dose to optic nerve and pontine structures revealed a significant correlation between distance and dose. Much lower correlation coefficients were found between tumor volume and dose. One lesion in this series had evidence of transient progression and later regression on follow-up radiographic studies. No other lesions in this series were demonstrated to have exhibited progression. Complications after radiosurgical treatment were uncommon. Two patients had cranial nerve deficits after treatment. One patient with a surgical Grade III pituitary adenoma had VIth cranial nerve palsy 25 months after radiosurgical treatment that spontaneously resolved 10 months later. A patient with a bilateral pituitary adenoma experienced bilateral VIth cranial nerve palsy 3 months after treatment that had not resolved at 35 months after treatment. Six patients with preoperative cranial nerve deficits experienced resolution or improvement of their deficits after treatment. One patient with a prolactin-secreting adenoma experienced normalization of endocrine function with return of menses.

Conclusions

Radiosurgical treatment represents an important advance in the management of cavernous sinus tumors, with low risk of neurological deficit in comparison with open surgical treatment, even in patients with high surgical grades.

Gamma knife radiosurgery in the management of cavernous sinus meningiomas.

J Neurosurg. 2000;93(3)(suppl):68–73.
PMID: 11143266 DOI: 10.3171/jns.2000.93.supplement

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Objective
The authors sought to assess the functional tolerance and tumor control rate of cavernous sinus meningiomas treated by gamma knife radiosurgery (GKS).

Method
Between July 1992 and October 1998, 92 patients harboring benign cavernous sinus meningiomas underwent GKS. The present study is concerned with the first 80 consecutive patients (63 women and 17 men). Gamma knife radiosurgery was performed as an alternative to surgical removal in 50 cases and as an adjuvant to microsurgery in 30 cases. The mean patient age was 49 years (range 6–71 years). The mean tumor volume was 5.8 cm3 (range 0.9–18.6 cm3). On magnetic resonance (MR) imaging the tumor was confined in 66 cases and extensive in 14 cases. The mean prescription dose was 28 Gy (range 12–50 Gy), delivered with an average of eight isocenters (range two–18). The median peripheral isodose was 50% (range 30–70%). Patients were evaluated at 6 months, and at 1, 2, 3, 5, and 7 years after GKS. The median follow-up period was 30.5 months (range 12–79 months). Tumor stabilization after GKS was noted in 51 patients, tumor shrinkage in 25 patients, and enlargement in four patients requiring surgical removal in two cases. The 5-year actuarial progression-free survival was 92.8%. No new oculomotor deficit was observed. Among the 54 patients with oculomotor nerve deficits, 15 improved, eight recovered, and one worsened. Among the 13 patients with trigeminal neuralgia, one worsened (contemporary of tumor growing), five remained unchanged, four improved, and three recovered. In a patient with a remnant surrounding the optic nerve and preoperative low vision (3/10) the decision was to treat the lesion and deliberately sacrifice the residual visual acuity. Only one transient unexpected optic neuropathy has been observed. One case of delayed intracavernous carotid artery occlusion occurred 3 months after GKS, without permanent deficit. Another patient presented with partial complex seizures 18 months after GKS. All cases of tumor growth and neurological deficits observed after GKS occurred before the use of GammaPlan. Since the initiation of systematic use of stereotactic MR imaging and computer-assisted modern dose planning, no more side effects or cases of tumor growth have occurred.

Conclusions
Gamma knife radiosurgery was found to be an effective low morbidity-related tool for the treatment of cavernous sinus meningioma. In a significant number of patients, oculomotor functional restoration was observed. The treatment appears to be an alternative to surgical removal of confined enclosed cavernous sinus meningioma and should be proposed as an adjuvant to surgery in case of extensive meningiomas.

Gamma knife radiosurgery of meningiomas in the cavernous sinus region.

Acta Neurochir (Wien). 1999;141(5):473–480.
PMID: 10392202 DOI: 10.1007/s007010050327

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For 6 years (1992–1998) we have treated 67 patients with cavernous sinus meningioma using the Leksell gamma knife in the Hospital Na Homolce, Prague. The age of the patients ranged between 19–82 years, median 57 years. Radiosurgery was the primary treatment in 64.2% of the patients, in the rest a microsurgical resection preceded. The volume of the tumour ranged from 0.9–31.4 cm3, median 7.8 cm3. The meningioma was distant from the optic tract in 58% of the cases, in 12% of the cases there was a contact with the tumour and the optic tract without its compression and in 30% of the cases there was a compression of the optic tract caused by the meningioma. The dose to the tumour margin ranged from 10–14 Gy, median 12 Gy. The follow up was available in 53 patients, in intervals of 2–60 months, median 19 months. There was no change in the tumour volume in 48% of the cases, in 52% of the cases a decrease of the tumour volume occurred. No increase of the tumour volume was observed. Clinical symptoms and signs improved in 35.8% of the patients, temporary morbidity was 3.8%. The mortality of the treatment was zero. Hitherto, the results of gamma knife radiosurgery of cavernous sinus meningioma have proved its safety and efficiency, although long term experience with a large group of patients is missing. Advances in neuroradiology and radiosurgical technique have allowed us to treat tumours with a closer contact to the optic tract and nerves compared with the past.

Value of gamma knife radiosurgery for tumors invading cavernous sinus.

Japanese Journal of Neurosurgery. 1999;8(6):403–412.
DOI: 10.7887/jcns.8.403
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The usefulness of radiosurgery for cavernous sinus tumors was evaluated based on our experience and recent published reports from other institutes. Twenty-six meningiomas involving the cavernous sinus were treated by radiosurgery. The length of follow-up averaged 3 years. Tumors regressed in 40% and remained stable in 56% of cases. A total of 96% of the tumors were controlled with only a few minor complications. We believe surgical resection to reduce the volume of the tumor without causing new neurological deficits, followed by radiosurgery on the tumor located in the cavernous sinus is the best choice in many cases. Twenty-five pituitary adenomas with cavernous sinus invasion were treated by a combination of trans-sphenoidal removal and radiosurgery. All the tumors are controlled in terms of volume during the follow-up (average of 34 months). There were no new neurological deficits, including visual disturbance. Hormone elevation was able to be corrected at an early stage without pituritary insufficiency more by radiosurgery than by fractionated radiation. However, to obtain good results by radiosurgery, it must be preceeded by complete surgical decompression of optic nerves and chiasma from the tumor.

Cavernous sinus meningiomas-what is the strategy: Upfront or adjuvant gamma knife surgery?

Stereotact Funct Neurosurg. 1998;70(1)(suppl):33–40.
PMID: 9782233 DOI: 10.1159/000056404
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43 patients with meningiomas of the cavernous sinus form the basis of this study. Two patients were treated with microsurgery alone, 17 patients were treated by Gamma Knife radiosurgery (GKRS) as a primary treatment modality, and 24 patients underwent a combined treatment of microsurgery followed by GKRS. Therefore, in 17 patients the diagnosis rested on clinical and radiological criteria alone. Cranial nerve disorders (CND) related to open surgical treatment were infrequent in this material (3 of 13 patients) due to deliberate strategies of partial or subtotal resection aimed at sparing cranial nerves from surgical maneuvers. In contrast, 6 of 11 patients, admitted for GKRS from other institutions suffered from considerable CND after open surgery and showed only partial improvement after GKRS. In all GKRS cases, no radiation-related complications were seen after a follow-up of 18–62 months (mean 39 months). Moreover, in all cases tumor control was obtained with a stable tumor volume in 63%, reduction of volume in 34.5% and a disappearance of tumor in 2.5%. GKRS is not only an additional treatment for meningiomas involving the cavernous sinus, but may be offered to the patient as an alternative primary treatment.

Role of radiosurgery in the management of cavernous sinus meningiomas.

Acta Neurol Scand. 1997;96(5):297–304.
PMID: 9404999 DOI: 10.1111/j.1600-0404.1997.tb00287.x

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Objective
To provide our early experience and philosophy in the utility of radiosurgery in the management of cavernous sinus meningiomas.

Method
Twenty-five consecutive cases with cavernous sinus meningiomas treated between 1990 and 1995 were reviewed. Three cases were treated with gamma-knife radiosurgery, 15 with preceding surgery and gamma knife, 7 with surgery. Mean follow-up following radiosurgery and surgery were 34.8 and 25.4 months, respectively.

Results
The 5-year actuarial tumor control rate following radiosurgery was 85.7% and tumor remission rate was 61.4%. Permanent neurological deterioration after radiosurgery was seen in 1 case (5.9%), whereas newly developed or worsened neurological deficits permanently persisted in 59.1% of patients after surgery. There was a clear correlation between surgical radicality and postoperative morbidity rate.

Conclusions
Gamma-knife radiosurgery is a valuable addition to surgical removal in the treatment of cavernous sinus meningiomas. Combination of non-radical resection and subsequent radiosurgery is recommended to improve treatment-associated morbidity.

Radiosurgery of cavernous sinus meningiomas with gamma-knife.

No Shinkei Geka. 1996;24(6):529–533.
PMID: 8677001

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The treatment results of cavernous sinus meningioma with gamma- radiosurgery are reported. There were 18 cases of cavernous sinus meningioma, including 2 males and 16 females, whose age ranged from 39 to 63 with an average of 51.0 years. As prior treatments, operative tumor resection or biopsy had been carried out in 14 cases, and the pathology was verified. The other 4 cases were diagnosed clinically with radiological studies. The mean tumor diameter was 28.3 mm (17.7–35.0) during the radiosurgery. The maximum dose ranged from 22 to 36 Gy (mean 28.0 Gy), with the marginal tumor dose ranging from 11 to 18 Gy (mean 13.9 Gy). Irradiation to the near-by optic nerves was less than 10 Gy. Follow-up period ranged from 12 to 50 months with a mean of 25.5 months. MRI showed a minor tumor shrinkage in 9 (50.0%) and no obvious change in 8 (44.4%), and tumor progression in 1 (5.6%), which required a 2nd radiosurgery. Neurologically facial pain and facial dysesthesia were well improved (7/13). However the ophthalmoparesis was usually unchanged and only 1 out of 11 (9.1%) improved after radiosurgery. Deterioration of neurological signs was rare. Symptomatic edema presenting neurological signs was not seen. In conclusion, radiosurgery with a gamma-knife is one of the useful alternatives to operative intervention in the treatment of cavernous sinus meningiomas, not only for tumor control, but also for relief from the symptoms.

Stereotactic radiosurgery of cavernous sinus meningiomas as an addition or alternative to microsurgery.
Neurosurg. 1993;32(5):699–704.
PMID: 8492844 DOI: 10.1227/00006123-199305000-00001
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To evaluate the response of cavernous sinus meningiomas to stereotactic radiosurgery, we reviewed our 54-month experience with 34 patients. All patients underwent radiosurgery with a 201-source cobalt-60 gamma unit. Twenty-eight patients (82%) had previous histological confirmation of a meningioma (1 to 5 cranial base craniotomies per patient); 6 (18%) were treated on the basis of neuroimaging criteria alone. The single-fraction radiation tumor margin dose (10 to 20 Gy) was designed to conform to the irregular tumor volumes in all patients. The maximum radiation dose to the optic nerve or tract was reduced to 9 Gy in 31 patients. No patient had tumor growth (100% tumor control) during the follow-up interval (median, 26 mo). Tumor regression was observed in 56% of patients imaged at an average of 18 months. Eight patients (24%) improved clinically at follow-up examinations. Four patients developed new or worsened cranial nerve deficits during the follow-up interval; two had subsequent full improvement. No patient developed an endocrinopathy or new extraocular muscle paresis. Stereotactic radiosurgery, using multiple isocenter dosimetry facilitated by the gamma unit, is an accurate, safe, and effective technique to prevent the growth of tumors involving the cavernous sinus. Despite the proximity of such tumors to adjacent cranial nerves, complications were rare. The maximum length of hospital stay was 36 hours, and all patients returned to their preoperative employment status within 3 to 5 days.

Gamma knife radiosurgery for cavernous sinus meningiomas: analysis of outcome in 166 patients.
Stereotact Funct Neurosurg. 2017;95(4):259–267.
PID: 28797005 DOI: 10.1159/000478024
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Objective
The outcomes of Gamma Knife radiosurgery (GKRS) for cavernous sinus meningioma (CSM) are presented, and factors possibly affecting outcome are investigated.

Method
The medical records and imaging and procedural reports of 166 patients with CSM were retrospectively reviewed. Demographic data, procedural data, symptomatic improvement, radiological regression, and progression-free survival (PFS) rates were evaluated.

Results
There were 124 women and 42 men; including 44 postoperative and 122 primary GKRS cases. Mean follow-up was 32.4 months. Mean marginal dose was 13 Gy. Symptomatic improvement was seen in 40.4%, while neurologic deterioration occurred in 9.6%; 50% remained symptomatically stable. Radiological regression was noted in 57.2%; the tumor remained stable in 35.5%, and 7.2% of the patients experienced tumor progression. The actuarial 5- and 10-year PFS rates were 90.1% (±3.3) and 75.8% (±8.8), respectively. History of previous surgery or radiotherapy were associated with lower symptomatic improvement. Higher tumor coverage and isodose lines were accompanied with better radiological prognosis. However, a history of conventional radiotherapy, presence of facial sensory deficits at presentation, a higher tumor volume, and tumor extension to the suprasellar compartment affected the radiologic outcome negatively.

Conclusions
This study revealed a high efficacy and safety for GKRS in both postoperative and primary GKRS patients. Achievability of a good profile of tumor coverage and isodose lines at radiosurgical planning predict a better outcome.

Microsurgical resectability, outcomes, and tumor control in meningiomas occupying the cavernous sinus.

J Neurosurg. 2016;125(2):378–392.

PMID: 26745483 DOI: 10.3171/2015.3.JNS142494

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Objective

Cavernous sinus meningiomas (CSMs) represent a cohort of challenging skull base tumors. Proper management requires achieving a balance between optimal resection, restoration of cranial nerve (CN) function, and maintaining or improving quality of life. The objective of this study was to assess the pre-, intra-, and postoperative factors related to clinical and neurological outcomes, morbidity, mortality, and tumor control in patients with CSM.

Method

A retrospective review of a single surgeon's experience with microsurgical removal of CSM in 65 patients between January 1996 and August 2013 was done. Sekhar's classification, modified Kobayashi grading, and the Karnofsky Performance Scale were used to define tumor extension, tumor removal, and clinical outcomes, respectively.

Results

Preoperative CN dysfunction was evident in 64.6% of patients. CN II deficits were most common. The greatest improvement was seen for CN V deficits, whereas CN II and CN IV deficits showed the smallest degree of recovery. Complete resection was achieved in 41.5% of cases and was not significantly associated with functional CN recovery. Internal carotid artery encasement significantly limited the complete microscopic resection of CSM ($p < 0.0001$). Overall, 18.5% of patients showed symptomatic recurrence after their initial surgery (mean follow-up 60.8 months [range 3–199 months]). The use of adjuvant stereotactic radiosurgery (SRS) after microsurgery independently decreased the recurrence rate ($p = 0.009$; OR 0.036; 95% CI 0.003–0.430).

Conclusions

Modified Kobayashi tumor resection (Grades I–IIIB) was possible in 41.5% of patients. CN recovery and tumor control were independent of extent of tumor removal. The combination of resection and adjuvant SRS can achieve excellent tumor control. Furthermore, the use of adjuvant SRS independently decreases the recurrence rates of CSM.

Stereotactic gamma knife surgery safety and efficacy in the management of symptomatic benign confined cavernous sinus meningioma.

Acta Neuro-chir (Wien). 2015;157(9):1559–1564.
PMID: 26231629 DOI: 10.1007/s00701-015-2509-2

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Background
Considering the proximity to cranial nerves from II to VI and the internal carotid artery microsurgery for cavernous sinus meningioma (CSM) has its limits of complete resection, with high potential tumor recurrences, cranial nerve and vascular morbidity. Gamma Knife surgery (GKS) is an advanced modality as primary treatment for patients harboring symptomatic benign confined CSM as well as adjuvant therapy to postoperative residual tumor giving a high rate of tumor control, stabilizing or even improving clinical condition with low morbidity.

Materials and method
The aim of this study is to evaluate the safety and efficacy of GKS used in the management of 62 patients with symptomatic benign confined CSM < 3 cm in maximum diameters treated at the International Medical Centre (IMC), Cairo, Egypt, from 2005 to end of 2012, with mean follow-up period of 36 months (range 24–96 months) by reviewing their clinical and radiological data. For 51 patients GKS was performed as a primary treatment. The diagnosis was based on typical clinical and imaging findings and in 11 patients GKS was used as adjuvant to post-operative tumor residual with histological confirmation.

Results
There were 43 females and 19 males. The median age at the time of treatment was 48 years. The mean tumor volume was 5.7 cc, the mean tumor marginal radiation dose was 14.4 Gy, the mean isodose line was 38 %, and the mean tumor coverage was 94.4 %. The optic pathway received < 8 Gy and the brain stem <10 Gy. At most recent follow-up, 57 patients (92 %) had stable or improved cranial nerve deficits. Post-GKS cranial nerve complications were detected in five patients (8 %). Tumor volume was controlled in 60 patients (96 %) at most recent follow-up MRI; 12 patients had a reduction in tumor size and 42 had stable tumor size, while tumor size progression was detected in two patients. The tumor progression-free survival at 3 and 5 years in 40 patients who completed at least 5 years of follow-up was 95 %.

Conclusions
Gamma Knife surgery is a safe and effective option for the treatment of cavernous sinus meningioma not only as an adjuvant to surgery but also as an alternative to surgical removal in tumors confined mainly to the cavernous sinus.

Cerebellopontine angle

Gamma knife radiosurgery for cerebellopontine angle meningiomas: a multicenter study.
Neurosurg. 2014;75(4):398–408.
PMID: 24991710 DOI: 10.1227/NEU.0000000000000480
Ding D, Starke RM, Kano H, Nakaji P, Barnett GH, Mathieu D, Chiang V, Omay SB, Hess J, McBride HL, Honea N, Lee JY, Rahmathulla G, Evanoff WA, Alonso-Basanta M, Lunsford LD, Sheehan JP.
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Background
Resection of cerebellopontine angle (CPA) meningiomas may result in significant neurological morbidity. Radiosurgery offers a minimally invasive alternative to surgery.

Objective
To evaluate, in a multicenter cohort study, the outcomes of patients harboring CPA meningiomas who underwent Gamma Knife radiosurgery (GKRS).

Method
From 7 institutions participating in the North American Gamma Knife Consortium, 177 patients with benign CPA meningiomas treated with GKRS and at least 6 months radiologic follow-up were included for analysis. The mean age was 59 years and 84% were female. Dizziness or imbalance (48%) and cranial nerve (CN) VIII dysfunction (45%) were the most common presenting symptoms. The median tumor volume and prescription dose were 3.6 cc and 13 Gy, respectively. The mean radiologic and clinical follow-up durations were 47 and 46 months, respectively. Multivariate regression analyses were performed to identify the predictors of tumor progression and neurological deterioration.

Results
The actuarial rates of progression-free survival at 5 and 10 years were 93% and 77%, respectively. Male sex (P = .014), prior fractionated radiation therapy (P = .010), and ataxia at presentation (P = .002) were independent predictors of tumor progression. Symptomatic adverse radiation effects and permanent neurological deterioration were observed in 1.1% and 9% of patients, respectively. Facial spasms at presentation (P = .007) and lower maximal dose (P = .011) were independently associated with neurological deterioration.

Conclusions
GKRS is an effective therapy for CPA meningiomas. Depending on the patient and tumor characteristics, radiosurgery can be an adjuvant treatment to initial surgical resection or a standalone procedure that obviates the need for resection in most patients.

Late onset aneurysm development following radiosurgical obliteration of a cerebellopontine angle meningioma.
BMJ Case Rep. 2014.
PMID: 24827655 DOI: 10.1136/bcr-2014-011206
Kellner CP, McDowell MM, Connolly ES Jr, Sisti MB, Lavine SD.
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The development of de novo intracranial aneurysms following stereotactic radiosurgery for intracranial pathology is a rare complication secondary to vascular injury. Typically, these aneurysms develop within the first few years after radiation surgery. We present the first case of an aneurysm developing 10 years after radiosurgery for a cerebellopontine angle meningioma. This case highlights the importance of careful long-term follow-up of patients who undergo radiosurgery for lesions abutting major vessels and/or who suffer post-radiation complications.

Hearing preservation after stereotactic radiosurgery for bilateral cerebellopontine angle meningiomas.
Minim Invasive Neurosurg. 2009;52(5–6):259-262.
PMID: 20077370 DOI: 10.1055/s-0029-1243242
Tanaka S, Pollock BE.
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Background
Preservation of cranial nerve function is critical in the management of patients with cerebellopontine angle (CPA) tumors.

Case report
A 51-year-old woman with tinnitus and dizziness was discovered to have bilateral CPA dural-based masses extending into the internal auditory canals (IAC). Pre-operatively, the patient had normal hearing on the right (SRT, 5 dB; SDS 100% at 30 dB) and left (SRT, 10 dB; SDS 90% at 40 dB). The patient underwent two Leksell Gamma Knife (Elekta Instruments, Norcross, GA) radiosurgeries initially for the larger left-sided tumor, then one year later for the right. The margin dose for each tumor was 14 Gy. Six years after the first radiosurgery, the tumors have not progressed and she has retained normal hearing and facial function bilaterally.

Conclusions
Preservation of cranial nerve function is generally possible after stereotactic radiosurgery of CPA meningiomas.

Normal pressure hydrocephalus after gamma knife radiosurgery for cerebellopontine angle meningioma.
J Clin Neurosci. 2004;11(7):785–787.
PMID: 15337152 DOI: 10.1016/j.jocn.2003.12.016
Fujimoto A[1], Matsumura A, Maruno T, Yasuda S, Yamamoto M, Nose T.
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There are no reports of hydrocephalus following radiosurgery for a meningioma. We report on a case where gamma knife therapy for a 4 cm diameter right cerebellopontine meningioma accelerated hydrocephalus three months post treatment. Examination of the cerebrospinal fluid (CSF) revealed a high protein level and thus, CSF malabsorption and CSF obstruction might have occurred after the radio surgery. It is important to consider this pathology, and the need for long term follow up.

Hemifacial spasm due to cerebellopontine angle meningiomas--two case reports.

Neurol Med Chir (Tokyo). 2001;41(2):87–89.
PMID: 11255633 DOI: 10.2176/nmc.41.87

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A 54-year-old female and a 49-year-old female presented with complaints of hemifacial spasm. Both patients underwent surgery to remove cerebellopontine angle meningiomas. In one case, no vascular compression was observed at the root exit zone. The tumor was removed subtotally leaving residual tumor adhered to the lower cranial nerves. The hemifacial spasm disappeared immediately after the operation. The residual tumor was treated using gamma knife radiosurgery. In the other case, the root exit zone of the facial nerve was compressed by both the tumor and anterior inferior cerebellar artery and the tumor was removed totally. Postoperatively, the hemifacial spasm disappeared, but the patient suffered facial nerve paresis and deafness that was probably due to intraoperative manipulation. However, the facial nerve paresis gradually improved. Cerebellopontine angle meningioma with hemifacial spasm must be treated by surgical resection limited to preserve cranial nerve function. Subtotal removal with subsequent radiosurgery to treat the remaining tumor tissue is one option for the treatment of cerebellopontine angle meningioma.

Radiosurgery of tumors of the cerebellopontine angle.

Clin Neurosurg. 1994;41:168–184.
PMID: 7842602

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Efficacy and outcomes of facial nerve-sparing treatment approach to cerebellopontine angle meningiomas.
J Neurosurg. 2017;127(6):1–11.
PMID: 28186449 DOI: 10.3171/2016.10.JNS161982
D'Amico RS,[1] Banu MA,[1] Petridis P,[1] Bercow AS,[1] Malone H,[1] Praver M,[1] Wang TJ,[2] Isaacson SR,[1,2] Sisti MB.[1,2]
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Objective
Advanced microsurgical techniques contribute to reduced morbidity and improved surgical management of meningiomas arising within the cerebellopontine angle (CPA). However, the goal of surgery has evolved to preserve the quality of the patient's life, even if it means leaving residual tumor. Concurrently, Gamma Knife radiosurgery (GKRS) has become an acceptable and effective treatment modality for newly diagnosed, recurrent, or progressive meningiomas of the CPA. The authors review their institutional experience with CPA meningiomas treated with GKRS, surgery, or a combination of surgery and GKRS. They specifically focus on rates of facial nerve preservation and characterize specific anatomical features of tumor location with respect to the internal auditory canal (IAC).

Method
Medical records of 76 patients with radiographic evidence or a postoperative diagnosis of CPA meningioma, treated by a single surgeon between 1992 and 2016, were retrospectively reviewed. Patients with CPA meningiomas smaller than 2.5 cm in greatest dimension were treated with GKRS, while patients with tumors 2.5 cm or larger underwent facial nerve-sparing microsurgical resection where appropriate. Various patient, clinical, and tumor data were gathered. Anatomical features of the tumor origin as seen on preoperative imaging confirmed by intraoperative investigation were evaluated for prognostic significance. Facial nerve preservation rates were evaluated.

Results
According to our treatment paradigm, 51 (67.1%) patients underwent microsurgical resection and 25 (32.9%) patients underwent GKRS. Gross-total resection (GTR) was achieved in 34 (66.7%) patients, and subtotal resection (STR) in 17 (33.3%) patients. Tumors recurred in 12 (23.5%) patients initially treated surgically, requiring additional surgery and/or GKRS. Facial nerve function was unchanged or improved in 68 (89.5%) patients. Worsening facial nerve function occurred in 8 (10.5%) patients, all of whom had undergone microsurgical resection. Upfront treatment with GKRS for CPA meningiomas smaller than 2.5 cm was associated with preservation of facial nerve function in all patients over a median follow-up of 46 months, regardless of IAC invasion and tumor origin. Anatomical origin was associated with extent of resection but did not correlate with postoperative facial nerve function. Tumor size, extent of resection, and the presence of an arachnoid plane separating the tumor and the contents of the IAC were associated with postoperative facial nerve outcomes.

Conclusions
CPA meningiomas remain challenging lesions to treat, given their proximity to critical neurovascular structures. GKRS is a safe and effective option for managing CPA meningiomas smaller than 2.5 cm without associated mass effect or acute neurological symptoms. Maximal safe resection with preservation of neurological function can be performed for tumors 2.5 cm or larger without significant risk of facial nerve dysfunction, and, when combined with GKRS for recurrence and/or progression, provides excellent disease control. Anatomical features of the tumor origin offer critical insights for optimizing facial nerve preservation in this cohort.

Petroclival

Stereotactic radiosurgery of petroclival meningiomas: a multicenter study.

J Neurooncol. 2014;119(1):169–176.
PMID: 24821284 DOI: 10.1007/s11060-014-1470-x

Starke R[1], Kano H, Ding D, Nakaji P, Barnett GH, Mathieu D, Chiang V, Yu JB, Hess J, McBride HL, Honea N, Lee JY, Rahmathulla G, Evanoff WA, Alonso-Basanta M, Lunsford LD, Sheehan JP.
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Petroclival meningiomas are difficult to treat due to their intimate location with critical structures, and complete microsurgical resection is often associated with significant morbidity. In this study, we evaluate the outcomes of petroclival meningiomas treated with Gamma Knife radiosurgery (GKRS) as an adjunct to microsurgery or a primary treatment modality. A multicenter study of 254 patients with a benign petroclival meningioma was conducted through the North American Gamma Knife Consortium. One hundred and forty patients were treated with upfront radiosurgery, and 114 following surgery. Multivariate analysis was used to determine predictors of favorable defined as no tumor progression following radiosurgery and the absence of any new or worsening neurological function. At mean follow up of 71 months (range 6–252), tumor volumes increased in 9% of tumors, remained stable in 52%, and decreased in 39%. Kaplan-Meier actuarial progression free survival rates at 3, 5, 8, 10, and 12 years were 97, 93, 87, 84, and 80% respectively. At last clinical follow-up, 93.6% of patients demonstrated no change or improvement in their neurological condition whereas 6.4% of patients experienced progression of symptoms. Favorable outcome was achieved in 87% of patients and multivariate predictors of favorable outcome included smaller tumor volume (OR = 0.92; 95% CI 0.87–0.97, p = 0.003), female gender (OR 0.37; 95% CI 0.15–0.89, p = 0.027), no prior radiotherapy (OR 0.03; 95% CI 0.01–0.36, p = 0.006), and decreasing maximal dose (OR 0.92; 95% CI 0.96–0.98, p = 0.010). GKRS of petroclival meningiomas achieves neurological preservation in most patients and with a high rate of tumor control.

Decreased calcification of a petroclival meningioma after gamma knife radiosurgery.

BMJ Case Rep. 2014 Jul 8.
PMID: 25006056 DOI: 10.1136/bcr-2014-204272

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Stereotactic radiosurgery (SRS) has been well reported in the treatment of certain calcified intracranial lesions such as meningiomas. However, reduction in the calcified portion of the tumour after SRS treatment has not been reported. We present the case of a 76-year-old man with a right petroclival lesion consistent on imaging with a calcified meningioma. The lesion progressed on serial neuroimaging studies, and the patient elected to undergo Gamma Knife radiosurgery. No complications were encountered during the radiosurgery. The patient underwent follow-up imaging at 4 and 8 months, during which the lesion was seen to remain stable in overall size, but with marked decrease in the calcified component. Stereotactic radiosurgery can lead to the reduction of all aspects of meninigomas including the calcified component. The radiobiological effects of high dose ionising radiation may result in bony changes and, thereby, decrease intratumoural calcification of an intracranial tumour.

Petroclival meningiomas: study on outcomes, complications and recurrence rates.

J Neurosurg. 2011;114(5):1268–1277.
PMID: 21184632 DOI: 10.3171/2010.11.JNS10326

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Objective
Petroclival meningiomas are notoriously difficult lesions to manage surgically, given the critical neurovascular structures that are intimately associated with the tumors. In this paper, the authors' aim was to review their series of patients with petroclival meningiomas who underwent surgical treatment; emphasis was placed on evaluating modes of presentation, postoperative neurological outcome, complications, and recurrence rates.

Method
Fifty patients underwent surgical treatment for petroclival meningiomas. The majority of the patients were women (72%). The authors retrospectively reviewed the patients' medical records, imaging studies, and pathology reports to analyze presentation, surgical approach, neurological outcomes, complications, and recurrence rates.

Results
Headache was the most common presentation (58%). The most commonly used approach was the transpetrous approach (in 16 patients), followed by the orbitozygomatic approach (in 13). Gross-total resection was performed in 14 patients (28%), and in the remaining patients there was residual tumor (72%). Eighteen patients with tumor remnants were treated with Gamma Knife surgery. New postoperative cranial neuropathies were noted in 22 patients (44%). The most common cranial nerve (CN) deficit following surgery was CN III dysfunction (in 11 patients) and facial weakness (in 10). In 9 patients, the CN dysfunction was transient (41%), and 7 patients had permanent dysfunction (32%). Eight patients developed hydrocephalus and all required placement of a ventriculoperitoneal shunt. A CSF leak was noted in only 2 patients (4%), and wound dehiscence was noted in 1. The CSF leaks and the wound dehiscence occurred in patients who were undergoing reoperations. Adequate radiographic follow-up (minimum 6 months) was available for 31 patients (62%). The mean follow-up was 22.1 months. In 6 patients, tumor progression or recurrences were noted. The median time to recurrence was 84 months. At the time of discharge from the hospital, 92% of the patients had good outcomes (Glasgow Outcome Scale Scores 4 and 5). Three patients died of causes not directly related to the surgery.

Conclusions
Petroclival meningiomas still pose a formidable challenge to neurosurgeons. In their series, the authors used multiple skull base approaches and careful microneurosurgical technique to achieve a good functional outcome (Glasgow Outcome Scale Score 4 or 5) in 92% of patients, although the extent of gross-total resection was only 28%. The authors' primary surgical goal was to achieve maximal tumor resection while maintaining or improving neurological function. The authors favor the treatment of residual tumor or recurrent tumor with stereotactic radiosurgery.

Long-term control of petroclival meningiomas through radiosurgery.

J Neurosurg. 2010;112(5):957–964.
PMID: 19731986 DOI: 10.3171/2009.8.JNS09695

Flannery TJ, Kano H, Lunsford LD, Sirin S, Tormenti M, Niranjan A, Flickinger JC, Kondziolka D.
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Objective
Because of their critical location adjacent to brain, cranial nerve, and vascular structures, petroclival meningiomas remain a clinical challenge. The authors evaluated outcomes in 168 patients with petroclival meningiomas who underwent Gamma Knife surgery (GKS) during a 21-year interval.

Method
Gamma Knife surgery was used as either primary or adjuvant treatment of 168 petroclival meningiomas involving the region between the petrous apex and the upper two-thirds of the clivus. The most common presenting symptoms were trigeminal nerve dysfunction, balance problems, diplopia, and hearing loss. The median tumor volume was 6.1 cm3 (range 0.3–32.5 cm3), and the median radiation dose to the tumor margin was 13 Gy (range 9–18 Gy).

