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RESEARCH

Outcomes after gamma knife radiosurgery for intraventricular meningiomas

Alberto Daza-Ovalle[1,2] · Othman Bin-Alamer[1] · John Flickinger[1] · Ajay Niranjan[1] · L. Dade Lunsford[1]

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Abstract

Background Intraventricular meningiomas (IVMs) are rare tumors with considerable treatment-associated morbidity due to their challenging location. Treatment with stereotactic radiosurgery (SRS) is sparsely reported in the literature. We describe our experience over the last 35 years using Gamma knife radiosurgery (GKRS) for IVMs.

Methods We retrospectively reviewed the GKRS database identifying 2501 meningiomas treated at the University of Pittsburgh Medical Center over the last 35 years. Nineteen patients with (12 males, mean age = 53.2 years, range 14–84) 20 IVMs were identified. Headache was the most frequent presenting symptom (N = 12), and the trigone of the lateral ventricle was the most common location (N = 18). The median tumor volume was 4.8 cc (range, 0.8–17). The median margin dose was 14 Gy (range, 12–25) delivered at 50% isodose line.

Results At a median follow-up of 63.1 months (range, 6–322.4) symptom control was achieved in 18 (94.7%) patients. The overall progression-free survival (PFS) was 95% at 5 years, and 85% at 10-years. After Log-rank test, patients who underwent GKRS within 12 months after diagnosis (vs. ≥ 12 months, X^2: 4.455, p = 0.035), patients treated with primary GKRS without prior biopsy (vs. prior biopsy, X^2: 4.000, p = 0.046), and patients with WHO grade I meningioma (vs. WHO II, X^2: 9.000, p = 0.003) had a longer PFS. Imaging showed peritumoral edema in seven cases at a median of 10.5 (range, 6.13–24.3) months after GKRS. Only three of these patients were symptomatic and were successfully managed with oral medications. Cox´s regression revealed that a V12Gy ≥ 10 cc [HR: 10.09 (95% CI: 2.11–48.21), p = 0.004], and tumor volume ≥ 8 cc [HR: 5.87 (95% CI: 1.28–26.97), p = 0.023] were associated with a higher risk of peritumoral edema.

Conclusion GKRS is an effective and safe management option for intraventricular meningiomas. Early GKRS should be considered as a primary management modality for small and medium sized IVM and adjuvant management for residual IVMs.

Keyword Intraventricular meningiomas · Meningioma. Stereotactic radiosurgery · Gamma Knife radiosurgery · Edema · Adverse radiation effects

Abbreviations

IVMs	Intraventricular meningiomas
SRS	Stereotactic radiosurgery
GKRS	Gamma Knife radiosurgery
WHO	World Health Organization
V12Gy	Volume of normal brain tissue exposed to 12 Gy
CSF	Cerebrospinal fluid
STR	Subtotal resection
ARE	Adverse radiation effects
PFS	Progression-free survival

Introduction

Meningiomas are the most common benign intracranial tumor, representing 39.2% of all primary central nervous system tumors [1]. Arising from arachnoid cap cells within the choroid plexus, intraventricular meningiomas (IVMs) account for a small percentage (0.5–3%) of intracranial meningiomas, typically invading the atrium or trigone of the lateral ventricle, the third ventricle and the fourth ventricle in 80%, 15%, and 5% of the cases, respectively [2–7].

✉ Ajay Niranjan
niraax@upmc.edu

[1] Department of Neurological Surgery, University of Pittsburgh Medical Center, 200 Lothrop Street, Suite B-400, Pittsburgh, PA 15213, USA

[2] Neurosurgery Department, Center for Research and Training in Neurosurgery (CIEN), Samaritana University Hospital, Universidad del Rosario School of Medicine, Bogota, Colombia

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Cushing and Eisenhardt described five neurological symptoms associated with lateral ventricle tumors, including ipsilateral headache, contralateral macula splitting homonymous hemianopia, contralateral sensory and motor deficit, cerebellar signs, and dyslexia [8]. Patients with third and fourth ventricle meningiomas usually present earlier with more acute symptoms due to cerebrospinal fluid (CSF) pathways obstruction and subsequent non-communicating hydrocephalus [5]. Although imaging features of intraventricular tumors frequently overlap, the differential diagnosis is narrowed by lesion location, patient age, and recognition of prototypical features on CT and MRI [9–11]. Such features include their circumscribed nature, intense homogeneous contrast enhancement, brain T2 signal, and often calcification changes [9].

