JAVMA

AVMA

Characteristics and outcomes for 61 cats that underwent either surgery or stereotactic radiotherapy as treatment for intracranial meningioma (2005–2017)

Michelle Tichenor, DVM[1]; Kendra Hearon, VMD, DACVS[2*]; Laura E. Selmic, BVetMed, MPH, DACVS-SA, DECVS[3*]

[1]Animal Specialty Center, Yonkers, NY
[2]Metropolitan Veterinary Associates, Norristown, PA
[3]Department of Veterinary Clinical Sciences, The Ohio State University, Columbus, OH

*Corresponding authors: Dr. Hearon (khearon@metro-vet.com) and Dr. Selmic (selmic.1@osu.edu)

Received February 17, 2023
Accepted July 5, 2023

doi.org/10.2460/javma.23.02.0083

OBJECTIVE
To report clinical features and outcomes of cats undergoing either stereotactic radiotherapy (SRT) or surgical excision for the treatment of intracranial meningioma.

ANIMALS
61 client-owned cats.

METHODS
Medical records were retrospectively reviewed of cats with intracranial meningiomas that were treated with surgical removal and/or SRT between 2005 and 2017. Signalment, clinical signs, duration of clinical signs, diagnostic imaging reports, histopathology reports, treatment protocol, complications, recurrence or progression, and survival time were obtained from the medical record and through follow-up phone calls.

RESULTS
Of the 61 patients, 46 had surgery, 14 had SRT, and 1 had surgery followed by SRT for initial treatment. Significantly more cats that underwent surgery had peritreatment complications compared to the SRT group ($P < .0001$). Cats that received surgery initially had a significantly longer median survival time (MST) of 1,345 days compared to the MST of 339 days for the SRT cats ($P = .002$). Fourteen (30%) cats in the surgery group and 4 cats in the SRT group (28%) had MRI- or CT-confirmed tumor regrowth or new tumor growth ($P = 1.00$). Five cases that had SRT for subsequent recurrence had an MST of 700 days (range, 335 to 1,460 days) after the last treatment.

CLINICAL RELEVANCE
SRT proved to be a safe, alternative treatment option for feline patients with intracranial meningiomas; however, the survival times with surgery alone were significantly longer. SRT for the treatment of recurrence following initial surgery may show promising results.

Keywords: cats, surgery, stereotactic radiation therapy, treatment, intracranial

Primary brain tumors occur with a reported incidence of 2.2% in cats, and meningioma is the most reported primary brain tumor in cats,[1–6] accounting for 56% to 58% of all intracranial tumors.[1,7] Cats with meningiomas are significantly older than cats with other types of intracranial tumors,[1,8,9] and no sex predilection has been consistently demonstrated.

Feline meningiomas are considered benign, slow-growing, and mostly solitary tumors that are typically well circumscribed and delineated from the surrounding brain tissue.[10,11] Median survival times following surgical excision of meningiomas range from 693 to 1,125 days (22.8 to 37 months),[1,9,12,13] with a 2-year survival rate of 50%.[13] Due to these characteristics, the recommendations for treatment of intracranial meningiomas in cats is primarily surgery. However, surgery is not without risks and complications, and occasionally the location and size of the tumor, or patient comorbidities, may preclude surgery as a treatment option.[14] Morbidity associated with brain surgery can be quite high, and reported complications include hemorrhage, anemia, central blindness, acute renal failure, pneumocephalus, increased intracranial pressure, seizures, brain herniation, infections, and aspiration pneumonia.[10–13,15] An immediate postoperative mortality rate of 6% to 19% has been described in cats.[9,12,13] Recurrence following surgical excision ranges from 12% to 21.4%.[1,12,13] The median postoperative time to recurrence in 6 cats was noted to be 285 days (range, 123 to 683 days).[1]

Radiation therapy has become a mainstay of treatment for intracranial neoplasia in both humans and animals as both a primary and adjunctive treatment.[3] Stereotactic radiotherapy (SRT) delivers a curative dose of radiation from numerous different angles to focus the radiation while sparing the surrounding normal tissue from damage.[16] The large number of beams allows for highly conformal target treatment with a steep dose gradient, while the nonintersecting arcs minimize exposure of normal overlying tissue, allowing a larger single treatment dose and, therefore, a lower total dose to be applied. SRT involves fewer treatments, typically 1 to 3, called "fractions," with a larger amount of radiation applied at each administration as compared to the traditional or conventional RT, which typically involves multiple, smaller-dose fractions delivered 3 to 5 times weekly over 3 to 4 weeks.[17] Advantages of this noninvasive, single-dose to hypofractionated form of treatment of brain tumors in animals are that only a few episodes of general anesthesia are required and radiation exposure of normal brain tissue is substantially reduced, thereby avoiding complications associated with conventional RT.[18,19] The CyberKnife system is an RT device manufactured by Accuray Inc and is 1 type of SRT system that can facilitate SRT through a linear accelerator placed on a robotic arm, giving it many degrees of freedom. This freedom allows for increased accuracy in the delivered radiation to the area of interest and for the sparing of normal surrounding tissue. To our knowledge, no literature regarding SRT involving 1 to 3 high-dose fractions or the use of a CyberKnife system for the specific treatment of feline meningiomas is available and no prior studies have evaluated whether SRT alone significantly prolongs survival time. The purpose of this retrospective study was to report clinical features, outcomes, and survival times of cats undergoing either SRT or surgical excision for the treatment of intracranial meningioma.