Results
During a median follow-up of 72 months, neurological status improved in 44 patients (26%), remained stable in 98 (58%), and worsened in 26 (15%). Tumor volume decreased in 78 patients (46%), remained stable in 74 (44%), and increased in 16 (10%), all of whom were subjected to additional management strategies. Overall 5- and 10-year progression-free survival rates were 91 and 86%, respectively. Patients followed up for at least 10 years (31 patients) had tumor and symptom control rates of 97 and 94%, respectively. Eight patients had repeat radiosurgery, 4 underwent delayed resection, and 4 had fractionated radiation therapy. Cerebrospinal fluid diversion was performed in 7 patients (4%). Significant risk factors for tumor progression were a tumor volume > or = 8 cm3 (p = 0.001) and male sex (p = 0.02).

Conclusions
In this 21-year experience, GKS for petroclival meningiomas obviated initial or further resection in 98% of patients and was associated with a low risk of adverse radiation effects. The authors believe that radiosurgery should be considered as an initial option for patients with smaller-volume, symptomatic petroclival meningiomas.

Evolution of surgical approaches in the treatment of petroclival meningiomas: a retrospective review.

Neurosurg. 2007;61(2)(suppl):202–209.
PMID: 18091234 DOI: 10.1227/01.neu.0000303218.61230.39

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Objective
We examined the surgical approaches used at a single institution to treat petroclival meningioma and evaluated changes in method utilization over time.

Method
Craniotomies performed to treat petroclival meningioma between September of 1994 and July of 2005 were examined retrospectively. We reviewed 46 patients (mean follow-up, 3.6 yr). Techniques included combined petrosal or transcochlear approaches (15% of patients), retrosigmoid craniotomies with or without some degree of petrosectomy (59% of patients), orbitozygomatic craniotomies (7% of patients), and combined orbitozygomatic-retrosigmoid approaches (19% of patients). In 18 patients, the tumor extended supratentorially. Overall, the rate of gross total resection was 43%. Seven patients demonstrated progression over a mean of 5.9 years. No patients died. At 36 months, the progression-free survival rate for patients treated without petrosal approaches was 96%. Of 14 patients treated with stereotactic radiosurgery, none developed progression.

Conclusions
Over the study period, a diminishing proportion of patients with petroclival meningioma were treated using petrosal approaches. Utilization of the orbitozygomatic and retrosigmoid approaches alone or in combination provided a viable alternative to petrosal approaches for treatment of petroclival meningioma. Regardless of approach, progression-free survival rates were excellent over short-term follow-up period.

The selection of the optimal therapeutic strategy for petroclival meningiomas.

Surg Neurol. 2006;66(2):160–165.
PMID: 16876612 DOI: 10.1016/j.sumeu.2005.12.024

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Background
Broad experience with the management of petroclival meningiomas was analyzed to optimize therapeutic strategy.

Method
The records of 75 patients with petroclival meningioma were reviewed. The population was divided into a microsurgery group (n = 49), a radiosurgery group (n = 12), a radiation therapy group (n = 5), and an observation group (n = 9) according to the modality of primary treatment. In the microsurgery group, the tumor was completely resected in 10 patients. Eleven of the 39 patients with incomplete resections sequentially underwent adjuvant radiation therapy or radiosurgery. The median follow-up period was 86 months (range, 48–210 months). The median follow-up period of the radiosurgery, the radiation therapy, and the observation group was 52 months (range, 48–71 months), 56 months (range, 51–72 months), and 63 months (range, 53–68 months), respectively. Management outcomes were evaluated with respect to tumor control rate, neurological deficit, and functional status assessed by the Karnofsky Performance Score.

Results
In the microsurgery group, 11 (22.4%) patients eventually showed tumor progression. However, there was only one recurrence if adjuvant therapy was used after incomplete removal. The incidence of favorable outcomes for cranial neuropathies was better in the incomplete resection group (69.2%) than for patients in the complete resection group (20%, P = .032). Moreover, a favorable functional outcome predominated in the incomplete resection group (76.9%) compared with the complete resection group (30%, P = .049). The disease was stable in both the radiation therapy and the radiosurgery groups during the follow-up period, with functional status and cranial nerve function perfectly preserved in these patients. No predictive factor other than short symptom duration was found to be significant.

Conclusions
Because the growth rate of petroclival meningioma is low and good functional status can be guaranteed, intended incomplete resection should be considered as an acceptable treatment option. Adjuvant treatment after surgery is useful in the control of residual tumors. Radiosurgery may be appropriate as the primary treatment in asymptomatic patients with small tumor; however, more aggressive treatment is needed in young patients or patients with short symptom durations.

Gamma knife radiosurgical management of petroclival meningiomas results and indications.

Acta Neurochir (Wien). 2003;145(10):883-888.
PMID: 14577010 DOI: 10.1007/s00701-003-0123-1

Roche PH[1], Pellet W, Fuentes S, Thomassin JM, Régis J.
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Background
Surgical treatment of petroclival meningiomas remains challenging. In order to refine indications for the use of stereotactic radiosurgery in the treatment of these tumours, we retrospectively evaluated our experience in this field.

Method
Thirty-two patients harboring a petroclival meningioma were treated consecutively using a Gamma knife between December 92 and June 1998. Eight patients underwent radiosurgery after one or more attempted surgical removals and 24 had radiosurgery as the primary treatment. The main symptoms before radiosurgery were cranial nerve palsies, including a sixth nerve deficit in 10 patients and a trigeminal nerve disturbance in 9. All patients underwent a conformal multi-isocentric treatment (mean isocenter's number 8.8) and the dose delivered at the tumour margin ranged from 10 to 15 Gy (mean dose 13 Gy).

Results
The duration of follow-up varied from 24 to 118 months (mean clinical follow-up 56 months, mean radiological follow-up 52.6 months). All 32 patients survived. The tumour volume remained unchanged in 28 patients and decreased slightly in 4. Neurological status worsened permanently in 2 patients with a delayed hemiparesis due to focal pontine infarction. These complications were associated with large meningiomas with vascular involvement and ventral brainstem compression, and occurred at the very early stage of our experience. At last follow-up, preoperative fifth or sixth cranial nerve deficits had improved or recovered in 13 out of 19 patients and any delayed worsening or new cranial nerve deficits were not observed after radiosurgery.

Conclusions
Stereotactic radiosurgery with a Gamma knife provides effective management of small to middle sized petroclival meningiomas and is an alternative to microsurgery. Careful selection of patients and use of major technical refinements should improve the safety of this treatment.

Stereotactic radiosurgery for petroclival meningioma.

Japanese Journal of Neurosurgery. 2002;11(3):230–236.
DOI: 10.7887/jcns.11.230

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Department of Neurosurgery, Gamma Knife Center, Komaki City Hospital, Komaki, Aichi, Japan.

We evaluated the results of Gamma Knife radiosurgery for petroclival meningioma in 50 patients (11 males and 39 females). The mean of the patients' age was 55.5 (range: 15 to 79) years old. Stereotactic radiosurgery was performed as a primary treatment in 29 patients. Twenty-one patients had undergone one to five prior resections. Tumors were located at the clivus in 2 patients. In the other 48 cases, tumors were located around the petrous apex or spread over the petro- clival region. Seventeen of the 48 tumors extended into the cavernous sinus. The mean tumor volume was 14.9 (range: 0.7 to 75) ml. The mean maximum dose was 27.2 (range: 18 to 35.7) Gy and the mean tumor margin dose was 13.6 (range: 8.1 to 25) Gy. In a median follow-up period of 36 (range: 6 to 112) months, 20 tumors (40%) decreased in size and 27 tumors (54%) remained unchanged. Only 3 tumors (6%) had radiographic evidence of progression in the treated part of the tumor. Surgical resection was performed in 3 patients after radiosurgery. In 1 patient, a second radiosurgery and then surgical resection was done. A second radiosurgery was also performed in 4 other patients. In 2 of these 4 patients, the second radiosurgery was done for tumor relapse outside the treatment field. The overall tumor control rate was 94%. Cranial nerve deficits without the evidence of tumor growth developed in only 3 patients (6%). Stereotactic radiosurgery was safe and effective in the management of patients with petroclival meningiomas, despite of the proximity of the tumors to critica neural and vascular structures.

Management of petroclival meningiomas by stereotactic radiosurgery.

Neurosurg. 1998;42(3):437–443.
PMID: 9526975 DOI: 10.1097/00006123-199808000-00001

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Objective
To evaluate the role of stereotactic radiosurgery in the management of petroclival meningiomas, we retrospectively reviewed our experience with 62 patients managed at the University of Pittsburgh during an 8-year period.

Method
All patients had cranial base meningiomas involving the region between the petrous apex and the upper two-thirds of the clivus. Some tumors extended into the cavernous sinus. Each of 39 patients (63%) had previously undergone one or more attempts at surgical resection. Seven patients (11%) had received fractionated external beam radiation therapy. Using the gamma knife, conformal multiple isocenter radiosurgery was performed with tumor margin doses of 11 to 20 Gy.

Results
During the median follow-up period of 37 months, neurological statuses improved in 13 patients (21%), remained stable in 41 patients (66%), and eventually worsened in 8 patients (13%). Tumor volumes decreased in 14 patients (23%), remained stable in 42 patients (68%), and increased in 5 patients (8%) . Despite the proximity of these tumors to critical neural and vascular structures, complications resulting from radiosurgery were rare. Five patients (8%) developed new cranial nerve deficits within 24 months of radiosurgery, although none had evidence of tumor progression. These deficits resolved completely in two patients within 6 months of onset.

Conclusions
Although an even longer follow-up period is desirable, we conclude that stereotactic radiosurgery provides a safe and effective management strategy for petroclival meningiomas, both as a primary procedure and as an adjunct to incomplete resection.

Sellar/Parasellar

Gamma knife radiosurgery for sellar and parasellar meningiomas: a multicenter study.

J Neurosurg. 2014;120(6):1268–1277.
PMID: 24678777 DOI: 10.3171/2014.2.JNS13139

Sheehan JP[1], Starke RM, Kano H, Kaufmann AM, Mathieu D, Zeiler FA, West M, Chao ST, Varma G, Chiang VL, Yu JB, McBride HL, Nakaji P, Youssef E, Honea N, Rush S, Kondziolka D, Lee JY, Bailey RL, Kunwar S, Petti P, Lunsford LD.
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Objective
Parasellar and sellar meningiomas are challenging tumors owing in part to their proximity to important neurovascular and endocrine structures. Complete resection can be associated with significant morbidity, and incomplete resections are common. In this study, the authors evaluated the outcomes of parasellar and sellar meningiomas managed with Gamma Knife radiosurgery (GKRS) both as an adjunct to microsurgical removal or conventional radiation therapy and as a primary treatment modality.

Method
A multicenter study of patients with benign sellar and parasellar meningiomas was conducted through the North American Gamma Knife Consortium. For the period spanning 1988 to 2011 at 10 centers, the authors identified all patients with sellar and/or parasellar meningiomas treated with GKRS. Patients were also required to have a minimum of 6 months of imaging and clinical follow-up after GKRS. Factors predictive of new neurological deficits following GKRS were assessed via univariate and multivariate analyses. Kaplan-Meier analysis and Cox multivariate regression analysis were used to assess factors predictive of tumor progression.

Results
The authors identified 763 patients with sellar and/or parasellar meningiomas treated with GKRS. Patients were assessed clinically and with neuroimaging at routine intervals following GKRS. There were 567 females (74.3%) and 196 males (25.7%) with a median age of 56 years (range 8–90 years). Three hundred fifty-five patients (50.7%) had undergone at least one resection before GKRS, and 3.8% had undergone prior radiation therapy. The median follow-up after GKRS was 66.7 months (range 6–216 months). At the last follow-up, tumor volumes remained stable or decreased in 90.2% of patients. Actuarial progression-free survival rates at 3, 5, 8, and 10 years were 98%, 95%, 88%, and 82%, respectively. More than one prior surgery, prior radiation therapy, or a tumor margin dose <13 Gy significantly increased the likelihood of tumor progression after GKRS. At the last clinical follow-up, 86.2% of patients demonstrated no change or improvement in their neurological condition, whereas 13.8% of patients experienced symptom progression. New or worsening cranial nerve deficits were seen in 9.6% of patients, with cranial nerve (CN) V being the most adversely affected nerve. Functional improvements in CNs, especially in CNs V and VI, were observed in 34% of patients with preexisting deficits. New or worsened endocrinopathies were demonstrated in 1.6% of patients; hypothyroidism was the most frequent deficiency. Unfavorable outcome with tumor growth and accompanying neurological decline was statistically more likely in patients with larger tumor volumes ($p = 0.022$) and more than 1 prior surgery ($p = 0.021$).

Conclusions
Gamma Knife radiosurgery provides a high rate of tumor control for patients with parasellar or sellar meningiomas, and tumor control is accompanied by neurological preservation or improvement in most patients.

Gamma knife surgery for parasellar meningiomas: long-term results including complications, predictive factors, and progression-free survival.

J Neurosurg. 2011;114(6):1571–1577.
PMID: 21314269 DOI: 10.3171/2011.1.JNS091939

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Objective
Stereotactic radiosurgery serves as an important primary and adjuvant treatment option for patients with many types of intracranial meningiomas. This is particularly true for patients with parasellar meningiomas. In this study, the authors evaluated the outcomes of Gamma Knife surgery (GKS) used to treat parasellar meningiomas.

Method
The study is a retrospective review of the outcomes in 138 patients with meningiomas treated at the University of Virginia from 1989 to 2006; all patients had a minimum follow-up of 24 months. There were 31 men and 107 women whose mean age was 54 years (range 19–85 years). Eighty-four patients had previously undergone resection. The mean pre-GKS tumor volume was 7.5 ml (range 0.2–54.8 ml). Clinical and radiographic evaluations were performed, and factors related to favorable outcomes in each case were assessed.

Results
The mean follow-up duration was 84 months (median 75.5 months, range 24–216 months). In 118 patients (86%), the tumor volume was unchanged or had decreased at last follow-up. Kaplan-Meier analysis demonstrated radiographic progression-free survival at 5 and 10 years to be 95.4% and 69%, respectively. Fourteen patients (10%) developed new cranial nerve palsies following GKS. Factors associated with tumor control included younger age, a higher isodose, and smaller tumor volume. A longer follow-up duration was associated with either a decrease or increase in tumor volume. Fourteen patients (10%) experienced new or worsening cranial nerve deficits after treatment. Factors associated with this occurrence were larger pretreatment tumor volume, lower peripheral radiation dose, lower maximum dose, tumor progression, and longer follow-up.

Conclusions
Gamma Knife surgery offers an acceptable rate of tumor control for parasellar meningiomas and accomplishes this with a low incidence of neurological deficits. Radiological control after radiosurgery is more likely in those patients with a smaller tumor volume and a higher prescription dose.

The surgical treatment strategy and results of parasellar meningiomas in the era of radiosurgery.

No Shinkei Geka. 2003;31(6):649–655.
PMID: 12833874

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We evaluated the surgical treatment results of parasellar meningiomas in the era of radiosurgery. We treated 24 patients of parasellar meningiomas surgically. The median age was 60 yrs (ranging from 29 to 82 yrs). The most common tumor location was the sphenoid ridge in 12 patients and the tuberculum sellae in 7 patients. The pterional approach using fronto-temporal craniotomy was performed for all patients. The residual or recurrent tumors were treated by gamma knife radiosurgery (GKS). We are able to follow up these cases for a median of 3.8 yrs (ranging from 1 to 8 yrs) after the operations. The radicality of tumor resection was Simpson grade II in 13 patients (54%), grade III in 3 patients (13%) and grade IV in 7 patients (33%). Clinical improvement was achieved in 81% of the patients. Of the patients who had visual disturbance preoperatively, 8 patients (73%) showed improvement, but 3 patients suffered deterioration postoperatively. None of the patients died. One patient suffered transient memory disturbance and one patient suffered mild facial numbness postoperatively. Boost radiosurgery for the residual tumors was performed for six patients and tumor growth control was able to be achieved in all patients, with a median of 3.1 years follow-up period (ranging from 0.5 to 6 yrs). Five patients with tumor regrowth or recurrence were treated by GKS. We recommend fronto-temporal craniotomy with nonradical resection for parasellar meningiomas and radiosurgery for residual and recurrent tumors. This strategy will achieve good functional outcome with long-term tumor growth control.

Preservation of visual fields after peri-sellar gamma-knife radiosurgery.

Int J Cancer. 2000;90(6):343–350.

PMID: 11180138 DOI: 10.1002/1097-0215(20001220)90:63.0.CO;2-H

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Radiosurgical treatment of pituitary and peri-sellar tumors has become an increasingly utilized modality as an alternative to conventional radiotherapy and surgery. Such radiosurgery results in a relatively high dose of radiation to the optic chiasm. The clinical data establishing safe single-fraction doses to the chiasm is immature, although taken together previous literature suggests a recommended maximal dose of 8 Gy. Optic neuropathy, when it occurs, tends to take place within 2 years of treatment. We evaluated the visual fields of 20 sequential patients that received significant doses to the optic chiasm by Gamma-knife radiosurgery. There were 17 cases of pituitary adenoma and 3 cases of meningioma, and two patients refused follow-up testing. Preoperative visual field and cranial nerve examinations were done prior to radiosurgery and in follow-up, with a median follow-up of 24 months. There were no cases of quantitative visual field deficit induced by treatment. No patients developed symptomatic visual deterioration. Radiat. Oncol. Invest. 90:343-350, 2000. 2000 Wiley-Liss, Inc.

Stereotactic radiosurgery in the treatment of parasellar meningiomas: long-term volumetric evaluation.

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PMID: 28338439 DOI: 10.3171/2016.11.JNS161402

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Objective
Parasellar meningiomas tend to invade the suprasellar, cavernous sinus, and petroclival regions, encroaching on adjacent neurovascular structures. As such, they prove difficult to safely and completely resect. Stereotactic radiosurgery (SRS) has played a central role in the treatment of parasellar meningiomas. Evaluation of tumor control rates at this location using simplified single-dimension measurements may prove misleading. The authors report the influence of SRS treatment parameters and the timing and volumetric changes of benign WHO Grade I parasellar meningiomas after SRS on long-term outcome.

Method
Patients with WHO Grade I parasellar meningiomas treated with single-session SRS and a minimum of 6 months of follow-up were selected. A total of 189 patients (22.2% males, n = 42) form the cohort. The median patient age was 54 years (range 19–88 years). SRS was performed as a primary upfront treatment for 44.4% (n = 84) of patients. Most (41.8%, n = 79) patients had undergone 1 resection prior to SRS. The median tumor volume at the time of SRS was 5.6 cm3 (0.2–54.8 cm3). The median margin dose was 14 Gy (range 5–35 Gy). The volumes of the parasellar meningioma were determined on follow-up scans, computed by segmenting the meningioma on a slice-by-slice basis with numerical integration using the trapezoidal rule.

Results
The median follow-up was 71 months (range 6–298 months). Tumor volume control was achieved in 91.5% (n = 173). Tumor progression was documented in 8.5% (n = 16), equally divided among infield recurrences (4.2%, n = 8) and out-of-field recurrences (4.2%, n = 8). Post-SRS, new or worsening CN deficits were observed in 54 instances, of which 19 involved trigeminal nerve dysfunction and were 18 related to optic nerve dysfunction. Of these, 90.7% (n = 49) were due to tumor progression and only 9.3% (n = 5) were attributable to SRS. Overall, this translates to a 2.64% (n = 5/189) incidence of direct SRS-related complications. These patients were treated with repeat SRS (6.3%, n = 12), repeat resection (2.1%, n = 4), or both (3.2%, n = 6). For patients treated with a margin dose ≥ 16 Gy, the 2-, 4-, 6-, 8-, 10-, 12-, and 15-year actuarial progression-free survival rates are 100%, 100%, 95.7%, 95.7%, 95.7%, 95.7%, and 95.7%, respectively. Patients treated with a margin dose < 16 Gy, had 2-, 4-, 6-, 8-, 10-, 12-, and 15-year actuarial progression-free survival rates of 99.4%, 97.7%, 95.1%, 88.1%, 82.1%, 79.4%, and 79.4%, respectively. This difference was deemed statistically significant (p = 0.043). Reviewing the volumetric patient-specific measurements, the early follow-up volumetric measurements (at the 3-year follow-up) reliably predicted long-term volume changes and tumor volume control (at the 10-year follow-up) (p = 0.029).

Conclusions
SRS is a durable and minimally invasive treatment modality for benign parasellar meningiomas. SRS offers high rates of growth control with a low incidence of neurological deficits compared with other treatment modalities for meningiomas in this region. Volumetric regression or stability during short-term follow-up of 3 years after SRS was shown to be predictive of long-term tumor control.

Orbital

Gamma knife surgery in the management of orbital tumors.

J Neurosurg. 2010;113(suppl):34–38.
PMID: 21121785 DOI: 10.3171/2010.7.GKS10857

Xu D[1], Liu D, Zhang Z, Zhang Y, Li Y, Liu X, Jia Q, Zheng L, Song G.
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Objective
The authors evaluated the results they obtained using Gamma Knife surgery (GKS) in patients with orbital tumors.

Method
This is a retrospective clinical evaluation of 202 patients with orbital tumors who were treated with GKS between September 1995 and October 2008. The series included 84 men and 118 women with a mean age of 39.5 +/- 14.6 years (range 5–85 years). The diagnoses were determined based on pathological analyses in 113 patients and presumed based on characteristic clinical and imaging findings in 89 patients. There were 84 meningiomas, 38 epithelial tumors of the lacrimal gland, 23 schwannomas, 18 malignant choroidal melanomas, 12 optic nerve gliomas,11 orbital metastases, 10 pseudotumors of the orbit, 3 retinoblastomas, and 3 cases of fibromatosis. The median target volume was 5.4 cm (3) (range 0.04–35.6 cm (3)). The tumor margin dose ranged from 10 to 40 Gy.

Results
At a median follow-up period of 34.5 +/- 14.7 months (range 12–114 months), tumor shrinkage was observed in 118 patients (58.4%) and stable tumor size in 71 patients (35.1%). Regularly scheduled neuroimaging studies demonstrated evidence of tumor progression in only 13 patients (6.4%): 9 of these patients underwent repeated GKS and 4 received surgical treatment. Visual acuity was preserved in 129 patients. Seventy-two patients experienced some degree of improvement in vision. Severe deterioration of visual acuity was found in 18 of 147 patients who had useful vision before treatment. Nineteen patients (9.4%) experienced transient conjunctival edema; no other serious acute side effect was observed.

Conclusions
Gamma Knife surgery provides an effective management strategy in patients with orbital tumors; it achieves excellent preservation of neurological function and is associated with few treatment-related complications.

Gamma knife radiosurgery for orbital tumors.

Clin Neurol Neurosurg. 2008;110(10):1003–1007.
PMID: 18653273 DOI: 10.1016/j.clineuro.2008.06.008

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Objective
This study was performed to investigate the radiological and functional outcomes of patients with orbital tumors treated by gamma knife radiosurgery (GKS).

Patients and methods
Fifteen patients with orbital tumors (7 meningiomas, 3 cavernous hemangiomas, 2 schwannomas, 2 metastatic tumors and 1 adenoid cystic carcinoma of the lacrimal gland) were treated. Seven patients with preserved vision and tumors located near the optic nerve were treated with multisession (3 or 4 fractions) radiosurgery. The mean tumor volume was 3695 mm3 (737–13,300). The median marginal dose was 14 Gy (13–20) in single-session radiosurgery, and the median cumulative marginal dose was 20 Gy (15–20) in multisession radiosurgery.

Results
After a mean follow-up of 20.9 months (6–50), tumor control was confirmed in 12 of 15 patients. Three patients with malignant lesions had to undergo another operation due to tumor progression. Of the 13 patients whose preoperative vision was preserved, 6 patients showed improvement in visual acuity and/or visual field, 4 patients showed no change in vision, and 3 patients showed deterioration (2 related to tumor progression).

Conclusions
As with intracranial tumors with similar pathologies, GKS may be an effective treatment option for orbital tumors. Multisession radiosurgery may be a good strategy for increasing the possibility of visual function preservation in selected cases in which the lesion is adjacent to the optic apparatus.

Optic nerve sheath

Long-term results of gamma knife surgery for optic nerve sheath meningioma.

J Neurosurg. 2010;113(suppl):28–33.
PMID: 21121784 DOI: 10.3171/2010.7.GKS10869

Liu D, Xu D, Zhang Z, Zhang Y, Li Y, Liu X, Jia Q, Zheng L, Song G.
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Objective
The goal of this study was to assess the long-term results of Gamma Knife surgery (GKS) in patients harboring an optic nerve sheath meningioma (ONSM).

Methods
Thirty patients harboring an ONSM were treated with GKS between 1998 and 2003. Gamma Knife surgery was performed as the sole treatment option in 21 of these patients and resection had been performed previously in 9 patients. The mean volume of the tumor at the time of GKS was 3.6 cm(3) (range 1.4–9.7 cm(3)), and the mean prescription peripheral dose was 13.3 Gy (range 10–17 Gy). The mean number of isocenters used to treat these lesions was 8 (range 5–14 isocenters).

Results
At a median follow-up of 56 months, visual acuity improved in 11 patients, remained stable in 13 patients (including 4 patients who were completely blind before GKS), and deteriorated in 6 patients. Follow-up images were available in all patients and showed tumor regression in 20 patients and stable tumor in 8 patients. Persistent imaging evidence of progression was only present in 2 patients. With the exception of reversible conjunctival edema in 4 cases, no other serious acute side effect was observed.

Conclusions
Gamma Knife surgery provides long-term tumor control for ONSM. The results of this study add substantial evidence that GKS may definitely become a standard treatment approach in selected cases of ONSM.

Preservation of residual vision 2 years after stereotactic radiosurgery for a presumed optic nerve sheath meningioma.

J Neuroophthalmol. 1998;18(2):117–120.
PMID: 9621268

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We performed stereotactic radiosurgery on a patient with a presumed optic nerve sheath meningioma with a progressive optic neuropathy and an intact peripheral visual field. The patient's visual acuity and visual field have remained stable for 2 years following treatment, and the appearance of the tumor has not changed by neuroimaging. We believe that stereotactic radiosurgery is a viable option for treating optic nerve sheath meningioma.

Tentorial

Gamma Knife radiosurgery for meningiomas arising from the tentorium: a 22-year experience.

J Neurooncol. 2015;121(1):129–134.
PMID: 25186087 DOI: 10.1007/s11060-014-1605-0

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In order to evaluate long term clinical and imaging outcomes, the authors retrospectively reviewed our 22-year experience using stereotactic radiosurgery (SRS) for tentorial meningiomas. Thirty-nine patients with tentorial meningiomas underwent SRS using various Gamma Knife technologies between 1988 and 2010. The most common presenting symptoms were headache, dizziness or disequilibrium, and ataxia. The median tumor volume was 4.6 cm3 (range 0.5–36.6 cm3) and the median radiation dose to the tumor margin was 14 Gy (range 8.9–18 Gy). The median follow-up period was 41 months (range 6–183 months). At the last imaging follow-up, tumor volumes decreased in 22 patients (57%), remained stable in 13 patients (33%), and increased in 4 patients (10%). The progression-free survival after SRS was 97% at 1 year, and 92% at 5 years. At the last clinical follow-up, 35 patients (90%) showed no change in symptoms, 1 patient (2%) showed improvement of their neurologic symptom, and 3 patients (8%) demonstrated worsening symptoms. The rate of symptom worsening after SRS was 5% at 1 year, and 10% at 5 years. Asymptomatic peritumoral edema after SRS occurred in 2 patients (5%). Symptomatic adverse radiation effect developed in 2 patients (5%). SRS for tentorial meningiomas provided long-term effective tumor control and a low risk of radiation related complications.

Stereotactic radiosurgery for tentorial meningiomas.

Acta Neurochirur (Wien). 1998;140(4):315–320.
PMID: 9689322 DOI: 10.1007/s007010050104

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Radical microsurgical resection is the procedure of choice for tentorial meningiomas. Despite advances in microsurgery, tentorial meningiomas continue to challenge surgeons and patients. To evaluate the response of tentorial meningiomas, we evaluated 41 patients who had Gamma knife stereotactic radiosurgery during a 9 year period. Patient age varied from 32 to 79 years. Headache, trigeminal neuralgia, or facial paraesthesia were the most common presenting symptoms. Sensory deficits in the distribution of the trigeminal nerve were the most common finding. Eighteen patients (44%) had undergone between 1 and 5 (mean, 1.9) resections prior to radiosurgery; 23 had tumors diagnosed by neuroimaging. The average tumor diameter in this series was 20 mm. The maximum tumor dose varied from 24 to 40 Gy (mean, 30.5 Gy), and the tumor margin dose varied from 12 to 20 Gy (mean, 15.3 Gy). During the average follow-up interval of 3 years (range, 1–8 years), 19 patients had clinical improvement, 20 remained stable, and 2 patients deteriorated. Follow-up imaging showed a reduction in tumor size in 18 patients, no further tumor growth in 22, and an increase in tumor size in one (overall tumor control rate of 98%). Stereotactic radiosurgery using the Gamma Knife was a safe and effective primary or adjuvant treatment for patients with tentorial meningiomas.

A case of clear cell meningioma originating from the cerebellar tentorium.

No Shinkei Geka. 1998;26(3):265–270.
PMID: 9558660

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We report herein on a case of clear cell meningioma originating from the cerebellar tentorium, surgically treated by occipital transtentorial approach (OTT). A 67-year-old woman was admitted to our hospital in September, 1996, complaining of gait disturbance. MRI revealed an isointense mass on T1 and T2 WI, clearly enhanced with gadolinium in the right upper cerebellum originating from the tentorium. A left vertebral angiogram showed tumor stain from the right superior cerebellar artery. The tumor was subtotally removed by OTT on September 24, 1996. Gamma knife radiosurgery was performed for regrowing tumor 6 months after surgery. Histological examination revealed that the tumors were composed of sheets of clear, glycogen-rich cells and lobulated by thin connective tissues. There were no malignant findings, but some tumor cells had infiltrated into the cerebellar cortex. Immunohistochemistry showed that tumor cells were positive for EMA and vimentin, but negative for keratin. MIB-1 staining index was 7.02%. From these findings, this case was diagnosed as a typical clear cell meningioma originating from the cerebellar tentorium. From a review of the literature including our case, clear cell meningioma may be clinicopathologically malignant, so careful follow-up will be necessary.

Venous sinuses

Meningiomas engaging major venous sinuses.

World Neurosurg. 2014;81(1):116–124.
PMID: 23376533 DOI: 10.1016/j.wneu.2013.01.095

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Background
Meningiomas with growth onto or into the major venous sinuses, that is, venous meningiomas, provide management problems regarding their radical removal and preservation of venous drainage. The relationship to venous structures often precludes radical surgery; the risk of recurrence and aggressive histology is greater for parasagittal meningiomas than in other locations. Older series reflect the conflict between radical surgery and subtotal removal followed by the "wait-and-scan" approach for the residual. This review summarizes our experience of a more contemporary series of venous meningiomas, after to the introduction of gamma-knife radiosurgery, for residual tumors and a long follow-up of 10 years.

Method
Treatment, histopathology, and follow-up data of 100 consecutive patients undergoing surgery for venous meningiomas were prospectively collected. Gamma-knife surgery was considered as a direct postsurgical adjunct or as an adjunct after a period of radiological follow-up. The proliferation marker MIB-1 was prospectively analyzed. Two patients were lost to follow-up after 5 years, and 98 were followed until their death or a minimum of 10 years.

Results
The 6-month outcome was good-to-excellent in 94 patients; one patient died. Eighteen patients died within 10 years. Ten had aggressive or anaplastic meningiomas. In 10 years, tumor recurrence or progression was noted in 23 patients. One important reason was that only 42% of patients undergoing Simpson grade 1 removal had free resection margins at microscopic examination. Patients with Simpson grade 1 surgery had a recurrence rate of 10%. Patients with deliberate nonradical surgery (Simpson grade IV) had a tumor recurrence rate of 72%, whereas a combined treatment of direct gamma-knife radiosurgery after a tailored microsurgical resection (Simpson IV gamma) allowed return to a low recurrence rate of 10%. The tumor proliferation indices (MIB-1/Ki-67) were prognostically relevant for recurrence after either microsurgery or gamma-knife radiosurgery.

Conclusions
Surgical microscopic radicality was unexpectedly difficult to achieve. Gamma-knife radiosurgery was a useful adjunct but only in patients with tumors of low proliferative index. It should probably be used as part of the initial surgical management. As expected, treatment results for these patients seem to have improved during the last decades but recurrence and malignancy remained a problem, which is not always solved by repeated radiosurgery.

Atypical meningiomas

A retrospective analysis of survival and prognostic factors after stereotactic radiosurgery for aggressive meningiomas.

Radiat Oncol. 2014;9:38.
PMID: 24467972 DOI: 10.1186/1748-717X-9-38

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Background
While most meningiomas are benign, aggressive meningiomas are associated with high levels of recurrence and mortality. A single institution's Gamma Knife radiosurgical experience with atypical and malignant meningiomas is presented, stratified by the most recent WHO classification.

Method
Thirty-one patients with atypical and 4 patients with malignant meningiomas treated with Gamma Knife radiosurgery between July 2000 and July 2011 were retrospectively reviewed. All patients underwent prior surgical resection. Overall survival was the primary endpoint and rate of disease recurrence in the brain was a secondary endpoint. Patients who had previous radiotherapy or prior surgical resection were included. Kaplan-Meier and Cox proportional hazards models were used to estimate survival and identify factors predictive of recurrence and survival.

