

## Radiosurgery using the Cyberknife for benign spinal tumors: Korea Cancer Center Hospital experience

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**Abstract** This study evaluated clinical outcome and safety of radiosurgery using the Cyberknife for treatment of benign spinal tumors. The authors treated 30 benign spinal tumors in 20 patients with the Cyberknife (Accuray, Inc., Sunnyvale, CA, USA) from 2002 to 2008. Among these there were 20 neurogenic tumors, eight hemangioblastomas, and two meningiomas. Four patients with neurofibromatosis (NF) type 2 and four patients with Von Hippel Lindau disease were also included. Radiosurgery was done as primary treatment for 22 lesions, for postoperative residual tumor control for four lesions, and for the remaining four lesions with image-based progression after initial subtotal resection. The distribution of lesions was cervical (18 tumors), thoracic (six), and cauda equina level (six). Follow-up data included imaging studies, clinical findings, and radiotherapy data. Tumor volume ranged from 0.04 to 33.65 cm<sup>3</sup> (mean, 4.52 cm<sup>3</sup>). A 14–33 Gy marginal dose was delivered in 1–5 fractions. The mean follow-up period was 35.6 months (range, 12–84 months). On follow-up, most lesions decreased in size (57%) or remained unchanged (33%). Two lesions initially decreased, then increased later. One lesion increased without response. With regard to clinical aspects, radicular

pain and myelopathic pain improved after radiosurgery in most cases (94%). Motor weakness recovered in two out of five patients and recovery of sensory change occurred in four out of ten patients. In two patients, symptoms were aggravated by tumor enlargement and the occurrence of new lesion. Mean spinal cord volumes receiving more than 10 and 8 Gy were  $0.40 \pm 0.4$  and  $0.81 \pm 0.7$  cm<sup>3</sup>, respectively. Stereotactic radiosurgery (SRS) using the Cyberknife showed the ability to control benign spinal tumors without complication in most cases.

**Keywords** Benign spinal tumor · Cyberknife · Radiosurgery

### Introduction

The first trial of spinal radiosurgery using the Cyberknife was performed in 1996 at Stanford University Medical Center [1]. Since then, many studies on radiosurgery for primary and metastatic vertebral column tumors have been reported by several authors [1–4]. Their results were indicative of both radiological control and clinical improvement after radiosurgery, and confirmed the safety and feasibility of radiosurgery for vertebral column tumors. Recent technical advances in radiosurgery have made it possible to try epidural decompression in selected cases. The application extent of the spinal radiosurgery is being widened to intradural extramedullary lesions, intramedullary lesions, and peripheral lesions [5–11].

Although there is much evidence supporting the use of radiosurgery for malignant spinal tumors, there is still controversy regarding the clinical effectiveness of radiosurgery in benign spinal tumors. Use of stereotactic radiosurgery (SRS) for treatment of intracranial benign

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tumors is well established. Kondziolka et al. recently reported that the long-term tumor control rate for 85 benign intracranial tumor patients treated with SRS at the University of Pittsburgh was 93%, with 53% of lesions decreasing in size [12]. Especially in vestibular schwannomas, the ten-year control rate reaches 95–98% with 73% size reduction [13].

Promising results have been obtained in several trials of radiosurgery with the Cyberknife for benign spinal extramedullary and intramedullary lesions [5, 6, 14–16]. A phase I feasibility study on Cyberknife radiosurgery for benign spinal tumors was performed in Stanford University Cyberknife Center [4]. Of 16 spinal lesions, ten intradural lesions were included. There were no procedure-related complications or disease progression in a minimum six-month follow-up period. Gerszten et al. treated 15 cases of spinal benign tumors including two cases of chordoma and reported no tumor progression on 12 months follow-up [2, 17] (Table 1).

Although the technical advance of image-guided radiosurgery has enabled high radiation to be delivered to lesions adjacent to the spinal cord, radiation myelopathy cannot be completely avoided. A few cases of spinal cord injury associated with radiosurgery have been reported, but we do not know the correct radiation tolerance limit of the spinal cord [18]. We have some experience of radiosurgical treatment using the Cyberknife for benign spinal tumors and report treatment results with data on spinal cord radiation tolerance.