Methods

Case selection criteria

Medical records of client-owned cats that underwent either surgical removal or SRT for the management of intracranial tumors consistent with meningioma between January 2005 and March 2017 were reviewed. Inclusion criteria for this study were cats with a presumptive or definitive diagnosis of meningioma based on either histopathology or highly suggestive features on advanced imaging (MRI or CT) that underwent surgical excision or SRT. Exclusion criteria were patients that had > 2 differential diagnoses, not including meningioma.

Medical record review—Information obtained from the medical records included age, sex, breed, duration of clinical signs, clinical signs present at initial examination, advanced imaging findings, treatment (surgery vs SRT), radiation protocol, peritreatment complications, histologic tumor type, survival time after diagnosis, time to recurrence, and subsequent treatment of recurrence. If date of death or follow-up was not available in the medical records, referring veterinarians and clients were contacted by telephone for additional information.

Diagnostics

All available imaging studies were initially reviewed by a board-certified radiologist or neurologist. Tumor location was classified into 3 groups on the basis of location in the brain: forebrain (cerebrum, olfactory lobes, and diencephalon), cerebellum, or brain stem (midbrain, medulla, pons, and cerebellomedullary angle). Multiple locations were noted when diagnosed, and the largest lesion was used for data calculations.

The histopathologic diagnosis was recorded from the available histopathology report or the medical records. Diagnosis of meningioma was considered presumptive if the CT or MRI characteristics were consistent with previously reported lesion characteristics.[1,3,11,20,21]

Treatment

Tumor removal surgery—Surgical techniques that have been used to remove feline and canine meningiomas have been previously detailed elsewhere.[15,22] All biopsies were collected intraoperatively.

Stereotactic radiotherapy—SRT performed at the Animal Specialty Center was with a CyberKnife Radiosurgery System (Accuray Inc). SRT consisted of either 1 or 3 daily fractions ranging from 800 to 3,000 cGy to equal 2,400 to 9,000 cGy total treatment dose.

Outcomes—Peritreatment complications were defined as complications occurring during surgery or during hospitalization following treatment. Posttreatment complications were defined as complications occurring after discharge from the hospital. Initial recurrence was defined as return of or new clinical signs consistent with the previous diagnosis and was confirmed via advanced imaging (CT or MRI).

Statistical analysis

Continuous data were described using median and IQR due to nonnormal distributions. Frequencies and percentages were used to describe categorical data. Associations between treatment used and categorical variables were assessed using Fisher exact tests. Kruskal-Wallis tests were used to test between differences in continuous variables on the basis of the treatment used. Kaplan-Meier methodology was used to draw survival curves for time to progression or recurrence and survival time **(Figure 1)**. Cats were censored in the time to recurrence or progression analysis if there was no documentation

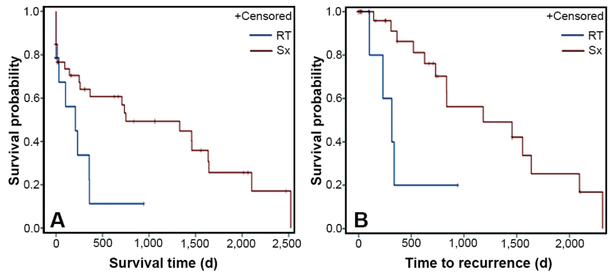

Figure 1—Kaplan-Meier curve to show survival probability (A) and recurrence probability (B) in 61 cats with cranial meningiomas by treatment type.

of progression or recurrence before data collection for study, loss to follow-up, or death. In the survival time analysis, cats were censored if alive at last follow-up or if lost to follow-up. Log rank tests were used to compare survival distributions between treatment groups.

Statistical significance was set at *P* = .05, and the statistical analysis was performed using a commercially available software package (SAS software version 9.4; SAS Institute Inc).

Results

Study population

Sixty-one cats met the criteria for inclusion in the study. Domestic shorthair was the most-represented breed with 48 (79%) cats, followed by 8 (13%) pure breeds, 3 (5%) mixed breeds, and 2 (3.2%) domestic longhairs. Pure breeds that were represented included Persian (n = 3), Maine Coon (3), Himalayan (1), and Norwegian Forest Cat (1). The median age at diagnosis was 11 years in the surgery group and 12.5 years in the SRT group (overall range, 5 to 18 years), and there were twice as many neutered males compared to spayed females in this population (20 spayed females and 41 neutered males). No significant difference in breed, age, or neuter status was found regarding treatment group.