The management plan relies on several factors. Although recent evidence support radiosurgery (SRS) superiority over observation, conservative treatment can be considered for patients with asymptomatic tumors, smaller volume, and calcified lesions, especially in the context of advanced age or major surgical comorbidities [12–14]. Resection is associated with significant potential neurological morbidity, related to the tumor´s deep location and the need for transcortical approaches [15–17]. Stereotactic radiosurgery is a minimally invasive treatment strategy for IVMs but outcome reports are sparse [18–22]. We describe our cumulative 35-year experience using Gamma Knife radiosurgery (GKRS) for IVMs.

Methods and materials

All procedures performed in this study were under the institutional and national ethical standards. The Institutional Review Board approved this study at the University of Pittsburgh. From our database of more than 17,600 patients undergoing Gamma Knife radiosurgery at the University of Pittsburgh Medical Center Presbyterian Hospital, we retrospectively review the record of patients diagnosed with IVMs and treated with GKRS from 1987 to 2021.

Patients

All subjects provided informed consent for GKRS. Patients were required to have at least one available follow-up image to be included in this study. Nineteen patients with 20 tumors were included in the study. No patients were excluded. Patients underwent GKRS as primary management (for imaging defined, N = 10; or after initial biopsy, N = 4), or after initial resection (for residual tumor, N = 3; and for recurrent tumor, N = 3). After biopsy (N = 4) or initial resection (N = 6) the following histological diagnoses were obtained: WHO I (N = 9) or atypical WHO II meningioma (N = 1). No patients had histologically confirmed WHO grade III (anaplastic) meningiomas. Subtotal resection (STR) was achieved in all six patients who underwent prior surgery. GKRS was performed in these patients as early adjuvant treatment for residual tumors or as delayed salvage treatment after evidence of recurrence of prior dormant residual tumor. The median Karnofsky Performance Status Scale at the time of radiosurgery was 90% (range, 70–100%).

Radiosurgery protocol

GKRS was performed using models U, B, C, 4C, Perfexion, and ICON depending on the year of the procedure. A Leksell Model G stereotactic frame (Elekta AB, Stockholm, Sweden) was applied to the head using four-point fixation and intravenous conscious sedation supplemented by local anesthesia. A thin-slice volumetric contrast-enhanced MRI was obtained for target definition and treatment planning (Fig. 1A–B). GKRS treatment parameters included tumor volume, marginal dose, isodose line, number of isocenters, and volume of normal brain tissue exposed to ≥ 12 Gy (V12Gy). Tumor volume, marginal dose, number of isocenters, and V12Gy were dichotomized to explore their association with adverse radiation effects (AREs). Single-session GKRS was employed in all patients. The median time from the initial diagnosis to GKRS was 12 (range, 1–156) months. The median tumor volume was 4.8 cc (range, 0.8–17). The median margin dose delivered was 14 Gy (range, 12–25). The median isodose line used was 50% (range, 50–80). The median number of isocenters was 6.5 (range, 1–14). The median 12 Gy volume was 8.6 cc (range, 1.4–22.8). After radiosurgery, 40 mg of methylprednisolone was administered intravenously to all patients.

Clinical and neuroimaging follow-up

Clinical and neuroimaging follow-ups were performed at 6, 12, and 24 months and 2–3 years intervals thereafter, in order to assess symptom control, tumor response, and the incidence of adverse radiation effects (ARE). We defined clinical control as improved or unchanged symptoms after GKRS. Tumor volume increase > 20% from baseline was defined as progression, tumor volume shrinkage > 20% was defined as regression, and changes within ± 20% of the initial volume were considered unchanged. Patients with smaller or unchanged tumor volumes were recategorized as stable. Peritumoral edema following GKRS was defined as either worsening of preexisting edema or development of new peritumoral edema. The median follow-up was 63.1 months (range, 6–322.4).