## Patients and methods

We performed 290 spinal radiosurgical procedures with the Cyberknife from July, 2002 to December, 2008. Among these, 30 lesions of benign spinal tumors (10.3%) were included. These 30 tumors occurred in 20 patients, seven of which had multiple tumors. Age distribution was from 15 to 82 years with a mean of 45.2 years. Female patients (13) outnumbered male patients (7). For 22 lesions, radiosurgery was chosen as a primary treatment without any precedent procedures. For the remaining eight lesions, surgery was the initial treatment. After the operation, radiosurgery was performed as postoperative adjuvant therapy for four lesions and for control of regrowing tumor on follow-up for four lesions. For one lesion, conventional irradiation was performed after the operation. Lesion location was cervical (18 lesions), thoracic (six), and cauda equina (six). Eight lesions were intramedullary and 22 were extramedullary. Pathologic classification was schwannoma (five lesions), neurogenic tumor without prior biopsy (15), hemangioblastoma (eight), and meningioma (two). Among the 15 neurogenic tumors with no biopsy, ten lesions were associated with NF. However, the pathologic identities of the lesions in the NF patients could be neurofibroma or schwannoma. Pain was the most frequent symptom (53%) either as radicular or myelopathic pain. Moreover, sensory loss (ten lesions, 33%), motor weakness (five lesions, 17%), and bladder symptom (one lesion) were detected (Table 2). Systemic work up revealed 11 asymptomatic

**Table 1** Results from radiosurgery for benign spinal tumors, with references

Authors, year	No of cases/location	Tumor volume (ml)	Marginal radiation dose (Gy)	Mean follow up (mo)/outcome
Ryu SI, 2001	10/intramedullary and extramedullary	NM	11–25	6 mo/no progression
Gerszten PC, 2003	15>IDEM	0.3–29.3 (m; 6.4)	12–20	12 mo/no progression
Ryu SI, 2003	10/intramedullary	NM	18–25	12 mo/three regressed, seven stable
Dodd L, 2006	55>IDEM	0.136–24.6	16–30	36 mo/61% stable, 39% decreased. One case of RM
Gerszten PC, 2008	73>IDEM	0.3–93.4	15–25 (Dmax)	37 mo/all controlled, three cases of RM
Sahgal A, 2007	19 benign tumors (including four chordoma)	0.2–274	10–30 (m; 21)	25 mo/three progressed, three regressed, 13 no change
Cheshier SH, 2007	25 benign tumors	0.08–14.5 (m; 3.8)	16–30 (m; 19)	NM about benign tumors only
Murovic JA, 2009	17 benign PNST	1.36–16.9	16–24 (1–3 fx)	Eleven tumors decreased
Moss JM, 2009	16 HBL	NM	20–25 (m; 21)	33.5 mo/3 year control rate 92%
Chang UK, 2010	30 benign spinal tumors including HBL	0.04–33.5 (m; 4.52)	14–33	35.6 mo/control rate 86%

No number, NM not mentioned, IDEM intradural extramedullary, mo months, m mean, PNST peripheral nerve sheath tumors, HBL hemangioblastomas, RM radiation myelopathy

**Table 2** Change of clinical symptoms at pretreatment and posttreatment

Symptoms	Number of patients at pretreatment	Number of patients at posttreatment
Radicular pain	12	11 improved
Myelopathic pain	4	4 improved
Posterior column sign	2	1 improved
Motor weakness	4 due to cord compression 1 due to root compression	1 improved 1 improved
Sensory change	10	4 recovered
Asymptomatic	11	11

spinal lesions in both cerebral hemangioblastoma patients and neurofibromatosis patients.

Radiosurgery was performed as described for a previously published series. After diagnosis was made with MRI, fiducial markers were inserted around the posterior lamina of the region of interest. All patients were treated in a supine position using either a noninvasive molded Aquaplast face mask or other suitable immobilization device which was used during computed tomography (CT) imaging and treatment. CT scans were acquired using 2-mm thick slices to include the region of interest. However, in one case of recurrent meningioma at the T8–9 level, the normal CT image did not delineate the tumor margin, so CT myelography was performed (Fig. 1). CT myelography is more accurate for spinal cord delineation than MRI, particularly in the presence of ferromagnetic artifacts in heavily pretreated patients or in patients with severe spinal compression [19].

Characteristics of the Cyberknife system and treatment procedures have been explained in detail by previous authors. For analysis of spinal cord radiation dose, exposed spinal cord volume was measured beginning just cephalad to and ending just caudal to the target lesion and a dose–volume histogram was produced. Patients were followed up every 6 months with CT or MRI images. Neurologic status was also evaluated.