Pretreatment evaluation

Of the 56 cats that had documented clinical signs prior to diagnosis, 73% (41/56) had behavior/mentation changes, 68% (38/56) cranial nerve deficits, 59% (33/56) gait abnormalities, 23% (13/56) seizures, and 18% (10/56) for other changes (ie, weight loss/decreased appetite, head shaking, decreased hearing, urination issues, nasal discharge, and collapsing episodes). Five patients did not have documented clinical signs in the available medical records. Twenty-eight of 56 (50%) cats presented with 3 or more of the clinical signs listed above while 6 (11%) were presented solely for seizures. Of the 38 cats that were found to have cranial nerve deficits, 26% (10/38) were found to have nystagmus; 5 cats had vertical nystagmus, 2 cats had downbeat nystagmus, and 2 cats had rotary nystagmus. Vision changes/loss were noted in 5 patients. The remainder of the cases with cranial nerve deficits were not elaborated on in the available medical records. The median duration of clinical signs was 28 days (range, 1 to 406 days) for the surgery group and 84 days (range, 13 to 730 days) for the SRT group (range, 1 day to 2 years). Thirteen (21%) cats did not have duration of clinical signs documented in their medical records. No significant difference was found between treatment groups related to duration of clinical signs (*P* = .08).

Sixty cats underwent MRI, and a single cat underwent CT imaging, with detailed imaging findings described in 55 of 61 (90%) cats. On the basis of accessible reports, 87% (48/55) were described as forebrain in location, 7% (4/55) were in the cerebellum, and 5% (3/55) were in the region of the brain stem **(Table 1)**. Lesion localization between the 2 groups nearly reached significance (*P* = .07), with the only 3 lesions located in the brain stem in the SRT group. A single cat in the SRT group and 5 cats in the surgery group were noted to have 2 or more masses located within the brain at the time of diagnosis (*P* = .680).

Treatment

Forty-six cats had surgical removal of the intracranial tumor initially, 14 had SRT initially, and 1 had

Table 1—Characteristics of study population of 61 cats with cranial meningiomas that underwent surgery or stereotactic radiotherapy (SRT).

		Treatment						
		SRT (n = 14)		Surgery (n = 46)		Surgery and RT (n = 1)		
Variable	**Category**	**n**	**%**	**n**	**%**	**n**	**%**	***P* value**
Lesion localization	Brain stem	3	21.4	-	-	-	-	.070
	Cerebellum	0	0.0	4.0	8.7	-	-	
	Forebrain	10	71.4	37.0	80.4	1.0	100.0	
	Not noted	1	7.1	5.0	10.9	-	-	
Peritreatment complications	Total	1	7.1	34	73.9	-	-	< .0001
	Anemia	-	-	25	54.4	-	-	.000
	Other	-	-	15	44.1	-	-	.010
Recurrence or progression		4	28.6	14	30.4	-	-	1.000
Time to recurrence	Median (95% CI)	315 (104–NC)	-	1183 (731–1,638)	-	-	-	.009
Survival outcome	Alive	5	35.7	21.0	45.7	-	-	.740
	Dead	9	64.3	25.0	54.4	1.0	100.0	
Survival time	Median (95% CI)	339 (102–339)	-	1345.0 (709–1,642)	-	1,903.0*		.0020

*Values represent 1 cat, not median.
NC = Not calculated.

surgery followed by SRT due to incomplete surgical removal. Of the 47 surgical cases, 55% (26/47) had craniotomy listed as the surgical approach, followed by a rostrotentorial approach in 38% (18/47), suboccipital approach in 4% (2/47), and transfrontal approach in a single case. Of the 14 cats treated with SRT initially, 10 cats received an average of 3,476 cGy (range, 2,400 to 9,000 cGY) over 3 treatment sessions/fractions. Four cases did not have the amount of cGY received documented, including the single case that had surgery (rostrotentorial approach) followed by a single fraction of SRT due to incomplete removal. The 3 cases with tumors in the brain stem location received SRT as primary treatment (Table 1). Histopathologic diagnosis of meningioma was provided in 98% of the 47 surgery cases. Twenty-five (53%) of the reports included subtypes. These subtypes included the following: psammomatous (11/25 [44%]), meningothelial (7/25 [28%]), transitional (4/25 [16%]), and fibroblastic/fibrous variant (3/25 [12%]).

Peritreatment complications

For the 46 initial surgical events, 34 (74%) had peritreatment complications; the most common was anemia (25/46 [54%]), followed by inappetence (n = 5), hypokalemia (4), cranial nerve deficits (3), hyperthermia (3), ataxia (2), hyperglycemia (2), and seizures (2). The degree of anemia ranged from 13% to 28%, and none were noted to have received treatment in the available medical records. The specific cranial nerve deficits in the 3 initial surgical events cases were not specified. Two cats required a second surgical procedure during the peritreatment period due to cerebral/cerebellar herniation and hemorrhage, both of which recovered without further issues. One cat developed seizures in the immediate postoperative period and arrested. Of the 15 total cats treated with SRT, the only immediate complication was hyperthermia and tachypnea in the same cat, both of which resolved. Significantly more cats that underwent surgery had peritreatment complications compared to the SRT group ($P < .0001$; Table 1).