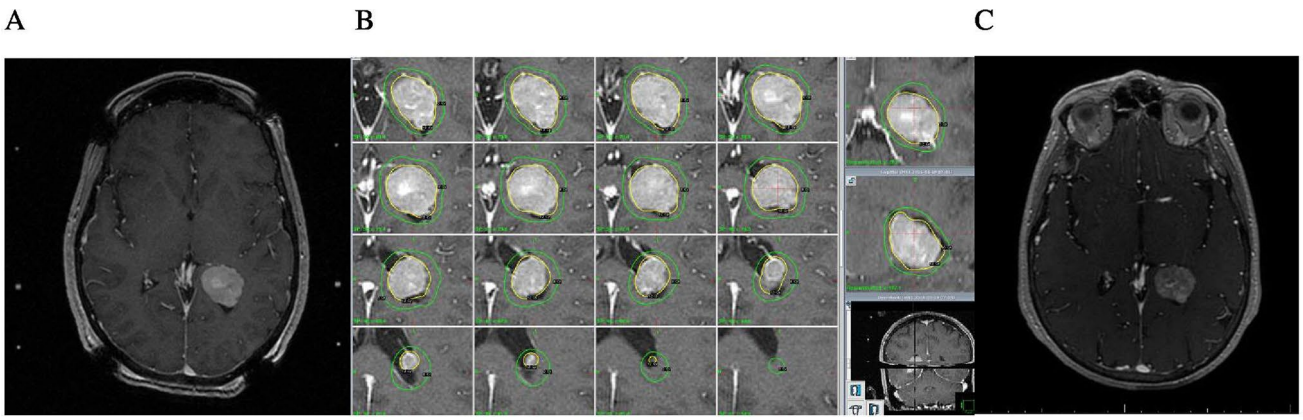

Fig. 1 A 67-yo female was diagnosed with an incidental left trigone IVM **(A)**. She underwent GKRS using a margin dose of 12 Gy. The axial poster with coronal and sagittal reformation of volumetric contrast-enhanced MRI shows radiosurgery dose plan with the 50% isodose (yellow line) line corresponding to 12 Gy marginal dose **(B)**. Follow-up MRI 48 months after GKRS shows a regressed and stable tumor without evidence of AREs **(C)**

Statistical analysis

IBM SPSS Statistics version 28.0 (IBM Corporation, Armonk, New York, USA) was used for analysis. Mean and median described continuous variables, and frequencies and percentages described categorical variables. The time from the initial diagnosis to GKRS was calculated from the date at which the first symptom was reported by symptomatic patients or from the date of the first imaging (CT or MRI) that confirmed an incidental IVM. The follow-up time was calculated from the date of GKRS to the last follow-up. The time until edema detection was calculated from the GKRS date to the imaging that confirmed a new or worsened peritumoral edema. Optimal cut-points for continuous predictors were identified using the area under the ROC curve. Time to events was plotted using the Kaplan–Meier method for survival. Log-rank test was applied to compare the progression-free survival (PFS) between groups. Cox´s proportional hazard regression model was used to explore factors correlated with peritumoral edema after GKRS. A p-value ≤ 0.05 was regarded as significant. The statistical analyses were performed using the number of lesions as a reference.

Results:

IVMs as a subset of our meningioma radiosurgery experience

We identified nineteen IVM patients, representing a total of 0.76% of our meningioma radiosurgical experience (2501 meningioma patients) during 35- years. The mean patient age was 53.2 years (range, 14–84), and 12 were male (Table 1). The most frequent clinical presentation was headaches in 12 patients, followed by incidental diagnosis (N = 2), motor neurologic deficit (N = 2), seizures (N = 2), and non-communicating hydrocephalus (in a patient with fourth ventricle meningioma) (N = 1). This patient required a ventriculoperitoneal shunt placement before GKRS. The most common location was the trigone of the lateral ventricle in 18/20 cases (N = 10, left trigone; N = 8, right trigone), posterior aspect of the third ventricle (N = 1) and fourth ventricle (N = 1). One patient had bilateral trigone meningiomas and two patients had multiple intracranial meningiomas. No patients were diagnosed with neurofibromatosis type 1 or 2.