## Results

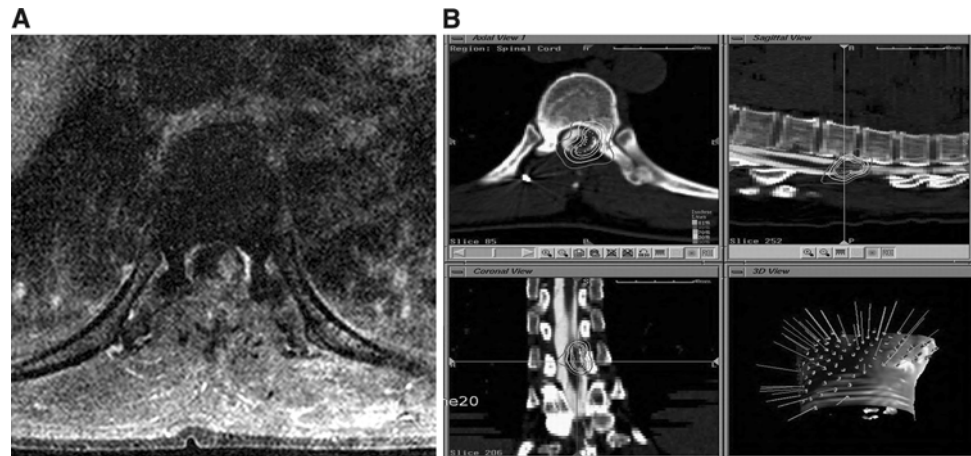
Lesion volume ranged from 0.04 to 33.65 cm<sup>3</sup> with a mean of 4.52 cm<sup>3</sup>. A marginal dose of 14–33 Gy was delivered in 1–5 fractions. A three-fraction schedule was usually preformed. A five-fraction schedule was planned in cases of high probability of spinal cord radiation injury, a single session was considered when the lesion volume was less than 1 cm<sup>3</sup>. When each radiation dose was converted to single equivalent dose ( $\alpha/\beta = 10$ ), they ranged from 13 to

23 Gy. Delivered radiation dose did not differ with regard to lesion volume. Coverage index ranged from 86.9 to 99.8% with a mean of 96.5%. The mean follow-up period was 35.6 months (range, 12–84 months). In the hemangioblastoma group, the lesion volume ranged from 0.038 to 0.71 cm<sup>3</sup>, with a mean of 0.25 cm<sup>3</sup>, which is much smaller than that of the total group (4.52 cm<sup>3</sup>). The delivered radiation dose in the hemangioblastoma group was similar to that in the total group. The volume of exposed spinal cord during radiosurgery ranged from 0.28 to 9.1 cm<sup>3</sup> with a mean of 1.88 cm<sup>3</sup>. Maximum point dose delivered to the spinal cord was 14.5 ± 3.3 Gy. Spinal cord volume receiving more than 10 Gy as single equivalent dose was from 0.02 to 1.7 cm<sup>3</sup> with a mean of 0.40 cm<sup>3</sup>. Spinal cord volume receiving more than 8 Gy was a mean of 0.81 ± 0.7 cm<sup>3</sup>.

The change in tumor size was observed on follow-up images for 20 tumors. For 17 tumors (57%), the size decreased and was maintained. For two tumors (7%), the size decreased at first, but increased later. One lesion increased with no response to treatment. For ten tumors (33%), no change in size was detected. Internal necrosis was observed for 12 of the 20 neurogenic tumors from 3 to 9 months after radiosurgery. In the hemangioblastoma group, six out of eight tumors showed size reduction after treatment.

With regard to clinical aspects, most patients showed stable or improved condition. For 16 lesions with radiating pain or myelopathic pain, symptoms improved for 15 lesions (94%). Pain mostly disappeared 1–2 weeks after radiosurgery. When pain severity was evaluated with a visual analog score (VAS), pretreatment mean VAS was 4.7. At last follow-up, mean VAS was 2.5. Motor weakness observed in five patients was caused by spinal cord compression for four lesions and by root compression for one lesion. Motor recovery was observed for two of these five patients; one patient with root compression lesion and the other patient with cord compression lesion. Pretreatment motor function was grade 4+ and improved to grade 5 after treatment. Four out of ten patients with sensory loss showed improvement after treatment (Table 2). Although symptom improvement was noted in all patients with tumor reduction, it was observed in some cases with unchanged tumor size. For example, for one case of a C5 neurogenic tumor, right arm pain improved after radiosurgery and early follow-up image showed mass shrinkage. Follow-up MRI at 27 months revealed a slight increase of mass size, however clinical deterioration did not occur. Symptom aggravation was seen for two patients only. One patient, an NF type 2, had three intradural extramedullary tumors successfully treated at C2, T8, and L2 levels. Follow-up image confirmed mass size reduction and clinical symptoms improved. However, 18 months later, a new mass was