Results
Post-Gamma Knife recurrence was identified in 11 patients (31.4%) with a median overall survival of 36 months and progression-free survival of 25.8 months. Nine patients (25.7%) had died. Three-year overall survival (OS) and progression-free survival (PFS) rates were 78.0% and 65.0%, respectively. WHO grade II 3-year OS and PFS were 83.4% and 70.1%, while WHO grade III 3-year OS and PFS were 33.3% and 0%. Recurrence rate was significantly higher in patients with a prior history of benign meningioma, nuclear atypia, high mitotic rate, spontaneous necrosis, and WHO grade III diagnosis on univariate analysis; only WHO grade III diagnosis was significant on multivariate analysis. Overall survival was adversely affected in patients with WHO grade III diagnosis, prior history of benign meningioma, prior fractionated radiotherapy, larger tumor volume, and higher isocenter number on univariate analysis; WHO grade III diagnosis and larger treated tumor volume were significant on multivariate analysis.

Conclusions
Atypical and anaplastic meningiomas remain difficult tumors to treat. WHO grade III diagnosis and treated tumor volume were significantly predictive of recurrence and survival on multivariate analysis in aggressive meningioma patients treated with radiosurgery. Larger tumor size predicts poor survival, while nuclear atypia, necrosis, and increased mitotic rate are risk factors for recurrence. Clinical and pathologic predictors may help identify patients that are at higher risk for recurrence.

Radiosurgery for atypical and anaplastic meningiomas: histopathological predictors of local tumor control.
Stereotact Funct Neurosurg. 2012;90(5):316–324.
PMID: 22797807 DOI: 10.1159/000338253
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Objective
We investigated the radiosurgical outcomes of patients with nonbenign meningiomas retrospectively and sought to identify prognostic factors for local tumor control after radiosurgery with an emphasis on histopathology.

Method
Between 1998 and 2010, 35 patients with 49 atypical or anaplastic meningiomas were treated with radiosurgery. The mean tumor volume and marginal irradiation dose were 3.5 cm(3) (range 0.3–25.3) and 16 Gy (range 12–21), respectively.

Results
The actuarial local tumor control rates for patients with atypical meningiomas at 1, 2 and 3 years after radiosurgery were 78, 53 and 36%, respectively, whereas those for anaplastic meningiomas were 35% at 1 year and 10% at 2 years. Multivariate analysis revealed that the mitotic count (</=8 per 10 high-power fields; HPF) and the MIB-1 proliferation marker labeling index (LI; </=8%) were significant favorable prognostic factors for the radiosurgical outcomes of patients with nonbenign meningiomas (p = 0.014 and p = 0.012, respectively).

Conclusions
Radiosurgery could be a treatment option for patients with atypical meningiomas, but more aggressive treatments are needed for those with anaplastic meningiomas. Histopathological factors such as mitotic count and MIB-1 LI are significant prognostic factors for the radiosurgical outcomes of patients with nonbenign.

Patterns of failure after treatment of atypical meningioma with gamma knife radiosurgery.
J Neurooncol. 2012;108(1):179–185.
PMID: 22359231 DOI: 10.1007/s11060-012-0828-1
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Atypical meningiomas have poor local control with emerging literature indicating the use of radiosurgery in treatment. The purpose of this study was to evaluate clinical outcomes including local control and failure pattern after Gamma Knife radiosurgery (GKRS) and factors that may affect these outcomes. Between 1999 and 2008, 24 patients were treated with GKRS as either primary or salvage treatment for pathologically proven atypical meningiomas. Treatment failures were determined by serial magnetic resonance imaging. A median marginal dose of 14 Gy was used (range 10.5–18 Gy). Overall local control rates at 1, 2, and 5 years were 75, 51, and 44%, respectively. With median follow-up time of 42.5 months, 14 of 24 patients experienced a treatment failure at time of last follow-up. Eight recurrences were in-field, four were marginal failures, and two were distant failures. Wilcoxon analysis revealed that the conformality index (CI) was a significant predictor of local recurrence (P = 0.04). CI did not predict for distant recurrences (P = 0.16). On multivariate analysis evaluating factors predicting progression free survival, dose >14 Gy was found to be statistically significant (P = 0.01). There appears to be a dose response using GKRS beyond 14 Gy but given the suboptimal local control rates in this study, higher doses may still be needed to obtain better local control.

Major intratumoral hemorrhage of a petroclival atypical meningioma: case report and review of literature.
Skull Base. 2010;20(6):469–474.
PMID: 21772807 DOI: 10.1055/s-0030-1261266
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Spontaneous intratumoral hemorrhage associated with a meningioma is an extremely rare event and has a very high rate of morbidity and mortality. We report a patient with a history of subtotal resection of a petroclival meningioma followed by gamma knife radiosurgery who presented with sudden neurological deterioration following intratumoral hemorrhage after 4 asymptomatic years. The patient underwent early resection of this atypical meningioma and evacuation of hematoma via a retrosigmoid transpetrosal approach and had rapid neurological improvement.

Gamma knife surgery for atypical meningiomas.
J Neurosurg. 2005;102(suppl):283–286.
PMID: 28306448 DOI: 10.317/jns.2005.102.s_supplement0283
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Objective
Complete resection is the optimal treatment for atypical meningiomas (AMs) but its feasibility depends on the tumor site. The object of this study was to assess the effect of gamma knife surgery (GKS) on AM.

Method
In 15 patients 21 AMs were treated by GKS. Four patients had residual lesions and 10 patients had recurrent tumors after one or more microsurgical interventions. Three patients were treated twice with GKS because of tumor tissue outside the treatment volume, either at the margin or at a distant location. The median clinical and neuroimaging follow-up period was 35 months (range 21–67 months). Ten tumors shrank 6 to 12 months after GKS, 10 remained stable, and one grew. Between 18 and 36 months after GKS, four patients had a distant recurrence, and two had a margin recurrence. In one of these cases, an additional local recurrence was demonstrated 1 year later, and the patient underwent standard radiotherapy. No patient suffered persistent adverse effects after radiosurgery.

Conclusions
After early tumor shrinkage, high recurrence rates were demonstrated both at the treatment margin and at distant locations in cases treated for AM. There was only one recurrence within the GKS radiation field. For small- and medium-sized AMs GKS may be a safe adjunct to other treatment modalities.

The effect of radiosurgery during management of aggressive meningiomas.

Surg Neurol. 2003;60(4):298–305.
PMID: 14505844 DOI: 10.1016/S0090-3019(03)00320-3

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Background
Aggressive (atypical or malignant) meningiomas are difficult tumors to manage. We review the local control and survival rates of patients with aggressive meningiomas after multi-modality therapy that included stereotactic radiosurgery (SRS).

Method
Thirty patients had SRS for treatment of malignant (n = 12) or atypical (n = 18) meningiomas. There were 17 (57%) males and 13 (43%) females with an average age of 58 years. The mean number of prior surgical resections was two. The median imaging follow-up was 2.3 (0.1–11.4) years; median clinical follow-up was 3.8 (0.25–11.5) years.

Results
After SRS, the overall median time until progression of neurologic signs was 48.0 (+/-6.51) months. Median time to neurologic progression was significantly worse for patients treated late after recurrence versus early after craniotomy. Atypical meningiomas had 5- and 10-year overall actuarial survival rates of 59% (+/-13), while malignant meningiomas had 5- and 10-year overall actuarial survival rates of 59% (+/-16) and 0%. These curves were not significantly different from one another. Atypical meningiomas had a 5-year progression-free survival (PFS) of 83% (+/-7%), while malignant meningiomas had a 5-year PFS of 72% (+/-10) (p = 0.018). On multivariate analysis, early SRS and smaller tumor volumes were associated with better PFS, while younger age was associated with better survival. One patient had an adverse radiation effect after SRS.

Conclusions
Stereotactic radiosurgery is an important adjuvant management strategy for residual tumors identified early after craniotomy and partial resection. Aggressive use of early boost radiosurgery following craniotomy and radiation therapy is recommended for patients with malignant meningiomas.

Different responses of benign and atypical meningiomas to gamma-knife radiosurgery: report of two cases with immunohistochemical analysis.

Brain Tumor Pathol. 2001;18(2):61–66.
PMID: 11908875 DOI: 10.1007/BF02479417

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Recent reports have shown that gamma-knife radiosurgery provides a safe and effective strategy for the management of brain tumors. To evaluate the role of stereotactic radiosurgery in the management of meningiomas, we investigated the histopathology of two patients. The patients, a 37-year-old man and a 54-year-old woman, presented with visual field disturbance or headache. Imaging studies demonstrated intracranial meningiomas--tentorial and sphenoid ridge, respectively. Each patient undewent subtotal surgical resection (more than 90% in both patients), followed by gamma-knife radiosurgery of the remnant tumor marginal doses of 15 Gy. Pathological examination of the original tumors revealed a meningothelial meningioma and an atypical meningioma, respectively. Enlargement of the remnant tumors 4 months after radiosurgery resulted in total surgical resection in both patients. Thirteen months later, the patient with the atypical meningioma underwent a third operation for early recurrence of the tumor. Histopathology was investigated, and MIB-1, p53, and bcl-2 labeling indexes (LI) were analyzed immunohistochemically. Histopathologically, the specimens showed necrosis and intratumoral vessel obliteration after radiosurgery in both cases. However, more remnant tumor cells survived in the atypical meningioma. Immunohistochemically, increased wild-type p53, decreased bcl-2 expression, and decreased MIB-1 LI were observed in the benign meningioma. In the atypical meningioma, on the contrary, MIB-1 LI was decreased and mutant-type p53 and bcl-2 expression were unchanged. The specimen from the third operation revealed an anaplastic meningioma, and MIB-1 LI was markedly increased. These findings suggest that the efficacy of radiosurgery may differ between benign and atypical meningiomas.

Radiosurgery for malignant meningioma: results in 22 patients.

J Neurosurg. 2000;93(3)(suppl):62–67.

PMID: 11143265 DOI: 10.3171/jns.2000.93.supplement

Ojemann SG[1], Sneed PK, Larson DA, Gutin PH, Berger MS, Verhey L, Smith V, Petti P, Wara W, Park E, McDermott MW.

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Objective

The initial treatment of malignant meningiomas in the past has included surgical removal followed by fractionated external-beam radiotherapy. Radiosurgery has been added to the options for treatment of primary or recurrent tumors over the last 10 years. The authors report their results of using gamma knife radiosurgery (GKS) to treat 22 patients over an 8-year period.

Method

Twenty-two patients who underwent GKS for malignant meningioma between December 1991 and May 1999 were evaluated. Three patients were treated with GKS as a boost to radiotherapy and 19 for recurrence following radiotherapy. Outcome factors including patient survival, freedom from progression, and complications were analyzed. In addition, in the recurrent group, variables such as patient age, sex, tumor location, target volume, margin dose, and maximum dose were also analyzed. Univariate and multivariate analyses were performed. Overall 5-year survival and progression-free survival estimates were 40% and 26%, respectively. Age ($p < or = 0.003$) and tumor volume ($p < or = 0.05$) were significant predictors of time to progression and survival in both univariate and multivariate analyses. Five patients (23%) developed radiation necrosis. Significant relationships between complications and treatment variables or patient characteristics could not be established.

Conclusions

Tumor control following GKS is greater in patients with smaller-sized tumors (<8 cm3) and in younger patients. Gamma knife radiosurgery can be performed to treat malignant meningioma with acceptable toxicity. The efficacy of GKS relative to other therapies for recurrent malignant meningioma as well as the value of GKS as a boost to radiotherapy will require further evaluation.

Gamma knife stereotactic radiosurgery for grade 2 meningiomas.

J Neurol Surg B Skull Base. 2017;78(4):288–294.
PMID: 28725514 DOI: 10.1055/s-0036-1597834

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Objective
This study aims to report long-term clinical outcomes after Gamma Knife radiosurgery (GKRS) for intracranial grade 2 meningiomas.

Method
In this Institutional Review Board approved study, we reviewed records of all patients with grade 2 meningiomas treated with GKRS between 1998 and 2014.

Results
A total of 97 postoperative histopathologically confirmed grade 2 meningiomas in 75 patients were treated and are included in this study. After a mean follow-up of 41 months, 28 meningiomas had local recurrence (29.79%). Median time to local recurrence was 89 months (mean: 69, range: 47–168). The 3- and 5-year actuarial local control (LC) rates were 68.9 and 55.7%, respectively. The 3- and 5-year overall survival rates were 88.6 and 81.1%, respectively. There was a trend toward worse LC with tumors treated with radiation doses ≤13 versus >13 Gy. There was no radiation necrosis or second malignant tumors noted in our series.

Conclusions
This report, one of the largest GKRS series for grade 2 meningiomas, demonstrates that GKRS is a safe and effective treatment modality for patients with grade 2 meningiomas with durable tumor control and minimal toxicity. Adjuvant GKRS could be considered as a reasonable treatment approach for patients with grade 2 meningiomas.

Grade II meningiomas and gamma knife radiosurgery: analysis of success and failure to improve treatment paradigm.

J Neurosurg. 2016;125(suppl):89–96.
PMID: 27903189 DOI: 10.3171/2016.7.GKS161521

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Objective
Grade II meningiomas, which currently account for 25% of all meningiomas, are subject to multiple recurrences throughout the course of the disease and represent a challenge for the neurosurgeon. Radiosurgery is increasingly performed for the treatment of Grade II meningiomas and is quite efficient in controlling relapses locally at the site of the lesion, but it cannot prevent margin relapses. The aim of this retrospective study was to analyze the technical parameters involved in producing marginal relapses and to optimize loco-marginal control to improve therapeutic strategy.

Method
Eighteen patients presenting 58 lesions were treated by Gamma Knife radiosurgery (GKRS) between 2010 and 2015 in Hopital de la Pitié-Salpêtrière. The median patient age was 68 years (25%–75% interval: 61–72 years), and the sex ratio (M/F) was 13:5. The median delay between surgery and first GKRS was 3 years. Patients were classified as having Grade II meningioma using World Health Organization (WHO) 2007 criteria. The tumor growth rate was computed by comparing 2 volumetric measurements before treatment. After GKRS, iterative MRI, performed every 6 months, detected a relapse if tumor volume increased by more than 20%. Patterns of relapse were defined as being local, marginal, or distal. Survival curves were estimated using the Kaplan-Meier method, and the relationship between criterion and potential risk factors was tested by the log-rank test and univariable Cox model.

Results
The median follow-up was 36 months (range 8–57 months). During this period, 3 patients presented with a local relapse, 5 patients with a marginal relapse, and 7 patients with a distal relapse. Crude local control was 84.5%. The local control actuarial rate was 89% at 1 year and 71% at 3 years. The marginal control actuarial rate was 81% at 1 year and 74% at 2 years. The distal control actuarial rate was 100% at 1 year, 81% at 2 years, and 53% at 3 years. Median distal control was 38 months. Progression-free survival (PFS) was 71% at 1 year, 36% at 2 years, and 23% at 3 years. Median PFS was 18 months. Lesions treated with a minimum radiation dose of ≤ 12 Gy had significantly more local relapses than those treated with a dose > 12 Gy ($p = 0.04$) in univariate analysis. Marginal control was significantly influenced by tumor growth rate, with a lower growth rate being highly associated with improved marginal control ($p = 0.002$). There was a trend toward a relationship between dose and marginal control, but it was not significant ($p = 0.09$). PFS was significantly associated with delay between first surgery and GKRS ($p = 0.03$). The authors noticed few complications with no sequelae.

Conclusions
In order to optimize loco-marginal control, radiosurgical treatment should require a minimum dose of > 12 Gy and an extended target volume along the dural insertion. Ideally, these parameters should correspond to the aggressiveness of the lesion, based on genetic features of the tumor.

Gamma knife radiosurgery for atypical and anaplastic meningiomas.

World Neurosurg. 2016;87:557–564.

PMID: 26485417 DOI: 10.1016/j.wneu.2015.10.021

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Background

Atypical and anaplastic meningiomas have much higher recurrence rates after surgical resection compared with benign meningiomas, but the role of adjuvant radiosurgery remains unclear. This study was undertaken to evaluate the outcomes of gamma knife radiosurgery for patients with atypical and anaplastic meningiomas.

Method

In this retrospective analysis of a prospectively maintained database, 46 patients with histologically proven atypical or anaplastic meningiomas by current World Health Organization (WHO) criteria underwent postoperative Gamma Knife radiosurgery between 1993 and 2013. The median follow-up period was 32.6 months. The median tumor volume and margin dose were 11.7 mL (range 2–53 mL) and 13.1 Gy (range 12.0–16.5 Gy), respectively.

Results

Local control at 3 and 5 years was 50.6% and 32.1%, respectively. Gender (P = 0.013) and marginal dose less than or equal to 13 Gy (P = 0.049) were associated with the local control. The 3- and 5-year overall survival for patients with WHO grade II was 97.1% and 88.3%, respectively, compared with 66.7% and 66.7% for patients with WHO grade III meningiomas. Radiation therapy before Gamma Knife radiosurgery (GKRS; P = 0.018) and tumor grade (P = 0.019) were the factors associated with a worse overall survival rate. Fourteen patients (30.4%) developed adverse radiation effects after GKRS treatment, and all were Radiation Therapy Oncology Group grade I.

Conclusions

Postoperative GKRS treatment for patients with atypical and anaplastic meningioma is challenging. More aggressive treatment, including of safely maximizing the extent of surgical resection and using a higher margin dose (>13Gy), should be applied to achieve better local control.

Cost effectiveness

A microcosting study of microsurgery, LINAC radiosurgery, and gamma knife radiosurgery in meningioma patients.
J Neurooncol. 2011;101(2):237–245.
PMID: 20526795 DOI: 10.1007/s11060-010-0243-4
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The aim of the present study is to determine and compare initial treatment costs of microsurgery, linear accelerator (LINAC) radiosurgery, and gamma knife radiosurgery in meningioma patients. Additionally, the follow-up costs in the first year after initial treatment were assessed. Cost analyses were performed at two neurosurgical departments in The Netherlands from the healthcare providers' perspective. A total of 59 patients were included, of whom 18 underwent microsurgery, 15 underwent LINAC radiosurgery, and 26 underwent gamma knife radiosurgery. A standardized microcosting methodology was employed to ensure that the identified cost differences would reflect only actual cost differences. Initial treatment costs, using equipment costs per fraction, were <euro>12,288 for microsurgery, <euro>1,547 for LINAC radiosurgery, and <euro>2,412 for gamma knife radiosurgery. Higher initial treatment costs for microsurgery were predominantly due to inpatient stay (<euro>5,321) and indirect costs (<euro>4,350). LINAC and gamma knife radiosurgery were equally expensive when equipment was valued per treatment (<euro>2,198 and <euro>2,412, respectively). Follow-up costs were slightly, but not significantly, higher for microsurgery compared with LINAC and gamma knife radiosurgery. Even though initial treatment costs were over five times higher for microsurgery compared with both radiosurgical treatments, our study gives indications that the relative cost difference may decrease when follow-up costs occurring during the first year after initial treatment are incorporated. This reinforces the need to consider follow-up costs after initial treatment when examining the relative costs of alternative treatments.

Cyst formation

Cyst formation after stereotactic radiosurgery for intracranial meningioma.

Stereotact Funct Neurosurg. 2008;86(4):231–236.
PMID: 18480602 DOI: 10.1159/000131661

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The authors report 2 cases of delayed cyst formation after gamma knife radiosurgery for 3 meningioma lesions. All 3 lesions reported here had a distinctive feature before gamma knife treatment of small and spotty intratumoral cysts. One patient experienced an intriguing clinical course of spontaneous regression of the enlarged cyst, and 2 of the 3 lesions became symptomatic requiring surgical interventions. Cyst formation as a postradiosurgical complication is relatively rare in meningioma patients in the literature, and its pathogenesis is unclear. We describe herein the clinical courses of these 2 patients and review the relevant literature in this report. From our experience of these 2 cases, we suggest that we should be aware of the possible development of spotty intratumoral cysts into larger cysts after stereotactic radiosurgery and that we should carefully observe such patients after the treatment.

Cyst formation following gamma knife surgery for intracranial meningioma.

J Neurosurg. 2005;102(suppl):134–139.
PMID: 15662796 DOI: 10.3171/jns.2005.102.s_supplement.0134.

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Objective
The authors conducted a study to evaluate the clinical significance of cyst formation or enlargement after gamma knife surgery (GKS) for intracranial benign meningiomas

Method
The medical records of 160 patients with 184 tumors were examined for those with follow-up data of more than 2 years among 270 patients who underwent GKS for intracranial meningiomas between February 1992 and November 2001. Cyst formation or enlargement following GKS was observed in five patients, one man and four women (mean age 61.2 years). The tumor location was the sphenoid ridge in one case, petroclival in two, tentorium in one, and parasagittal region in one. All patients underwent surgery before GKS. The mean tumor volume was 10.5 cm3, the mean margin dose was 13.4 Gy (median 14 Gy), and the mean maximum dose was 27.5 Gy (median 24.1 Gy). At the time of GKS three tumors were associated with cyst, of which two enlarged after radiosurgery. Three cysts developed de novo after GKS. Three of the five patients needed surgery to treat the cyst formation or enlargement. Histological examination demonstrated various findings such as tumor necrosis, proliferation of small vessels, vascular obliteration, and hemosiderin deposits.

Conclusions
New cyst formation following GKS for benign intracranial meningioma is relatively rare; however, both preexisting and newly developed cysts tend to enlarge after GKS and often require surgery.

Elderly

Multimodal strategy for managing meningiomas in the elderly.

Acta Neurochir (Wien). 2005;147(2):131–136.
PMID: 15570440 DOI: 10.1007/s00701-004-0391-4

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Background
The incidence of brain tumors in elderly patients is increasing. It has become possible to treat meningiomas in the elderly by several modalities. We developed a successful multimodal strategy to treat these patients.

Methods
We registered 35 patients with meningiomas. Symptomatic meningiomas were treated surgically at the time of diagnosis (n=19). Of the 16 asymptomatic meningiomas, 5 were removed at the time of diagnosis. The other asymptomatic meningiomas (n=11) were treated conservatively and when the tumors increased in size, surgical treatment was considered. Operated patients with residual or recurrent tumors underwent radiosurgery with a gamma knife.

Results
Surgical mortality and morbidity were 4% and 16%, respectively. Of the 25 operated patients, 21 (84.0%) had a good Karnofsky scale (> or =80%) at discharge. In all but two of the 11 patients with asymptomatic, conservatively treated meningiomas, the tumors did not increase during the follow-up period. Gamma knife radiosurgery, performed to treat 3 residual and 1 recurrent tumor, resulted in very good tumor control and none of the tumors increased after gamma knife surgery.

Conclusions
Meningiomas in elderly patients require a multimodal approach. Our strategy, which includes surgery, radiosurgery, and conservative treatment, resulted in good tumor control and made it possible for patients to pursue their activities of daily life.

GKRS after surgery

Surgery followed by radiosurgery: a deliberate valuable strategy in the treatment of intracranial meningioma.

Clin Neurol Neurosurg. 2014;124:123–126.
PMID: 25043442 DOI: 10.1016/j.clineuro.2014.06.035

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Objective
The aim of our study is to show that surgery followed by Gamma Knife Radiosurgery is an effective and safe combined treatment for the control of intracranial meningiomas located close to critical structures.

Materials and method
This retrospective study followed 31 patients with intracranial meningioma between 2005 and 2010. We included patients when initial therapeutic decision was deliberate subtotal surgical resection preparing a target for early postoperative GKR. Early MRI was performed to evaluate the tumor residual volume after surgical procedure. Annual MRI was performed to detect any tumor progression.

Results
The mean follow-up was 4.5 years. The mean margin dose was 14.5 Gy and the mean target volume was 2.4 cm(3). The mean progression free survival after combined treatment was 4.4 years in the irradiated target volume and 3.9 years on the limit or remotely of irradiated target volume. Of all patients, we recorded 5 tumor progressions after combined treatment, in-field in 1 case and out-of-field in 4 cases. All tumor progressions were high-grade meningiomas.

Conclusions
Surgery followed by radiosurgery is a safe and effective combined treatment for intracranial meningiomas. We recommend it in case of meningioma located close to critical structures for which it is safer to leave in place a tumor remnant to reduce morbidity.

Stereotactic radiosurgery of meningiomas following resection: predictors of progression.

J Clin Neurosci. 2015;22(1):161–165.
PMID: 25439747 DOI: 10.1016/j.jocn.2014.07.028

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Residual or recurrent meningiomas after initial surgical resection are commonly treated with stereotactic radiosurgery (SRS), but progression of these tumors following radiosurgery is difficult to predict. We performed a retrospective review of 60 consecutive patients who underwent resection and subsequent Gamma Knife (Elekta AB, Stockholm, Sweden) radiosurgery for residual or recurrent meningiomas at our institution from 2001–2012. Patients were subdivided by Simpson resection grade and World Health Organization (WHO) grade. Cox multivariate regression and Kaplan-Meier analyses were performed to assess risk of tumor progression. There were 45 men (75%) and 15 women (25%) with a median age of 56.8 years (range 26.5–82 years). The median follow-up period was 34.9 months (range 6–108.4 months). Simpson grade 1–3 resection was achieved in 17 patients (28.3%) and grade 4 resection in 43 patients (71.7%). Thirty-four tumors (56.7%) were WHO grade 1, and 22 (36.7%) were WHO grade 2–3. Time from resection to SRS was significantly shorter in patients with Simpson grade 4 resection compared to grade 1–3 resection ($p < 0.01$), but did not differ by WHO grade ($p = 0.17$). Post-SRS complications occurred in five patients (8.3%). Overall, 19 patients (31.7%) experienced progression at a median of 15.3 months (range 1.2–61.4 months). Maximum tumor diameter >2.5 cm at the time of SRS ($p = 0.02$) and increasing WHO grade ($p < 0.01$) were predictive of progression in multivariate analysis. Simpson resection grade did not affect progression-free survival ($p = 0.90$). The mortality rate over the study period was 8.3%. SRS offers effective tumor control for residual or recurrent meningiomas following resection, especially for small benign tumors.

Staged gamma knife radiosurgery for large critically located benign meningiomas: evaluation of a series comprising 20 patients.

J Neurol Neurosurg Psychiatry. 2009;80(10):1172–1175.
PMID: 19762911 DOI: 10.1136/jnnp.2008.156745

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Objective
This study investigated the efficacy of staged radiosurgical treatment for intracranial meningiomas exceeding 3 cm in diameter.

Method
Between April 1992 and May 2008, staged gamma knife radiosurgery was performed in 20 patients with large benign meningiomas. 14 patients had undergone surgery at least once. The patients' ages ranged between 26 and 73 years (median 60.5). Tumour volumes measured between 13.6 and 79.8 cm(3) (median 33.3) and treatment volumes between 5.4 and 42.9 cm(3) (median 19.0). Of 41 treatments, the prescription dose at the tumour margin was 12 Gy for 33 treatments, 10 Gy for one treatment, 14 Gy for four treatments, 15 Gy for one treatment and 25 Gy for a further two treatments (median 12 Gy to a marginal isodose of 45%). Median follow-up was 7.5 years.

Results
Tumour control was achieved in 90% of our series (25% tumour regression, 65% stable size). Two patients (10%) experienced tumour progression outlying the planning target volumes treated by an additional radiosurgical procedure. Thereafter tumour volume decreased in one patient and remained stable in the second one. Clinically, nine patients (45%) improved within the time of follow-up and 11 (55%) remained unchanged.

Conclusions
As a result of excellent tumour control at a low concomitant morbidity, staged radiosurgical treatment for meningiomas represents a safe treatment modality that can be recommended for meningiomas in critical locations either after incomplete surgery or as primary treatment for patients with significant comorbidity.

Adjuvant gamma knife radiosurgery after meningioma resection.

J Clin Neurosci. 2004;11(7):715–718.
PMID: 15337131 DOI: 10.1016/j.jocn.2003.10.027

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We evaluated the usefulness of adjuvant treatment with gamma knife radiosurgery following meningioma surgery. During the past 8 years, we operated on 78 patients with meningiomas. Among these, 28 patients (36%) received gamma knife radiosurgery postoperatively. The indications for radiosurgery were as follows: residual tumour after surgery in 13 patients (46.4%), regrowth of residual tumour during the follow-up period in 7 patients (25%), recurrence after total removal (Simpson grade 1 or 2) in 7 patients (25%), and another intracranial meningioma in one patient (3.6%). The tumour diameter at the time of radiosurgery ranged from 5.2 to 48.1 mm (median 21.6 mm). Larger tumours with a mean diameter above 40 mm in two patients were treated with two-staged radiosurgery. The tumor marginal dose ranged from 8 to 23 Gy (median 12 Gy). The follow-up period was 3–84 months (median 30 months) after radiosurgery. The tumour size decreased in 17 patients (60.7%), remained unchanged in 9 patients (32.1%), and increased in 2 patients (7.2%). No radiation injury was experienced. Adjuvant therapy using gamma knife radiosurgery for meningiomas can achieve control of tumour growth and may improve patient outcomes. Careful surgical planning and follow-up are required to understand the usefulness and limitations of radiosurgery in this setting.

GKRS plus surgery

Complex cranial base meningioma: combined management.

Techniques in Neurosurgery. 2003;9(2):86–92.

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The management of giant cranial base meningiomas is challenging. The optimal treatment paradigm for such lesions remains poorly defined. Based on earlier studies, the authors have evaluated treatment outcomes for these complex lesions comparing attempted gross total resection in a single sitting (9 patients) versus staged surgical resection (6 patients) versus staged surgery plus gamma knife stereotactic radiosurgery (11 patients). Cranial nerve deficits were found in 33%, 16%, and 27% in the respective groups, whereas major neurologic deficits occurred in 22%, 0%, and 0% respectively. Mortality was 11%, 0%, and 0% in the single surgery, staged surgery, and surgery plus gamma knife groups, whereas hospital stay dropped from 15.5 days for single surgery to 9.3 days for staged surgery and 7.6 days for surgery plus gamma knife. Tumor control was excellent, with long-term tumor control in 24 of 26 patients (92%) over a mean 69.8-month follow-up. The authors conclude that although every patient should be evaluated on an individual basis, single-stage surgical resection may present increased risk of morbidity and a longer hospital stay. The long-term safety and efficacy of gamma knife treatment of these lesions remains unclear, but may play an important role in a combined surgical and radiosurgical treatment paradigm.

The treatment of skull base meningiomas--combining surgery and radiosurgery.

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PMID: 11683599 DOI: 10/1054/jocn.2000.0890

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While the operative results for treating skull base meningiomas have improved due to modern microsurgical techniques, surgery is still accompanied by a high morbidity rate. Over the last 6 years, we operated on 50 patients with intracranial meningiomas, 23 of which were skull-based lesions. Among these patients with skull base meningiomas, seven (30%) were treated with both surgery and radiosurgery. All patients received standard operative procedures. Five patients received subtotal resections and two patients received partial resections. No mortalities occurred in our series. Following the operations, the clinical status improved in six patients, while only one patient (with a tuberculum sellae meningioma) experienced deterioration of a preexisting visual disturbance. Radiosurgery was performed at a mean of 4.3 months after the operations. One patient was treated by a two-staged radiosurgery regimen in light of the patient's large tumour volume (57.5 cm(3)). The treatment volume of the series ranged from 0.3 to 29.6 cm(3) (mean 11.6 cm(3)), and the minimum dose for the tumours was from 8 Gy to 12 Gy (mean, 11.6 Gy). Tumour regression was observed in three patients (43%) during the follow up period for radiosurgery (mean: 28 months). No patients revealed tumour growth in the follow up period or suffered symptomatic radiation injury. The clinical status remained unchanged in each of the seven patients after radiosurgery. Although we treated only seven patients with skull base meningiomas using surgery combined with radiosurgery, and the follow up period has been short, we believe that such combination treatment may be a very useful option in selected patients.

Two-staged gamma knife radiosurgery for the treatment of large petroclival and cavernous sinus meningiomas.

Surg Neurol. 2001;56(5):308–314.
PMID: 11750001 DOI: 10.1016/S0090-3019(01)00622-X

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Background
In this study, we report on the effectiveness and usefulness of two-staged gamma knife radiosurgery (GKS) for large petroclival and cavernous sinus meningiomas that have a high rate of surgical morbidity.

Method
We have treated 7 patients suffering from large petroclival and cavernous sinus meningiomas using two-staged radiosurgery since March 1995. The tumors were located in the petroclival region in 4 patients, the cavernous sinus region in 2 patients, and in the petrocavernous region in the remaining patient. Three of the patients had been surgically treated and 4 patients (57%) were only followed with MR imaging. The volume of the tumors ranged between 34.5 to 101 cm(3) (mean 53.5 cm(3)). The treatment volume was between 6.8 to 29.6 cm(3) (mean 18.6 cm(3)). The treatment interval between the first GKS and second GKS was 6 months. The marginal doses for the tumors were 8 to 12 Gy (mean, 9 Gy).

Results
Six patients demonstrated tumor growth control during the follow-up period after the first radiosurgery (mean 39 months). Tumor regression was observed in 3 patients (43%). Three patients (43%) had improved clinically by the time of the follow-up examinations. No patient suffered from symptomatic radiation injury.

Conclusions
Although we have treated only 7 patients using two-staged GKS, we believe this treatment may be a very useful option for large petroclival and cavernous sinus meningiomas in selected patients.