Clinical outcomes

Symptomatic control was achieved in 18 (94.7%) patients after GKRS. Fourteen patients showed symptomatic improvement, whereas 4 patients remained unchanged. A single patient developed worsening of his right hemiparesis noted before radiosurgery. Of twelve patients with headache as an initial symptom, ten patients improved during the follow-up. Two patients with residual headaches required continued medical management. A single patient with a mild contralateral motor deficit benefitted from physical therapy and recovered normal function. Two patients with seizures were managed successfully with antiepileptic drugs (levetiracetam or phenytoin). One patient who underwent CSF shunting for obstructive hydrocephalus noted before GKRS remained clinically and radiographically stable. Two asymptomatic patients with an incidentally diagnosed meningioma remained asymptomatic after GKRS. At last follow-up, 18 of 19 patients were functionally independent. A single patient persisted with severe right hemiparesis despite CSF shunting to relieve temporal horn entrapment.

Table 1 Summary of characteristics of 19 patients with intraventricular meningiomas [20 tumors]

Patient characteristic	Value n (range)
Sex	
Female	7/19
Male	12/19
Age (yrs)	53.2 (14–84)
Clinical presentation	
Headaches	12/19
Incidental	2/19
Neurologic deficit	2/19
Seizures	2/19
Hydrocephalus	1/19
Number of IVMs	20
Location[a]	
Left trigone	10/20
Right trigone	8/20
Third ventricle	1/20
Fourth ventricle	1/20
Indication of GKRS[a]	
Primary	14/20
Residual	3/20
Recurrence	3/20
Diagnosis modality[a]	
Imaging criteria[a]	10/20
Histologic diagnosis[a]	10/20
WHO grade I	9/10
WHO grade II	1/10
WHO grade III	–
Radiosurgery parameters[a]	
Time from diagnosis to GKRS (months)[b]	12 (1–156)
Tumor volume (cc)[b]	4.8 (0.8–17)
Marginal dose (Gy)[b]	14 (12–25)
Isodose line (%)[b]	50 (50–80)
Number of isocenters[b]	6.5 (1–14)
V12Gy (cc)[b]	8.6 (1.4–22.8)
Adverse radiation effects[a]	
Peritumoral edema	7/20
Cystic degeneration	2/20
Follow-up (months)[b]	63.1 (6–322.4)

[a]Values are based on number of tumors; [b]Values reported as median

IVMs Intraventricular meningiomas, *GKRS* Gamma Knife radiosurgery, *WHO* World Health Organization, *V12Gy* volume of normal brain tissue exposed to 12 Gy

Tumor control

Ten IVM had tumor volume regression, while seven had no further growth (Fig. 1C). The overall actuarial PFS rates were 95% and 85% at 5- and 10 years, respectively Fig. 2A). The median PFS time was 63.1 months (range, 6–322.4). Tumor control was achieved in all female patients (vs. Male; Log-rank test, $p = 0.374$) (Table 2). GKRS within the first year from diagnosis or first symptom correlated with better tumor control (Log-rank test, $p = 0.035$) compared to later treatment (Table 2). Five and 10-years PFS rates were 100% and 92.9% after primary GKRS, 100% and 100% in GKRS for residual tumor after resection, and 66.6% and 33.3% for GKRS after the recurrent tumors (Log-rank test, $p = 0.154$) (Table 2 and Fig. 2B). The PFS for primary GKRS in patients with imaging defined IVM (no prior biopsy) was 100% at 5 and 10 years. The PFS for primary GKRS in patients after initial biopsy was 100%; and 75% at 5 and 10-years (Log-rank test, $p = 0.046$) (Table 2). There was no statistically significant difference in PFS between primary GKRS and adjuvant GKRS (for either, residual or recurrent tumor) (Log-rank test, $p = 0.322$) (Table 2). Nine patients had histology confirmed WHO grade I meningiomas which correlated with longer PFS (vs. WHO II, Log-rank test, $p = 0.003$) (Table 2). The actuarial PFS rates at 5 and 10-years were 100% and 77.8% for WHO grade I meningiomas.

