Stereotactic radiosurgery (SRS) has afforded an effective technique in the treatment of skull base tumours, and has become an important addition to, or replacement of, microsurgical resection of these lesions. The unique ability to precisely focus external radiation sources and minimize radiation fall off on normal surrounding structures offers a minimally-invasive management option for cavernous sinus meningiomas. Linac, Cyberknife, and Gamma Knife (GK) based SRS have been shown to offer high rates of local tumour control with long term follow-up demonstrating good local control and functional independence.

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This study describes our institutional experience with GK stereotactic radiosurgery in the treatment of cavernous sinus meningiomas.

**METHODS**

Between November 2003 and April 2011, 30 patients with cavernous sinus meningiomas underwent GK radiosurgery at the Health Sciences Center in Winnipeg, Manitoba. We retrospectively reviewed the records of these patients and recorded data on: age, sex, tumour diameter and volume, GK treatment parameters, complications, time until tumour response, local control rates, and clinical outcomes. Local research ethics board approval was obtained prior to starting this study.

**RESULTS**

*Patient Demographics and Meningioma Characteristics*

All thirty patients received a single GK treatment at our institution and none had previous SRS at any other institution. Nineteen patients were treated with the Leksell Model C system, while eleven were treated with the Perfexion system. Of the thirty patients treated, twelve (40%) had previous surgical debulking prior to GK radiosurgery, with an average time from surgery to GK of 34 months (range: eight months - six years). All patients demonstrated growth of the tumour upon post-surgical follow-up imaging prior to GK. The average patient age of the population was 55.1 years (range: 29 - 79), with 8 (26.7%) being male and 22 (73.3%) female. Mean follow-up time of all patients was 36.1 months (range: 3 - 80 months), with 4 patients (13.3%) lost to follow-up, all residing in other provinces. Patient demographics are displayed in Table 1. The data of those patients lost to follow-up can be seen in Table 2.

Of the four patients lost to follow-up, all were referred to our facility by out of province physicians. They were subsequently lost to post-treatment follow-up after returning to their respective provinces.

Patients typically had multiple clinical symptoms at time of GK surgery including: diplopia (13), non-specific headache (9), ipsilateral trigeminal dysesthesias (13), blurred vision (9), Horner’s syndrome (2), and new onset seizure (1). In one case the tumor was an incidental asymptomatic finding (1), with growth demonstrated on imaging follow-up. Neurological findings were also typically multiple in most patients, and consisted of: ipsilateral oculomotor nerve palsy (8), ipsilateral abducens nerve palsy (8), ipsilateral trigeminal nerve ophthalmic (8) and maxillary (6) hypoesthesia, ipsilateral Horner’s syndrome (2), proptosis (1), temporal visual field cut (1), and a relative afferent pupilary defect (1).

Seventeen patients (56.7%) had right sided cavernous sinus meningiomas, while thirteen (43.3%) were left sided. Meningioma extensions included Meckel’s cave (5), prepontine cistern (4), sellar/suprasellar (7), and middle fossa (3). Twelve patients (40.0%) had partial cavernous internal carotid artery (ICA) encasement without vessel narrowing. Ten (33.3%) patients had complete cavernous ICA encasement; only 2 (6.7%) demonstrated ICA narrowing. Eight (26.7%) patients had no direct magnetic resonance imaging (MRI) evidence of contact with the cavernous carotid. The average maximum diameter and volume of the tumour was 3.4 cm (range: 1.81 – 4.82cm) and 7.9 cm³ (range: 3.25 – 16.1 cm³) respectively.

A SRS grading scheme was developed in 2001 by DeSalles et al. for cavernous sinus meningiomas. Grade I was described as lesions strictly in the cavernous sinus. Grade II cavernous sinus meningiomas extended to the clivus and/or the petrous bone.

<table>
<thead>
<tr>
<th>Table 1: Demographic and treatment characteristics of patients with follow-up treated with Gamma Knife for Cavernous Sinus Meningioma</th>
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</thead>
<tbody>
<tr>
<td><strong>Demographic/Treatment Category (n=26 Patients)</strong></td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Tumor Volume (cm³)</td>
</tr>
<tr>
<td>Avg Tumor Diameter (cm)</td>
</tr>
</tbody>
</table>

n = number, avg = average, SRS = stereotactic radiosurgery grade, Gy = Gray. Serious complications were defined as those that resulted in permanent deficits for the patient.
occipital neuralgic pain.