Judicious resection and/or radiosurgery for parasagittal meningiomas: outcomes from a multicenter review.
Neurosurgery. 1998;43(3):405–413.
PMID: 9733295 DOI: 10.1097/00006123-199809000-00001
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Objective
Parasagittal meningiomas, especially when associated with the middle or posterior third of the superior sagittal sinus, pose difficult management challenges. Initial surgical excision is associated with high morbidity and frequent tumor recurrence after subtotal resection. Neurological deficits are cumulative when multiple resections are required. No consistent management approach exists for patients with such tumors. In addition to observation, management options include resection, stereotactic radiosurgery, or fractionated radiation therapy used alone or in combination.

Method
Sixteen centers where resection, gamma knife radiosurgery, and/or radiation therapy were available provided management data on 203 patients with histologically benign meningiomas from the time of initial diagnosis through follow-up after radiosurgery. The timing of resections, parameters of radiosurgery, rates of tumor control, morbidity, and functional patient outcomes were studied. The median follow-up duration in this study was 3.5 years (maximum, 33 yr after presentation and 6 yr after radiosurgery).

Results
The tumors were located in the anterior superior sagittal sinus in 52 patients, at the middle of the sinus in 91, and at the posterior portion of the sinus in 60. The mean tumor volume at the time of radiosurgery was 10 cc. In patients who underwent radiosurgery as the primary therapy (n = 66), the 5-year actuarial tumor control rate was 93 +- 4%. No clinical failure (need for additional therapy or worsened neurological function) occurred in patients who had smaller tumors (<7.5 cc) and who had never undergone resection (n = 41). The 5-year control rate for patients with previous surgery was only 60 +- 10%; the control rate for the radiosurgery treated volume was 85%. Most failures resulted from remote tumor growth. Multivariate analyses identified significantly decreased tumor control 'With increasing tumor volume (P = 0.002) and previous neurological deficits (P = 0.002). The rate of transient, symptomatic edema after radiosurgery was 16%, was more common with larger tumors, and occurred within 2 years. Of 33 patients who were employed at the time of radiosurgery for whom a minimum of 1 year of follow-up data were available, 30 remained employed (91 %). A decrease in functional status after radiosurgery was noted in only 3 of 33 (9%) employed and 7 of 77 (9%) unemployed patients.

Conclusions
In patients with smaller tumors (<3 cm in diameter) and patent sagittal sinuses, we advocate radiosurgery alone as the first surgical procedure. Patients with larger tumors and those with progressive neurological deficits resulting from brain compression should first undergo resection. Planned second-stage radiosurgery should be performed soon afterward for any residual tumor nodule or neoplastic dural remnant. Multimodality management may enhance long-term tumor control, reduce the need for multiple resections, and maintain the functional status of the patient.

GKRS versus surgery

Relative roles of microsurgery and stereotactic radiosurgery for the treatment of patients with cranial meningiomas: a single-surgeon 4-year integrated experience with both modalities.

J Neurosurg. 2005;102(suppl):59–70.
PMID: 15662783 DOI: 10.3171/jns.2005.102.s_supplement.0059

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Objective
The authors sought to assess the respective roles of microsurgery and gamma knife surgery (GKS) in the treatment of patients with meningiomas.

Method
The authors culled from a 4-year prospective database data on 74 cases of meningiomas. Thirty-eight were treated with GKS and 35 with microsurgery. Simpson Grade 1 or 2 resection was achieved in 86.1 % of patients who underwent microsurgery. Patients who underwent GKS received a mean margin dose of 16.4 Gy (range 14-20 Gy). The mean tumor coverage was 94.7%, and the mean conformity index was 1.76. Significant differences between the two treatment groups (GKS compared with microsurgery) included age (mean 60 compared with 50.7 years), volume (mean 7.85 cm3 compared with 44.4 cm3), treatment history (55.3% compared with 14.3%), and tumor location (cavernous sinus/petroclival, 14 compared with three). The median follow up was 21.5 months (range 1.5–50 months). In patients with benign meningiomas GKS tumor control was 96.8% with one recurrence at the margin. The recurrence rate was zero of 27 for Simpson Grade 1 or 2 resection and three of four for higher grades in those patients who underwent microsurgery. There was no procedure-related mortality or permanent major neurological morbidity. The mean Karnofsky Performance Scale score was maintained for both forms of treatment. Symptoms improved in 48.4% of patients undergoing microsurgery and 16.7% of those who underwent GKS. Transient and permanent cranial nerve morbidity was 7.9 compared with 2.9%, and 5.3 compared with 8.5% for GKS and microsurgery, respectively. In a patient satisfaction survey 93.1% of microsurgery patients and 91.2% of GKS patients were highly satisfied.

Conclusions
Both GKS and microsurgery serve important roles in the overall management of patients with meningiomas. Both are safe and effective and provide high degrees of satisfaction when used for differentially selected patients.

Stereotactic radiosurgery provides equivalent tumor control to Simpson grade 1 resection for patients with small- to medium-size meningiomas.

Int J Radiat Oncol Biol Phys. 2003;55(4):1000–1005.
PMID: 12605979 DOI: 10.1016/S0360-3016(02)04356-0

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Purpose
To compare tumor control rates after surgical resection or stereotactic radiosurgery for patients with small- to medium-size intracranial meningiomas.

Materials and methods
Between 1990 and 1997, 198 adult meningioma patients treated at our center underwent either surgical resection (n = 136) or radiosurgery (n = 62) as primary management for benign meningiomas <35 mm in average diameter. Tumor recurrence or progression rates were calculated by the Kaplan- Meier method according to an independent radiographic review. The mean follow-up was 64 months.

Results
The tumor resections were Simpson Grade 1 in 57 (42%), Grade 2 in 57 (42%), and Grade 3–4 in 22 (16%). The mean margin and maximal radiation dose at radiosurgery was 17.7 Gy and 34.9 Gy, respectively. Tumor recurrence/progression was more frequent in the surgical resection group (12%) than in the radiosurgical group (2%; p = 0.04). No statistically significant difference was detected in the 3- and 7-year actuarial progression- free survival (PFS) rate between patients with Simpson Grade 1 resections (100% and 96%, respectively) and patients who underwent radiosurgery (100% and 95%, respectively; p = 0.94). Radiosurgery provided a higher PFS rate compared with patients with Simpson Grade 2 (3- and 7-year PFS rate, 91% and 82%, respectively; p <0.05) and Grade 3–4 (3- and 7-year PFS rate, 68% and 34%, respectively; p <0.001) resections. Subsequent tumor treatments were more common after surgical resection (15% vs. 3%, p = 0.02). Complications occurred in 10% of patients after radiosurgery compared with 22% of patients after surgical resection (p = 0.06).

Conclusions
The PFS rate after radiosurgery was equivalent to that after resection of a Simpson Grade 1 tumor and was superior to Grade 2 and 3–4 resections in our study. If long-term follow-up confirms the high tumor control rate and low morbidity of radiosurgery, this technique will likely become the preferred treatment for most patients with small- to moderate-size meningiomas without symptomatic mass effect.

Imaging

1-11C-acetate versus 18F-FDG PET in detection of meningioma and monitoring the effect of gamma-knife radiosurgery.

J Nucl Med. 2010;51(6):883–891.
PMID: 20484430 DOI: 10.2967/jnumed.109.070565

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Objective
This study aimed to define the potential of 1-(11) C-acetate PET, compared with (18) F-FDG, in detecting meningiomas and monitoring the effect of gamma-knife radiosurgery.

Method
Twenty-two patients with the neuroradiologic diagnosis of meningioma were examined by 1-(11) C-acetate and (18) F-FDG PET on the same day. There were 12 cases of histopathologically proven meningioma (8 grade I, 2 grade II, and 2 grade III), 1 of tuberculous granuloma, and 1 of degenerative tissue. 1-(11) C-acetate PET scans of fasting patients were obtained 10 min after intravenous administration of 740 MBq of 1-(11) C-acetate. (18)F-FDG PET was performed at 2 h after 1-(11) C-acetate scanning. The PET images were evaluated by a qualitative method and semiquantitative analysis using standardized uptake value and tumor-to-cortex ratio.

Results
The (18)F-FDG PET study revealed a hypometabolic focus in 17 meningiomas (8 grade I, 1 grade II, and 8 unknown grade) and hypermetabolism in 1 grade II and 2 grade III meningiomas. High uptake of 1-(11) C-acetate was observed in all 20 meningiomas, in contrast to the low uptake in surrounding normal brain tissue, allowing a clearer demarcation of the tumor boundary than that provided by (18) F-FDG. Dissociation of regional accumulation of 1-(11) C-acetate and (18) F-FDG within the tumor was also noted on the coregistered images. The standardized uptake value for 1-(11) C-acetate was not different from that for (18) F-FDG (mean +/- SD, 3.16 +/- 1.75 vs. 3.22 +/- 1.50, P = 0.601), but the tumor-to-cortex ratio for 1-(11) C-acetate was higher than that for (18) F-FDG (3.46 +/- 1.38 vs. 0.93 +/- 1.08, P <0.005). (18) F-FDG was able to differentiate grade I from grade II-III meningiomas, whereas 1-(11) C-acetate was unable to do so. Tuberculous granuloma had a high 1-(11) C-acetate and (18) F-FDG uptake similar to that of grade II/III meningioma. Five patients received 1-(11) C-acetate and (18) F-FDG PET before and after gamma-knife surgery. 1-(11) C-acetate performed better than did (18) F-FDG in monitoring the response of tumor metabolism to radiosurgery.

Conclusions
1-(11) C-acetate was found to be useful for detecting meningiomas and evaluating the extent of meningiomas and potentially useful for monitoring tumor response to radiosurgery. However, 1-(11) C-acetate was not useful for evaluating the tumor grade. (18) F-FDG was found to be less useful than 1-(11) C-acetate for evaluating the extent of meningiomas and the response to radiosurgical treatment but may be useful for differentiating benign from malignant meningiomas. (18)F-FDG and 1-(11) C-acetate are complementary for assessing diverse cell metabolism of meningioma.

Image-guided microradiosurgery for skull base tumors: advantages of using gadolinium-enhanced constructive interference in steady-state imaging.

J Neurosurg. 2006;105(suppl):12–17.
PMID: 18503324 DOI: 10.3171/sup.2006.105.7.12

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Gamma Knife surgery (GKS) is image-guided surgery for brain tumors. Precise tumor visualization is needed in dose planning to control tumor progression. The surrounding vital structures must also be clearly defined to allow the preservation of their function. A special magnetic resonance (MR) imaging sequence was chosen for use with GKS to treat skull base and suprasellar tumors. Gadolinium-enhanced 0.5 mm constructive interference in steady-state (CISS) slices were obtained in skull base and suprasellar tumors. Each structure that was adjacent to the tumor could be visualized more clearly by using this imaging technique because the tumor became transparent even though there was no change in the appearance of the surrounding structures after injection of Gd. Use of this technique in acoustic tumors allowed the seventh and eighth cranial nerves to be visualized in the cisternal and intrameatal portions; both of which were distinguishable from the tumor. Suprasellar tumor could be distinguished from the adjacent optic pathway. The use of Gd-enhanced CISS imaging allowed for optimal dose planning with very high conformity in every tumor. Achieving this high conformity allowed the preservation of adjacent structures and their functions. Establishing optimal dose planning in brain tumors is very important to overcome the problem of producing new neurological deficits in patients who may already be suffering disease-related deficits. The use of this special CISS MR imaging sequence may help accomplish this goal.

The role of 111indium-octreotide brain scintigraphy in the diagnosis of cranial, dural-based meningiomas.

J Neurooncol. 2007;81(2):167–174.
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Objective
Meningiomas are common brain tumors with somatostatin receptors that bind octreotide. We report the use of (111) indium-octreotide brain scintigraphy (OBS) for the non-invasive differentiation of meningiomas from other cranial dural-based pathology.

Method
A retrospective analysis of our experience with OBS for non-invasive identification of meningiomas was performed. Two neuroradiologists, blinded to clinical data, utilized a standardized grading scheme to define the uptake of octreotide at 6 and 24 h post-administration. The correlation between (18) F-fluoro-2-deoxy-d-glucose positron emission tomography (FDG-PET), magnetic resonance imaging (MRI) scans, and octreotide uptake was assessed.

Results
The cohort consisted of 50 patients having a mean age of 62.4 years and a median follow-up time of 24 months. Management consisted of biopsy (n = 4); resection (n = 10); observation (n = 16); radiosurgery (n = 21); and external beam radiotherapy (n = 3). OBS was correlated with MRI (n = 50); FDG-PET brain studies (n = 38); histology (n = 14), and angiography (n = 1). In cases where definitive diagnosis could be made, the sensitivity, specificity, positive and negative predictor values for OBS alone were 100; 50; 75; and 100, respectively. OBS provided false positive data in 3 patients (metastasis, chronic inflammation, lymphoma). Use of OBS with MRI to differentiate meningiomas from other lesions was highly significant (P <0.001). FDG-PET correctly identified malignant pathology with 100% sensitivity and specificity.

Conclusions
OBS may increase the diagnostic specificity of conventional MRI when differentiating meningioma from other dural-based pathologies, while the addition of FDG-PET differentiates benign from malignant lesions.

111Indium-octreotide brain scintigraphy: a prognostic factor in skull base meningiomas treated with gamma knife radiosurgery.

Q J Nucl Med Mol Imaging. 2004;48(1):26–32.
PMID: 15195001

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Objective
The purpose of this study is to prospectively investigate the prognostic role of somatostatin receptor scintigraphy (SRS) using an 111Indium-labelled somatostatin analogue, Octreotide, in skull base meningiomas (SBMs) treated with gamma knife (GK) radiosurgery.

Method
From December 1997 to March 2000, SRS was performed both before and within 1 year of radiosurgery on 12 patients. Semi- quantitative data were calculated as SRS index; the index decrease was arbitrarily considered significant above 10%. A potential correlation between the decrease in post/pre-GK SRS index and radiosurgical outcome was evaluated.

Results
The follow-up period was at least 30 months in the whole series (median, 43 months). In all 12 patients, the pre-GK SRS index was always >1, averaging 3.73+/-2.9. A decrease in the post-GK average SRS index (2.35+/-1.5) was observed. The difference between the pre- and post-GK average values was statistically significant ($p<0.03$). At the 1st high-resolution magnetic resonance imaging (MRI) follow-up within 1 year of GK, there was no tumor shrinkage in any of the 12 patients of our series. A post/pre-GK SRS index decrease >10% was observed in 9 patients and <10% in 3. Delayed MRI follow-up documented tumor reduction in all 9 cases having a 111-in uptake decrease >10%, with stable imaging in the others ($p = 0.00024$).

Conclusions
Our preliminary findings suggest a prognostic correlation between a decrease in concentration of somatostatin receptors on meningioma cells within 1 year of radiosurgery and delayed meningioma shrinkage.

Prognostic value of diffusion tensor imaging parameters for gamma knife radiosurgery in meningiomas.

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Objective
Diffusion tensor imaging (DTI) parameters are able to differentiate between meningioma subtypes. The hypothesis that there is a correlation between DTI parameters and the change in tumor size after Gamma Knife radiosurgery (GKRS) was analyzed.

Method
DTI parameters were measured using MRI before GKRS in 26 patients with meningiomas. The findings were correlated with the change in tumor size after treatment as measured at the last follow-up (range 12.5–45 months).

Results
Only those meningiomas that showed the highest fractional anisotropy (FA), the lowest spherical index of the tensor ellipsoid (Cs), and the lowest radial diffusivity (RD) either increased or remained stable in terms of volume, whereas all other meningiomas decreased in volume. The correlation between the DTI parameters (correlation values of -0.81 for FA, 0.75 for Cs, 0.66 for RD, and 0.66 for mean diffusivity) and the rate of volume change per month was significant ($p \leq 0.001$). Other factors, including original tumor size, prescription dose, and patient age, did not correlate significantly.

Conclusions
Meningiomas that show high FA values—as well as low Cs, low RD, and low mean diffusivity values—do not respond as well to GKRS in comparison with meningiomas with low FA values. This finding might be due to their higher content level of fibrous tissue. In particular, the meningioma with the highest FA value (0.444) considerably increased in volume (by 32.3% after 37 months), whereas the meningioma with the lowest FA value (0.151) showed the highest rate of reduction (3.3% per month) in this study.

Adaptive fractionated stereotactic gamma knife radiotherapy of meningioma using integrated stereotactic cone-beam-CT and adaptive re-planning (a-gkFSRT).

Strahlenther Onkol. 2016;192(11):815–819.
PMID: 27380001 DOI: 10.1007/s00066-016-1008-6

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Objective
The Gamma Knife Icon (Elekta AB, Stockholm, Sweden) allows frameless stereotactic treatment using a combination of cone beam computer tomography (CBCT), a thermoplastic mask system, and an infrared-based high-definition motion management (HDMM) camera system for patient tracking during treatment. We report on the first patient with meningioma at the left petrous bone treated with adaptive fractionated stereotactic radiotherapy (a-gkFSRT).

Method
The first patient treated with Gamma Knife Icon at our institute received MR imaging for preplanning before treatment. For each treatment fraction, a daily CBCT was performed to verify the actual scull/tumor position. The system automatically adapted the planned shot positions to the daily position and recalculated the dose distribution (online adaptive planning). During treatment, the HDMM system recorded the intrafractional patient motion. Furthermore, the required times were recorded to define a clinical treatment slot.

Results
Total treatment time was around 20 min. Patient positioning needed 0.8 min, CBCT positioning plus acquisition 1.65 min, CT data processing and adaptive planning 2.66 min, and treatment 15.6 min. The differences for the five daily CBCTs compared to the reference are for rotation: -0.59 ± 0.49°/0.18 ± 0.20°/0.05 ± 0.36° and for translation: 0.94 ± 0.52 mm/-0.08 ± 0.08 mm/-1.13 ± 0.89 mm. Over all fractions, an intrafractional movement of 0.13 ± 0.04 mm was observed.

Conclusions
The Gamma Knife Icon allows combining the accuracy of the stereotactic Gamma Knife system with the flexibility of fractionated treatment with the mask system and CBCT. Furthermore, the Icon system introduces a new online patient tracking system to the clinical routine. The interfractional accuracy of patient positioning was controlled with a thermoplastic mask and CBCT.

Large meningiomas

Gamma knife radiosurgery of large skull base meningiomas.

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PMID: 25479122 DOI: 10.3171/2014.10.JNS14198

Starke RM,[1] Przybylowski CJ, Sugoto M, Fezeu F, Awad AJ, Ding D, Nguyen JH, Sheehan JP.
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Objective
Stereotactic radiosurgery (SRS) has become a common treatment modality for intracranial meningiomas. Skull base meningiomas greater than 8 cm3 in volume have been found to have worse outcomes following SRS. When symptomatic, patients with these tumors are often initially treated with resection. For tumors located in close proximity to eloquent structures or in patients unwilling or unable to undergo a resection, SRS may be an acceptable therapeutic approach. In this study, the authors review the SRS outcomes of skull base meningiomas greater than 8 cm3 in volume, which corresponds to a lesion with an approximate diameter of 2.5 cm.

Method
The authors reviewed the data in a prospectively compiled database documenting the outcomes of 469 patients with skull base meningiomas treated with single-session Gamma Knife radiosurgery (GKRS). Seventy-five patients had tumors greater than 8 cm3 in volume, which was defined as a large tumor. All patients had a minimum follow-up of 6 months, but patients were included if they had a complication at any time point. Thirty patients were treated with upfront GKRS, and 45 were treated following microsurgery. Patient and tumor characteristics were assessed to determine predictors of new or worsening neurological function and tumor progression following GKRS.

Results
After a mean follow-up of 6.5 years (range 0.5–21 years), the tumor volume was unchanged in 37 patients (49%), decreased in 26 patients (35%), and increased in 12 patients (16%). Actuarial rates of progression-free survival at 3, 5, and 10 years were 90.3%, 88.6%, and 77.2%, respectively. Four patients had new or worsened edema following GKRS, but preexisting edema decreased in 3 patients. In Cox multivariable analysis, covariates associated with tumor progression were 1) presentation with any cranial nerve (CN) deficit from III to VI (hazard ratio [HR] 3.78, 95% CI 1.91–7.45; p <0.001), history of radiotherapy (HR 12.06, 95% CI 2.04–71.27; p = 0.006), and tumor volume greater than 14 cm3 (HR 6.86, 95% CI 0.88–53.36; p = 0.066). In those patients with detailed clinical follow-up (n = 64), neurological function was unchanged in 37 patients (58%), improved in 16 patients (25%), and deteriorated in 11 patients (17%). In multivariate analysis, the factors predictive of new or worsening neurological function were history of surgery (OR 3.00, 95% CI 1.13–7.95; p = 0.027), presentation with any CN deficit from III to VI (OR 3.94, 95% CI 1.49–10.24; p = 0.007), and decreasing maximal dose (OR 0.76, 95% CI 0.63–0.93; p = 0.007). Tumor progression was present in 64% of patients with new or worsening neurological decline.

Conclusions
Stereotactic radiosurgery affords a reasonable rate of tumor control for large skull base meningiomas and does so with a low incidence of neurological deficits. Those with a tumor less than 14 cm3 in volume and without presenting CN deficit from III to VI were more likely to have effective tumor control.

Radiosurgery for large-volume (> 10 cm3) benign meningiomas.

J Neurosurg. 2010;112(5):951–956.
PMID: 19764829 DOI: 10.3171/2009.8.JNS09703

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Objective
Stereotactic radiosurgery (SRS) has proven to be a safe and effective treatment for many patients with intracranial meningiomas. Nevertheless, the morbidity associated with radiosurgery of larger meningiomas is poorly understood.

Method
The authors performed a retrospective review of 116 patients who underwent SRS for meningiomas (WHO Grade I) > 10 cm3 between 1990 and 2007, with a minimum follow-up of 12 months. Patients with atypical or malignant meningiomas and those who received prior radiotherapy were excluded. The average tumor volume was 17.5 cm3 (range 10.1–48.6 cm3); the average tumor margin dose was 15.1 Gy (range 12–18 Gy); and the mean follow-up duration was 70.1 months (range 12–199 months).

Results
Tumor control was 99% at 3 years and 92% at 7 years after radiosurgery. Thirty complications after radiosurgery were noted in 27 patients (23%), including 7 cases of seizures, 6 cases of hemiparesis, 5 cases of trigeminal injury, 4 cases of headaches, 3 cases of diplopia, 2 cases each of cerebral infarction and ataxia, and 1 case of hearing loss. Patients with supratentorial tumors experienced a higher complication rate compared with patients with skull base tumors (44% compared with 18%) (hazard ratio 2.9, 95% CI 1.3–6.7, p = 0.01).

Conclusions
The morbidity associated with SRS for patients with benign meningiomas > 10 cm(3) is greater for supratentorial tumors compared with skull base tumors. Whereas radiosurgery is relatively safe for patients with large-volume skull base meningiomas, resection should remain the primary disease management for the majority of patients with large-volume supratentorial meningiomas.

Gamma Knife surgery of large meningiomas: early response to treatment.

Acta Neurochir (Wien). 2009;151(1):1–8.
PMID: 19093071 DOI: 10-1007/s00701-008-0166-4

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Objective
Gamma Knife treatment is traditionally limited to tumours with a diameter not exceeding 3–3.5 cm. The current paper presents 97 patients with meningiomas with a minimum volume of 10 cm(3), treated with a prescription dose of 12 Gy (or sometimes less to protect neighbouring structures). The post-treatment assessment of these patients, the early response to treatment and the complications of treatment are presented.

Method
There were 97 patients, 70 females and 27 males. The mean age was 48.1 years (range 20.4–87.2 years). The mean follow-up was 54 months (range 25–86 months). All tumours had a volume of 10 cm(3) or more. The mean volume was 15.9 cm(3) (range 10.0–43.2 cm(3)). Post-treatment follow-up used quantitative and qualitative assessments, which are described.

Results
No tumour continued to grow. Twenty-seven were smaller and 72 unchanged in volume. Three patients suffered adverse radiation effects (defined as a new post-treatment oedema detected on the magnetic resonance image with or without contrast leakage). In one case this was silent. In two cases the clinical and radiological effects were temporary and resolved completely.

Conclusions
It is suggested on the basis of this material that the dosimetry used here permits the safe Gamma Knife treatment of larger meningiomas within the range reported. The early radiological response is encouraging, but further follow-up is needed to check long term tumour control. A qualitative method of tumour volume assessment is presented. It seems to be a simpler and more reliable way of assessing tumour volume changes than other methods currently in routine use.

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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Objective
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

Method
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.

Conclusions
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.

Is fractionated gamma knife radiosurgery a safe and effective treatment approach for large-volume (>10 cm3) intracranial meningiomas?

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PMID: 28017757 DOI: 10.1016/j.wneu.2016.12.056

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Background
Even with great advances in surgery and improved clinical outcome, morbidity and mortality are still high for large-volume intracranial meningiomas (MNGs). Recently, Gamma Knife radiosurgery (GKS) has proven to be a safe and effective treatment for many patients with intracranial MNGs. However, single-session GKS may increase the risk of radiation-induced toxicity for large MNGs. Recently, fractionated GKS (FGKS) has been performed for an increasing number of patients with surgically high-risk and large intracranial tumors. In this study, we report our results on the efficacy and safety of FGKS for large MNGs.

Method
The authors performed a retrospective review of 70 patients who underwent GKS for large-volume (>10 cm3) intracranial MNGs between 2004 and 2015, with a minimum follow-up of 12 months. The authors classified these patients into 2 groups of single-session GKS, FGKS. The patients were followed by clinical examination and serial imaging with magnetic resonance imaging.

Results
In the single-session GKS group (42 patients), the median tumor volume was 15.2 cm3 (range 10.3–48.3 cm3); the median prescription dose was 12 Gy (range 8–14 Gy), and the median follow-up duration was 57.8 months (range 14.5–128.4 months). In the FGKS group (28 patients), the median tumor volume was 21 cm3 (range 10.2–54.7 cm3), and the median prescription was 7.5 Gy in 2 fractions (range 5–8 Gy), 6 Gy in 3 fractions (range 5–6.5 Gy), and 4.5 Gy in 4 fractions. The median follow-up duration for the FGKS group was 50 months (range 12.5–90.6 months). The overall 5-year tumor control rate was 92.9% in the FGKS group and 88.1% in the single-session GKS group. Fourteen (33.3%) symptomatic complications after single-session GKS were noted, including 5 cases of hemiparesis, 4 of seizure, 3of peritumoral edema, and 2 of hydrocephalus. Two (7.1%) symptomatic complications after FGKS were noted, including 2 cases of hemiparesis. The FGKS group had higher progression-free survival (PFS) rate at 5 years (92.9% vs. 88.1%), but the differences did not reach statistical significance (P = 0.389). The patients in the FGKS group, however, experienced a lower complication rate compared with patients with a single-session GKS group (P = 0.017, hazard ratio, 5.7:1).

Conclusions
When the large-volume (>10 cm3) intracranial MNGs are expected to have high morbidity after microsurgery and for patients that have a poor medical status for surgery, FGKS can be considered an alternative with good tumor control and lower complications rates compared with single-session GKS (P = 0.017).

Quality of life

Gamma knife radiosurgery for skull base meningiomas: the treatment results and patient satisfaction expressed in answers to a questionnaire.

No Shinkei Geka. 2000;28(5):411–415.
PMID: 10806623

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Skull base meningiomas can be treated by radiosurgery with low morbidity. We evaluated the effectiveness of gamma knife radiosurgery for skull base meningiomas. We also evaluated patient satisfaction through answers to a questionnaire. We treated 77 patients of skull base meningiomas using gamma knife radiosurgery from January 1994 to June 1998. Among these patients, 73 patients were able to be followed up from 6 to 60 months (average 25 months). The diagnosis was made by operations on 39 patients (53%), and on magnetic resonance imagings in 34 patients (47%). 21 patients (28.7%) had residual tumors after operations and 18 patients (24.3%) had recurrence after operations. 40% of neurological deficits occurred after previous operations and 20% of the patients were asymptomatic. The locations of the tumors were mainly the cavernous sinus region in 35 patients and the petroclival region in 20 patients. The tumor sizes were 8.6 to 58.3 mm (average 24.7 mm) and five cases of tumors with a mean diameter above 40 mm were treated by two-staged radiosurgery. Treatment volume was 0.3 to 31 ml (average 9.8 ml). The treatment dose was 8 to 16 Gy (average 11.2 Gy) at the tumor margin. The tumor decreased in size in 50 patients (68%) and was unchanged in 20 patients (28%) and we were able to achieve 96% tumor growth control. The clinical symptoms improved in 22 patients (30.1%) and were unchanged in 47 patients (64.4%) and only 4 patients (5.5%) showed deterioration. 50 patients (68%) felt clinical improvement and only 3 patients (4%) sensed deterioration. 58 patients (79%) were able to continue their previous work. Gamma knife radiosurgery has a very low morbidity rate and enables good tumor control, and patients with skull base meningiomas express satisfaction with the treatment results.

Long-term outcomes after meningioma radiosurgery: physician and patient perspectives.

J Neurosurg. 1999;91(1):44–50.
PMID: 10389879 DOI: 10.3171/jns.1999.91.1.0044

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Objective
Stereotactic radiosurgery is a primary or adjuvant management approach used to treat patients with intracranial meningiomas. The goal of radiosurgery is long-term prevention of tumor growth, maintenance of the patient's neurological function, and prevention of new neurological deficits. The object of this study is to report longer-term patient outcomes.

Method
The authors evaluated 99 consecutive patients who underwent radiosurgery for meningioma between 1987 and 1992. Evaluation was performed using serial imaging tests, clinical evaluations, and a patient survey that was administered between 5 and 10 years after radiosurgery. Four patients underwent two radiosurgery procedures for separate meningiomas. The average tumor margin dose was 16 Gy and the median tumor volume was 4.7 ml (range 0.24-24 ml). Fifty-seven patients (57%) had undergone prior resection, of which 12 procedures were considered total. Five patients received fractionated radiation therapy before radiosurgery. Eighty-nine patients (89%) had skull base tumors. The clinical tumor control rate (no resection required) was 93%. Sixty-one (63%) of 97 tumors became smaller, 31 (32%) remained unchanged in size, and five (5%) were enlarged. Resection was performed in seven patients (7%), six of whom had undergone prior resection. New neurological deficits developed in five patients (5%) 3 to 31 months after radiosurgery. Twenty-seven (42%) of 65 responding patients were employed at the time of radiosurgery and 20 (74%) of these remained so. Radiosurgery was believed to have been successful by 67 of 70 patients who completed an outcomes questionnaire 5 to 10 years later. At least one complication was described by nine patients (14%) and in four patients the complications resolved.

Conclusions
Five to 10 years after radiosurgery, 96% of surveyed patients believed that radiosurgery provided a satisfactory outcome for their meningioma. Overall, 93% of patients required no other tumor surgery. Incidences of morbidity in this early experience were usually transitory and relatively mild. Radiosurgery provided long-term tumor control associated with high rates of neurological function preservation and patient satisfaction.
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Radiation-induced meningiomas

Gamma knife stereotactic radiosurgery for radiation-induced meningiomas.

Stereotact Funct Neurosurg. 2012;90(6):365–369.
PMID: 22922437 DOI: 10.1159/000339636

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Background
Radiation-induced meningiomas present a unique clinical dilemma given the fact that patients with these tumors have often received a prior full course of radiotherapy. As such, traditional radiotherapy is limited by lifetime tissue tolerances to radiation, leaving surgery and radiosurgery as attractive treatment options.

Objective
To ascertain the safety and efficacy of Gamma Knife radiosurgery as a treatment for radiation-induced meningiomas.

Method
A retrospective chart review was conducted to identify patients who received Gamma Knife radiosurgery for a meningioma and met the criteria for this being a radiation-induced tumor. Serial imaging was used to determine the outcome of treatment and clinical notes used to assess for toxicity.

Results
We present our series of 12 patients with radiation-induced meningiomas treated with Gamma Knife stereotactic radiosurgery over a 12-year period at our institution. With a median follow-up of 35 months, local control was 100%. Two patients experienced distant brain failure (>2 cm from previous radiosurgical volume). Two patients experienced posttreatment toxicity related to treatment-related edema. A review of data collected from the scientific literature suggests that tumor volume predicts for treatment failure of radiosurgery.

Conclusions
Gamma Knife radiosurgery is both a safe and effective treatment for radiation-induced meningiomas.

Stereotactic radiosurgery for radiation-induced meningiomas.

Neurosurgery. 2009;64(3):463–469.
PMID: 19240608 DOI: 10.1227/01.NEU.0000336765.85922.D9

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Objective
Radiation-induced meningiomas of the brain are typically managed with surgical resection. Stereotactic radiosurgery (SRS) has become an important primary or adjuvant management for patients with intracranial meningiomas, but the value of this approach for radiation-induced tumors is unclear.

Method
This series consisted of 19 patients (mean age, 40 years) with 24 tumors. The patients met criteria for a radiation-induced meningioma and underwent gamma knife radiosurgery. Seven patients had undergone a previous resection. The World Health Organization tumor grades for those with prior histology were Grade I (n = 5) and Grade II (n = 2). The median tumor volume was 4.4 cm3. Radiosurgery was performed using a median margin dose of 13 Gy.