Tumor progression after GKRS was identified in three (15%) IVMs during follow-up. Despite initial primary GKRS one patient required surgical resection because of sustained additional growth detected 73 months after GKRS. Pathological review confirmed a WHO grade I meningioma. Two patients had continued tumor progression despite salvage GKRS performed after initial resection. A single patient with a recurrent atypical meningioma (WHO II) had two resections prior to GKRS and subsequently had further external beam radiation therapy nine months after GKRS. This patient eventually died due to shunt failure. One additional patient underwent GKRS after two prior resections. Because of continued growth noted at 169 months this patient underwent a second radiosurgery at an outside institution.

Adverse radiation effects

Seven (35%) IVMs developed new or increased evidence of peritumoral edema (T2 demonstrated white matter changes). Only three of these patients were symptomatic. The median time from GKRS to edema detection was 10.5 (range, 6.13–24.3) months. Two patients were treated with a short course of steroids with headaches resolution. A third patient required additional treatment with vitamin E 400 IU b.i.d and pentoxifylline 400 mg b.i.d for three months and had complete resolution of his symptoms.

New or worsened peritumoral edema after GKRS was detected in 80% of patients with $V12Gy \geq 10$ cc, compared to 20% of patients with $V12Gy < 10$ cc [HR: 10.09 (95% CI: 2.11–48.21), $p = 0.004$) (Table 3). Larger tumor volumes correlated with a higher rate of peritumoral edema following GKRS. It was found in 21.4% of patients with

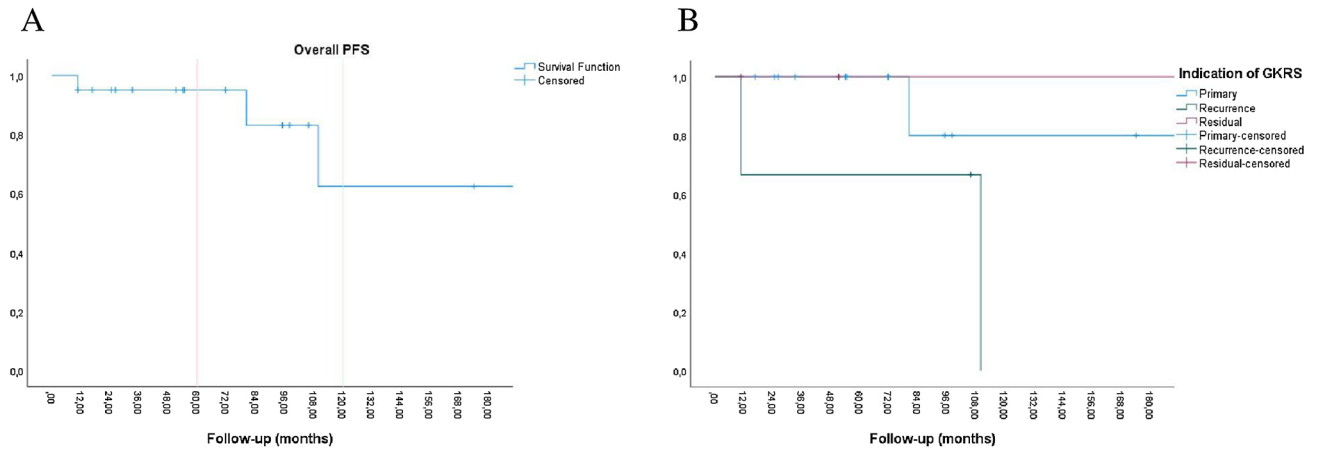

Fig. 2 **A** Kaplan–Meier survival curves showing an overall actuarial progression-free survival (PFS) rates of 95% and 85% at 5- and 10 years. **B** The actuarial 5- and 10-years PFS rates were 100% and 92.9% after primary GKRS, 100% and 100% in GKRS for residual tumor after resection, and 66.6% and 33.3% for GKRS after recurrence of prior resected tumor, respectively (Log-rank test, p = 0.154)

Table 2 Factors associated with longer progression-free survival after GKRS for IVMs

Variable	Univariate analysis	
	Log-rank test	
	X^2	p
Age (< 40 yrs vs. > 40 yrs)	0.004	0.948
Female vs. Male	0.789	0.374
Time from initial diagnosis to GKRS (< 12 months vs. ≥ 12 months)	4.455	0.035*
No prior biopsy vs. Prior biopsy	4.000	0.046*
WHO grade (I vs. II) [a]	9.000	0.003*
Indication of GKRS	3.741	0.154
1) Primary vs. Residual	0.200	0.655
2) Primary vs. Recurrent	2.538	0.111
3) Residual vs. Recurrent	2.000	0.157
4) Primary vs. Adjuvant [b]	0.980	0.322