19 (42.1%) displayed stability and 2 (10.9%) demonstrated growth or decrease in size on follow-up imaging occurred in 26 patients (92.3%) and included: new trigeminal neuropathic pain (1), new occipital neuralgic pain related to frame placement (1), symptomatic cerebral edema/trigeminal neuropathic pain (1), worsening post-treatment seizures (1), and panhypopituitarism (1). The patient with new onset trigeminal neuropathic pain post GK, had a 9.3 cm³ left meningocele extending into Meckel’s cave and presented with left ophthalmic/maxillary trigeminal distribution numbness and partial abducens nerve dysfunction. Currently he remains with treatment refractory left TN. The patient with new occipital neuralgic pain, developed this discomfort post stereotactic frame removal, and is likely a result of frame placement. The patient with minor symptomatic cerebral edema not requiring treatment and trigeminal neuropathic pain had a right 12.5 cm³ meningocele extending into Meckel’s cave and presented with an oculomotor and abducens nerve dysfunction. No trigeminal nerve symptoms were present initially. Currently, he has ongoing atypical right sided facial discomfort in ophthalmic distribution of the trigeminal nerve, and slowly improving oculomotor and abducens nerve function. The patient with pre-GK seizures secondary to previous microsurgical debulking (three months previous to GK), had worsening post-GK seizures requiring a permanent increase in baseline dose of antiepileptic drug(s). Finally, the patient with panhypopituitarism had a 10.0 cm³ meningocele in the right cavernous sinus, sphenoid sinus and suprasellar cistern. Currently, this individual remains on cortisol, thyroid and testosterone replacement 63 months out from GK.

A MRI diagnosis of “central tumour radiation necrosis” occurred in 4 of 26 (15.4%) patients, but was asymptomatic in all. None was confirmed with pathological specimens. One patient (3.4%) developed localized asymptomatic cerebral edema on regular scheduled follow-up imaging.

When we review the control rates utilizing the SRS grading scheme developed by DeSalles et al13, the local control rates without compression of the brainstem. Grade III tumours had superior and/or anterior extension with compression of the optic nerve or tract. Grade IV lesions compressed the brain stem, and Grade V were bilateral lesions. We had eight patients with Grade I, seven patients with Grade II, six patients with Grade III, and five patients with Grade IV lesions. The average SRS grade in our study was 2.2, with a range from 1 to 4.

SRS treatment planning was performed using MRI and computed tomogram (CT) in 17 (56.7%), and only MRI in 13 (43.3%). Gamma Knife treatment parameters consisted of an average maximum tumour dose of 27.3 Gy, with a range from 26 to 32.5 Gy, and average number of collimator shots being 20.1 per treatment (range: 10 – 38). Dose prescription was 13.5 Gy to the 50% isodose line, with a range from 12.5 to 15 Gy. The average total volume covered (TVC) was 7.2 cm³ (range: 3.2 – 16.3 cm³), with average percent coverage of 96.8% (range: 90 – 100%). Twenty-eight (93.3%) patients had a recorded dose including the optic apparatus that was on average 8.2 Gy (range: 3.4 – 11.7 Gy), with four patients having a dose greater than 10 Gy.

Patients received post-treatment follow-up phone interviews at two weeks of GK treatment. Follow-up clinic visits were conducted six to eight weeks post treatment. Imaging was conducted at six months and yearly post treatment with MRI to assess tumour control and growth. Follow-up was available in 26 of 30 patients.

### Tumour Control

Local control, which was defined as the absence of lesion growth or decrease in size on follow-up imaging occurred in 24/26 (92.3%); 9 (34.6%) demonstrated regression and 2 (7.7%) displayed interval growth. Nineteen patients had a minimum two years of follow-up, with local control in 17 of 19 (89.5%). Nine of these 19 (47.4%) patients had tumour regression, while 8 of 19 (42.1%) displayed stability and 2 (10.9%) demonstrated growth.