Outcome

At the time of data collection, 54% (n = 25) of cats in the surgery group and 64% (9) of the SRT group were either euthanized or had died ($P = .740$) with a median survival time (MST) of 1,345 days (range, 708 to 1,642 days) and 339 days (range, 102 to 339 days), respectively ($P = .02$). Of the surgery group, 11 (44%) cats were euthanized or died due to recurrence or continuance of neurologic signs, 11 cats did not have a reason for death noted, and 3 cats died due to other reasons (ie, old age, weight loss, and hyporexia). Of the cats that died or were euthanized due to neurologic abnormalities, 6 had seizures (one of which expired in the peritreatment period), 1 was noted to be hiding and going into corners inappropriately, 1 was noted to be weak and ataxic, and 1 was noted to have the same clinical signs (behavior change) as prior to treatment. One cat was noted to have neurologic deterioration and was found to have pancreatic carcinoma with pulmonary metastasis and subsequently euthanized.

Death in the SRT group (9 cases) was attributed to neurologic signs in 4 (44%) cats, 4 cats did not have a reason for death noted, and 1 for other reasons (hiding and anorexia). Of the cats that died or were euthanized due to neurologic abnormalities, 1 cat had progressive neurologic signs and was euthanized after a new brain tumor was noted on MRI, 1 cat was euthanized after presenting obtunded/minimally responsive (suspect regrowth; no diagnostics/imaging were performed at that time), 1 cat died after a subtle personality change was noted, and the final cat became nonambulatory roughly 107 days following initial SRT treatment and never regained the ability to walk.

Fourteen (30%) cats in the surgery group and 4 (28%) cats in the SRT group had MRI- or CT-confirmed tumor regrowth or new tumor growth ($P = 1.00$; **Tables 2 and 3**). The median time to progression was 1,183 days (range, 731 to 1,638 days) in the surgery group and 315 days (range, 104 to censored) in the SRT group ($P = .009$). Two (14%) cases in the SRT group and 10 (22%) cases in the surgery group had additional treatment for recurrence. Following initial recurrence, 6 cats had a second surgery, 3 cases that had surgery initially had SRT, 1 cat received no treatment, 1 had surgery initially followed by conventional RT (18 treatments), and 1 had a second round of SRT.

Fourteen (30%) cats that received surgery as the initial treatment had evidence of recurrence based on MRI findings (Table 3). Six cases in the initial surgery group had documented meningioma recur-

Table 2—Summary of characteristics of 4 cases with documented recurrence following SRT as initial treatment for intracranial meningioma.

Case No.	Age	Sex	Breed	Location	Clinical signs	Treatment	No. of recurrences	Time to recurrence	Tx for recurrence	Outcome
11	12	MN	DSH	Forebrain	Behavior change, vision loss	RT (3 treatment)	1	8 mo	None	Deceased, 1 mo
15	14	FS	DSH	Forebrain	Mentation, gait changes, CN deficits	RT (3 treatments)	1	10 mo	RT (3 treatments)	Euthanized, 12 mo
43	15	FS	DSH	Forebrain	Behavior, gait changes, CN deficits	RT (1 treatment)	1	13 mo	None	Euthanized, 13 mo
59	12	MN	DSH	Brain stem	Gait change, CN deficits	RT (3 treatments)	1	5 mo	Added in Lomustine	Deceased, lost to follow-up

CN = Cranial nerve. DSH = Domestic shorthair. FS = Female spayed. MN = Male neutered. RT = Radiation therapy. Tx = Treatment.

Table 3—Summary of characteristics of the 14 cases with documented recurrence of meningioma following surgery as initial treatment for intracranial meningioma.