[a]A single patient had a WHO grade II meningioma

[b]GKRS after prior resection for either, residual or recurrent tumor

*Significant at the level of p ≤ 0.05

GKRS Gamma Knife radiosurgery, *IVMs* intraventricular meningiomas, *WHO* World Health Organization

a target volume < 8 cc, while it was presented in 66.7% of patients with a target volume ≥ 8 cc [HR: 5.87 (95% CI: 1.28–26.97), p = 0.023] (Table 3). Brain edema before GKRS [HR: 4.47 (95% CI: 0.86–23.23), p = 0.075], higher marginal dose (≥ 15 Gy vs < 15 Gy) [HR: 1.77 (95% CI: 0.39–7.95), p = 0.459] and higher the number of isocenters (≥ 7 vs. < 7) [HR: 1.41 (95% CI: 0.32–6.32), p = 0.652], did not correlate with new or worsened post GKRS peritumoral edema (Table 3).

Table 3 Factors associated with higher risk of peritumoral edema after GKRS for IVMs

Variable	Univariate analysis		
	Cox´s proportional hazards model		
	HR	95% CI	p
Brain edema before GKRS (Yes vs. No)	4.47	0.86–23.23	0.075
Tumoral volume (≥ 8 cc vs. < 8 cc)	5.87	1.28–26.97	0.023*
Marginal dose (≥ 15 Gy vs. < 15 Gy)	1.77	0.39–7.95	0.459
Number of isocenters (≥ 7 vs. < 7)	1.41	0.32–6.32	0.652
V12Gy (≥ 10 cc vs. < 10 cc)	10.09	2.11–48.21	0.004*

*Significant at the level of p ≤ 0.05

GKRS Gamma Knife radiosurgery, *IVMs* intraventricular meningiomas, *V12Gy* volume of normal brain tissue exposed to ≥ 12 Gy

One patient (bilateral trigone intraventricular meningioma) developed asymptomatic subependymal region microcysts 5 years after GKRS. Another patient with a left trigone meningioma also developed asymptomatic peritumoral cyst formation at 7 years following GKRS. Both patients had tumor regression and unchanged cyst volume at the time of last follow-up.

Discussion

Several factors influence the treatment decision on IVMs, including but not limited to clinical presentation, age, comorbidities, tumor volume, and location. Observation with further imaging may be appropriate for incidentally detected IVMs, especially in the absence of calcification or

peritumoral edema [12, 23]. Interestingly in the IMPASSE study, Sheehan, et al., demonstrated that in patients with incidental meningiomas, early primary SRS was associated with improved outcomes compared to patients who had observation and delayed surgery [13, 14].

Surgical removal of larger volume IVMs can be challenging because of their vascularity, and because resection requires transcortical approaches [15]. Grujicic, et al. reported a gross total resection in 86.7%–100% patients with IVMs [15]. Despite surgery the reported recurrence rate is as high as 8.3% (range 0–13%) at a follow-up time of 3–5.8 years with a postoperative morbidity reported in 6%–25% of cases [3, 15–17]. Early morbidity defined as postoperative Glasgow outcome scale > 2 has been reported to be as high as 70% [15]. The craniotomy mortality rate is estimated between 2.4 and 4% (range from 0% to 8.3%) [3, 15–17].

Radiosurgery outcomes

One of the goals of radiosurgery is to improve existing symptoms and reduce the chances of new management related deficits. In the present study, symptoms control was achieved in 18/19 (94.7%) patients after single-session GKRS. A radiosurgery meningioma meta-analysis based on fifteen studies reported a 92.3% [95% CI: 88.4–95.6%] of overall symptom control [24]. The overall PFS in this study was 95% at 5 years, and 85% at 10 years (Fig. 2A). These results conform with the overall tumor control rate of 91% and actuarial rates of freedom from tumor progression of 87.7% at 10 years, and 87.2% at 20 years reported in a prior radiosurgery study with 290 patients with meningiomas who underwent GKRS [25]. In this study we did not find any difference in PFS between primary GKRS (with or without prior biopsy) and adjuvant GKRS (for either, residual or recurrent tumor) (Table 2 and Fig. 2B). All patients treated with primary GKRS without prior biopsy showed tumor control at last follow-up (vs. prior biopsy, Log-rank test, $p = 0.046$) (Table 2). These results are comparable to PFS of a Simpson Grade 1 resection [26].