Of the two patients with tumour growth, follow-up is continuing. One is asymptomatic, and the other has continuing issues with persisting facial numbness and new frame related occipital neuralgic pain.

## Table 2: Characteristics of patients lost to follow-up

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>Presentation</th>
<th>Location</th>
<th>Volume of Tumour (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>66</td>
<td>Lt facial pain x 3 years, Diplopia</td>
<td>Left Cav Sinus</td>
<td>13.6</td>
</tr>
<tr>
<td>M</td>
<td>51</td>
<td>Lt retro-orbital pain, RAPD</td>
<td>Left Cav Sinus</td>
<td>7.6</td>
</tr>
<tr>
<td>F</td>
<td>71</td>
<td>Rt vision loss, 3rd nerve palsy</td>
<td>Right Cav Sinus</td>
<td>4.6</td>
</tr>
<tr>
<td>F</td>
<td>36</td>
<td>Rt vision blurr, papilledema</td>
<td>Rt Cav Sinus, Orbital Apex</td>
<td>3.6</td>
</tr>
</tbody>
</table>

F = female, M = male, Lt = left, Rt = right, Cav = cavernous

### Complications

Overall, complications occurred as a result of GK treatment in 17 of 26 patients (65.4%). The majority of the complications were minor and transient effects seen in 12 patients (one patient had two): pin site infection (1), headache described as new or different from pre-treatment (7), pin site edema (3), right vision blurring (1), and ataxia (1). Serious complications, which we defined as those resulting in permanent deficits as a result of treatment occurred in 5 of 26 patients (19.2%) and included: new trigeminal neuropathic pain (1), new occipital neuralgic pain related to frame placement (1), symptomatic cerebral edema/trigeminal neuropathic pain (1), worsening pre-treatment seizures (1), and panhypopituitarism (1). The patient with new onset trigeminal neuropathic pain post GK, had a 9.3 cm³ left meningocele extending into Meckle’s cave and presented with left ophthalmic/maxillary trigeminal distribution numbness and partial abducens nerve dysfunction. Currently he remains with treatment refractory left TN. The patient with new occipital neuralgic pain, developed this discomfort post stereotactic frame removal, and is likely a result of frame placement. The patient with minor symptomatic cerebral edema not requiring treatment and trigeminal neuropathic pain had a right 12.5 cm³ meningocele extending into Meckel’s cave and presented with an oculomotor and abducens nerve dysfunction. No trigeminal nerve symptoms were present initially. Currently, he has ongoing atypical right sided facial discomfort in ophthalmic distribution of the trigeminal nerve, and slowly improving oculomotor and abducens nerve function. The patient with pre-GK seizures secondary to previous microsurgical debulking (three months previous to GK), had worsening post-GK seizures requiring a permanent increase in baseline dose of antiepileptic drug(s). Finally, the patient with panhypopituitarism had a 10.0 cm³ meningocele in the right cavernous sinus, sphenoid sinus and suprasellar cistern. Currently, this individual remains on cortisol, thyroid and testosterone replacement 63 months out from GK.

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When we review the control rates utilizing the SRS grading scheme developed by DeSalles et al13, the local control rates...
were: Grade 1 (n=8) 87.5% with three decreasing in size, Grade 2 (n=7) 100% with two decreasing in size, Grade 3 (n=6) 100% with three decreasing in size, and Grade 4 (n=5) 80.0% with one decreasing in size. Serious complication rates were 0%, 28.6%, 16.7%, and 20.0% respectively. Asymptomatic MRI declared “radiation effect” was documented in 12.5%, 14.3%, 16.7%, and 20.0% respectively as seen in Table 3.

**Symptom Control**

Overall average follow up was 36.1 months (range: 3 – 80). Clinical improvement or stability of neurological symptoms occurred in 21 of the 26 patients (80.8%). Fourteen patients had stable signs and symptoms, including: headache (4), trigeminal nerve dysfunction (only one with pain) (3), oculomotor and abducens combined (3), oculomotor nerve palsy and Horner’s (1), Horner’s (1), stable complex partial seizures on Tegretol (1), and right blurred vision (1). Six patients (23.1%) had improvement of their pre-GK symptoms and included: trigeminal dysesthesias and abducens nerve palsy (1), headache (1), oculomotor nerve palsy (1), abducens nerve palsy (2), and trigeminal neuropathy/blurred vision (1). One patient developed gradual worsening of pre-existing seizures (seizures developed from previous surgical debulking and subsequent temporal lobe gliosis). Four patients developed new deficits post GK treatment, as described under the complications section. Finally, one patient remained asymptomatic throughout discovery, treatment, and follow-up.