Case No.	Age	Sex	Breed	Location	Clinical signs	Subtype	No. of recurrences	Time to recurrence	Tx for recurrence	Outcome
13	7	MN	Maine Coon	Forebrain	Behavior, gait changes, CN deficits	MT	1	72 mo	Craniotomy	Alive
17	10	MN	DSH	Forebrain	Behavior, gait changes, CN deficits, other	PS	1	37 mo	Craniotomy	Alive
20	8	MN	DSH	Forebrain	Seizures	N/A	2	36 mo; 12 mo	RT (18 tx); RT (3 tx)	Euthanized due to other disease, 11 mo later
30	12	MN	DSH	N/A	Behavior change	N/A	1	12 mo	RT (3 tx)	Died, 48 mo late, neurologic signs noted
31	15	MN	DSH	Forebrain	Seizures	PS	1	9 mo	None noted	Lost to follow-up
35	10	FS	DSH	Forebrain	N/A	N/A	2	53 mo; 65 mo	Craniotomy; meds	Lost to follow-up
36	12	MN	DSH	Forebrain	Behavior changes, CN deficits	N/A	1	5 mo	Meds	Died, 25 mo, no neurologic signs noted
38	12	MN	DSH	Forebrain	Mentation changes	PS	3	12 mo; 24 mo; 24 mo	Craniotomy; craniotomy; RT (3 tx)	Lost to follow-up
41	9	MN	DLH	Forebrain	Behavior, gait changes, CN deficits	FB	1	48 mo	RT	Euthanized due to recurrence of neurologic signs, 22 mo later
46	10	FS	DSH	Forebrain	Behavior, gait change	N/A	2	10 mo; 12 mo	Craniotomy; meds	Lost to follow-up
49	15	MN	Persian	Forebrain	N/A	N/A	1	21 mo	Meds	Lost to follow-up
58	14	MN	DSH	Forebrain	Mentation, gait change, CN deficits	PS	2	1 mo; 17 mo	RT (1 tx); RT (3 tx)	Lost to follow-up
60	13	FS	DSH	N/A	Behavior change	N/A	2	5 wk; 39 mo	Craniotomy; RT (3 tx)	Euthanized due to seizures, respiratory distress, 16 mo later
61	8	FS	DSH	Cerebellar	N/A	N/A	1	60 mo	RT (3 tx)	Euthanized, not for neurologic signs, 20 mo later

DLH = Domestic longhair. FB = Fibroblastic/fibrous variant. MT = Meningothelial. N/A = Not applicable. PS = Psammomatous. Tx = Treatment. ***See*** Table 2 for remainder of key.

rence a second time and received either SRT (n = 4) or medications (2) including dexamethasone, phenobarbital, and Palladia as treatment. Three cases, again all in the initial surgery group, had presumptive recurrence of meningioma based on abnormal neurologic signs but did not receive advanced imaging to confirm recurrence. A single case (Table 3; case 38) had 3 surgeries and a final SRT treatment to treat the tumor and its recurrence. This case was eventually lost to follow-up roughly 2,700 days (7.5 years) after the last treatment.

In the SRT group, 4 (26.6%) cats that received SRT initially had evidence of recurrence on repeat imaging with a median time to recurrence of 315 days (Table 2). Case 11 had recurrence after progressive neurologic signs were noted 243 days post–initial treatment and was noted to be deceased 1 month later with no additional treatment. Case 15 had regrowth noted on MRI after 304 days, had SRT again (3 treatments), and was euthanized 1 year later due to behavioral changes. Case 43 had evidence of recurrence 395 days later and was euthanized with no additional treatment. Case 59 had evidence of regrowth on MRI 152 days post–initial treatment and after adding in lomustine the patient was lost to follow-up. The MST for the 5 of 7 cases that had RT for subsequent recurrence following either surgery or SRT initially was 700 days (range, 335 to 1,461 days) after the last treatment, with 2 cases lost to follow-up.

Five (36%) cats in the SRT group and 21 (46%) in the surgery group were counted as alive at the time of data collection. Of these cases, 19 (73%) were lost to follow-up, 15 of the surgery group and 4 of the SRT group. Six cats that underwent surgery initially were noted to be alive and doing well at the time of data collection, whereas a single cat that received SRT initially was noted to be alive and doing well.

Discussion

Historically, curative-intent RT treatments have been utilized in the treatment of both feline and canine intracranial tumors.[3,6,10,11,17,18,23–26] However, there is a paucity of literature on feline patients diagnosed with intracranial meningiomas treated with SRT. In a 2003 paper by Troxel et al,[1] a total of 4 cats underwent RT for treatment of presumed intracranial meningiomas; however, the radiation protocol was only specified for 1 cat that received 3 doses weekly of 400 cGY for a total dose of 48 Gy. This cat survived 240 days and was euthanized for an unrelated neoplasm.[1] Sessums and Mariani[10] reported treating 2 cats with MRI-diagnosed cerebral meningiomas using a linear accelerator–based SRT unit; however, the case series is unpublished and data cannot be gathered from this review. Eleven client-owned cats with MRI-diagnosed pituitary tumors were treated with modified linear accelerator–based radiosurgery receiving 1 to 3 treatments.[19] Improvement in clinical signs was noted in 63.6% of treated cats, and there were no confirmed acute or late adverse radiation effects.[19] In the largest and most recent study evaluating the outcome of cats with intracranial tumors treated with RT, 21 cats were treated with various definitive-intent daily fractionated protocols, from 3 to 20 fractions.[6] The single case that received 3 fractions was diagnosed with a choroid plexus tumor and was censored at 588 days post-treatment.[6] Eleven cats were diagnosed with meningioma and received anywhere from 10 to 20 fractions of between 40 and 45 Gy (total dose), with an average overall survival time of 315 days (range, 50 to 963 days).[6] Three cats were alive at the time of data evaluation (overall survival range, 121 to 225 days), 1 cat was reirradiated resulting in an additional progression-free interval of 223 days, and 3 cats died from tumor- or treatment-related causes.[6]