In the present study, patients who underwent GKRS within 12 months after diagnosis had longer PFS ($p = 0.035$) (Table 2). A study with 238 patients focusing on the relationship between tumor control and the time interval between resection of a histologically confirmed WHO grade I meningioma and GKRS did not show statistical significance at 3, 6, 12 and 24 months ($p = 0.9$); however, neurological symptomatic improvement was more likely with early radiosurgery intervention ($p = 0.007$) [27]. A shortened interval between surgery and SRS improved PFS for atypical (WHO II) meningiomas ($HR = 0.99$, $p = 0.02$) in a multicenter study with 233 patients [28]. Patients with pathologically confirmed WHO grade I meningioma ($p = 0.003$) had a longer PFS (Table 2). In this experience, tumor progression after GKRS was identified in two patients after initial long-term tumor control (> 5 years), and in one patient with atypical (WHO II) meningioma within one year after GKRS. A multicenter study, evaluating outcomes after SRS for atypical (WHO II) and anaplastic meningiomas (WHO III) reported a 5-yr PFS of 33.6% [28]. These results highlight the importance of early adjuvant radiosurgery, especially for non-typical meningiomas.

In this study, peritumoral edema following GKRS was found in seven IVMs at a median of 10.5 (range, 6.13–24.3) months. Clinical symptoms were noted in only three cases and responded to non-surgical management. Cox´s regression revealed that a $V12Gy \geq 10$ cc was at tenfold higher risk of peritumoral edema ($p = 0.004$), and tumor volume ≥ 8 cc was a sixfold higher risk of peritumoral edema ($p = 0.023$) (Table 3). Tumor-brain contact interface area, preexisting peritumoral edema, larger tumors, convexity, and parasagittal location, and venous sinus invasion/compression are described as factors predicting post-radiosurgical edema [29–31]. However, the intraventricular location has not been previously linked with an increased risk of edema after GKRS for intracranial meningiomas. Additional studies are required to clarify this potential association.

Gamma knife radiosurgery has been progressively used to treat intracranial meningiomas in different locations including the skull base, tentorium, falx, and convexity. To date GKRS for IVMs has limited published experience. The literature review identified four cases series on IVMs treated with radiosurgery [19–22] (Table 4).

Kim, et al. reported nine patients with IVMs treated with GKRS [19]. The overall tumor control rate was 67% and there were no AREs after 64 months of follow-up [19]. Samanci, et al. reported outcomes of primary GKRS for five patients and adjuvant GKRS for one patient [22]. All patients had neurologic symptoms improvement and tumor regression after median follow-up of 71.5 months [22]. Nundkumar, et al. described two patients with extensive symptomatic peritumoral edema at 5- and 12 months after primary GKRS for IVMs [20]. These patients required surgical removal of IVMs due to progressive worsening of neurologic symptoms [20]. Mindermann, et al. reported four patients with transient peritumoral edema following primary GKRS for IVMs at a mean interval of 6.4 months [21]. Peritumoral edema regressed spontaneously in all patients after conservative management [21].

Limitations

This study has several limitations. The retrospective study design has an inherent bias. All patients were treated in a single institution. The small sample size hampers deep statistical analysis. Finally, only patients treated with radiosurgery

Table 4 Intraventricular meningiomas cases series summary[a]