Results
Serial imaging was evaluated in all patients at a median follow-up of 44 months. The control rate was 75% after primary radiosurgery. Delayed resection after radiosurgery was performed in 5 patients (26%) at an average of 39 months. The median latency between radiation therapy for original disease and SRS for radiation-induced meningiomas was 29.7 years (range, 7.3–59.0 years). The overall survival after SRS was 94.1% and 80.7% at 3 and 5 years, respectively. No patient developed a subsequent radiation-induced tumor. The overall morbidity rate was 5.3% (1 optic neuropathy). Asymptomatic peritumoral imaging changes compatible with an adverse radiation effect developed in 1 patient.

Conclusions
SRS provides satisfactory control rates either after resection or as an alternative to resection. Its role is most valuable for patients whose tumors affect critical neurological regions and who are poor candidates for resection.

Gamma knife radiosurgery of radiation-induced intracranial tumors: local control, outcomes, and complications.
Int J Radiat Oncol Biol Phys. 2005;62(1):32–37.
PMID: 15850899 DOI: 10.1016/j.ijrobp.2004.09.033
Jensen AW, Brown PD, Pollock BE, Stafford SL, Link MJ, Garces YI, Foote RL, Gorman DA, Schomberg PJ.
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Purpose
To determine local control (LC) and complication rates for patients who underwent radiosurgery for radiation-induced intracranial tumors.

Materials and methods
Review of a prospectively maintained database (2,714 patients) identified 16 patients (20 tumors) with radiation-induced tumors treated with radiosurgery between 1990 and 2004. Tumor types included typical meningioma (n = 17), atypical meningioma (n = 2), and schwannoma (n = 1). Median patient age at radiosurgery was 47.5 years (range, 27–70 years). The median tumor margin dose was 16 Gy (range, 12–20 Gy). Median follow-up was 40.2 months (range, 10.8–146.2 months). Time-to-event outcomes were calculated with Kaplan-Meier estimates.

Results
Three-year and 5-year LC rates were 100%. Three-year and 5-year overall survival rates were 92% and 80%, respectively. Cause-specific survival rates at 3 and 5 years were 100%. Three patients died: 1 had in-field progression 65.1 months after radiosurgery and later died of the tumor, 1 died of progression of a preexisting brain malignancy, and 1 died of an unrelated cause. One patient had increased seizure activity that correlated with development of edema seen on neuroimaging.

Conclusions
LC, survival, and complication rates in our series are comparable to those in previous reports of radiosurgery for intracranial meningiomas. Also, LC rates with radiosurgery are at least comparable to those of surgical series for radiation-induced meningiomas. Radiosurgery is a safe and effective treatment option for radiation-induced intracranial tumors, most of which are typical meningiomas.

Trigeminal/facial pain

Stereotactic radiosurgery for trigeminal pain secondary to benign skull base tumors.

World Neurosurg. 2013;80(3-4):371–377.
PMID: 22381855 DOI: 10.1016/j.wneu.2012.01.057

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Purpose

To assess the outcome of stereotactic radiosurgery (SRS) for patients with benign skull base tumors and trigeminal-related facial pain.

Methods

Retrospective review of 31 consecutive patients (25 women, 6 men) with benign skull base tumors and trigeminal pain undergoing SRS between 1991 and 2008. The tumors included 17 posterior fossa meningiomas, 9 cavernous sinus meningiomas and 5 trigeminal schwannomas. The median patient age was 62 years (range, 17–81). In all cases the tumor was the primary target for SRS. The median follow-up after SRS was 50 months (range, 12–184).

Results

The actuarial tumor control rate after SRS was 95% at both 3 years and 5 years. Eighteen patients (58%) initially achieved complete resolution of trigeminal pain. Higher maximum dose was associated with initial complete pain resolution on a multivariate analysis. However, 7 patients had recurrent pain during follow-up. At last follow-up, only 7 patients (23%) remained pain-free off medications. Further treatment in addition to medical therapy was required for 6 patients (19%).

Conclusions

Although SRS offers excellent radiographic tumor control for benign skull base tumors, durable relief of tumor-related trigeminal pain without medication was noted in only one-fourth of patients at last follow-up.

Gamma knife surgery for trigeminal pain caused by benign brain tumors.

J Neurosurg. 2008;109(suppl):154–159.
PMID: 19123903 DOI: 10.3171/JNS/2008/109/12/S24

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Objective
The authors report the effects of Gamma Knife surgery (GKS) on benign tumor-related trigeminal pain in patients who underwent follow-up for a mean 57.8 months.

Method
From 1999 to 2004, 21 patients with benign tumor-related trigeminal pain (12 meningiomas and 9 schwannomas) underwent GKS as a primary or repeated treatment. These patients harbored tumors within the radiosurgical target area. For meningiomas, the mean radiosurgical treatment volume was 8.2 ml (range 1.1–21 ml), and the mean radiosurgical tumor margin dose was 12.7 Gy (range 12–15 Gy); for schwannomas, the mean volume was 5.6 ml (range 2–9.2 ml), and the mean marginal dose was 13 Gy (range 11.5–16 Gy). Seven patients underwent retreatment for recurrent or persistent pain; the ipsilateral trigeminal nerve or ganglion was identified and a mean maximal dose of 60.7 Gy (range 40–70 Gy) was delivered to these targets. In 1 patient undergoing retreatment, the margin dose was 12 Gy. The mean age at the time of radiosurgery was 54.5 years (range 18–79 years).

Results
The mean follow-up period was 57.8 months (range 36–94 months). Overall, 12 (57%) of 21 patients experienced pain relief without medication after the first GKS and the mean time to drug discontinuation was 10.5 months (range 2–24 months). Initial pain improvement was noted in 17 patients (81%) with a mean time of 3.7 months (range 1 week–10 months) after GKS. Eight patients underwent repeated GKS for persistent and recurrent pain. Four patients (50%) had complete pain relief. The final results of the first and repeated GKS were excellent in 16 patients (76%), and in only 1 patient did GKS fail, and this patient later underwent open surgery. For all 21 patients (100%), control of tumor growth was documented at a mean of 46 months after GKS. Three of 6 patients with pre-GKS facial numbness reported improvement, but 4 suffered new facial numbness after repeated GKS.

Conclusions
Gamma Knife surgery appears to be an effective tool to treat benign tumor-related trigeminal pain and control tumor growth. Repeated GKS targeting the trigeminal root or ganglion can be considered a tool to enhance the efficacy of pain management if pain persists or recurs, but the optimum treatment dose needs further investigation.

Stereotactic radiosurgery for tumor-related trigeminal pain.

Neurosurgery. 2000;46(3):576–582.
PMID: 10719853 DOI: 10.1097/00006123-200003000-00010

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Objective
Between 1 and 6% of patients who are diagnosed with facial pain syndromes have tumors that involve the trigeminal nerve. We report the effects of stereotactic radiosurgery on tumor-related trigeminal pain.

Method
We reviewed results, from a prospective database, for 24 consecutive patients with cranial base tumors and either trigeminal neuralgia (n = 9) or painful trigeminal neuropathy (n = 15) who underwent stereotactic radiosurgery during an 8-year period. The tumor was the radiosurgical target for these patients (not the trigeminal nerve or ganglion). The median clinical follow-up period after radiosurgery was 45 months (range, 12–90 mo); the median neuroimaging follow-up period was 36 months (range, 5–86 mo).

Results
There were 20 women and 3 men, with an average age of 57 years (range, 33–79 yr). One patient had bilateral facial pain and underwent staged radiosurgery. Pathological classification indicated 16 meningiomas and 8 malignant cranial base tumors (adenoid cystic carcinoma, n = 6; squamous cell carcinoma, n = 2). Twelve of 24 patients (50%) were initially free of pain, and another 11 patients (46%) reported that they experienced significant improvements in their trigeminal pain syndromes after radiosurgery. The tumor histological type, quality of facial pain, preexisting facial numbness, and marginal and maximal radiation doses were not related to postradiosurgical facial pain outcomes. Three patients with malignant cranial base carcinomas developed recurrent facial pain, 1 to 9 months after radiosurgery, which was related to tumor progression outside the irradiated volume. One patient (4%) developed new partial V2 numbness after radiosurgery.

Conclusions
Radiosurgery proved to be effective in improving tumor-related trigeminal pain for the majority of patients with either benign or malignant cranial base tumors. Recurrence of trigeminal pain is frequent for patients with malignant cranial base carcinomas and is related to tumor progression.

Two-session tumor and retrogasserian trigeminal nerve-targeted gamma knife radiosurgery for secondary trigeminal neuralgia associated with benign tumors.

World Neurosurg. 2016;96:136–147.
PMID: 27576768 DOI: 10.1016/j.wneu.2016.08.082

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Objective
To investigate gamma knife radiosurgery (GKS) for benign tumor-associated secondary trigeminal neuralgia (TN).

Method
Between 2006 and 2015, 21 patients with secondary TN due to meningioma were treated using GKS. Their mean age was 56.5 ± 12.2 years. The 50% isodose was 12.5 ± 1.1 Gy for the first GKS for the meningioma. Retrogasserian targeting of the trigeminal nerve at 90 Gy with a 4-mm collimator was used for the second GKS.

Results
The pain duration until GKS was 1.9 ± 1.9 years. The meningiomas were located in the cisternal space in 13 patients (56.5%) and involved the skull base in 8 patients (43.5%). The mean duration of follow-up was 3.7 ± 2.7 years. The pain control outcome was a Marseilles Pain Scale (MPS) score of I to IV in 15 patients (71%) and a score of V in 6 patients (29%). For these latter patients, we performed a second GKS targeting the trigeminal nerve and resulting in MPS scores of I to IV. The tumor size did not increase in any patient and decreased by >10% in 12 (80%) of the 15 patients who were followed for at least 1 year. Trigeminal nerve visibility may improve after tumor shrinkage. Retrogasserian trigeminal nerve targets may be used even with invisible trigeminal nerves using Meckel's cave as an anatomic marker.

Conclusions
Here we show the reproducible feasibility of a 2-session GKS procedure using higher radiation doses, the first dose to treat the tumor and the second to treat the trigeminal nerves using retrogasserian targeting.

General/other meningioma topics

Change in plasma vascular endothelial growth factor after gamma knife radiosurgery for meningioma: a preliminary study.

J Korean Neurosurg Soc. 2015;57(2):77–81.
PMID: 25733986 DOI: 10.3340/jkns.2015.57.2.77

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Objective
The purpose of this study was to investigate changes in the plasma level of vascular endothelial growth factor (VEGF) after Gamma Knife radiosurgery (GKRS) for the treatment of meningioma.

Method
Fourteen patients with meningiomas had peripheral venous blood collected at the time of GKRS and at 1 week, 1 month, 3 month and 6 month visits. Plasma VEGF levels were measured using commercially available enzyme-linked immunosorbent assay. For controls, peripheral blood samples were obtained from 20 healthy volunteers.

Results
The mean plasma VEGF level (29.6 pg/mL) in patients with meningiomas before GKRS was significantly lower than that of the control group (62.4 pg/mL, p=0.019). At 1 week after GKRS, the mean plasma VEGF levels decreased to 23.4 pg/mL, and dropped to 13.9 pg/mL at 1 month, 14.8 pg/mL at 3 months, then increased to 27.7 pg/mL at 6 months. Two patients (14.3%) with peritumoral edema (PTE) showed a level of VEGF 6 months after GKRS higher than their preradiosurgical level. There was no significant association found in an analysis of correlation between PTE and tumor size, marginal dose, age, and sex.

Conclusions
Our study is first in demonstrating changes of plasma VEGF after stereotactic radiosurgery (SRS) for meningioma. This study may provide a stimulus for more work related to whether measurement of plasma level has a correlation with tumor response after SRS for meningioma.

Gamma knife radiosurgery for meningiomas in patients with neurofibromatosis type 2.

J Neurosurg. 2015;122(3):536–542.
PMID: 25555193 DOI: 10.3171/2014.10.JNS132593

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Objective
Neurofibromatosis Type 2 (NF2) is a rare autosomal dominant disorder predisposing patients to meningiomatosis. The role of stereotactic radiosurgery (SRS) is poorly defined in NF2, and although the procedure has excellent control rates in the non-NF2 population, its utility has been questioned because radiation has been hypothesized to predispose patients to malignant transformation of benign tumors. To the authors' knowledge, this is the first study to examine the use of SRS specifically for meningiomas in patients with NF2.

Method
The authors searched a tumor registry for all patients with NF2 who had undergone Gamma Knife radiosurgery (GKRS) for meningioma in the period from January 1, 1999, to September 19, 2013, at a single tertiary care cancer center. Medical records were retrospectively reviewed for patient and tumor characteristics and outcomes.

Results
Among the 12 patients who met the search criteria, 125 meningiomas were identified, 87 (70%) of which were symptomatic or progressive and thus treated with GKRS. The median age at the first GKRS was 31 years (interquartile range [IQR] 27–37 years). Five patients (42%) had multiple treatments with a median of 27 months (IQR 14–50 months) until the subsequent GKRS. The median follow-up in surviving patients was 43 months (IQR 34–110 months). The 5-year local tumor control and distant treatment failure rates were 92% and 77%, respectively. Toxicities occurred in 25% of the GKRS treatments, although the majority were Grade 1 or 2. At the last follow-up, 4 patients (33%) had died a neurological death at a median age of 39 years (IQR 37–46 years), and their cases accounted for 45% of all tumors, 55% of all treated tumors, and 58% of all GKRSs. Univariate analysis revealed several predictive variables for distant failure, including male sex (HR 0.28, 95% CI 0.086–0.92, p = 0.036), age at distant failure (HR 0.92, 95% CI 0.90–0.95, p <0.0001), and prior number of GKRS treatments (HR 1.2, 95% CI 1.1–1.4, p = 0.0049). Local failure, maximum size of the treated tumor, delivered tumor margin dose, and WHO grade were not significant. On multivariate analysis, age at distant failure (HR 0.91, 95% CI 0.88–0.95, p <0.0001) and prior number of GKRSs (HR 1.3, 95% CI 1.1–1.5, p = 0.004) remained significant. No malignant transformation events among treated tumors were observed.

Conclusions
Radiosurgery represents a feasible modality with minimal toxicity for NF2-associated meningiomas. Increasing patient age was associated with a decreased rate of distant failure, whereas an increasing number of prior GKRS treatments predicted distant failure. Further studies are necessary to determine the long-term patterns of treatment failure in these patients.

Gamma knife radiosurgery for lymphoplasmacyte-rich meningioma.

Clin Neurol Neurosurg. 2013;115(7):1110-1113.
PMID: 22964347 DOI: 10.1016/j.clineuro.2012.08.031

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Single-fraction radiosurgery of benign intracranial meningiomas.

Neurosurgery. 2012;71(3):604–612.
PMID: 22710378 DOI: 10.1227/NEU.0b013e31825ea557

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Background
Stereotactic radiosurgery (SRS) of benign intracranial meningiomas is an accepted management option for well-selected patients.

Objective
To analyze patients who had single-fraction SRS for benign intracranial meningiomas to determine factors associated with tumor control and neurologic complications.

Method
Retrospective review was performed of 416 patients (304 women/112 men) who had single-fraction SRS for imaging defined (n = 252) or confirmed World Health Organization grade I (n = 164) meningiomas from 1990 to 2008. Excluded were patients with radiation-induced tumors, multiple meningiomas, neurofibromatosis type 2, and previous or concurrent radiotherapy. The majority of tumors (n = 337; 81%) involved the cranial base or tentorium. The median tumor volume was 7.3 cm; the median tumor margin dose was 16 Gy. The median follow-up was 60 months.

Results
The disease-specific survival rate was 97% at 5 years and 94% at 10 years. The 5- and 10-year local tumor control rate was 96% and 89%, respectively. Male sex (hazard ratio [HR]: 2.5, P = .03), previous surgery (HR: 6.9, P = .002) and patients with tumors located in the parasagittal/falx/convexity regions (HR: 2.8, P = .02) were negative risk factors for local tumor control. In 45 patients (11%) permanent radiation-related complications developed at a median of 9 months after SRS. The 1- and 5-year radiation-related complication rate was 6% and 11%, respectively. Risk factors for permanent radiation-related complication rate were increasing tumor volume (HR: 1.05, P = .008) and patients with tumors of the parasagittal/falx/convexity regions (HR: 3.0, P = .005).

Conclusions
Single-fraction SRS at the studied dose range provided a high rate of tumor control for patients with benign intracranial meningiomas. Patients with small volume, nonoperated cranial base or tentorial meningiomas had the best outcomes after single-fraction SRS.

Glioblastoma following radiosurgery for meningioma.

J Korean Neurosurg Soc. 2012;51(2):98–101.
PMID: 22500202 DOI: 10.3340/jkns.2012.51.2.98

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We report a patient who underwent gamma knife radiosurgery to treat recurrent meningioma after microsurgery and thereafter developed secondary malignancy adjacent to the original tumor. A 47-year-old woman had underwent resection of the olfactory groove meningioma. Then radiosurgery was done three times over 4-year period for the recurrent tumor. After 58 months from the initial radiosurgery, she presented with headache and progressive mental dullness. Huge tumor in bifrontal location was revealed in MRI. Subsequent operation and pathological examination confirmed diagnosis of glioblastoma. This case fits the criteria of radiation-induced tumor and the clinical implication of the issue is discussed.

Single-fraction radiosurgery for presumed intracranial meningiomas: efficacy and complications from a 22-year experience.

Int J Radiat Oncol Biol Phys. 2012;83(5):1414–1418.
PMID: 22209154 DOI: 10.1016/j.ijrobp.2011.10.033

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Purpose
To define the rate of tumor control and factors associated with radiation-related complications after single-fraction radiosurgery (SRS) for patients with imaging defined intracranial meningiomas.

Materials and methods
Retrospective review of 251 patients (192 women, 59 men) having SRS for imaging-defined intracranial meningiomas between 1990 and 2008. Excluded were patients with radiation-induced tumors, meningiomatosis, or neurofibromatosis. The mean patient age was 58.6 +/- 13.4 years. The majority of tumors involved the skull base/tentorium (n = 210, 83.7%). The mean treatment volume was 7.7 +/- 6.2 cm(3); the mean tumor margin dose was 15.8 +/- 2.0 Gy. Follow-up (mean, 62.9 +/- 43.9 months) was censored at last evaluation (n = 224), death (n = 22), or tumor resection (n = 5).

Results
No patient died from tumor progression or radiation-related complications. Tumor size decreased in 181 patients (72.1%) and was unchanged in 67 patients (26.7%). Three patients (1.2%) had in-field tumor progression noted at 28, 145, and 150 months, respectively. No patient had a marginal tumor progression. The 3- and 10-year local control rate was 99.4%. One patient had distant tumor progression at 105 months and underwent repeat SRS. Thirty-one patients (12.4%) had either temporary (n = 8, 3.2%) or permanent (n = 23, 9.2%) symptomatic radiation-related complications including cranial nerve deficits (n = 14), headaches (n = 5), hemiparesis (n = 5), new/worsened seizure (n = 4), cyst-formation (n = 1), hemifacial spasm (n = 1), and stroke (n = 1). The 1- and 5-year complication rates were 8.3% and 11.5%, respectively. Radiation-related complications were associated with convexity/falx tumors (HR = 2.8, 95% CI 1.3–6.1, p = 0.009) and increasing tumor volume (HR = 1.05, 95% CI 1.0–1.1, p = 0.04) on multivariate analysis. No patient developed a radiation-induced tumor.

Conclusions
Single-fraction SRS at the used dose range provides a high rate of tumor control for patients with imaging defined intracranial meningiomas. However, treatment failures were noted after 10 years emphasizing the need for long-term imaging follow-up after meningioma SRS.

The Importance of the conformality, heterogeneity, and gradient indices in evaluating gamma knife radiosurgery treatment plans for intracranial meningiomas.

Int J Radiat Oncol Biol Phys. 2012; 83(5):1406–1416.
PMID: 22209151 DOI: 10.1016/j.ijrobp.2011.10.024

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Purpose
To investigate the relationship between the conformality index (CIn), heterogeneity index (HIn), and gradient index (GIn) and the development of toxicity in patients treated with Gamma Knife radiosurgery (GKRS) for intracranial meningiomas.

Materials and methods
Treatment records of patients treated from 1997 to 2009 with at least 6 months of follow-up were reviewed. The following parameters were collected: CIn, HIn, GIn (ratio of the volume receiving half the prescription isodose to the volume receiving the full prescription isodose), brainstem (BS) maximum dose (MD), BS volume receiving >/=12 Gy (V12), optic apparatus (OA) MD, OA V8 Gy, OA V10, number of isocenters, number of isocenters outside target volume, and the occurrence of six toxicities. Univariate and multivariate logistic regression modeling were used for analysis.

Results
This study included 145 patients (148 meningiomas) with a median follow-up time of 27 months (range, 6–113.9 months). The majority of meningiomas were located in the skull base (53%). The median prescription dose was 13 Gy (range, 10–24 Gy) to the 51.50% (range, 50–92%) isodose. A lower HIn was correlated with a higher GIn (p = 0.007). CIn was not associated with any toxicity. Higher HIn was associated with the development of dizziness (odds ratio [OR] 1.9; p = 0.02), whereas a lower GIn was associated with motor deficits (OR 0.38; p = 0.04) and auditory changes (OR 0.59; p = 0.04). The OA MD, V8, and V12 were not associated with visual changes, but visual changes were associated with a higher number of isocenters outside the target volume (OR 1.93; p = 0.07). BS V12 was correlated with the development of auditory changes (OR 1.05; p = 0.05), whereas patients with higher BS MD tended to have increased toxicity.

Conclusions
Close attention must be paid to all three indices (CIn, HIn, GIn) when optimal treatment plans are determined. We recommend that the target CIn should be </=2.0, the HIn </=2.0, and the GIn >/=3.0 for intracranial meningiomas.

Risk factors for post-treatment edema in patients treated with stereotactic radiosurgery for meningiomas.
Neurosurgery. 2012;70(3):639–645.
PMID: 21904263 DOI: 10.1227/NEU.0b013e3182351ae7
Unger KR[1], Lominska CE, Chanyasulkit J, Randolph-Jackson P, White RL, Aulisi E, Jacobson J, Jean W, Gagnon GJ.
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Background
Peritumoral edema is a recognized complication following stereotactic radiosurgery (SRS).

Objective
To evaluate the risk of post-treatment peritumoral edema following SRS for intracranial meningiomas and determine predictive factors.

Method
Between 2002 and 2008, 173evaluable patients underwent CyberKnife or Gamma Knife SRS for meningiomas. Eighty-four patients (49%) had prior surgical resections, 13 patients had WHO grade II (atypical) meningiomas, and 117 patients had a neurologic deficit prior to SRS. Sixty-two tumors were in parasagittal, parafalcine, and convexity locations. The median tumor volume was 4.7 mL (range, 0.1–231.8 mL). The median prescribed dose and median prescribed biologically equivalent dose (BED) were 15 Gy (range, 9–40 Gy) and 67 Gy (range, 14–116 Gy), respectively. Ninety-seven patients were treated with single fraction SRS, 74 received 2 to 5 fractions, and 2 got >5 fractions.

Results
The median follow-up was 21.0 months. Thirteen patients (8%) developed symptomatic peritumoral edema, with a median onset time of 4.5 months (range, 0.2–9.5 months). The 3-, 6-, 12-, and 24-month actuarial symptomatic edema rates were 2.9%, 4.9%, 7.7%, and 8.5%, respectively. The crude tumor control rate was 94%. On univariate analysis, large tumor volume ($p = 0.01$) and single fraction SRS ($p = 0.04$) were predictive for development of post-treatment edema.

Conclusions
SRS meningioma treatment demonstrated a low incidence of toxicity; however, large tumor volumes and single fraction SRS treatment had an increased risk for post-treatment edema. Risk factors for edema should be considered in meningiomas treatment.

Long-term tumor control of benign intracranial meningiomas after radiosurgery in a series of 4565 patients.
Neurosurgery. 2012;70(1):32–39.
PMID: 21765282 DOI: 10.1227/NEU.0b013e31822d408a
Santacroce A,[1] Walier M, Regis J, Liscak R, Motti E, Lindquist C, Kemeny A, Kitz K, Lippitz B, Alvarez RM, Pedersen PH, Yomo S, Lupidi F, Dominikus K, Blackburn P, Mindermann T, Bundschuh O, van Eck AT, Fimmers R, Horstmann GA.
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Background
Radiosurgery is the main alternative to microsurgical resection for benign meningiomas.

Objective
To assess the long-term efficacy and safety of radiosurgery for meningiomas with respect to tumor growth and prevention of associated neurological deterioration. Medium- to long-term outcomes have been widely reported, but no large multicenter series with long-term follow-up have been published.

Method
From 15 participating centers, we performed a retrospective observational analysis of 4565 consecutive patients harboring 5300 benign meningiomas. All were treated with Gamma Knife radiosurgery at least 5 years before assessment for this study. Clinical and imaging data were retrieved from each center and uniformly entered into a database by 1 author (A.S.).

Results
Median tumor volume was 4.8 cm, and median dose to tumor margin was 14 Gy. All tumors with imaging follow-up <24 months were excluded. Detailed results from 3768 meningiomas (71%) were analyzed. Median imaging follow-up was 63 months. The volume of treated tumors decreased in 2187 lesions (58%), remained unchanged in 1300 lesions (34.5%), and increased in 281 lesions (7.5%), giving a control rate of 92.5%. Only 84 (2.2%) enlarging tumors required further treatment. Five- and 10-year progression-free survival rates were 95.2% and 88.6%, respectively. Tumor control was higher for imaging defined tumors vs grade I meningiomas (P <.001), for female vs male patients (P <.001), for sporadic vs multiple meningiomas (P <.001), and for skull base vs convexity tumors (P <.001). Permanent morbidity rate was 6.6% at the last follow-up.

Conclusions
Radiosurgery is a safe and effective method for treating benign meningiomas even in the medium to long term.

Gamma knife robotic microradiosurgery for benign skull base meningiomas: tumor shrinkage may depend on the amount of radiation energy delivered per lesion volume (unit energy).

Stereotact Funct Neurosurg. 2011;89(1):6–16.
PMID: 21124047 DOI: 10.1159/000321184

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Background/aims
The objective of the present study was the evaluation of the effectiveness of robotic microradiosurgery of skull base meningiomas using Leksell Gamma Knife model C with an automatic positioning system.

Method
The results of the management of 66 tumors were analyzed retrospectively. Their volume varied from 0.3 to 50.6 cm(3) (mean = 6.6). The treatment plan was based on the use of multiple small isocenters compactly positioned within the border of the lesion with resultant improved homogeneity of high-dose distribution, increased average dose within the target and sharp dose fall outside the treated volume. The marginal dose varied from 10 to 14 Gy (mean = 12). The length of follow-up ranged from 26 to 80 months (mean = 46).

Results
The overall tumor growth control was 99%. Reduction of the mass volume was marked in 54 patients (82%), and in 15 of them it constituted >/= 50%. In other 11 cases (17%) stabilization of the lesion growth was noted. The shrinkage rate significantly correlated with amount of radiation energy delivered per tumor volume, designated as unit energy (p = 0.007). One meningioma (1%) regrew 3.5 years after radiosurgery. The treatment-related morbidity was limited to transient abducens nerve palsy in 1 patient (1%).

Conclusions
Application of the concept of Gamma Knife robotic microradiosurgery for the management of skull base meningiomas may change the paradigm of their treatment from stabilization of growth to reduction of the volume of the neoplasm. The tumor shrinkage rate may depend on the amount of radiation energy delivered per lesion volume (unit energy).

Stereotactic radiosurgery for WHO grade I meningiomas.

J Neurooncol. 2010;99(3):407–416.
PMID: 20734218 DOI: 10.1007/s11060-010-0363-x

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Meningiomas represent a common intracranial tumor in the adult population. Although extirpation to achieve a gross total resection or at least decrease mass effect has been the mainstay of treatment, stereotactic radiosurgery has come to play an increasingly important role in the management of patients with meningiomas. Radiosurgery utilizes highly focused, beams of ionizing radiation to inactivate tumor cells. Image guidance and a steep dose fall off are critical features of this approach. The radiobiology of radiosurgery differs in certain advantageous ways from conventional radiotherapy. Radiosurgery initially was utilized to treat recurrent or residual skull base meningiomas. As success was observed in this setting, radiosurgery has gradually expanded its role so as to treat convexity meningiomas; it is also used as an upfront treatment for patients for whom clinical and neuro-imaging findings are consistent with a meningioma. Most large series demonstrate tumor control rates for patients with grade I meningiomas in excess of 85%. Neurological function is generally preserved or improved for patients with meningiomas. However, complications can occur. Longitudinal follow-up including neurologic and radiologic assessment is required. Single and multisession stereotactic radiosurgery will likely play an expanded role in the treatment of patients with meningiomas.

Long-term outcomes and patterns of tumor progression after gamma knife radiosurgery for benign meningiomas.
Neurosurgery. 2010;67(2):322–328.
PMID: 20644417 DOI: 10.1227/01.NEU.0000371974.88873.15
Zada G[1], Pagnini PG, Yu C, Erickson KT, Hirschbein J, Zelman V, Apuzzo ML.
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Objective
To characterize the timing and patterns of long-term treatment failure after Gamma Knife radiosurgery (GKRS) for benign meningiomas.

Method
Data were retrospectively reviewed in 116 patients who underwent 136 GKRS treatments for benign intracranial meningiomas from 1996 to 2004. Patients with atypical or malignant meningiomas were excluded. Surgical resection preceded GKRS in 72 patients (62%). The median tumor volume was 3.4 cm, and the median prescription dose to the 50% isodose line was 16 Gy.

Results
The median follow-up time was 75 months (range, 4-146 months). Overall tumor control was achieved in 128 of 136 lesions (94%), of which tumor size was stable in 68% and decreased in 26%. Seven patients experienced disease progression in 8 tumors, occurring at a mean time of 90 months. The overall 5-year and 10-year actuarial tumor control rate was 98.9% and 84%, respectively. Characteristics corresponding to tumor progression included insufficient tumor coverage (98% vs 93%, P = .007), cavernous sinus lesions, and meningiomatosis. Complications after GKRS developed in 8% of patients, in whom the mean tumor volume was nearly double that in patients with no adverse effects (11 vs 5.7 cm3, P = .003).

Conclusions
GKRS demonstrates excellent long-term tumor control in the management of benign meningiomas. Tumor progression occurred at a mean time of 7.5 years after GKRS, reinforcing the need for long-term surveillance despite initial tumor control. Treatment failure was related to undercoverage of lesions in the majority of cases, with the remainder demonstrating evidence of abnormal tumor biology.

Gamma knife radiosurgery for benign tumors with symptoms from brainstem compression.

Int J Radiat Oncol Biol Phys. 2010;77(4):988–995.
PMID: 20381265 DOI: 10.1016/j.ijrobp.2009.06.089

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Purpose

This study evaluated the role of radiosurgery in the management of symptomatic patients with brainstem compression from benign basal tumors.

Materials and methods

Over a 17-year, period 246 patients (202 vestibular schwannomas and 44 meningiomas) with brainstem compression from benign skull-base tumors were managed with Gamma Knife radiosurgery. Median tumor volumes were 3.9 cm(3) (range, 0.8–39.0 mL) and 6.6 mL (range, 1.6–25.1 mL) for vestibular schwannomas and meningiomas, respectively. For both tumors, a median marginal dose of 13 Gy was prescribed. Median follow-up of patients was 65 months for vestibular schwannomas and 60 months for meningiomas. Patients were categorized into four groups on the basis of the tumor-brainstem relationship on neuroimaging.

Results

Preservation of function was stratified according to grade of brainstem compression. We analyzed the effect of radiosurgery on symptoms of brainstem compression. The tumor control rate was 100% for meningioma and 97% for vestibular schwannomas (although 5% required an additional procedure such as a ventriculoperitoneal shunt). In patients with vestibular schwannoma, serviceable hearing was preserved in 72.0%. Balance improved in 31.9%, remained unchanged in 56.5%, and deteriorated in 11.6% of patients who had imbalance at presentation. Balance improved significantly in patients who had less tumor compression ($p = 0.0357$) after radiosurgery. Symptoms improved in 43.2% of patients with meningioma.

Conclusions

Radiosurgery is a minimally invasive option for patients with benign basal tumors that indent or distort the brainstem. A high tumor growth control rate and satisfactory rate of neurological preservation and symptom control can be obtained with radiosurgery.

Protection of the anterior visual pathways during gamma knife treatment of meningiomas.

Br J Neurosurg. 2010;24(3):233–243.
PMID: 20233030 DOI: 10.31090/02688690903536611

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The anterior visual pathway (AVP) can be at risk during gamma knife surgery (GKS). There is no standardised published methodology for protecting the AVP. This paper suggests such an approach in relation to the treatment of meningiomas. There were 67 patients with a mean age of 48.8 years and a minimum follow-up of 25 months. A recent perimetry was available on the day of treatment. The visual pathway was outlined and the maximum radiation dose was recorded. In some cases a dose volume histogram (DVH) of the AVP was constructed to assess the volume receiving more than the desired maximum dose. The aim was a maximum dose between 8 and 10 Gy. A principle of sub-optimal dose planning was used to protect vision. Follow-up included new visual field examinations. Various anatomical locations place different parts of the AVP at risk. No patient suffered a deterioration of vision. In 21 (38.7%) patients there was an improvement in the visual field and in 7 (44%) associated diplopia improved. Vision could improve without corresponding tumour shrinkage. A standard measure of radiation toleration of the AVP could be the maximum dose within its volume, probably at least 10 Gy. Computerised perimetry should be available on the day of treatment and at follow-up. There is no need to have a distance between the tumour margin and the visual pathway. Sub-optimal dose-planning has been advantageous. Improvement in vision is not necessarily a consequence of tumour shrinkage.