**Fig. 1** A case of recurrent meningioma at the T8–9 level. **a** Pretreatment MRI (gadolinium-enhanced axial view) shows enhancing mass on left posterolateral side of spinal cord. **b** Treatment planning figure; after myelography, subarachnoid space is seen as white color and tumor mass as a space-occupying lesion on the left side of spinal canal. Delivered marginal dose of radiation was 24 Gy in three fractions



detected at the T4 level, resulting in motor weakness. Surgical resection was performed and his paraparesis recovered. For the second patient, postoperative residual schwannoma at the C4 level was treated with radiosurgery. Twenty-four months after radiosurgery, she experienced pain aggravation and follow-up MRI showed tumor recurrence.

#### A case demonstration of hemangioblastoma

A 26-year-old female patient presented with gait disturbance. She had already undergone craniotomy because of a brain tumor, which was histologically proven to be hemangioblastoma. Her spine MRI showed three well-circumscribed masses at the C1, C7, and T11 levels with surrounding syringomyelia. The lesion volumes were 0.034, 0.038 and 0.549 cm<sup>3</sup>, respectively. A radiation dose of 33 Gy was delivered to the C1 mass in five fractions, 26.7 Gy to the C7 mass in three fractions, and 31 Gy to the T11 mass in five fractions. These values correspond to single session of 19, 18, and 18 Gy, respectively. Follow-up MRI 15 months after radiosurgery showed mass shrinkage at C1 and T11 and partial resolution of syringomyelia. Along with mass shrinkage, gait disturbance improved. Three years later the C7 mass also decreased in size (Fig. 2).

#### A failed radiosurgery case

This was a 34-year-old female patient whose initial MRI showed well enhanced intradural and extradural mass at the C4 level. Initially, operative resection was done for the intradural portion. The biopsy result was schwannoma. Therefore, radiosurgery was applied for the extradural mass with a marginal dose of 27 Gy in five fractions. During the follow-up period, right arm pain improved and internal necrosis was seen in the extradural mass. However, two years later, myelopathic symptoms recurred and