In this paper, we reported the outcome of either surgery or SRT for the treatment of intracranial meningiomas in a subset of feline patients. As previously noted, the MST for surgically treated intracranial meningiomas in cats is 693 to 1,125 days (22.8 to 37 months)[1,9,12,13] with a 2-year survival rate of 50%[13] in the literature. In this study, cats that had initial surgery were found to have an MST of 1,345 days, which is equivalent to 44 months. Median survival time for cats in the SRT group was 339 days, equivalent to 11 months. The difference in MST between the surgery group and the SRT group did reach statistical significance ($P = .002$; Figure 1). The MST for the SRT group is below the documented MST for surgical treatment; however, it is close to the value noted in the single case that received 3 fractions of SRT and lived for 240 days described by Troxel.[1] Historically, RT has been utilized in lesions not easily accessible by surgical approaches in human and veterinary medicine. No known literature is available that evaluates the relationship between the intracranial location of feline meningiomas and prognosis and rate of recurrence; however, in a 2009 paper by Klopp et al[30] discussing endoscopic-assisted meningioma removal in dogs, the MST for dogs with forebrain meningiomas was significantly longer when compared with the dogs with caudal brain/brain stem meningiomas ($P = .05$). In that paper, the MST for forebrain meningiomas was 2,104 days compared with 702 days for caudal brain meningiomas.[27] Forterre et al[15] found that for tumors in less-accessible locations, such as tentorially located meningiomas, survival time was found to decrease to 19 months (578 days) postoperatively in feline patients. Lesion localization between the 2 groups in the current paper nearly reached significance ($P = .07$; Table 1) with the only 3 lesions located in the brain stem in the SRT group. Location of the tumor may have contributed to the lower MST found in the SRT group.

A single cat in the SRT group and 5 cats in the surgery group were noted to have 2 or more masses located within the brain at the time of diagnosis. In addition to single meningioma, there is also a high incidence of multiple meningiomas in cats noted in the literature.[28] In a 2003 paper[1] retrospectively reviewing feline intracranial neoplasms, 17.2% were found to have multiple meningiomas at the time of diagnosis. A 2007 paper[28] evaluating multiple meningiomas in cats that underwent surgery suggests that the postoperative outcome does not seem to be influenced by the number of meningiomas present. This paper evaluated only 4 cats, all of which had surgery to remove the masses, and they all were administered hydroxyurea postoperatively in an attempt to diminish tumor regrowth.[28] While the number of cases diagnosed with multiple tumors in this paper was low, the effect this finding had on the outcome of both treatment groups was not explicitly evaluated and therefore cannot be disregarded. Significantly more cats in the surgery group had peritreatment complications compared to the SRT group ($P < .0001$). The most common peritreatment complication in the surgery group was anemia (54%), and 1 case developed seizures following surgery and arrested. A paper[13] that evaluated 42 cats that underwent surgery for their intracranial meningiomas reported 31% of cases were anemic postoperatively (range, 10% to 25%) and 19% died or were euthanized in the immediate postoperative period. Intracranial hemorrhage can be significant during surgery and can continue after recovery from anesthesia, thus leading to anemia. Due to the retrospective nature of the current study, specifics relating to intraoperative hemorrhage and technique for hemostasis were not consistently documented. Whereas the available literature reports a 6% to 19% mortality rate in the immediate postoperative period, this paper only had a single perioperative death. Much of the available information regarding surgical treatment for feline intracranial meningiomas is from studies performed decades ago. Perhaps the risk of mortality with surgery may be lower than originally reported now that newer surgical approaches and improved technique have been utilized. The most recent paper[9] discussing surgical treatment in 121 cats reported an immediate postoperative mortality rate of 6%. A single cat in the SRT group was noted to have peritreatment complications, which included hyperthermia and tachypnea, both of which resolved. In this study, SRT treatment, delivered by the CyberKnife system, required anywhere from 1 to 3 anesthetic events compared to the single event for surgery. According to a 2007 paper by Bley et al,[29] repeated propofol-associated anesthesia does not lead to clinically relevant hematologic changes or adverse events in cats undergoing short-duration radiotherapy.

Four (28.6%) cats in the SRT group and 14 (30.4%) cats in the surgery group had CT- or MRI-confirmed recurrence following initial surgery. According to the literature, a 14% to 21.4% recurrence rate has been noted for surgical treatment[1,12,13] and the 1 case that received SRT for an intracranial meningioma did not have documented recurrence.[1] Lack of repeat advanced imaging to confirm tumor growth in previous reports may have contributed to a lower than actual tumor recurrence in cats with intracranial meningioma. To the authors' knowledge, the recurrence rate following initial SRT treatment for feline intracranial meningioma is not available. The median time to recurrence for cats receiving surgery as the primary treatment was 1,183 days compared to 315 days in the SRT treatment group ($P = .009$; Figure 1). The MST for the 5 of 7 cases that had SRT for subsequent recurrence was 700 days (range, 335 to 1,461 days; 11 to 48 months) after the last treatment, with 2 cases lost to follow-up. We were unable to compare the significance of overall survival times of patients that had SRT as an adjuvant treatment for recurrence of meningioma. This lack of significance could be a result of a type 2 error given the small patient population.