In terms of Glasgow Outcome Scores (GOS) in those patients with follow-up, only four patients had a change in their pre-treatment functional status. Four of the patients with a GOS of 4 were previously a GOS of 5 pre-treatment. These were those patients that developed serious complications as a result of their Gamma Knife treatment. The one patient with a GOS of 3 suffered worsening seizures related to temporal lobe gliosis from previous surgical resection, this not being a complication of GK.

**DISCUSSION**

Meningiomas of the cavernous sinus are a subset of skull base meningiomas that pose a treatment challenge. The location and surrounding critical anatomical structures provide a difficult environment for a standard open surgical approach. The presence of cranial nerves III, IV, V, and VI, in addition to the cavernous carotid artery and the surrounding carotid sympathetics, make this location challenging to operate in. Prior to the microsurgical era, surgery for cavernous meningiomas resulted in high mortality and morbidity with the operative approaches available. The watch and wait approach could also lead to significant morbidity due to multiple cranial neuropathies.

Through the advent of the operating microscope, advances in operative techniques, and further study into the anatomical relationships of the cavernous sinus, a safer means of surgical management evolved.

Within the last 20 years many case series and operative series have been published demonstrating the efficacy of the open microsurgical approach to cavernous sinus meningiomas. Total resection rates varied from 12 to 80%, with tumour control rates reported at 86 to 90%. However, operative mortality in some cases was as high as 7.3%, with complications ranging up to 59.6%. Such described complications included: cranial nerve palsy (II, III, IV, V, VI), occlusion of the cavernous carotid artery, cerebrospinal fluid leak, and death. Thus, despite all the advances and developments which optimized current surgical techniques, a significant morbidity and mortality remain.

GK SRS has offered impressive local control rates from 91 up to 100%, with complications ranging from 0 to 5%. Of note is the substantial decrease in mortality in the GK SRS patients, compared to the formal open microsurgical approach. With long term follow up, GK for cavernous meningiomas results in up to a 93.1% local control rate, with up to an 88% patient functional independence rate.

Being the only neurosurgical referral center in the province of Manitoba, has given us the ability to estimate yearly incidence and treatment rates on a population basis. Nineteen of 26 (73.1%) of patients treated were Manitoba residents. We have follow-up data on all of these patients. Analyzing our data from 2003 – 2011, this would indicate a yearly incidence and treatment rate of 2.4 per million population (approximate population of Manitoba over eight years since GK is ~1 million) in Manitoba.

Our experience so far demonstrates a good local control rate of 92.3%, with 34.6% tumour regression rate. This is comparable to those rates described in the literature. Furthermore, local control rate for SRS grade cavernous meningiomas I, II, and IV were 87.5%, 100%, 100%, and 80.0% respectively, thus demonstrating control rates higher than predicted by De Salles’ study, though our follow-up is ongoing and not as extensive as demonstrated by De Salles’ et al.

### Table 3: Stereotactic radiosurgery grade and local control rates in patients with follow-up

<table>
<thead>
<tr>
<th>SRS Grade</th>
<th>Number of Patients</th>
<th>% of Tumours Controlled</th>
<th>% of Tumours Regressed</th>
<th>Serious Complications (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>87.5</td>
<td>37.5</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>100</td>
<td>28.6</td>
<td>28.6</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>100</td>
<td>50.0</td>
<td>16.7</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>80.0</td>
<td>20.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

SRS = stereotactic radiosurgery grade. Serious complications were defined as those that resulted in permanent deficits for the patient.
In terms of greater than 24 month control, in those patients with minimum of 24 months follow-up, we achieved an 89.5% tumour stability/regression rate. Skeie et al.\textsuperscript{12} demonstrate a long term control rate of 84.0% in patients with an average of 82 months of follow-up. Lee et al.\textsuperscript{8} demonstrated a long term control rate of 93.1% at five and ten years for non-malignant meningiomas. Currently, the number of patients with greater than four years follow-up is small, and such extensive long term control conclusions cannot yet be made.