Principal risk of peritumoral edema after stereotactic radiosurgery for intracranial meningioma is tumor-brain contact interface area.

Neurosurgery. 2010;66(3):513–522.
PMID: 20173546 DOI: 10.1227/0.1.NEU.0000365366.53337.88

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Objective
Stereotactic radiosurgery (SRS) of meningiomas is associated with posttreatment peritumoral edema (PTE). The purpose of this study was to evaluate the prevalence and risk factors of post-SRS PTE for intracranial meningiomas.

Method
A total of 163 patients with 182 meningiomas treated with SRS were retrospectively reviewed. Tumors were divided into 4 pre-SRS groups according to whether they had undergone previous surgery and whether they had preexisting PTE. Several risk factors were investigated by univariate and multivariate analysis in all tumors, tumors without previous surgery, tumors without preexisting PTE, and preexisting PTE.

Results
Of 182 tumors, 45 (24.7%) developed post-SRS PTE. Compared with tumors without preexisting PTE, the odds of developing post-SRS PTE in tumors with preexisting PTE were 6.0 times higher in all tumors, and 6.9 times higher in tumors without previous surgery. A 1-cm2 increase in tumor-brain contact interface area increased the odds of developing post-SRS PTE by 17% in all tumors, 16% in tumors without previous surgery, and 26% in tumors without preexisting PTE. Of 118 tumors without previous surgery, 13 had preexisting PTE, the existence of which had a significant relationship to both tumor-brain contact interface area and tumor volume.

Conclusions
Post-SRS PTE is common in patients with meningioma. Tumor-brain contact interface area and preexisting PTE were the most significant risk factors for post-SRS PTE. Tumor volume and tumor-brain contact interface area were significant risk factors for the development of preexisting PTE.

Risk factors for regrowth of intracranial meningiomas after gamma knife radiosurgery: importance of the histopathological grade and MIB-1 index.

Minimally Invasive Neurosurgery. 2009;52(5–6):216–221.
PMID: 20077361 DOI: 10.1055/s-0029-1243244

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Introduction
The influence of histopathological grade and MIB-1 index of intracranial meningioma on the results of its radiosurgical management is not clear. The objective of the present retrospective study was to make an evaluation of these factors along with an analysis of other variables associated with progression-free survival after gamma knife radiosurgery (GKR).

Patients and methods
Thirty-four intracranial meningiomas with known detailed histopathological diagnosis were analyzed. Tumors of WHO histopathological grades I, II, and III were diagnosed in 24, 3, and 7 cases, respectively. The median MIB-1 index was 1.3% (range: 0–31.9%). In 14 cases the MIB-1 index was 3.0% and more. In 26 cases the treatment was done at the time of tumor recurrence. Median volume of the neoplasm at the time of GKR was 4.1 mL (range: 0.4–43.1 mL). Median marginal dose was 12 Gy (range: 8–19 Gy). Median length of follow-up constituted 63 months (range: 19–132 months).

Results
Actuarial progression-free survival at 1, 3, 5, and 10 years constituted 100, 94, 83, and 58%, respectively. Histopathological grade II or III ($p < 0.0001$), MIB-1 index 3% and more ($p = 0.0004$), and non-skull base location ($p = 0.0026$) of the tumor showed negative associations with progression-free survival in multivariate analyses. Actuarial progression-free survival at 5 years after GKR for benign and non-benign meningiomas constituted 100 and 45%, respectively ($p < 0.0001$).

Conclusions
Radiosurgery is a highly effective management option for benign intracranial meningiomas, but growth control of non-benign ones is significantly worse. It requires close neuroradiological follow-up and necessitates the search for modified treatment strategies.

Stereotactic radiosurgery of benign intracranial tumors.

J Neurooncol. 2009;92(3):337–343.
PMID: 19357960 DOI: 10.1007/s11060-009-9831-6

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Stereotactic radiosurgery is a frequently performed procedure for patients with benign intracranial tumors. Benign tumors are good candidates for radiosurgery because they are generally non-invasive, are well visualized by magnetic resonance imaging, and their slow rate of proliferation makes conventional radiation dose fractionation unnecessary.

Stereotactic radiosurgery is now an important part of both neurosurgical and radiation oncology training. This chapter will review the indications and results of radiosurgery for patients with intracranial meningiomas, vestibular schwannomas, and pituitary adenomas having single-fraction radiosurgery at the Mayo Clinic since 1990.

Adverse radiation effects after gamma knife surgery in relation to dose and volume.

Acta Neurochir (Wien). 2009;151(1):9–19.
PMID: 19129961 DOI: 10.1007/s00701-008-0174-4

Ganz JC[1], Reda WA, Abdelkarim K.
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Introduction
The relationship between target volume and adverse radiation effects (AREs) at low prescription doses requires elucidation. The development of AREs in three series of patients treated in the Gamma Knife is analysed in relation to prescription dose and target volume.

Materials and methods
There were three groups. In group 1, there were of 275 patients with meningiomas; in group 2, 132 patients with vestibular schwannomas; and in group 3, 107 patients with arteriovenous malformations (AVMs). The minimum follow-up for each group was more than 24 months. All patients were followed up at six monthly intervals. The patients with tumours received a prescription dose of 12 Gy, which was varied to protect normal structures but not in relation to tumour volume per se. The desired AVM prescription dose was 25 Gy, but this was also reduced to protect normal structures and to keep the total dose within certain pre-defined limits. All AREs refer to intra-parenchymal increased perilesional T2 signal on MR irrespective of clinical correlation.

Results
There was no relationship between tumour volume and the development of ARE in the tumour groups. There was a highly significant relationship between target volume and the development of ARE for the AVMs with their much higher dose. Radiation-induced clinical trigeminal and facial nerve deficits with both vestibular schwannomas and meningiomas were always associated with an increased T2 signal in the neighbouring brainstem parenchyma.

Conclusions
The relationship between target volume and the risk of adverse radiation effects may not apply with lower prescription doses. Individual radiosensitivity may explain why a minority suffer AREs unrelated to target volume. It is possible that radiation-induced brainstem parenchymal damage with concomitant cranial nerve deficits may be commoner after radiosurgery than is usually thought. If tumour control with lower doses is adequate, radiosurgery could be safely considered for larger targets associated with a high risk from microsurgery.

Development of dose-volume relation model for gamma knife surgery of non-skull base intracranial meningiomas.

Int J Radiat Oncol Biol Phys. 2009;74(4):1027–1032.
PMID: 19056186 DOI: 10.1016/j.ijrobp.2008.09.007

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Purpose
To provide a dose-volume relationship for gamma knife surgery (GKS) of non-skull base intracranial meningiomas.

Materials and methods
The radiologic outcomes of GKS of 82 imaging-defined benign meningiomas located at non-skull base areas were analyzed. A total of 80 patients were included and all underwent treatment with GKS as the first and the only treatment modality. The mean patient age was 55.0 years (range, 26–78) and the mean tumor volume was 5.6 cm(3) (range, 0.5–16.8). On average, 14.6 Gy (range, 10–20) was applied to the 50% isodose surface. The binary logistic regression method was applied to find prognostic factors of signal change (SC) on T(2)-weighted magnetic resonance imaging after GKS.

Results
The actuarial tumor control rate was 91.6% at 5 years. A total of 29 lesions (35.4%) showed newly developed or aggravated SCs. The volume irradiated > or = 14 Gy was the only statistically significant ($p < .01$) prognostic factor of SC. A dose-volume relation model obtained from the cases without SC estimated a 12.2% SC probability.

Conclusions
This model can be used in GKS to treat small- to medium-size (<9.2 cm(3)) non-skull base meningiomas.

Radiosurgery as definitive management of intracranial meningiomas.

Neurosurgery. 2008;62(1):53–58.
PMID: 18300891 DOI: 10.1227/01.NEU.0000311061.72626.0D

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Objective
Stereotactic radiosurgery has become an important primary or adjuvant minimally invasive management strategy for patients with intracranial meningiomas with the goals of long-term tumor growth prevention and maintenance of patient neurological function. We evaluated clinical and imaging outcomes of meningiomas stratified by histological tumor grade.

Method
The patient cohort consisted of 972 patients with 1045 intracranial meningiomas managed during an 18-year period. The series included 70% women, 49% of whom had undergone a previous resection and 5% of whom had received previous fractionated radiation therapy. Tumor locations included middle fossa (n = 351), posterior fossa (n = 307), convexity (n = 126), anterior fossa (n = 88), parasagittal region (n = 113), or other (n = 115).

Results
The overall control rate for patients with benign meningiomas (World Health Organization Grade I) was 93%. In those without previous histological confirmation (n = 482), tumor control was 97%. However, for patients with World Health Organization Grade II and III tumors, tumor control was 50 and 17%, respectively. Delayed resection after radiosurgery was necessary in 51 patients (5%) at a mean of 35 months. After 10 years, Grade 1 tumors were controlled in 91% (n = 53); in those without histology, 95% (n = 22) were controlled. None of the patients developed a radiation-induced tumor. The overall morbidity rate was 7.7%. Symptomatic peritumoral imaging changes developed in 4% of the patients at a mean of 8 months.

Conclusions
Stereotactic radiosurgery provided high rates of tumor growth control or regression in patients with benign meningiomas with low risk. This study confirms the role of radiosurgery as an effective management choice for patients with small to medium-sized symptomatic, newly diagnosed or recurrent meningiomas of the brain.

Volumetric follow-up of meningiomas: a quantitative method to evaluate treatment outcome of gamma knife radiosurgery.

Neurosurgery. 2007;61(2):281–286.
PMID: 17762740 DOI: 10.1227/0.1.NEU.0000279999.95953.EA

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Objective
The most important treatment options for meningiomas are microsurgery, radiotherapy, and gamma knife radiosurgery (GKRS). The efficacy of GKRS in terms of local tumor control and tumor volume (TV) reduction can best be determined by accurate analysis of changes in tumor size in pre- and post-GKRS images. In this prospective study, we set the focus on evaluating TV changes and treatment outcome of meningiomas using a quantitative volumetric follow-up protocol after GKRS.

Method
Consecutive patients with World Health Organization Grade I and II meningiomas were included in this study. Most patients underwent a microsurgical TV reduction before being treated with GKRS. Follow-up examinations were performed according to a standardized protocol and included magnetic resonance imaging and quantitative volumetric tumor analyses as well as thorough neurological examinations.

Results
Complete follow-up data was available for 211 patients (243 tumors) with a mean age of 57.9 years. TVs ranging from 0.1 to 48.3 cm3 were treated with GKRS using prescription doses ranging from 10 to 22 Gy. The achieved overall tumor control rate determined with quantitative TV analyses after GKRS was 93.4%; a mean TV reduction of 42.1% was achieved in 74.5% of all treated patients.

Conclusions
Results of this study show that a quantitative volumetric follow-up study of meningiomas is a useful method to demonstrate the efficacy of GKRS for meningiomas. Statistically significant TV reductions with a low rate of side effects can be achieved with GKRS.

Gamma knife surgery for benign meningioma.

J Neurosurg. 2007;107(2):325–336.
PMID: 17695387 DOI: 10.3171/JNS-07/08/0325

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Objective
Meningioma is the most frequent benign tumor treated with Gamma Knife surgery (GKS); however, the assessment of its efficacy and safety in slow-growing tumors is an ongoing process, requiring analysis of long-term results.

Method
Three hundred sixty-eight patients harboring 400 meningiomas treated between 1992 and 1999 at Na Homolce Hospital were evaluated. The median patient age was 57 years (range 18–84 years). The median tumor volume was 4.4 cm3 (range 0.11–44.9 cm3). The median tumor margin dose to the 50% isodose line was 12.55 Gy (range 6.5–24 Gy). Descriptive analysis was performed in 331 patients (90%); 325 patients had a follow-up longer than 24 months (median 60 months), and six patients were included because of posttreatment complications. The volume of treated tumors decreased in 248 cases (69.7%), remained the same in 99 (27.8%), and increased in nine (2.5%). The actuarial tumor control rate was 97.9% at 5 years post-GKS. Perilesional edema after radiosurgery was confirmed on neuroimaging in 51 patients (15.4%). The temporary and permanent morbidity rates after radiosurgery were 10.2 and 5.7%, respectively.

Results
A significantly higher incidence of tumor volume increase was observed in men compared with women and in tumors treated with a margin dose lower than 12 Gy. Significant risk factors for edema included an age greater than 60 years, no previous surgery, perilesional edema before radiosurgery, a tumor volume greater than 10 cm3, a tumor location in the anterior fossa, and a margin dose greater than 16 Gy.

Conclusions
Stereotactic radiosurgery is a safe method of treatment for meningiomas. A minimum margin dose of 12 to 16 Gy seems to represent the therapeutic window for benign meningiomas with a high tumor control rate in a mid-term follow-up period.

Radiosurgical pathology of brain tumors: metastases, schwannomas, meningiomas, astrocytomas, hemangioblastomas.

Prog Neurol Surg. 2007;20:91–105.
PMID: 17317979 DOI: 10.1159/000100098

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Systematic human pathological background to brain tumor radiosurgery explaining biological and pathophysiological effects of focused irradiation barely exists. The goal of this study was to explore histopathological changes evoked by single high-dose irradiation in a set of different brain tumors following Gamma Knife radiosurgery (GKRS). Light microscopy revealed that GKRS evokes degenerative and proliferative pathological changes in the parenchyma, stroma and vessels of the irradiated tumors. Three main histological types of gamma radiolesions, that is acute, subacute and chronic variants of tissue reactions were recognized in different neoplasms irrespective of their ontogenetic nature. Acute type gamma radiolesions were characterized mainly with necrotic changes and appeared either early or in a delayed time interval. Subacute type gamma radiolesions expressed resorptive activity also with early or delayed chronology. Chronic type lesions showed a reparative tendency but presented only at the delayed stage. These changes seem to follow each other consecutively. There was no significant relation between morphological characteristics of the generated tissue reaction and the time interval elapsed after GKRS. This relative time and environment autonomy of the developed pathological lesions with similar histological picture in different neoplasms suggests either a vascular mechanism or/and a genetically directed origin presumably induced by the ionizing energy of high-dose irradiation.

Radiosurgery for intracranial meningiomas.

Prog Neurol Surg. 2007;20:142–149.
PMID: 17317982 DOI: 10.115/000100101

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Introduction
Meningiomas are common intracranial benign tumors that can be surgically excised. However, their intimate involvement with critical neurovascular structures often prevent their complete resection. Gamma Knife radiosurgery is a minimally invasive option which provides excellent tumor control as both an adjunct and primary therapy.

Materials and methods
Between September 1987 and December 2004, 964 patients underwent Gamma Knife radiosurgery at the University of Pittsburgh for the diagnosis of meningioma. The majority of patients had tumors located at the skull base. All imaging and clinical follow-up was reviewed.

Results
Overall, Gamma Knife radiosurgery provides 5- and 10-year actuarial tumor control rates of 93% for benign meningiomas. The 5-year actuarial control rate for patients with atypical and malignant meningiomas was 83 +/- 7 and 72 +/- 10%, respectively. The incidence of adverse radiation effect ranged from 5.7 to 16%; however, the incidence was gradually reduced with the advent of magnetic resonance imaging and lower dosing since 1991.

Conclusions
Gamma Knife radiosurgery is an attractive option for patients with intracranial meningiomas. It can be used as both primary treatment based on imaging diagnosis alone, or as an adjunct treatment after craniotomy. It provides long-term tumor control with minimal adverse sequelae

Prediction of intracranial edema after radiosurgery of meningiomas.

J Neurosurg. 2006;105(suppl):120–126.
PMID: 18503344 DOI: 10.3171/sup.2006.105.7.120

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Objective
This study was focused on the development of models with which to predict the occurrence of intracranial edema after Gamma Knife surgery (GKS) of meningiomas, based on clinical and imaging data collected in a large group of patients.

Method
Data in 368 patients with 381 meningiomas treated using the Leksell Gamma Knife unit were analyzed. Follow up of more than 24 months was available in 331 patients (90%); this time period ranged from 24 to 120 months (median 51 months). The actuarial tumor control rate was 97.9% at 5 years. Perilesional edema after GKS was radiologically confirmed in 51 patients (15.4%) and 32 of them (9.7%) were symptomatic; symptoms were temporary in 23 (6.9%) and permanent in nine (2.7%). Ten different factors were proposed as potential predictors for the occurrence of the intracranial edema after GKS: patient's sex, patient's age, previous surgery, edema before GKS treatment, lobulated margin of meningioma, heterogeneous appearance of the tumor, tumor volume, tumor location, maximum dose to the tumor, and dose to the tumor margin. To identify factors having influence on edema occurrence, univariate and multivariate statistical analyses were performed. There was a significant difference in the incidence of edema for different patient age groups and a significantly higher incidence of edema occurrence in patients in whom no surgical procedure was performed before GKS, those with edema present before GKS, those with a tumor volume larger than 10 cm3, those in whom the tumor was located in the anterior fossa, those in whom the maximum dose to the tumor was higher than 30 Gy, and for different tumor margin doses. A binary logistic regression multifactorial prediction model was used to identify the following significant factors to predict of edema occurrence after GKS: previous surgery, edema before the treatment, tumor volume, tumor location, and tumor margin dose.

Conclusions
Based on these models estimates of the occurrence of edema after the GKS can be made, and consequently treatment parameters can be adjusted to reduce the occurrence of edema. These results may provide grounds for additional patient care such as more frequent follow up or possibly administration of steroids.

Chasing your dural tail: factors predicting local tumor control after gamma knife stereotactic radiosurgery for benign intracranial meningiomas: in regard to DiBiase et al. (Int J Radiat Oncol Biol Phys 2004;60:1515–1519).

Int J Radiat Oncol Biol Phys. 2005;62(2):616–618.
PMID: 15890610 DOI: 10.1016/j.ijrobp.2005/02.026

Rogers L, Jensen R, Perry A.

The use of stereotactic radiosurgery in the management of meningiomas.

Br J Neurosurg. 2005;19(1):13–20.
PMID: 16147577 DOI: 10.1080/02688690500080885

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This is a systematic review of a consecutive series of 309 meningiomas treated with gamma knife stereotactic radiosurgery between 1994 and 2000. There was an extreme selection bias towards lesions unfavourable for surgery, determined by the patients referred for treatment: 70% of tumours involved the skull base, 47% specifically the cavernous sinus: 15% of patients had multiple meningiomatosis or type 2 neurofibromatosis. Tumour histology was the main determinant of growth control ($p < 0.001$), the 5-year actuarial control rates being 87% for typical meningiomas, 49% for atypical tumours and 0% for malignant lesions. Complications from radiosurgery were rare, occurring in 3% of tumours, and were most frequently trigeminal and eye movement disturbances treating cavernous sinus meningiomas. Given the problems inherent in managing these tumours, radiosurgery is a valuable strategy and adjuvant treatment for these meningiomas.

Malignant progression of benign brain tumors after gamma knife radiosurgery: is it really caused by irradiation?

Minim Invasive Neurosurg. 2005;48(6):334–339
PMID: 16432782 DOI: 10.1055/s-2005-915632

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Malignant transformation of benign neoplasm after radiosurgery is usually diagnosed based on the initial presence of benign tumor, its exposure to ionizing radiation, elapsed time from radiation exposure to malignant progression, and different histological characteristics or growth rate of the regrowing tumor comparing with those originally treated. Three presented cases fulfilled these diagnostic criteria; however, it seems that progression of the tumors (schwannoma, meningioma, chordoma) resulted from the natural course of the disease, rather than represented side effects of gamma knife radiosurgery. Evaluation of the proliferative potential of the benign neoplasm before radiosurgical treatment either directly, if tumor sampling is available, or indirectly, by calculation of the tumor growth rate and/or analysis of the data of the metabolic imaging (PET, MRS) is important for identification of aggressive subtypes, precise prediction of prognosis, and confirmation of the radiation-induced malignant transformation in cases of tumor regrowth.

Volume reduction in meningiomas after gamma knife surgery.

J Neurosurg. 2005;102(suppl):189–194.
PMID: 15662808 DOI: 10.3171/jns.2005.102.s_supplement.0189

Feigl GC[1], Bundschuh O, Gharabaghi A, Samii M, Horstmann GA.
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Objective
The purpose of this study was to evaluate the volume-reducing effects of gamma knife surgery (GKS) of meningiomas with and without previous surgical treatment.

Method
A group of 127 patients with a mean age of 57.1 years (range 9–81 years) with 142 meningiomas (128 World Health Organization Grade I and 14 Grade II) were included in this study. The management strategy reduces tumor volume with surgery when necessary (81 patients). Stereotactic GKS with a Gamma Knife model C was performed in all tumors of suitable size. Magnetic resonance imaging follow-up examinations with volumetric tumor analysis was performed 6 months after treatment and annually thereafter. The mean tumor volume was 5.9 cm3 (range <5 to >40 cm3). The mean follow-up time after GKS was 29.3 months (range 11–61 months). The mean prescription dose was 13.8 Gy (range 10–18 Gy). A reduction in volume occurred in 117 (82.4%) of all tumors, and in 20 tumors (14.1%) growth ceased. The overall tumor control rate of 96.4%. The mean volume reduction achieved with GKS was more than 46.1%. Only five tumors (3.5%) stowed a volume increase.

Conclusions
Gamma knife surgery was effective in reducing meningioma volume at short-term follow up. Further studies are needed to examine the development of these findings over a longer period.

Temporary symptomatic swelling of meningiomas following gamma knife surgery. Report of two cases.

J Neurosurg. 2005;102:293–296.
PMID: 15662829 DOI: 10.3171/sup.2005.102.s_supplement.0293

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In two patients in whom gamma knife surgery was performed for meningiomas clinically significant volume increases were observed in the first 3 months after treatment. Clinical examination and various imaging studies form the basis of the report in these patients. In each case, the volume increase was temporary.

Long-term control after resection and gamma knife surgery of an intracranial clear cell meningioma: case report.

J Neurosurg. 2005;102(3)(suppl):303–306.
PMID: 15881755 DOI: 10.3171/ped.2005.102.3.0303

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Clear cell meningioma (CCM) is a rare variant of meningioma characterized by sheets of polygonal cells with clear cytoplasm, a feature attributable to its high glycogen content. Authors have described its propensity to recur and metastasize despite its benign pathological characteristics. Clinical response to radiation in these reports has varied. The authors present the case of a 7-year-old girl with a large petroclival CCM who underwent a staged subtotal resection and subsequent gamma knife surgery (GKS). Initially, the residual tumor decreased in size, but 6 years later, it had regrown (9 mm in size). A second GKS treatment was performed and the mass completely regressed without further complication. The findings in this case suggest that GKS is a safe and effective adjunct for residual and recurrent CCM after resection. The delayed recurrence also emphasizes the importance of undertaking close follow-up examination after treating this potentially aggressive variant of meningioma.

Radionecrosis of the inferior occipital lobes with altitudinal visual field loss after gamma knife radiosurgery.

J Neuroophthalmol. 2004;24(3):195–199.
PMID: 15348983 DOI: 10.1097/00041327-200409000-00002

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A patient had bilateral superior altitudinal visual field defects because of radionecrosis of the inferior occipital lobes after gamma knife radiosurgery for a recurrent atypical cerebellar meningioma. Although radionecrosis of the anterior visual pathway has been well- documented, this is the first report of visual field loss associated with occipital lobe radionecrosis. The treatment dose this patient received is within the range of predicted tolerable radiosurgical dosing, although this patient was at increased risk for radionecrosis secondary to previous external beam radiotherapy. By offering an effective, noninvasive treatment, radiosurgery has changed the management of intracranial lesions. Radiosurgery targets a discrete volume of tissue and relatively spares the surrounding normal tissue. Radiation injury, or radionecrosis, is the only significant complication of radiosurgery (). We present a case of bilateral occipital lobe radionecrosis after gamma knife surgery that resulted in bilateral superior altitudinal defects.

The Leksell gamma knife model u versus model c: a quantitative comparison of radiosurgical treatment parameters.

Neurosurgery. 2004;55(1):168–172.
PMID: 15214986 DOI: 10.1227/01.NEU.0000126880.33125.E6

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Objective
We present a quantitative comparison of radiosurgery treatments for cavernous sinus tumors using the Leksell gamma knife

Method
At our medical center from August 1994 through May 2000, the Model U was used to treat 96 patients (37 men (39%) and 59 women (61%); median age, 54.5 yr) with benign cavernous sinus tumors: 43 meningiomas (45%), 48 pituitary tumors (50%), and 5 others (5%). From June 2000 through April 2002, the Model C with APS treated 45 patients (20 men (44%) and 25 women (56%); median age, 51.4 yr) with 15 meningiomas (33%), 29 pituitary tumors (65%), and 1 schwannoma (2%). The two groups had similar treated tumor volumes (Model U mean, 4.3 cm(3); Model C mean, 4.2 cm(3)), equivalent tumor distances from critical structures (optic nerve, chiasm, and pons), comparable distributions in Sekhar tumor grades, and the same median prescribed dose of 15 Gy to the 50% isodose line at the tumor periphery. All planning and treatments were performed by the same radiosurgery team to minimize dosage to adjacent critical tissues and to optimize conformity index.

Results
Analysis of multiple treatment parameters showed that the Model C plans were superior. Model C treatments had an improved conformity index (Model U mean, 1.7; Model C mean, 1.6; P <0.02) and a lower underdosed tumor volume (Model U mean, 0.4 cm(3); Model C mean, 0.1 cm(3); P <0.004). The total treated volume and the excess treated volume were similar. The Model C group had a reduction in optic chiasm dose (Model C mean dose, 3.8 Gy; Model U mean dose, 5.3 Gy; P< 0.0001). The average number of isocenters was slightly higher for the Model C group (6.7 versus 6 for the Model U), but with a lower mean number of collimator sizes (1 versus 2 for the Model U). Model C plans required a mean of 93 fewer plugs per treatment, thus contributing to an estimated 67.6 minutes saved per treatment session.

Conclusions
Comparison of radiosurgery treatments using the Leksell gamma knife Model U versus the Model C with APS was performed by quantitative analysis of treatment parameters on a cohort of benign cavernous sinus tumors. Treatment plans using the Model C resulted in better tumor coverage (improved conformity, less underdosed tumor volume) and decreased optic chiasm dose. An estimated average of 1 hour was saved per treatment when using the Model C with APS.

Rapid regrowth of intracranial clear cell meningioma after craniotomy and gamma knife radiosurgery—case report.

Neurol Med Chir (Tokyo). 2004;44(6):321–325.
PMID: 15253549 DOI: 10.2176/nmc.44.321

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A 24-year-old woman underwent craniotomy for falx meningioma (5 cm in diameter) on October 24, 1995. The deepest part of the tumor was located in the anterior horn of the lateral ventricle, which was not resected. The histology was clear cell meningioma (CCM), aggressive in nature. The MIB-1 labeling index was high (11%). She underwent gamma knife (GK) radiosurgery for the residual tumor with an irradiation dose of 16 Gy at the tumor periphery on May 24, 1996. The postradiosurgical course was uneventful. The residual intraventricular tumor gradually decreased in size, but the peripheral portion gradually grew into the diencephalic region. The patient remained in good condition for 5 years until September 2001, when she exhibited memory disturbance and lethargy. Magnetic resonance imaging demonstrated a large tumor (4.5 cm in diameter) in the diencephalon, compressing the optic nerves and fornix. The calculated tumor doubling time was 120 days. A second craniotomy was performed on October 9, 2001. The tumor was totally resected through the anterior transcallosal approach. The histology and the MIB-1 labeling index of the tissue from the second operation did not differ markedly from those of the first operation. Neither tumor recurrence nor metastasis has been observed to date. GK radiosurgery contributed to control of the residual intraventricular tumor, but the peripheral portion of the tumor, which received a relatively low radiation dose (16 Gy), grew rapidly. This suggests that a marginal dose of 16 Gy may not be sufficient for control of CCM.

Factors predicting local tumor control after gamma knife stereotactic radiosurgery for benign intracranial meningiomas.

Int J Radiat Oncol Biol Phys. 2004;60(5):1515–1519.
PMID: 15590183 DOI: 10.1016/j.ijrobp.2004.05.073

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Purpose
To determine the long-term outcomes and prognostic factors in benign intracranial meningiomas treated with gamma knife stereotactic radiosurgery (GK-SRS).

Materials and methods
Between 1992 and 2000, 162 patients with benign meningiomas were treated with GK-SRS at the University of Maryland Medical Center. Complete follow-up was available in 137 patients. All patients underwent magnetic resonance imaging (MRI)-based treatment planning. Serial MRIs and clinical exams were performed to assess tumor response. GK-SRS was the primary treatment in 85 patients (62%), whereas 52 patients (48%) had prior surgical resections. The median prescribed dose was 14 Gy (range, 4–25 Gy) to the 50% isodose line. The median tumor volume, treatment volume, and conformity index were 4.5 cc (range, 0.32–80.0 cc), 6.3 cc (range, 1.0–75.2 cc), and 1.34 (range, 0.65–3.16), respectively. The median follow-up for the entire cohort was 4.5 years (range, 0.33–10.5 years). The following factors were included in the statistical analysis for disease-free survival (DFS) and overall survival (OS): sex, age, dose, gross tumor volume (GTV), conformity index (CI), and dural tail coverage.

Results
Serial MRI analysis was available in 121 patients (88.3%). Decrease in tumor size was observed in 34 patients (28.1%), whereas there was no change in 77 patients (63.6%), for a crude radiographic control rate of 91.7%. Increase in tumor size was seen in 10 patients (8.3%). New neurologic deficits attributed to the treatment developed in 10 patients (8.3%). The mean DFS and OS for the entire cohort are 4.6 years and 5.0 years, respectively. The 5-year actuarial DFS and OS were 86.2% and 91.0%, respectively. Univariate analysis revealed GTV, sex, CI, and dural tail treatment to be significant prognostic factors. Patients with GTV < or = 10 cc also had longer survivals, with the 5-years DFS and OS of 91.9% vs. 68.0% ($p = 0.038$) and 100% vs. 59.7% ($p = 0.0001$), respectively. The 5-years actuarial DFS and OS for females vs. males were 90.2% vs. 74.2% ($p = 0.0094$) and 91.6% vs. 89.1% ($p = 0.016$), respectively. Patients with lower conformity (i.e., CI > or = 1.4) tended to have the dural tail covered in the prescription isodose line ($p = 0.04$). The only factor significant in the multivariate analysis was for patients with GTV >10 cc, who had a worse DFS (hazard ratio 4.58, $p = 0.05$).

Conclusions
This report adds to the literature that supports the efficacy and safety of GK-SRS in the management of patients with benign intracranial meningiomas. Our report identified male patients, patients with a CI <1.4, and tumor size greater than 10 cc to have a worse prognosis. Patients who were treated with less conformal plans to cover the dural tail had better outcomes. Our data clearly demonstrate the need to adequately cover the dural tail in patients treated with GK-SRS for benign intracranial meningiomas.

A study on the radiation tolerance of the optic nerves and chiasm after stereotactic radiosurgery.

Int J Radiat Onco Biol Phys. 2003;55(5):1177–1181.
PMID: 12654424 DOI: 10.1016/S0360-3016(02)04380-8

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Purpose
To evaluate the risk of clinically significant radiation optic neuropathy (RON) for patients having stereotactic radiosurgery of benign tumors adjacent to the optic apparatus.

Materials and methods
We reviewed the dose plans and clinical outcomes of 218 gamma knife procedures (215 patients) for tumors of the sellar and parasellar region (meningiomas, n = 122; pituitary adenomas, n = 89; craniopharyngiomas, n = 7 patients). Previous surgery or radiation therapy was performed in 156 (66%) and 24 (11%) patients, respectively. Median follow-up was 40 months (range 4–115).

Results
The median maximum radiation dose to the optic nerve was 10 Gy (range 0.4-16.0). Four patients (1.9%) developed RON at a median of 48 months after radiosurgery. All had prior surgery, and 3 of 4 had external beam radiotherapy (EBRT) in their management either before (n = 2) or adjuvantly (n = 1). The risk of developing a clinically significant RON was 1.1% for patients receiving 12 Gy or less. Patients receiving prior or concurrent EBRT had a greater risk of developing RON after radiosurgery (p = 0.004).

Conclusions
RON occurred in less than 2% of our patients, despite the majority (73%) receiving more than 8 Gy to a short segment of the optic apparatus. Knowledge of the dose tolerance of these structures permits physicians to be more aggressive in treating patients with sellar or parasellar tumors, especially those with hormone-producing pituitary adenomas that appear to require higher doses to achieve biochemical remission.

Radiosurgery for intracranial meningiomas.

Neurosurg Q. 2003;13(2):77–86.