This study had several limitations. A definitive histologic diagnosis was obtained in all of the surgically treated cases; however, a presumptive diagnosis was made in the cats treated with SRT. The accuracy of advanced imaging, using CT or MRI, for diagnosis of primary brain tumors in cats, however, has been long established. In a 2004 study by Troxel et al,[20] MRI features of feline intracranial neoplasia were retrospectively reviewed and 96% of tumors were correctly identified as meningioma on the basis of MRI characteristics alone. MRI is the imaging modality of choice for the detection of brain tumors in humans and allows for superior resolution of intracranial lesions compared to CT.[30] Six cats were noted to have multiple tumors: 5 in the surgery group and 1 in the SRT group. The effect of multiple tumors on patients included in the study was not investigated; therefore, the influence in the overall clinical picture and survival cannot be elucidated. Additional limitations of this study include its retrospective nature, small case numbers (only 15 patients underwent SRT initially), and lack of follow-up imaging for all patients to determine the impact of SRT on the size of the tumor, determine the progression-free interval, and rule out the possibility of development of secondary delayed radiation effects.

In summary, SRT proved to be a safe, alternative treatment for feline patients with intracranial meningiomas that may have reasons to not undergo surgery, such as nonresectable tumors, comorbidities making surgery not an ideal option, or owners who decline surgery. While the MST for the surgery group was significantly longer, at 1,345 days (44 months), the SRT group lived for almost a year, at 339 days (11 months) post-treatment. Due to the low numbers that received SRT for subsequent recurrence, the evaluation of prolonged survival time and benefit was not able to be determined. Future studies with larger case populations evaluating cats with meningiomas treated with SRT alone, as an adjuvant to surgery, or as a treatment for recurrence would be needed to better highlight where SRT might be the most beneficial in the treatment of intracranial meningiomas in cats.

Acknowledgments

None reported.

Disclosures

The authors have nothing to disclose. No AI-assisted technologies were used in the generation of this manuscript.

Funding

The authors have nothing to disclose.