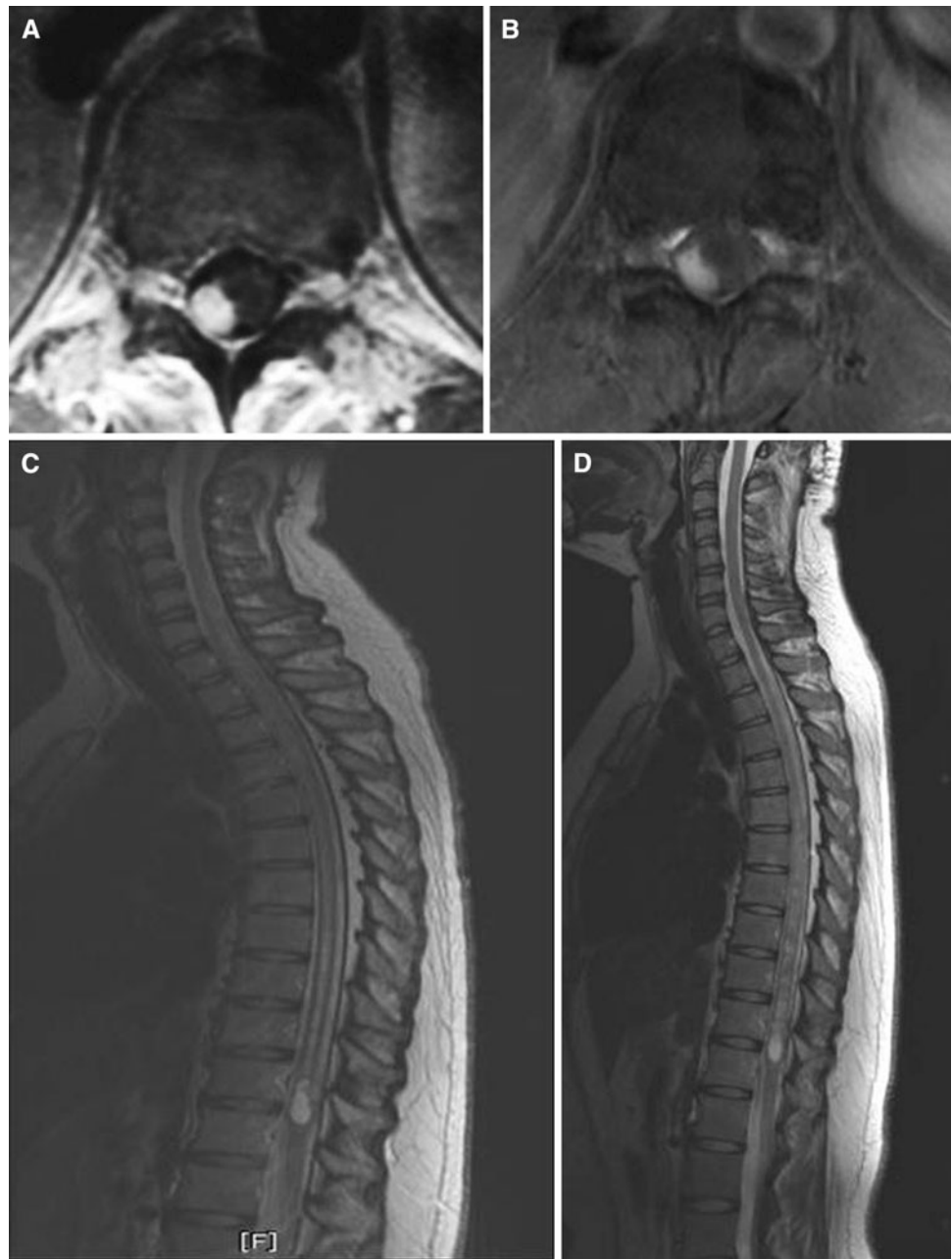
follow-up MRI showed recurred mass in the spinal canal, which was regarded as marginal recurrence (Fig. 3). Reoperation was performed for recurrent intradural mass. Interface between spinal cord and tumor mass was well maintained. Complete excision of the recurrent intradural mass was feasible as the mass could be readily dissected. Myelopathic symptoms disappeared thereafter.

#### Discussion

Our results showed that the overall tumor control rate was approximately 90% for 30 lesions of benign spinal tumors. Of the 30 lesions, two lesions showed enlargement 12 and 24 months after radiosurgery. Nearly half (40%) of the irradiated tumors showed internal necrosis at 6 months follow-up with mass shrinkage at a later date. In the series of Murovic et al., who reported results from radiosurgery of 17 benign foraminal peripheral nerve sheath tumors, central necrosis was observed in 47% of all the lesions, and mass shrinkage was seen in 67%. Tumor mass decrease was more evident in schwannoma (80%) than in neurofibroma (43%) [8].

Clinical safety, and early evidence of the efficacy of spinal radiosurgery for treatment of intradural extramedullary tumors has been validated by two large-scale investigations [5, 6] (Table 3). Dodd, et al. reported their radiosurgery results for 55 benign intradural extramedullary lesions treated with radiation doses ranging from 18.7 to 20.3 Gy. With 36 months follow-up, 61% of lesions showed no change in size and 31% showed decreased appearance. Another large series was reported by Gerszten et al. in which 73 cases of intradural extramedullary tumor patients were treated with single-session radiosurgery [6]. At 37 months follow-up all lesions were reported to be radiologically controlled irrespective of tumor histology. In a report by Saghal et al., 19 benign tumors were evaluated after radiosurgery with 25 months of follow-up. No change

**Fig. 2** A case of hemangioblastoma. **a** Pretreatment gadolinium (Gd)-enhanced axial MRI, at the T11 level; a well enhanced mass is seen on right posterolateral spinal cord. **b** Follow-up MRI Gd-enhanced axial view at the T11 level; enhanced mass size decreased. **c** Pretreatment T2 weighted image sagittal MRI; extensive syrinx is seen from the lower cervical level to the conus level. **d** Follow-up MRI T2 weighted sagittal view; extent of syrinx cavity decreased