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The purpose of this study was to review the results of stereotactic radiosurgery for intracranial meningiomas. A prospective computer database was queried for patient characteristics, radiosurgical parameters, tumor control, and complications of 310 patients having radiosurgery for 335 meningiomas at our center between January 1990 and October 2002. One hundred thirty-one patients (42%) had recurrent/residual tumors after prior surgical resection; 179 patients (58%) had radiosurgery as primary treatment. The majority of patients (69%) had skull-based tumors. The median tumor volume was 7.5 cc (range: 0.5–50.5 cc). The median tumor margin dose was 16 Gy (range: 12–20 Gy). Two hundred ninety-seven tumors (278 patients) had clinical and imaging follow-up at a mean of 43 months (range: 2–138 months) after radiosurgery. Two hundred seventy-nine tumors (94%) remained stable or decreased in size; 18 tumors progressed. Factors associated with progression were tumor histology and prior surgery. Treatment-related complications occurred in 26 patients (9%) and included cranial neuropathies, symptomatic edema, cyst formation, and stenosis of the internal carotid artery. Radiosurgery is safe and effective for many meningioma patients and has become the primary treatment of patients with small tumors in critical locations such as the cavernous sinus. Patients with atypical or malignant tumors have a high recurrence rate despite the use of radiosurgery. Further study is needed to determine the tumor control and complication rates 10 or more years after meningioma radiosurgery.

The treatment for asymptomatic meningiomas in the era of radiosurgery.

No Shinkei Geka. 2003;31(8):891–897.

PMID: 12968492.

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We evaluated the treatment results in asymptomatic meningiomas in the era of radiosurgery. We encountered 56 patients with asymptomatic meningiomas from January, 1994 to December, 2001. There were 16 male patients and 40 female patients. The most common location was the cerebral convexity. We performed gamma knife radiosurgery for three patients after diagnosis of cavernous sinus meningiomas. The other patients were followed-up after diagnosis for a mean follow-up period of 30.8 months (5 months to 8 years). Tumor growth was verified in 25 patients (43%) and two patients (3.7%) suffered neurological deficits. Among the tumor growth patients, operative resection was performed in six patients (11%) and gamma knife radiosurgery was performed in four patients (7.5%). The other patients were placed under observation. We decided the treatment strategy paying attention to the tumor location, tumor growth speed, tumor size and operative difficulty. The tumor growth rate was 0.1 cm/year among the patients with tumor growth. It was 0.72 cm/year (0.02 to 1.54 cm/year) in the operative group, 0.3 cm/year (0.04 to 0.76 cm/year) in the gamma knife radiosurgery group and 0.08 cm/year (0.01 to 0.76 cm/year) in the observed group. One patient suffered procedure-related deterioration of paresis after operation. The treatment of asymptomatic meningiomas must be decided depending on their natural history and locations. We recommend early radiosurgery for cavernous sinus meningiomas.

Gamma knife radiosurgery of imaging-diagnosed intracranial meningioma.

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Purpose

To evaluate tumor control and outcome from radiosurgery of meningiomas diagnosed by imaging without pathologic verification.

Materials and methods

A total of 219 meningiomas diagnosed by imaging criteria underwent gamma knife radiosurgery to a median marginal tumor dose of 14 Gy (range 8.9–20), a median treatment volume of 5.0 cm(3) (range 0.47–56.5), and a median maximal dose of 28 Gy (range 22–50). The median follow-up was 29 months (range 2–164).

Results

Tumor progression developed in 7 cases, 2 of which turned out to be different tumors (metastatic nasopharyngeal adenoid cystic carcinoma and chondrosarcoma). One tumor was controlled, but the development of other brain metastases suggested a different diagnosis. The actuarial tumor control rate was 93.2% +/- 2.7% at 5 and 10 years. The actuarial rate of identifying a diagnosis other than meningioma was 2.3% +/- 1.4% at 5 and 10 years. The actuarial rate of developing any postradiosurgical injury reaction was 8.8% +/- 3.0% at 5 and 10 years. No pretreatment variables correlated with tumor control in univariate or multivariate analysis. The risk of postradiosurgery sequelae was lower (5.3% +/- 2.3%) in patients treated after 1991 (with stereotactic MRI and lower doses; p = 0.0104) and tended to increase with treatment volume (p = 0.0537).

Conclusions

Radiosurgery of meningioma diagnosed by imaging without tissue confirmation is associated with a high rate of tumor control and acceptable morbidity but carries a small risk (2.3%) of an incorrect diagnosis.

Gamma knife radiosurgery for meningiomas of the convexity and cavernous sinus.

Seminars in Neurosurgery. 2003;14(3):267–277.
DOI: 10.1055/s-2004-828931

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Gamma knife radiosurgery, available since 1968, has been used increasingly in the past 15 years to treat intracranial meningiomas. The evolution of imaging techniques and dosing regimens is described. The modern experience with the use of gamma knife stereotactic radiosurgery for the treatment of intracranial meningiomas is summarized. Morbidity and mortality of gamma knife-treated patients are discussed and compared with tumor control rates and morbidity figures for other treatments for intracranial meningiomas.

Complications after gamma knife radiosurgery for benign meningiomas.

J Neurol Neurosurg Psychiatry. 2003;74(2):226–230.
PMID: 12531956 DOI: 10.1136/jnnp.74.2.226

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Objective
To analyse the results of gamma knife radiosurgery (GKS) for the treatment of intracranial meningiomas and to assess possible factors related to the outcome and complications of such treatment.

Method
The authors retrospectively reviewed the clinical and radiological data of 179 patients (194 lesions) treated with GKS for meningiomas between May 1992 and October 2000. The mean follow up duration was 37.3 months (range 6.4 to 86.3 months). The study determined the correlation between radiosurgical outcome including imaging changes after GKS and multiple factors such as tumour location and size, patient characteristics, venous sinus status, pre-GKS degree of oedema, other treatment modalities, and radiosurgical parameters.

Results
The radiological control rate was 97.1%. Magnetic resonance imaging (MRI) showed complications after GKS in 35 lesions (25.0%) among the 140 lesions followed up with MRI. Complications were divided into peritumorous imaging changes (33 lesions; 23.6%) and transient cranial nerve dysfunction (two lesions; 1.4%). Radiation induced imaging changes were seen mostly in convexity, parasagittal, and falx meningiomas that were deeply embedded in the cortex. About 60% of these were asymptomatic and the overall rate of symptomatic imaging changes was 9.3%. Neurological deficit related to imaging changes developed in only three patients, and all the symptoms were transient.

Conclusions
GKS for intracranial meningiomas seems to be a safe and effective treatment. However, meningiomas of the convexity, parasagittal region, or falx cerebri have a higher incidence of peritumorous imaging changes after GKS than those of the skull base. Therefore, the use of GKS needs to be considered very cautiously in cerebral hemispheric meningiomas, taking into consideration patient age and general condition, tumour size and location, pattern of cortical embedding, relation between the tumour and venous sinuses, presenting symptoms, and patient preference.

Intratumoral bleeding in meningioma after gamma knife radiosurgery.

J Neurosurg. 2002;97(5)(suppl):657–662.
PMID: 12507115 DOI: 10.3171/jns.2002.97.supplement

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Objective
The authors evaluated whether gamma knife radiosurgery (GKS) could be a causative factor in intratumoral bleeding in meningiomas.

Method
Gamma knife radiosurgery was used in the treatment of 173 meningiomas during a 10-year period. Four patients suffered post-GKS intratumoral hemorrhage. The course in these patients was reviewed. Four of 173 patients suffered an intratumoral hemorrhage during a follow-up period of 1 to 8 years. The risk of intratumoral bleeding after GKS for meningioma was 2.3%. Intracystic hemorrhage occurred in two patients 1 and 5 years, respectively, after radiosurgery. In the other two cases intratumoral bleeding occurred 2 and 8 years, respectively, after radiosurgery. Histological examination in three cases found no specific findings related to the postradiosurgical changes.

Conclusions
Because the reported risk of spontaneous intratumoral bleeding in meningiomas is 1.3 to 2.7%, the incidence in this series was not unduly high. Radiosurgery itself could not be shown to be a significant factor in the development of the intratumoral bleeding.

Meningioma radiosurgery: tumor control, outcomes, and complications among 190 consecutive patients.

Neurosurgery. 2001;49(5):1029–1037.
PMID: 11846894 DOI: 10.1097/00006123-200111000-00001

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Objective
To determine local control (LC) and complication rates for patients with intracranial meningiomas who underwent radiosurgery.

Method
One hundred ninety consecutive patients with 206 meningiomas underwent radiosurgery between 1990 and 1998. One hundred forty-seven tumors (77%) involved the cranial base. The median age at the time of radiosurgery was 58 years (range, 20–90 yr). There were 126 female patients (66%). One hundred twelve patients (59%) had undergone one or more previous operations (median, 1; range, 1–5). Twenty-two patients (12%) had either atypical (n = 13) or malignant (n = 9) tumors. The median prescription isodose volume was 8.2 cm(3) (range, 0.5–50.5 cm(3)), and the median tumor margin dose was 16 Gy (range, 12–36 Gy). The median imaging and clinical follow-up periods were 40 and 47 months, respectively.

Results
Overall survival rates for the entire cohort at 5 and 7 years were 82 and 82%, respectively; cause-specific survival rates at 5 and 7 years were 94 and 92%, respectively. The cause-specific survival rates at 5 years for patients with benign, atypical, and malignant tumors were 100, 76, and 0%, respectively (P <0.0001). The 5-year LC rate was 89%, with 114 tumors (56%) decreasing in size. LC rates were correlated with tumor histological features (P <0.0001); patients with benign tumors exhibited a 5-year LC rate of 93%, compared with 68 and 0% for patients with atypical or malignant meningiomas, respectively. No correlation was observed between radiation dose and LC rate. Twenty-four patients (13%) experienced treatment-related complications, including cranial nerve deficits (8%), symptomatic parenchymal changes (3%), internal carotid artery stenosis (1%), and symptomatic cyst formation (1%). Only six patients (3%) exhibited decreases in functional status that were directly related to radiosurgery. Tumor volume, tumor margin dose, or previous radiotherapy was not associated with the development of radiation- related complications.

Conclusion
Radiosurgery is an effective management strategy for many patients with meningiomas. Patients with atypical or malignant tumors exhibit high recurrence rates despite the use of radiosurgery, and these patients continue to exhibit worse cause-specific survival rates despite aggressive treatment, including surgery, external-beam radiotherapy, and radiosurgery. Further study is needed to determine the tumor control and complication rates 10 years or more after meningioma radiosurgery.

Long-term results of stereotactic gamma radiosurgery of meningiomas.

Surg Neurol. 2001;55(6):325–331.
PMID: 11483185 DOI: 10.1016S0090-3019(01)00467-0

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Background
The early effects at a mean of 30 months and long-term results at 7 years after gamma radiosurgery for meningiomas were evaluated.

Method
Changes in tumor size were evaluated every 3 to 6 months after treatment using a five-point grading system, as well as changes in neurological signs and general status.

Results
Early effects in 87 cases of benign meningioma showed a minimal size reduction of 16.1% and a response rate of 8.0%, but a higher control rate of 93%. The cavernous sinus meningioma showed a size reduction of 23.2%, a response rate of 11.1%, and control of 100%. A greater size reduction of 24.8% and response rate of 33.3%, but a lower control rate of 75% were obtained in 12 cases of malignant meningioma. Side effects were found in 12 cases (13.8%): radiation-induced edema in 9, hearing disturbance in 2, and visual deterioration in 1. Long-term results for 54 of 87 patients with benign tumors showed that response increased from 8% to 42.6% but control decreased slightly due to increased disease progression.

Conclusions
Gamma radiosurgery is effective and safe for meningiomas to control residual or recurrent tumors after surgery and initial tumors, with acceptable side effects and rate of tumor progression.

Glioblastoma induction after radiosurgery for meningioma.

Lancet. 2000;356(9241):1576–1577.
PMID: 11075777 DOI: 10.1016/S0140-6736(00)03134-2

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A 70-year-old woman developed a glioblastoma in the irradiated field 7 years after stereotactic radiosurgery for meningioma. Glioma induction has been previously reported after external beam radiation for leukaemia, pituitary adenoma, tinea capitus, and meningioma. This radiosurgery-induced malignancy may portend further reports of tumour induction. The theoretical risk of tumour induction by low doses of radiation to normal neural tissue after radiosurgery is now confirmed. Reports of additional cases of radiosurgery-induced tumours might temper the use of this increasingly used technique for benign surgically accessible lesions.

Early complications following gamma knife radiosurgery for intracranial meningiomas.

J Neurosurg. 2000;93(3)(suppl):57–61.
PMID: 11143263 DOI: 10.3171/jns.2000.93.supplement

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Objective
The purpose of this paper was to assess the early complications, defined as occurring within 1 year, following gamma knife radiosurgery (GKS) for the treatment of intracranial meningiomas.

Method
Seventy-seven of 306 patients undergoing GKS in the last 2.5 years harbored meningiomas. There were 35 men and 42 women with a mean age of 32.4 years (range 10–80 years). Tumor volume ranged from 0.35 to 28.6 cm3 (mean 7.9 cm3). Gamma knife radiosurgery was the primary therapy in 28 patients and followed surgery in 49 patients. There were 50 basal and 27 nonbasal meningiomas. The most common sites were parasagittal (23 patients) and cerebellopontine angle (14 patients). Ten to 15 Gy was administered to the tumor margins. Clinical and radiological follow up with a mean duration of 122 months was available in 40 patients. Seizures and increased headache were found in five and four patients, respectively. A temporary worsening of hemiparesis was seen in two patients (both with parasagittal tumors). One patient with a cavernous sinus meningioma developed a herpes labialis eruption. Perilesional edema was demonstrated in nine patients and was symptomatic in six. Six (22%) of the 27 patients with nonbasal tumors had edema (all parasagittal) and four patients were symptomatic. Only three (6%) of the 50 basal meningiomas had edema, and only one patient was symptomatic. The occurence of edema did not correlate with tumor volume, margin or maximum dose, or with radiation received by adjacent brain. A reduction in tumor size was seen in seven patients. In one patient a new recurrent lesion developed adjacent to the previously treated tumor.

Conclusions
Although GKS provides good results for selected patients with meningiomas, caution is required in treating patients with parasagittal tumors as the incidence of perilesional edema is considerable.

Gamma knife radiosurgery for meningiomas.

Seminars in Neurosurgery. 2000;11(3):365–372.
DOI: 10.1055/s-2000-9372

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The authors review the indications, technique, and results for stereotactic radiosurgery of intracranial meningiomas. Radiosurgery has become an important adjunct to resection for larger tumors, and an effective primary treatment for small, critically located meningiomas.

A comparison of single fraction radiosurgery tumor control and toxicity in the treatment of basal and nonbasal meningiomas.

Stereotact Funct Neurosurg. 1999;72(1)(suppl):60–66.
PMID: 10681692 DOI: 10.1159/000056440

Vermeulen S,[1] Young R, Li F, Meier R, Raisis J, Klein S, Kohler E.
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Between July 1993 and October 1997, 107 patients with 118 meningiomas were treated with Gamma Knife radiosurgery (GKRS). The most frequent site of tumor origin was the skull base (54%). The mean tumor diameter and volume were 2.5 cm and 9.4 cm3, respectively. The mean dose to the tumor periphery was 17 Gy, prescribed to a mean iso-dose of 47%. At a mean follow-up of 28 months, tumor control for basal and nonbasal meningiomas was 80%. Deteriorating peritumoral edema associated with symptoms was observed in 1 of 49 (2%) skull-base tumors and in 4 of 39 (10%) non-basal tumors, without associated tumor growth. (p=0.15 and 0.234 respectively, z-test). Stereotactic radiosurgery can achieve acceptable tumor control with low morbidity in the treatment of most meningiomas. However, when the tumor is nonbasal, the potential morbidity from peritumoral edema should be recognized and other treatment options considered, such as adjuvant surgery, partial fractionated irradiation or stereotactic radiotherapy.

Low-dose radiosurgery for meningiomas.

Stereotact Funct Neurosurg. 1999;72(1)(suppl):67–72.
PMID: 10681693 DOI: 10.1159/000056441

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Gamma Knife radiosurgery is an effective treatment for meningiomas. However, it may be difficult to deliver what is currently considered an optimal dose, especially if the tumor is large or adjacent to critical structures. Eleven cases are presented with a follow-up of more than 12 months where the margin dose did not exceed 10 Gy. The mean age was 48.8 years. The mean follow-up period was 35.7 months (range 21 to 57 months). The mean volume of the tumors was 9.4 cm3 (range 1.6 to 28.9 cm3). The margin dose was less than 10 Gy in all 11 cases, due to a large volume in two cases. Four tumors were close to the visual pathways. Five tumors were close to the brain stem. Imaging follow-up showed that four tumors had shrunk after radiosurgery. The remaining seven cases remained unchanged. There was no tumor growth after radiosurgery. A transient oculomotor palsy was observed in two cases after radiosurgery. It is suggested that Gamma Knife radiosurgery using lower dosage than usual is one of the options for the treatment of meningioma.

Meningioma followed up for radiological findings before and after radiosurgery: case report.

Minim Invasive Neurosurg. 1999;42(1):44–46.
PMID: 10228940 DOI: 10.1055/s-2008-1053368

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The present paper reports on serial image changes before and after radiosurgery regarding a falx meningioma incidentally discovered in a 79-year-old female. The tumor doubling time during the 3-year observation period before radiosurgery was 469 days. Following radiosurgery using a gamma knife, tumour volume temporarily increased, but then reduced to 55% in 22 months. No symptoms or signs are observable at present, when the patient is 84 years old. These findings suggest that in treating elderly patients with meningioma diagnosed by imaging, radiosurgery should be the first method considered. Also presented are changes in image findings over time.

Dose-volume effect in gamma knife radiosurgery of meningiomas.

Stereotact Funct Neurosurg. 1999;73(1–4):72–78.
PMID: 10853105 DOI: 10.1159/000029758

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Objective
To study the relationship between dose-volume effect and complication in gamma knife radiosurgery of intracranial meningiomas.

Method
By using an integrated logistic formula to establish mathematical models, the authors analyzed the relationship between treatment volume and logistic probability for 15 Gy, and the relationship between prescribed dose and treatment volume in 3% logistic probability. Furthermore, 37 meningiomas treated by gamma knife radiosurgery were analyzed retrospectively to investigate how the 3% isoeffect curve impacted on complication.

Results
There was a linear relation between treatment volume and logistic probability for 15 Gy. The regression formula was f(x) = 0.0042x + 0.0007. The 3% isoeffect curve indicated that the prescribed dose was inversely proportional to the treatment volume. During 16.3 months follow-up on average, 18 cases below the 3% isodose curve were without complication, but in 19 cases above the 3% isodose curve, 5 cases suffered complications, the difference being statistically significant.

Conclusions
Dose selection in gamma knife radiosurgery is volume dependent. The 3% isodose curve may possibly be the guideline in gamma knife radiosurgery of meningiomas.

The effectiveness and factors related to treatment results of gamma knife radiosurgery for meningiomas.

Stereotact Funct Neurosurg. 1998;70(1)(suppl):19–32.
PMID: 9782232 DOI: 10.1159/000056403

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A retrospective analysis was conducted on 80 patients with intracranial mengiomas treated with Gamma Knife radiosurgery between 1993 and 1996. The purpose was to analyze the efficacy of the treatment and to assess appropriate treatment parameters. The results were assessed by regular MR examinations, and tumor volume was measured at 6-month intervals. Mean follow-up duration was 21 months (range 6–45 months). 63 meningiomas were at the skull base and 17 were distal from the skull base. Tumor volumes <5 ml (n = 38), 5–10 ml (n = 21), 10–15 ml (n = 14), 15–20 ml (n = 7). The patients were divided into 3 groups according to the radiation dose. The groups were high-dose (peripheral dose 17–20 Gy, n = 19), medium-dose (15–16 Gy, n = 33) and low-dose (12–14 Gy, n = 28) groups. A statistical method (Generalized Estimation Equation) was applied to compare treatment results in these groups with different doses and tumor volumes. The volume measurement at the latest follow-up showed 74% (59/80) meningiomas decreased in volume, 17% (14/80) had no tumor enlargement and 9% (7/80) had increased in volume. The increased volume was found more frequently in the patients with a short (6–12 months) follow-up period. In this series, the tumors had 32% reduction in average tumor volume at 3 years after radiosurgery. At the range of 12–20 Gy peripheral dose (PD), radiosurgery was effective to reduce tumor volume 0.7% per month ($p < 0.05$). However, higher doses had no significant difference on tumor volume reduction ($p > 0.05$). On the other hand, high-dose (PD >17 Gy) treatment was associated with a higher risk of temporary tumor swelling and the development of adverse radiation effects (AREs). The AREs detected on MR images occurred in (25/80) 31% patients. Only 6/25 AREs were symptomatic and 2 had neurological sequelae. Peripheral doses, tumor volumes and their locations had significant impacts on the ARE ($p < 0.05$). In conclusion, a peripheral dose of 15–16 Gy may be adequate for meningiomas with small volumes (ltoreq 5 ml). In larger tumors (gtoreq10ml) a lower PD is preferred (12–14 Gy). To avoid initial tumor swelling and ARE, high-dose irradiation (PD >17 Gy) is not recommended for meningiomas larger than 5 ml.

Gamma knife treatment of meningiomas.

Hunan Yi Ke Da Xue Xue Bao. 1998;23(2):161–163.
PMID: 10681833

Ma Z,[1] Tang J, Qiu B, Hou Y, Peng Z, Liu Y.
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From October 1995 to July 1997, 52 cases of meningioma were treated with gamma knife radiosurgery. Twenty-eight cases were followed up by CT or MR. The follow-up period was from 2 to 22 months. Follow-up imaging evaluation showed tumor size shrinkage in 8 cases, central density decrease in 10 cases, no change in 8 cases and tumor volume increase in 2 cases. The actual 1-year tumor growth control rate was 92%. Radiation-induced edema was noted in 9 cases, including 7 cases of the nonbasal tumor and 2 cases of basal one. The indications and efficacy of gamma knife treatment of the meningioma were discussed. Our preliminary experience suggests that gamma knife is an effective and safe technique for carefully selected patients with meningiomas.

Gamma knife radiosurgery for meningiomas: four cases of radiation-induced edema.

Stereotact Funct Neurosurg. 1996;66(1)(suppl):142–145.
PMID: 9032855 DOI: 10.1159/000099804

Nakamura S,[1] Hiyama H, Arai K, Nakaya K, Sato H, Hayashi M, Kawamata T, Izawa M, Takakura K.
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We review 48 cases of meningioma treated with Gamma Knife radiosurgery. The mean marginal dose was 15 Gy and the mean follow-up was 12 months. Follow-up computed tomography and magnetic resonance imaging showed tumor shrinkage in 19 cases, central necrosis in 1 case, loss of contrast enhancement in 1 case, and no change in 27 cases. We noted 4 cases of radiation-induced edema in supratentorial meningiomas.

Gamma knife treatment of 100 consecutive meningiomas.

Stereotact Funct Neurosurg. 1996;66(1)(suppl):121–128.
PMID: 9032852 DOI: 10.1159/000099777

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Clinical and imaging results of Gamma Knife treatment of 100 consecutive patients with intracranial meningiomas are reported. Only 1 patient refused follow-up imaging and her symptoms remain improved after 1 year. Mean values for the patient and treatment parameters were age 61 years, duration of symptoms 3.6 years, time since diagnosis 3 years, average tumor diameter 2.4 cm, surface radiation dose 15 Gy and number of isocenters 5. Clinical outcomes revealed that 6 were improved, 75 were unchanged and 17 had deteriorated. Of the latter, 8 were operated, 4 were treated medically and 5 died. Imaging follow-up showed no growth in 87 patients. The size of tumors treated ranged from 0.66 to 6.8 cm average diameter. In the 77 patients with tumors with an average diameter of 3 cm or less, only 2 (3%) showed further growth, and none died of tumor-related causes.

Radiosurgical management of meningiomas.

Stereotact Funct Neurosurg. 1996;66(1–3):15–18.
PMID: 8938927

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The management of residual, recurrent, or small skull base meningiomas is controversial. Stereotactic radiosurgery has emerged as an alternative treatment. We report our experience from September 1991 to August 1994 of treatment of 20 such patients (18 females—age 19–82 years, followed for 6–36 months (mean 15.5 months)) with the Leksell Gamma Kniferegistered trade mark. Nine patients were treated either with recurrent (2 patients—2 operations each) or residual tumor. Twelve patients had skull base, 3 optic nerve, 3 parasagittal, and 1 residual torcular tumor. Mean volume/diameter was 9,172 mm3/25 mm.

Radiation-induced edema after gamma knife treatment for meningiomas.

Stereotact Funct Neurosurg. 1996;66(1)(suppl):129–133
PMID: 9032853

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A retrospective study was performed to analyze some parameters in a consecutive series of 35 Gamma Knife treatments in 34 patients with benign meningiomas. The minimum dose to the tumors was never less than 12 Gy. The follow-up period was from 1 to 3 years. A semiquantitative method of tumor volume assessment was used to measure the tumor response to treatment. The presence and clinical significance of postradiation edema were noted. Even in this short follow-up period, 11 of the 35 tumors were reduced in volume. No tumors increased in size. Edema developed preferentially in nonbasal tumors, especially those around the midline and sagittal sinus. In all but one case where radiation-induced edema was observed was the margin tumor dose 18 Gy or more. It is suggested that doses of 18 Gy or more should probably be avoided in the Gamma Knife treatment of meningiomas and that the greatest care should be taken in selecting non-skull base tumors for this form of treatment.

Radiosurgical treatment of meningioma with the Leksell gamma knife.

Cas Lek Cesk. 1995;134(17):534–538.
PMID: 7553755

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Objective
Up to the present time radical microsurgery of the tumour was considered the most satisfactory treatment. Now an ever more important part in the treatment of these tumours is played by radiosurgery. It involves minimal surgical stress, a minimal rate of complications and minimal change of lifestyle during the postoperative period. The objective of the submitted work was to evaluate the authors' results with the use of Leksell's gamma knife.

Method
In 1992-1994 48 patients with meningiomas were indicated for treatment with a gamma knife. The group comprised 12 men (25%) and 36 women (75%) aged 18–73 years (mean age 52.8 years which did not differ significantly in the two groups). In 19 patients (39.6%) one or more neurosurgical operations were carried out previously, in 4 patients (8.3%) fractionated radiotherapy. Karnofski's score, as an indicator of the general condition, varied between 30–90%, the mean value for the whole group being 71%. The calculated volume of the meningioma was between 0.7 and 25.8 cm3, the average being 7.4 cm3. Collateral oedema in the adjacent area of the tumour was found in 6 patients (12.5%). In 19 patients (39.6%) the tumour was at the base of the skull, in 29 patients (60.4%) at other sites. The radiosurgically administered dose was within the range of 6.5–24 Gy, on average 14,2 Gy, on the isodose on average 50.7% (range 40–75%). The dose below the maximum was within the range of 13–45 Gy), on average 28.3 Gy. Only in two patients fractionated administration of the dose was used. After a 6-month interval following operation 30 patients were examined. In 7 patients (23.3%) partial wrinkling of the meningioma occurred (range 6–18 months), Karnofski's score improved by 10% in 8 (26.6%) and deteriorated in 3 patients (10%). The neurodeficit improved in 7 (23.3%) and deteriorated in 4 patients (13.3%). Collateral oedema developed in 5 patients (16.6%) 5–7 months after operation, in about half the patients it was symptom free. During the follow up period 2 patients died (8 and 5 months following surgery): in one the cause of death was not associated with the basic disease, in the second patient (where radiotherapy was the third neurosurgical operation) the radiosurgical operation could not reverse tha fatal course of the disease.

Conclusions
Radiosurgery of meningiomas is a safe therapeutic method with zero mortality, minimal surgical stress, a minimal rate of complications and a minimal morbidity. It is indicated in meningiomas and possibly their residues after subtotal neurosurgery up to a maximal volume of 30 cm3. It is primary treatment suitable in particular in old.patients, patients with a high per- and postoperative risk and in patients refusing open neurosurgery.

Gamma knife radiosurgery in the treatment of a meningioma in a patient on maintenance hemodialysis: a case report.

Wien Klin Wochenschr. 1994;106(12):378–380.
PMID: 8073768

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To our knowledge, this is the first report ever on the implementation and results of gamma knife radiosurgery in a regularly dialysed patient. The case presented is that of a 59 year-old female patient with a meningioma. Her initial clinical presentation was with sustained headache. Diagnosis was made by using a brain CT scan and MR imaging. Treatment was performed literally without opening the skull. There was only one complication, namely that of postirradiation brain edema, which developed 19 weeks after the operation, and responded dramatically to steroid administration. This is one of the rare side effects of gamma knife therapy, but does not seem to be related to the fact that the patient was uremic. Gamma knife therapy was successful in this patient and her safety was no more compromised than that of a nonuremic patient undergoing radiosurgery.

Stereotactic radiosurgery for intracranial meningiomas.

Neurological Surgery. 1994;22(7):621–626.
PMID: 8078592

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Stereotactic radiosurgery for intracranial menigiomas was attempted using a 201-source cobalt gamma knife. Forty patients bearing 42 tumors were involved in this study. Their ages ranged from 30 to 91 years, with an average of 55.1 years. The most frequent sites of origin were the parasellar and petroclival regions. The mean tumor diameter was 27.2 mm and the marginal tumor dose of radiosurgery ranged from 10 to 20 Gy, depending on tumor location and size. Serial imaging studies with MRI were obtained in all 40 cases, in which minor tumor shrinkage was demonstrated in 7.9%, 40.0% and 53.3% at 6, 12 and 18 months after radiosurgery respectively. Only two tumors became enlarged after the treatment. Obvious low signal intensity on MRI, indicating central tumor necrosis, was found in 32% at 12 months and 40% at 18 months. Four large tumors over 40mm in mean diameter were treated by staged radiosurgery with intervals of 1.5 to 7 months. A similar good response was able to be obtained in all 4 cases, even though they were treated with a marginal dose less than 12 Gy. Symptomatic edema occurred in 5 cases (12.5%) within 12 months and required corticosteroid therapy and hyperosmotic diuresis. In conclusion stereotactic radiosurgery has proved to be an effective and relatively safe method for the treatment of intracranial meningiomas.

The results of gamma knife surgery of meningiomas, related to size of tumor and dose.

Stereotact Funct Neurosurg. 1993;61(1)(suppl):23–29.
PMID: 8115752 DOI: 10.1159.000100656

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In Bergen, 20 patients with meningiomas have been treated with a follow-up period in excess of 1 year. While this is too short a period to allow more than tentative conclusions to be drawn, some trends can be determined nonetheless. There has been some variation in the reporting of the results of treatment of meningiomas, with one group producing a reduction in size in 7% of patients and another in 34%. In the current material, 10 patients received 10 Gy or less to the edge of the tumor. In 4 of these 12 patients there was increase in the volume of the tumor within 1 year of treatment. Ten of the patients received 12 Gy or more to the edge of the tumor. Of these 10 patients, 4 had tumors which showed a reduction in volume. It is suggested that the difference in the reported rate of tumor volume reduction is related to differences in dose, which is discussed in relation to other treatment parameters.

Radiosurgery of meningiomas.

Neurosurg Clin North Am. 1992;3(1):219–230.
PMID: 1633448

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In early experience, radiosurgery proved to be a relatively safe and effective therapy for selected patients with symptomatic meningiomas, including those for whom surgical resection failed. Radiosurgery also has been an effective primary treatment alternative for patients whose advanced age, medical condition, or high-risk tumor location preclude microsurgery. The long-term response to treatment, as defined by imaging and clinical findings, is not yet available. In addition, further clinical and laboratory work is necessary to determine the appropriate tumoricidal radiosurgical dose, dose-volume relationships for individual tumors, and the variable radiation tolerance of the different brain structures that closely surround meningiomas.

Stereotactic radiosurgery of meningiomas.

J Neurosurg. 1991;74(4):552–559.
DOI: 10.3171/jns.1991.74.4.0552

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Stereotactic radiosurgery has an expanding role in the management of selected intracranial tumors. In an initial 30-month experience using the 201-source cobalt-60 gamma knife at the University of Pittsburgh, 50 patients with meningiomas were treated. The most frequent site of origin was the skull base. Previously, 36 patients (72%) had undergone at least one craniotomy and four patients (8%) had received fractionated external beam radiation therapy. Stereotactic radiosurgery was the primary treatment modality in 16 patients (32%) with symptomatic tumors demonstrated by neuroimaging. Computer imaging-generated isodose plans (with one to five irradiation isocenters) for single-treatment irradiation gave optimal (greater than or equal to 50% isodose line) coverage in 44 patients (88%). The proximity of cranial nerves or vascular, pituitary, and brain-stem structures to the often convoluted tumor mass was crucial to dose selection. Serial imaging studies were evaluated in all 50 patients. Twenty-four patients were examined between 12 and 36 months after treatment; 13 (54%) showed a reduction in tumor volume while nine (38%) showed no change. Of 26 patients evaluated between 6 and 12 months after treatment, four showed a decrease in tumor size while 22 showed no change. Two patients (both with large tumors that received suboptimal irradiation) had delayed tumor growth outside the radiosurgical treatment volume. The actuarial 2-year tumor growth control rate was 96%. Between 3 and 12 months after radiosurgery, three patients developed delayed neurological deficits that gradually improved, compatible with delayed radiation injury. Although extended follow-up monitoring over many years will be necessary to fully evaluate treatment, to date stereotactic radiosurgery has proved to be a relatively safe and effective therapy for selected patients with symptomatic meningiomas, including those who failed surgical resection. Radiosurgery was an effective primary treatment alternative for those patients whose advanced age, medical condition, or high-risk tumor location mitigated against surgical resection.

Gamma knife radiosurgery of meningiomas.