References

1. Troxel MT, Vite CH, Van Winkle TJ, et al. Feline intracranial neoplasia: retrospective review of 160 cases (1985–2001). *J Vet Intern Med*. 2003;17(6):850–859.
2. Tomek A, Cizinauskas S, Doherr M, Gandini G, Jaggy A. Intracranial neoplasia in 61 cats: localisation, tumour types and seizure patterns. *J Feline Med Surg*. 2006;8(4):243–253. doi:10.1016/j.jfms.2006.01.005
3. Dickinson PJ. Advances in diagnostic and treatment modalities for intracranial tumors. *J Vet Intern Med*. 2014;28(4):1165–1185. doi:10.1111/jvim.12370
4. Oakley RE, Patterson JS. Tumors of the central and peripheral nervous system. In: Slatter D, ed. *Textbook of Small Animal Surgery*. Elsevier Science; 2003:2405–2425.
5. Ijiri A, Yoshiki K, Tsuboi S, Shimazaki H, Akiyoshi H, Nakade T. Surgical resection of twenty-three cases of brain meningioma. *J Vet Med Sci*. 2014;76(3):331–338. doi:10.1292/jvms.12-0373
6. Körner M, Roos M, Meier VS, et al. Radiation therapy for intracranial tumours in cats with neurological signs. *J Feline Med Surg*. 2019;21(8):765–771. doi:10.1177/1098612X18801032
7. Zaki FA, Hurvitz AI. Spontaneous neoplasms of the central nervous system of the cat. *J Small Anim Pract*. 1976;17(12):773–782. doi:10.1111/j.1748-5827.1976.tb06943.x
8. Nafe LA. Meningiomas in cats: a retrospective clinical study of 36 cases. *J Am Vet Med Assoc*. 1979;174(11):1224–1227.
9. Cameron S, Rishniw M, Miller AD, Sturges B, Dewey CW. Characteristics and survival of 121 cats undergoing excision of intracranial meningiomas (1994–2011). *Vet Surg*. 2015;44(6):772–776. doi:10.1111/vsu.12340
10. Sessums K, Mariani C. Intracranial meningioma in dogs and cats: a comparative review. *Compend Contin Educ Vet*. 2009;31(7):330–339.
11. Motta L, Mandara MT, Skerritt GC. Canine and feline intracranial meningiomas: an updated review. *Vet J*. 2012;192(2):153–165. doi:10.1016/j.tvjl.2011.10.008
12. Gallagher JG, Berg J, Knowles KE, Williams LL, Bronson RT. Prognosis after surgical excision of cerebral meningiomas in cats: 17 cases (1986–1992). *J Am Vet Med Assoc*. 1993;203(10):1437–1440.
13. Gordon LE, Thacher C, Matthiesen DT, Joseph RJ. Results of craniotomy for the treatment of cerebral meningioma in 42 cats. *Vet Surg*. 1994;23(2):94–100. doi:10.1111/j.1532-950x.1994.tb00452.x
14. Griffin LR, Nolan MW, Selmic LE, Randall E, Custis J, LaRue S. Stereotactic radiation therapy for treatment of canine intracranial meningiomas. *Vet Comp Oncol*. 2016;14(4):e158–e170. doi:10.1111/vco.12129
15. Forterre F, Fritsch G, Kaiser S, Matiasek K, Brunnberg L. Surgical approach for tentorial meningiomas in cats: a review of six cases. *J Feline Med Surg*. 2006;8(4):227–233. doi:10.1016/j.jfms.2006.01.002
16. Bloomfield R. Stereotactic radiation therapy in veterinary medicine. *Can Vet J*. 2015;56(1):95–97.
17. Mariani CL, Schubert TA, House RA, et al. Frameless stereotactic radiosurgery for the treatment of primary intracranial tumours in dogs. *Vet Comp Oncol*. 2015;13(4):409–423. doi:10.1111/vco.12056
18. Lester NV, Hopkins AL, Bova FJ, et al. Radiosurgery using a stereotactic headframe system for irradiation of brain tumors in dogs. *J Am Vet Med Assoc*. 2001;219(11):1562–1567, 1550. doi:10.2460/javma.2001.219.1562
19. Sellon RK, Fidel J, Houston R, Gavin PR. Linear-accelerator-based modified radiosurgical treatment of pituitary tumors in cats: 11 cases (1997–2008). *J Vet Intern Med*. 2009;23(5):1038–1044. doi:10.1111/j.1939-1676.2009.0350.x
20. Troxel MT, Vite CH, Massicotte C, et al. Magnetic resonance imaging features of feline intracranial neoplasia: retrospective analysis of 46 cats. *J Vet Intern Med*. 2004;18(2):176–189. doi:10.1892/0891-6640(2004)18<176:mrifof>2.0.co;2
21. Graham JP, Newell SM, Voges AK, Roberts GD, Harrison JM. The dural tail sign in the diagnosis of meningiomas. *Vet Radiol Ultrasound*. 1998;39(4):297–302. doi:10.1111/j.1740-8261.1998.tb01609.x
22. Forterre F, Jaggy A, Rohrbach H, Dickomeit M, Konar M.

Modified temporal approach for a rostro-temporal basal meningioma in a cat. *J Feline Med Surg*. 2009;11(6):510–513. doi:10.1016/j.jfms.2008.11.002
23. Keyerleber MA, McEntee MC, Farrelly J, Thompson MS, Scrivani PV, Dewey CW. Three-dimensional conformal radiation therapy alone or in combination with surgery for treatment of canine intracranial meningiomas. *Vet Comp Oncol*. 2015;13(4):385–397. doi:10.1111/vco.12054
24. Axlund TW, McGlasson ML, Smith AN. Surgery alone or in combination with radiation therapy for treatment of intracranial meningiomas in dogs: 31 cases (1989–2002). *J Am Vet Med Assoc*. 2002;221(11):1597–1600. doi:10.2460/javma.2002.221.1597
25. Brearley MJ, Jeffery ND, Phillips SM, Dennis R. Hypofractionated radiation therapy of brain masses in dogs: a retrospective analysis of survival of 83 cases (1991–1996). *J Vet Intern Med*. 1999;13(5):408–412.
26. Bregazzi VS, LaRue SM, McNiel E, et al. Treatment with a combination of doxorubicin, surgery, and radiation versus surgery and radiation alone for cats with vaccine-associated sarcomas: 25 cases (1995–2000). *J Am Vet Med Assoc*. 2001;218(4):547–550. doi:10.2460/javma.2001.218.547
27. Klopp LS, Rao S. Endoscopic-assisted intracranial tumor removal in dogs and cats: long-term outcome of 39 cases. *J Vet Intern Med*. 2009;23(1):108–115. doi:10.1111/j.1939-1676.2008.0234.x
28. Forterre F, Tomek A, Konar M, Vandevelde M, Howard J, Jaggy A. Multiple meningiomas: clinical, radiological, surgical, and pathological findings with outcome in four cats. *J Feline Med Surg*. 2007;9(1):36–43. doi:10.1016/j.jfms.2006.07.001
29. Bley CR, Roos M, Price J, et al. Clinical assessment of repeated propofol-associated anesthesia in cats. *J Am Vet Med Assoc*. 2007;231(9):1347–1353. doi:10.2460/javma.231.9.1347
30. Grossman RI, Yousem DM. *Neuroradiology: The Requisites.* Mosby-Year Book; 1994:67–103.