Author	Kim et al. 2009 (21)	Nundkumar et al. 2013 (20)	Mindermann et al. 2020[d] [21]	Samanci et al. 2020 [22]	Current study et al. 2022 [f]
Cases n (M/F)	9 (6/3)	2 (0/2)	5 (0/5)-6 treatments [e]	6 (2/4)	19 (12/7)-20 IVMs
Age (years)	51 (14–81)	49.5 (49–50)	63 (50–81)	41.3 (30–71)	53.2 (14–84)
Clinical presentation	Headaches (3/9)	Headaches (2/2)	Visual field defect and gait disturbance (2/5)	Headaches (6/6)	Headaches (12/19)
			Nausea (2/5)		Incidental (2/19)
			Incidental (1/5)		Neurologic deficit (2/19)
					Seizures (2/19)
					Hydrocephalus (1/19)
Tumor location	Right trigone (5/9)	Left trigone (2/2)	Left trigone 4/5	Left trigone (4/6)	Left trigone (10/20)
	Left trigone (3/9)		Right trigone 1/5	Right trigone (2/6)	Right trigone (8/20)
	Midline (1/9)				Third ventricle (1/20)
					Fourth ventricle (1/20)
Histological diagnosis at GKRS	6/9	0	0	1/6	10/20
WHO grade I/II/III (n)	5; 1; 0	N/A	N/A	No data	9; 1; 0
NF 2	0	Not reported	Not reported	1/6	0
Indication of GKRS	Primary (5/9)	Primary (2/2)	Primary (5/5)	Primary (5/6)	Primary (14/20)
	Recurrence (3/9)			Residual (1/6)	Residual (3/20)
	Residual (1/9)				Recurrence (3/20)
Time from diagnosis to GKRS[b] (months)	No data	No data	No data	3 (1–6)[c]	12 (1–156)
Tumor volume[b] (cc)	3.9 (0.8–11.8)	3.3 (2.2–4.4)	4.7 (2.5–14.1)	5.5 (1.2–9.5)	4.8 (0.8–17)
Marginal dose[b] (Gy)	16 (14–25)	18	13.5 (12–15)	12 (11–13)	14 (12–25)
Isodose line[b] (%)	50	50	50	50 (40–60)	50 (50–80)
V12Gy[b] (cc)	No data	No data	No data	No data	8.6 (1.4–22.8)
Follow-up[b] (months)	64 (7–161) [c]	12.5 (8–17)	81.25 (19–240)	74.3 (24–139)	63.1 (6–322.4)
PFS[b] (months)	60 (7–161) [c]	12.5 (8–17)	81.25 (19–240)	74.3 (24–139)	63.1 (6–322.4)
Tumor control (%)	67%	100%	100%	100%	85%
Cystic degeneration	None	None	None	None	2/20
Post-GKRS edema	None	2/2	4/5	1/6	7/20
Time from GKRS to edema detection	N/A	8.5 months[c]	6 months[b]	3 months	10.5 (6.3–24.3)[b] months
Symptomatic post-GKRS edema	N/A	2/2	2/5	1/6	3/20
Additional treatment	N/A	Surgical resection after failure of steroids	Steroids	Steroids	Steroids in all three
					Vit E and pentoxifylline in one

[a]Case series with more than 1 case were included

[b]Values reported as median

[c]Values reported as mean

[d]Two cases treated with Cyberknife

[e]One of the patients underwent RS for the same IVM twice

[f]Values are based on number of lesions

GKRS Gamma Knife radiosurgery, *WHO* World Health Organization, *NF 2* Neurofibromatosis type 2, *V12Gy* volume of normal brain tissue exposed at least 12 Gy, *PFS* Progression-free survival

were included; thus, no conclusions for other treatment strategies may be drawn from our data.

Conclusion

GKRS is an effective alternative to surgery for patients with small and medium sized intraventricular meningiomas. Early primary or adjuvant GKRS is associated with high rate of long-term tumor control and low morbidity.

Author contributions Ajay Niranjan and L. Dade Lunsford designed the study. Material preparation, data collection and analysis were performed by Alberto Daza-Ovalle, and Othman Bin-Alamer. The first draft of the manuscript was written by Alberto Daza-Ovalle and all authors (Othman Bin-Alamer, John Flickinger, Ajay Niranjan, L. Dade Lunsford) commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The authors confirm the availability of data per reasonable requests.

Code availability Not applicable.

Declarations

Conflicts of interest Dr. Lunsford is a consultant for Insightec DSMB and has direct stock ownership in Elekta AB. The other authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Ethical approval Not applicable.

Consent to participate Not applicable.

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