Stereotact Funct Neurosurg. 1991;57(1–2):11–21.
DOI: 10.1159/000099552

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Fifty patients with meningiomas were treated during the initial 30 months experience using the 201 source cobalt-60 gamma knife at the University of Pittsburgh. The most frequent site of origin was the skull base. Stereotactic radiosurgery was the primary treatment modality in 16 (32%) patients with symptomatic tumors demonstrated by neuroimaging. Thirty-six patients (72%) had undergone at least one craniotomy, and 4 patients (8%) previously had fractionated external beam radiation therapy. The proximity of cranial nerves, vascular, pituitary and brainstem structures to the often convoluted tumor mass was crucial to dose selection. Follow-up imaging studies and clinical analysis of patients were performed at 6-month intervals. The actuarial 2-year tumor control rate was 96%. Only 2 patients have shown delayed tumor growth outside the radiosurgical treatment volume. To date, stereotactic radiosurgery proved to be a relatively safe and effective therapy for selected patients with symptomatic meningiomas, either as an adjuvant treatment to prior resection, or as a primary treatment alternative for patients whose advanced age, medical condition or high-risk tumor location mitigated against surgical resection.

Delayed malignant transformation of petroclival meningioma to chondrosarcoma after stereotactic radiosurgery.
J Clin Neurosci. 2014;21(7):1225–1228.
PMID: 24491582 DOI: 10.1016/j.jocn.2013.11.015
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Stereotactic radiosurgery (SRS) is often used as adjuvant treatment for residual or recurrent tumor following microsurgical resection of posterior fossa meningiomas. SRS is associated with excellent rates of local control, however long-term complications remain unclear. Secondary malignancy is an often discussed but rarely described complication of SRS. We present a 56-year-old woman who underwent near total resection of a petroclival meningioma, followed by two episodes of SRS over the ensuing 8 years for local recurrence. She returned 14 years after initial diagnosis with neurologic deterioration and was found to have massive recurrence. Pathology was consistent with high-grade chondrosarcoma. The tumor continued to progress despite debulking and proton-beam therapy and the patient died of medical complications. To our knowledge this is the first report of malignant transformation of a meningioma to high-grade chondrosarcoma, further notable due to the remarkable clinical course and delayed presentation after initial surgery and radiosurgery. Though this may have been a de novo tumor, it is also possible that this represents a case of radiation-induced neoplasm. Although SRS continues to gain favor as a treatment modality, delayed malignant degeneration is a potential complication and physicians should counsel patients of this risk.

Long-term outcomes after gamma knife radiosurgery for meningiomas.
Am J Clin Oncol. 2016;39(5):453–457.
PMID: 24755664 DOI: 10.1097/COC.0000000000000080
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Background
Gamma knife stereotactic radiosurgery (SRS) has become an important management strategy for patients with meningiomas. Although prior reports have studied early tumor control, neurological response, and associated morbidity, our purpose was to use clinical and imaging studies to determine whether long-term outcomes remain stable over time.

Materials and methods
We studied 290 consecutive patients (92 men and 198 women) who underwent gamma knife SRS for a meningioma between 1987 and 1997. The median tumor margin dose was 15 Gy and the median tumor volume was 5.5 mL. Target definition was performed using contrast enhanced computed tomography in 72 patients and magnetic resonance imaging in 218 patients. The median patient age at radiosurgery was 61 years. Twenty patients had a history of fractionated radiation therapy, 136 patients had undergone a subtotal resection, and 22 patients had recurrences after initial gross total resection.

Results
The overall tumor control rate was 91%. Twenty-six patients (9%) had evidence of delayed local tumor growth and 44 (15%) had regional tumor progression, which occurred at a median of 38 months. The 10- and 20-year actuarial rates of freedom from tumor progression of the targeted tumor were 87.7%+/-2.5% and 87.2%+/-4.2%. Of 234 patients who had symptoms before SRS (n=62, 26%) improved, 126 (54%) had no change in symptoms and 46 (20%) gradually worsened. Thirty-two of 34 (94%) asymptomatic patients remained asymptomatic. We found no difference in long-term tumor control rates between patients who had undergone craniotomy before radiosurgery (89%) and patients who underwent primary radiosurgery (93.1%). Adverse radiation effects were detected in 3.1% of patients. Factors associated with worse progression-free survival included prior radiation therapy (P <0.0001) and higher grade meningioma (P <0.0001). At a median of 8.7 years after SRS, 137 patients were dead at a median age of 77 years.

Conclusions
We found that gamma knife SRS provided durable tumor control with low morbidity in meningioma patients.

Clinical and pathological analysis of benign brain tumors resected after gamma knife surgery.

J Neurosurg. 2014;121(2)(suppl):179–187.
PMID: 25434951 DOI: 10.3171/2014.8.GKS141439

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Objective
The goal of this study was to assess the clinical and pathological features of benign brain tumors that had been treated with Gamma Knife surgery (GKS) followed by resection.

Method
In this retrospective chart review, the authors identified 61 patients with intracranial benign tumors who had undergone neurosurgical intervention after GKS. Of these 61 patients, 27 were male and 34 were female; mean age was 49.1 years (range 19–73 years). There were 24 meningiomas, 18 schwannomas, 14 pituitary adenomas, 3 hemangioblastomas, and 2 craniopharyngiomas. The interval between GKS and craniotomy was 2–168 months, with a median of 24 months; for 7 patients, the interval was 10 years or longer. For 21 patients, a craniotomy was performed before and after GKS; in 9 patients, pathological specimens were obtained before and after GKS. A total of 29 patients underwent GKS at the Beijing Tiantan Hospital. All specimens obtained by surgical intervention underwent histopathological examination.

Results
Most patients underwent craniotomy because of tumor recurrence and/or exacerbation of clinical signs and symptoms. Neuroimaging analyses indicated tumor growth in 42 patients, hydrocephalus in 10 patients with vestibular schwannoma, cystic formation with mass effect in 7 patients, and tumor hemorrhage in 13 patients, of whom 10 had pituitary adenoma. Pathological examination demonstrated that, regardless of the type of tumor, GKS mainly induced coagulative necrosis of tumor parenchyma and stroma with some apoptosis and, ultimately, scar formation. In addition, irradiation induced vasculature stenosis and occlusion and tumor degeneration as a result of reduced blood supply. GKS-induced vasculature reaction was rarely observed in patients with pituitary adenoma. Pathological analysis of tumor specimens obtained before and after GKS did not indicate increased tumor proliferation after GKS.

Conclusions
Radiosurgery is effective for intracranial benign tumors of small size and deep location and for tumor recurrence after surgical intervention; it is not effective for intracranial tumors with symptomatic mass effect. The radiobiological effects of stereotactic radiosurgery on the benign tumors are mainly caused by cellular and vascular mechanisms. Among the patients in this study, high-dose irradiation did not increase tumor proliferation. GKS can induce primary and secondary effects in tumors, which could last more than 10 years, thereby warranting long-term follow-up after GKS.

Role of stereotactic radiosurgery in meningiomas and vestibular schwannomas.

Curr Treat Options Neurol. 2014;16(8):308.
PMID: 25007984 DOI: 10.1007/s11940-014-0308-3

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Opinion statement

Intracranial meningiomas and vestibular schwannomas (VS, aka acoustic neuromas) are typically benign, slow-growing, non-invasive neoplasms. The imaging and radiobiologic characteristics of these tumors make them good candidates for stereotactic radiosurgery (SRS), a technique that has been in use for over three decades. Patient selection is critical for successful SRS: small- to moderate-sized tumors can be effectively treated with SRS if the patient does not have symptoms related to mass effect. Factors related to tumor control in meningioma SRS include histology, history of prior surgery, and volume. Tumor control rates after SRS is significantly lower for patients with WHO grade II or III meningiomas compared to patients with WHO grade I meningiomas. The risk of radiation-related complications is higher for patients with larger tumors and tumors located over the convexities or along the falx. Patients with small-volume non-operated skull base or tentorial WHO grade I meningiomas typically have the best outcomes after SRS. Radiosurgery of sporadic VS provides a high tumor control rate (92–95%), with less than a 5% risk of facial weakness. Hearing preservation progressively declines for 10 years or more after SRS, and the primary factors related to long-term preservation of useful hearing are tumor size and pre-SRS hearing class. Radiosurgery remains an important option for patients with neurofibromatosis type 2, but tumor control is lower and the risk of cranial nerve deficits is greater when compared to patients with sporadic VS.

Gamma knife radiosurgery for petroclival meningioma: long-term outcome and failure pattern.

Stereotact Funct Neurosurg. 2017;95(4):209–215.
PMID: 28683438 DOI: 10.1159/000475763

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Total removal of petroclival meningioma is difficult, and aggressive extirpation is often associated with significant surgical morbidity and mortality. The aim of this study was to evaluate the long-term outcome and failure pattern of treatment with Gamma Knife radiosurgery (GKRS) in patients with petroclival meningiomas. Eighty-nine consecutive patients with petroclival meningiomas underwent GKRS between 1998 and 2013. Fifty-eight patients received GKRS as a primary treatment and 31 patients underwent GKRS as a secondary treatment after microsurgery. The mean tumor volume was 6.7 cm3 (range 0.5–46.3 cm3) and the mean marginal dose was 13.2 Gy (range 8–17 Gy). At the last radiological follow-up, tumor volume was decreased in 50 patients (56.2%), stationary in 34 patients (38.2%), and increased in 5 patients (5.6%). The actuarial progression-free survival after GKRS was 94.7% at 5 years and 88.9% at 10 years. Favorable cranial nerve outcomes were found in 81 patients (91%). A regrowth pattern was present in all 4 patients of the primary treatment group, whereas cyst formation (3 patients) and regrowth (1 patient) were observed in the secondary treatment group. GKRS is an effective and reasonable option as a primary or secondary treatment for petroclival meningioma. Further studies of failure patterns after GKRS for petroclival meningioma are mandatory.

Emerging indications for fractionated gamma knife radiosurgery.

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Background
Gamma Knife radiosurgery (GKRS) allows for the treatment of intracranial tumors with a high degree of dose conformality and precision. There are, however, certain situations wherein the dose conformality of GKRS is desired, but single session treatment is contraindicated. In these situations, a traditional pin-based GKRS head frame cannot be used, as it precludes fractionated treatment.

Objective
To report our experience in treating patients with fractionated GKRS using a relocatable, noninvasive immobilization system.

Method
Patients were considered candidates for fractionated GKRS if they had one or more of the following indications: a benign tumor >10 cc in volume or abutting the optic pathway, a vestibular schwannoma with the intent of hearing preservation, or a tumor previously irradiated with single fraction GKRS. The immobilization device used for all patients was the Extend system (Leksell Gamma Knife Perfexion, Elekta, Kungstensgatan, Stockholm).

Results
We identified 34 patients treated with fractionated GKRS between August 2013 and February 2015. There were a total of 37 tumors treated including 15 meningiomas, 11 pituitary adenomas, 6 brain metastases, 4 vestibular schwannomas, and 1 hemangioma. At last follow-up, all 21 patients treated for perioptic tumors had stable or improved vision and all 4 patients treated for vestibular schwannoma maintained serviceable hearing. No severe adverse events were reported.

Conclusion
Fractionated GKRS was well-tolerated in the treatment of large meningiomas, perioptic tumors, vestibular schwannomas with intent of hearing preservation, and in reirradiation of previously treated tumors.

Inter- and intrafractional dose uncertainty in hypofractionated gamma knife radiosurgery.

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The purpose of this study is to evaluate inter- and intrafractional dose variations resulting from head position deviations for patients treated with the Extend relocatable frame system utilized in hypofractionated Gamma Knife radiosurgery (GKRS). While previous reports characterized the residual setup and intrafraction uncertainties of the system, the dosimetric consequences have not been investigated. A digital gauge was used to measure the head position of 16 consecutive Extend patients (62 fractions) at the time of simulation, before each fraction, and immediately following each fraction. Vector interfraction (difference between simulation and prefraction positions) and intrafraction (difference between postfraction and prefraction positions) shifts in patient position were calculated. Planned dose distributions were shifted by the offset to determine the time-of-treatment dose. Variations in mean and maximum target and organ at risk (OAR) doses as a function of positional shift were evaluated. The mean vector interfraction shift was 0.64 mm (Standard Deviation (SD): 0.25 mm, maximum: 1.17 mm). The mean intrafraction shift was 0.39 mm (SD: 0.25 mm, maximum: 1.44 mm). The mean variation in mean target dose was 0.66% (SD: 1.15%, maximum: 5.77%) for interfraction shifts and 0.26% (SD: 0.34%, maximum: 1.85%) for intrafraction shifts. The mean variation in maximum dose to OARs was 7.15% (SD: 5.73%, maximum: 30.59%) for interfraction shifts and 4.07% (SD: 4.22%, maximum: 17.04%) for intrafraction shifts. Linear fitting of the mean variation in maximum dose to OARs as a function of position yielded dose deviations of 10.58%/mm for interfractional shifts and 7.69%/mm for intrafractional shifts. Positional uncertainties when performing hypofractionated Gamma Knife radiosurgery with the Extend system are small and comparable to frame-based uncertainties (<1 mm). However, the steep dose gradient characteristics of GKRS mean that the dosimetric consequences of positional uncertainties should be considered as part of treatment planning. These dose uncertainties should be evaluated in the context of tumor response and OAR tolerance for hypofractionated treatment scenarios where any increase in dose may be tempered by the increased protection hypofractionation provides to normal tissue. PACS number(s): 87.52.-g.

Pediatric infratentorial meningiomas: a series of 19 cases and review of the literature.

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Purpose
Pediatric infratentorial meningiomas are extremely rare. In this article, we present a series of 19 cases operated at our institution in the last 8 years.

Method
During the 8-year period from January 2008 to December 2015, we encountered 21 cases suffered from infratentorial meningiomas. Two patients were excluded. The clinical profiles, radiological features, surgical procedures, intraoperative findings, and outcomes were extracted from the patient records and neuroimaging data.

Results
The 19 cases with pediatric infratentorial meningiomas account for about 12.8% of all pediatric intracranial meningiomas. The age distribution of the patients ranged from 7 to 18 years. There were 9 male and 10 female patients. Cranial nerve defects were the first common signs and symptoms found in most cases (n = 14). One meningioma localized in cerebellum, one originated in jugular foramen. Meningioma involving internal auditory canal was only seen in one of the six patients with CPA meningioma. One tumor was totally ossified. In all, total resection was achieved in 14 patients, subtotal resection in 5 patients. Gamma knife was used for the recurrent and subtotally resected tumors. Conventional radiotherapy was applied for high-grade meningiomas (WHO grade II and WHO grade III).

Conclusions
Pediatric infratentorial meningiomas are different from supratentorial ones in many aspects, such as onset age, gender ratio, and neuroradiological characteristics. Surgical excision is challenging. According to the locations of tumors, different surgical approaches would be chosen to maximally resect the lesions without damage to brain stem and cranial nerves. Gamma knife and conventional radiotherapy could be used as postoperative adjuvant therapies. Long-term clinical follow-up and serial imaging are recommended.

Analysis the causes of radiosurgical failure in intracranial meningiomas treated with radiosurgery.

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Objective
Surgical resection is a primary indication for intracranial meningioma. Radiosurgery is also an excellent treatment modality for postoperative residual tumors, or tumors in high-risk locations, such as the skull base. Despite multimodality treatments, there are some cases in which radiosurgery fails and surgical resection or re-radiosurgery is required. However, there has not been a comprehensive study focusing on the causes of secondary treatment for local recurrence or a new mass that develops outside the target area after radiosurgery. Hence, we analyzed the causes of radiosurgical failure in patients with meningioma.

Method
From 2000 to 2015, we retrospectively reviewed 1086 patients who underwent gamma knife radiosurgery (GKRS) for intracranial meningioma at the Asan Medical Center. Multiple meningiomas or tumors with a volume greater than 7000mm3 were excluded. All patients had a minimum follow-up of 12 months. Finally, 771 patients were enrolled in this study. Clinical symptoms and brain MRI findings were assessed by neurosurgeons. When the tumor size increased and was accompanied by newly developed neurological symptoms, further management was considered (e.g. microsurgical resection and stereotactic radiosurgery). Histological analyses of the resected tumors were performed by neuropathologists.

Results
Among the 771 patients, tumor growth was observed in 60 patients (7.78%). Seven patients showed transient tumor growth after GKRS. These patients have been under close observation without any further treatment. Thirty patients (3.89%) underwent re-radiosurgery for tumor control. Another 23 patients underwent procedures other than re-radiosurgery; 8 underwent microsurgical resection, 3 underwent cyber knife radiosurgery (CKRS), 1 underwent radiation therapy, and 8 were closely followed up. Three patients visited other clinics or were lost to follow-up. Of the remaining 30 patients, 22 (group 1) underwent microsurgical resection prior to their initial course of GKRS and the other 8 (group 2) were treated only with re-radiosurgery. In group 1, recurrence rates after radiosurgery were 2.47% (n = 19) and 0.39% (n = 3) for local and distant recurrence, respectively. In group 2, recurrence rates after radiosurgery were 0.52% (n = 4) and 0.52% (n = 4) for local and distant recurrence, respectively. An analysis was performed to determine the factors that may result in differences between the two groups. Of the many variables, local recurrence (p = 0.0331, Fisher's exact test) was the only significant factor.

Conclusions
We analyzed the causes of radiosurgical failure in meningioma patients and observed that microsurgery before radiosurgery was significantly associated with a high local recurrence rate compared with primary radiosurgery. Furthermore, the percentage of local recurrence cases that required secondary radiosurgery was as low as 2.98%. This result is comparable with that of microsurgical resection, which is the mainstay of treatment for meningioma.

Gamma knife radiosurgery for neurofibromatosis type 2–associated meningiomas: a 22-year patient series.

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Neurofibromatosis type 2 (NF2) is a debilitating genetic condition with potential development of multiple meningiomas. We report our experience treating a series of NF2-associated intracranial meningiomas with Gamma Knife radiosurgery (GKRS). Between 1992 and 2013, 15 consecutive patients (age 20–54 years) with 62 intracranial meningiomas were treated with single-fraction GKRS. Fifty-five percent of tumors involved the convexity or parasagittal/falx. The median prescription dose was 16 Gy (range 13–20 Gy). The median tumor diameter was 2.1 cm (range 0.7–4.5 cm). The median radiographic and clinical follow-up periods were 103 and 111 months, respectively. The 5-year and 10-year local controls were both 96 %. The disease specific survival was 93 % at 5 years and 68 % at 10 years. Fifty-three percent of patients had multiple meningiomas and received multiple GKRS treatments (range 1–7) for new or enlarging intracranial meningiomas. 11 (73 %) patients were alive at last follow-up, with 60 (97 %) tumors controlled (smaller or unchanged in size). There were 2 in-field failures, one at 1 year and the other at 3.5 years. There were no marginal failures. Major Complications after GKRS included: 1 case of radiation necrosis, 1 case of post treatment edema, and 1 case of a presumed radiation induced cavernous malformation 5 years after GKRS. GK is an effective treatment for enlarging NF2-associated meningiomas. No cases of malignant transformation or secondary malignancies were seen during the follow-up period.

Parameters influencing local control of meningiomas treated with radiosurgery.

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To identify parameters that influence local control after stereotactic radiosurgery (SRS) for meningiomas we retrospectively analyzed all meningiomas treated with Gamma Knife SRS at our institution from 1991 to 2007. Endpoints were measured from the date of SRS and estimated using the Kaplan-Meier method; subgroups were compared with log-rank tests. Sex, performance status, age, SRS setting, radiation dose, grade, volume and location were evaluated with univariate and multivariate Cox proportional hazards analyses. Of 280 patients with 438 tumors, 264 patients with clinical follow-up and 406 tumors with imaging follow-up were analyzed (median follow-up: 75.9 months). Thirty-seven percent of the tumors had no tissue diagnosis, 32% were benign (grade I), 12% atypical (grade II), and 19% malignant (grade III). Five-year freedom from progression (FFP) was 97% for presumed meningiomas, 87% for grade I tumors, 56% for grade II tumors, and 47% for grade III tumors ($p < 0.0001$). Five-year FFP probabilities for upfront SRS versus SRS at recurrence after surgery versus SRS at recurrence after RT were 97, 86, and 38%, respectively ($p < 0.0001$). Univariate analysis revealed that higher grade, larger target volume (median diameter: 2.4 cm) and SRS setting were associated with poorer FFP. Only target volume and SRS setting remained significant on multivariate analysis. Local control of presumed and grade I meningiomas is excellent with Gamma Knife SRS, but is suboptimal with high-grade tumors as well as for those treated at recurrence after RT or of large volume.

The contemporary role of stereotactic radiosurgery in the treatment of meningiomas.

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Meningiomas are among the most common intracranial tumors in adults. The mainstay of treatment has been extirpation. Stereotactic radiosurgery (SRS) is an important option in the management of inaccessible, recurrent, or residual benign meningiomas. Image guidance and a steep dose fall off are critical features. SRS offers durable tumor control for grade I meningiomas with a low incidence of complications or neurologic deficits. Neurologic function is generally preserved or improved. Complications are relatively rare. For many, the risk to benefit ratio seems favorable compared with treatment alternatives.
We present a short review of the literature on SRS for intracranial meningiomas.

Long-term outcomes following gamma knife radiosurgery for small, newly diagnosed meningiomas.

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Objective
Although stereotactic radiosurgery was established as an effective treatment modality for intracranial meningiomas, there have been no comprehensive studies focused on long-term outcomes and histologic results for purely small-sized meningiomas after radiosurgery. Therefore, we investigated long-term outcomes and histology of small-sized meningiomas after radiosurgery.

Method
The authors reviewed the data retrospectively of a total of 920 patients treated with single-session Gamma Knife radiosurgery with intracranial meningioma (Radiosurgery center, Asan Medical Center). After stratifying meningiomas by size, it was defined as small-sized meningiomas less than 1000 mm(3) in tumor volume. The patients with newly diagnosed small-sized meningiomas were enrolled in this study (113 patients). All patients had a minimum follow-up of 12 months (12–120 months), clinical symptoms and brain MRI were checked by neurosurgeons. When the tumors grew readily with newly developed neurologic symptoms, microsurgical resection was performed. Histologic analysis was done with resected tumors by neuropathologists.

Results
Among 113 patients, 9 patients (7.9%) showed the increased tumors with clinical symptoms after radiosurgery, followed by microsurgical resection in 4 patients (3.5%). The other 5 (4.4%) patients showed that the size of tumor slightly increased after GKRS that is transient. Interestingly, the histologic results of resected meningiomas due to increased volume after radiosurgery were all revealed as WHO grade II meningiomas (1 clear cell type and 3 atypical meningiomas). Although the histologic confirmation was performed only in 4 patients underwent surgery, it is interesting that all tumors readily grew after radiosurgery were high grade meningiomas.

Conclusions
In this study, we revealed the long-term outcomes of small meningiomas following stereotactic radiosurgery in the aspect of tumor control. The tumor control rate of radiosurgery in small meningiomas reached to 92.1% and there were perilesional edema in 6.1%. The 7.9% of tumors grew readily and 3.5% were finally underwent microsurgical resection. The histologic results were all WHO grade II meningiomas (1 clear cell and 3 atypical meningiomas).

Long-term results of gamma knife radiosurgery for intracranial meningioma.

Brain Tumor Res Treat. 2015;3(2):103–107.
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Background
The predominant treatment modality for meningioma is surgical resection. However, gamma knife radiosurgery is also an important treatment modality for meningioma that is small or cannot be completely removed because of its location. In this study, we evaluated the effectiveness and long-term results of radiosurgical treatment for meningioma in our institution.

Method
We studied 628 patients (130 men and 498 women) who underwent gamma knife radiosurgery for intracranial meningioma, which is radiologically diagnosed, from Jan 2008 to Nov 2012. We included patients with single lesion meningioma, and followed up after 6 months with imaging, and then at 24 months with a clinical examination. Patients with high-grade meningioma or multiple meningiomas were excluded. We analyzed each of the factors associated with progression free survival. The median patient's age was 56.8 years. Maximal dosage was 27.8 Gy and marginal dosage was 13.9 Gy.

Results
The overall tumor control rate was 95%. Twenty-eight patients (4.4%) showed evidence of tumor recurrence. Ninety-eight patients (15%) developed peritumoral edema (PTE) after gamma-knife surgery; two of them (2%) underwent surgical resections due to PTE. Nine patients had craniotomy and tumor removal after gamma knife surgery.

Conclusions
Gamma knife surgery for intracranial meningioma has proven to be a safe and effective treatment tool with successful long-term outcomes. Gamma knife radiosurgery can be especially effective in cases of remnant meningioma after surgical resection or where PTE is not present.

Dose-response relationships for meningioma radiosurgery.

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Objective
Dose-response relationships for meningioma radiosurgery are poorly characterized. We evaluated determinants of local recurrence for meningiomas treated with Gamma Knife radiosurgery (GKRS), to guide future treatment approaches to optimize tumor control.

Materials and method
A total of 101 consecutive patients (108 tumors) who underwent GKRS for benign, atypical, or malignant meningiomas between 1998 and 2011 were studied. Local recurrence was assessed. Cox proportional hazards and logistic regression analyses were used to determine the association of patient-related, tumor-related, and treatment-related characteristics with local recurrence. Acute and late toxicity was evaluated.

Results
World Health Organization (2007 classification) tumor grade was I (82%), II (11%), or III (7%). Median dose was 14 Gy (range 10 to 18 Gy) for grade I tumors and 16 Gy (range 12 to 20 Gy) for grade II and III tumors. Median follow-up was 25 months (maximum, 17 y). Two-/5-year actuarial local control rates were 100%/98% for grade I tumors and 76%/56% for grade II/III tumors. Higher tumor grade and lower GKRS dose were associated with local failure. In this cohort, there was a 42% relative reduction in local recurrence for each 1 Gy of dose escalation.

Conclusions
Treatment was well tolerated with no moderate or severe toxicity. Tumor control was excellent in benign tumors and suboptimal in higher grade tumors. Because the main determinant of local recurrence was GKRS dose, we recommend dose escalation for atypical or malignant tumors to doses between 16 and 20 Gy where critical structures allow.

Peritumoral brain edema after stereotactic radiosurgery for asymptomatic intracranial meningiomas: risks and pattern of evolution.

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Objective
To investigate the risks and pattern of evolution of peritumoral brain edema (PTE) after stereotactic radiosurgery (SRS) for asymptomatic intracranial meningiomas.

Method
A retrospective study was conducted on 320 patients (median age 56 years, range 24–87 years) who underwent primary Gamma Knife radiosurgery for asymptomatic meningiomas between 1998 and 2012. The median tumor volume was 2.7 cc (range 0.2–10.5 cc) and the median follow-up was 48 months (range 24–168 months). Volumetric data sets for tumors and PTE on serial MRIs were analyzed. The edema index (EI) was defined as the ratio of the volume of PTE including tumor to the tumor volume, and the relative edema indices (rEIs) were calculated from serial EIs normalized against the baseline EI. Risk factors for PTE were analyzed using logistic regression.

Results
Newly developed or increased PTE was noted in 49 patients (15.3%), among whom it was symptomatic in 28 patients (8.8%). Tumor volume larger than 4.2 cc ($p<0.001$), hemispheric tumor location ($p = 0.005$), and pre-treatment PTE ($p<0.001$) were associated with an increased risk of PTE. rEI reached its maximum value at 11 months after SRS and decreased thereafter, and symptoms resolved within 24 months in most patients (85.7%).

Conclusions
Caution should be exercised in decision-making on SRS for asymptomatic meningiomas of large volume (>4.2 cc), of hemispheric location, or with pre-treatment PTE. PTE usually develops within months, reaches its maximum degree until a year, and resolves within 2 years after SRS.

The geriatric scoring system (GSS) for risk stratification in meningioma patients as a predictor of outcome in patients treated with radiosurgery.

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Introduction
Meningiomas are the most common primary benign brain tumor. Radiosurgery (primary or adjuvant) allows excellent local control. The Geriatric Scoring System (GSS) for preoperative risk stratification and outcome prediction of patients with meningiomas has been reported previously. The GSS incorporates 8 tumor and patient parameters on admission. A GSS score greater than 16 was reported previously to be associated with a more favorable outcome. We assessed the validity of the GSS score and its influence on outcome in patients treated with Gamma-Knife radiosurgery (GKRS).

Patients and Method
Patients treated with single-session GKRS for World Health Organization grade I meningioma during 1989–2013 at the University of Virginia were reviewed. The cohort comprised 323 patients, 50.2% (n = 162) male. Median age was 56 years (29–84 years), and median follow-up was 53.6 months (6–235 months). Median tumor volume was 4.5 cm (3) (0.2–23). Median margin and maximal doses were 15 Gy (8–36) and 32.3 Gy (20–65), respectively.

Results
Tumor volume control was achieved in 87% (n = 281), and post-GKRS clinical neurologic improvement was reported in 66.3% (n = 214). The median change in KPS was +10 (range -30 to +40). The most common complication was intermittent headaches (34.1%, n = 110) and cranial nerve deficits (14.2%, n = 46). The GSS (calculated and grouped as GSS > 16 and GSS ≤ 16) was found to correlate with different post-GKRS functional status ($P < 0.0001$) and tumor control ($P = 0.028$).

Conclusions
The GSS, used for risk stratification and outcome prediction in patients with meningiomas, seems valid for patients undergoing single-session GRKS. A GSS score greater than 16 is associated with a better long-term functional status and tumor control.

Quantitative tumor volumetric responses after gamma knife radiosurgery for meningiomas.

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Objective
The reported tumor control rates for meningiomas after stereotactic radiosurgery (SRS) are high; however, early imaging assessment of tumor volumes may not accurately predict the eventual tumor response. The objective in this study was to quantitatively evaluate the volumetric responses of meningiomas after SRS and to determine whether early volume responses are predictive of longer-term tumor control.

Method
The authors performed a retrospective review of 252 patients (median age 56 years, range 14–87 years) who underwent Gamma Knife radiosurgery between 2002 and 2010. All patients had evaluable pre- and postoperative T1-weighted contrast-enhanced MRIs. The median baseline tumor volume was 3.5 cm(3) (range 0.2–33.8 cm(3)) and the median follow-up was 19.5 months (range 0.1–104.6 months). Follow-up tumor volumes were compared with baseline volumes. Tumor volume percent change and the tumor volume rate of change were compared at 3-month intervals. Eventual tumor responses were classified as progressed for > 15% volume change, regressed for ≤ 15% change, and stable for ± 15% of baseline volume at time of last follow-up. Volumetric data were compared with the final tumor status by using univariable and multivariable logistic regression.

Results
Tumor volume regression (median decrease of -40.2%) was demonstrated in 168 (67%) patients, tumor stabilization (median change of -2.7%) in 67 (26%) patients, and delayed tumor progression (median increase of 104%) in 17 (7%) patients ($p < 0.001$). Tumors that eventually regressed had an average volume reduction of -18.2% at 3 months. Tumors that eventually progressed all demonstrated volume increase by 6 months. Transient progression was observed in 15 tumors before eventual decrease, and transient regression was noted in 6 tumors before eventual volume increase.

Conclusions
The volume response of meningiomas after SRS is dynamic, and early imaging estimations of the tumor volume may not correlate with the final tumor response. However, tumors that ultimately regressed tended to respond in the first 3 months, whereas tumors that ultimately progressed showed progression within 6 months.

Predictors of response to gamma knife radiosurgery for intracranial meningiomas.

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Objective

In this paper, the authors' aim was to determine short-term volumetric and diametric tumor growth and identify clinical, radiological, and dosimetric predictors of adverse radiation events (AREs) following stereotactic radiosurgery (SRS) for intracranial WHO Grade I meningiomas.

Method

This is a retrospective review of all WHO Grade I meningiomas that were treated with SRS (primary or adjuvant) between December 2005 and June 2012 at the University Health Network. Seventy-five patients had at least 24 months of both clinical and radiological follow-up and were, therefore, included in this study. Tumor growth was defined as any volumetric or diametric change greater than 10% per year. Any variation less than +10% was considered growth stability. Volumetric measurements were made using T1-weighted gadolinium-enhanced 3-T MRI scans and ITK-SNAP software. Tumor growth rates were calculated using the specific growth rate (SGR). Univariate statistics were used to identify predictors of post-SRS AREs. All statistical analyses were performed using IBM SPSS.

Results

Women accounted for 69.3% of patients, and the mean treatment age was 58.6 years. Median follow-up was 36.2 months. Twenty-one (28%) patients had undergone prior resection. Two (3%) patients required salvage surgical intervention following SRS. The majority of the lesions (56%) were skull base tumors. Median tumor volume and diameter were 5.2 cm3 and 27.5 mm, respectively. The absence of tumor growth was observed in 39 cases (52%) based on the volumetric measurements, while the absence of tumor growth was observed in 69 cases (92%) based on the diametric measurements. Twenty-six patients (34.6%) experienced new-onset AREs, including headache (17.3%), cranial neuropathy (10.6%), speech impairment (2.7%), tremors (2.7%), and ataxia (1.3%). Fourteen patients (18.7%) experienced new-onset edema, and 4 of these patients were symptomatic. A lower conformity index (1.24 vs 1.4) was significantly associated with the development of edema ($p<0.001$ power>0.8). Patients with meningiomas that had growth rates of more than 10% per year were more likely to experience long-term headaches after SRS ($p = 0.022$).

Conclusions

Volume-based reporting of SRS outcomes for meningiomas may be a more accurate method given the complex morphology of some lesions. The conformity index was identified as a predictor of edema following radiosurgery.

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