For those patients that demonstrated tumour growth despite GK, there weren’t any specific tumor or treatment features that would indicate why there was a failure of response. Dosing and volume of treatment were within literature standard and not out of concert with those patients of ours who had demonstrated success post-GK. One could postulate that these lesions were not WHO grade I meningiomas at the time of GK. This may explain their resistance to the dosage applied. However, without pathology at the time of GK, we will never know.

Overall, our complication rate was high, at 16 out of 26. Of note though, the majority of the complications recorded were minor and transient in nature (12 of the 16). Permanent complications affected 5 of 26 patients (19.2%). This is higher than most series published in the literature to date. These complications stem from tumour location in 3 of the 4, resulting in panhypopituitarism and two with trigeminal neuropathic pain. The fourth stemmed from a rare complication of stereotactic frame placement, leading to persistent occipital neuralgia.

With such an elevated complication rate, one may argue the 50% isodose line dosage should be decreased. However, the majority of the complications were transient in nature. The permanent complications are the ones of real concern. Future treatment of these lesions close to the pituitary will have to be considered, and optimization of the dose to the infundibulum may circumvent the endocrine dysfunction post-GK. In terms of the new cranial neuropathy post-GK, our dosing is within recommendations for skull base meningiomas, and further dose reduction in these areas would increase the risk of treatment failure, subjecting the patient to further repeat SRS treatment and the complications associated with that. Overall, our permanent complication rate is high, but within reason considering the morbidity associated with microsurgery and our high tumour control rates.

Upon further analysis of the new trigeminal neuropathic pain post GK, one patient had presenting complaints of trigeminal numbness. This raises the question as to whether pre-treatment trigeminal nerve complaints predispose to post-treatment complications of neuropathic pain. We had trigeminal nerve complaints in 13 patients, with two demonstrating improvement, and 8 indicating stable nature of their symptoms post treatment. Finally, given that only one of the two new post treatment neuropathic pain patients had presenting complaints of trigeminal dyesthesias, we cannot make definitive comments on the relationship of SRS and pre-treatment trigeminal nerve symptoms at this time.

Optic apparatus preservation rate post SRS was high in our series, with no patients demonstrating worsening visual function as a result of treatment. Of all patients treated, we had an average ON dose of 8.2Gy, considered well within the tolerance of the optic apparatus\textsuperscript{4,25}.

We did reduce dosing in areas close to the optic apparatus and brainstem, in order to minimize the risk of post-GK optic neuropathy and brainstem injury.

Good results with GK in the treatment of cavernous sinus meningiomas are attributable to the following factors. First, we modelled our treatment planning according to the pre-existing groundwork done in the area of SRS in the cavernous sinus, in order to minimize complications and maximize tumour control. Second, we used the cavernous sinus SRS feasibility studies by De Salle\textsuperscript{26}, and dose recommendations by Tishler\textsuperscript{27}, Leber\textsuperscript{4}, Chen\textsuperscript{28} and Kenai\textsuperscript{29}. This offered safe recommendations as to a maximum cavernous sinus dose of 30-40 Gy and optic apparatus dosing less than 8 Gy that we could follow. Third, the addition of the cavernous meningioma grading system designed for stereotoxic radiosurgery\textsuperscript{13}, gave us the ability to predict pre-treatment, the likelihood of local tumour control, and modify treatment planning respectively. Finally, vigilant attempts at maintaining tumour conformity during treatment planning and utilizing multiple collimator shots allowed us to target the meningioma volume effectively and to minimize radiation fall out to surrounding vital structures.

CONCLUSION

In our experience, GK SRS offers good local control rates with acceptable complication rates, comparable to those already defined in the literature. Given the centralization of neurosurgical services in Manitoba, this study has afforded us the ability to determine population based incidence and treatment rates for cavernous sinus meningiomas. Based on our provincial service, we expect 0.24 cases per 100,000 population per year. Ongoing management of cavernous sinus and parasellar meningiomas will continue to rely on SRS to provide local control with acceptable complication rates.

REFERENCES