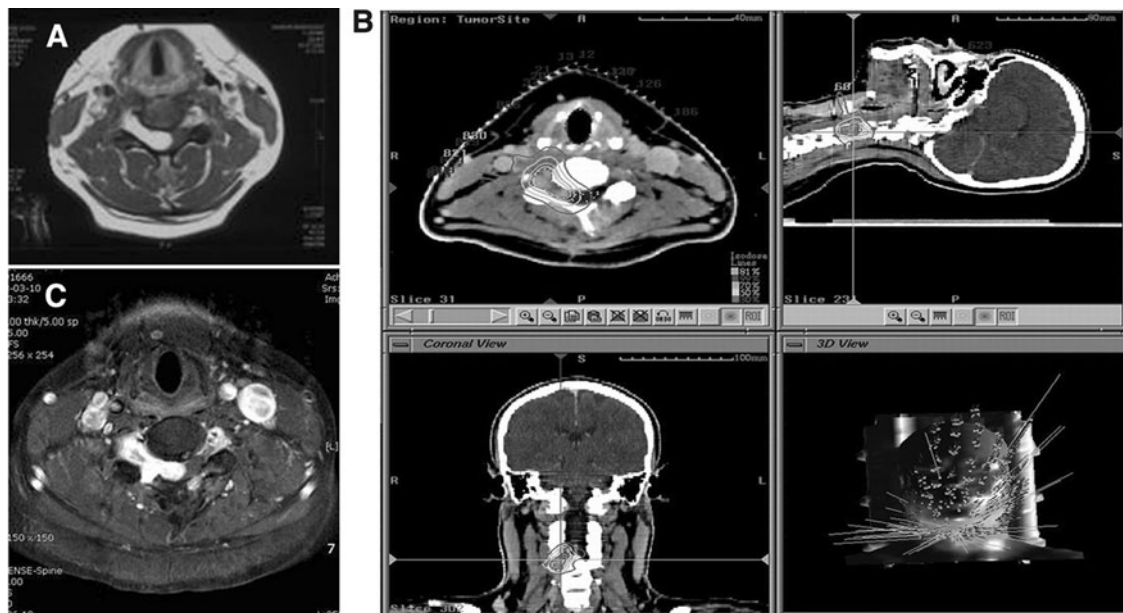


in tumor size was noted in 13 cases, regression in three, and progression in three. Progressed cases were two neurofibromas and one hemangioblastoma [10].

In most treated cases, radicular or myelopathic pain improved after radiosurgery. The exact pathophysiological mechanisms of pain relief after irradiation of spinal tumors remain poorly understood. Patients with schwannomas do better than those with neurofibromas with regard to improvement of presenting symptoms. According to Dodd et al., presenting symptoms improved in one-third of schwannoma patients, but rarely improved in neurofibroma patients. In neurofibroma, symptoms may worsen after radiosurgery even though tumor size is not changed, which

can be related to their infiltrating nature. In general, radicular pain responds well to radiosurgical treatment, but myelopathic weakness is known not to improve with radiosurgical ablation, which was consistent with our result.

In planning spinal radiosurgery, radiation dose depends on the proximity of the lesion to the spinal cord. For intracranial meningiomas and nerve sheath tumors, it is widely accepted that an effective single radiation dose ranges from 12 to 18 Gy depending on the size of the lesion [12]. The spinal cord is known to be able to tolerate up to 14 Gy of radiation in a single session. But when the volume factor is considered, the correct limit of volume



**Fig. 3** A failed radiosurgery case. **a** Preoperative MRI Gd-enhanced axial view; at the C4 level, a well circumscribed enhanced mass is seen on right side of spinal cord. **b** Cyberknife treatment planning scheme. A marginal dose of 27 Gy in five fractions was delivered to

the extradural portion after resection of the intradural mass. **c** Two years later, follow-up MRI shows recurrence of intradural portion of tumor mass. In extradural portion, necrosis is seen in the mass

**Table 3** Radiosurgery results according to pathology of spinal cord or nerve sheath tumors

Pathology	Author (number of cases)	Follow up (mo)	Clinical outcome	Radiological outcome	Radiation dose/fraction
Schwannoma	Dodd (30)	26	1/3 improved 18% worse	56% stable 40% decrease 4% increase	18.7/2
	Gerszten (35)		32/35 improved or stable 3/35 worse	No increase	22.3 (Dmax)/single
	Murovic (10 PNST)	29	6/10 improved 3/10 stable 1/10 worse	8/10 decrease 1/10 stable 1/10 increase	23.8 (Dmax)
Meningioma	Dodd (16)	27	70% improved or stable 30% worse	67% stable 33% decrease	20.3/2
	Gerzsten (13)	14		All controlled	21.2 (Dmax)/single
Neurofibroma	Dodd (9)	19.9	50% stable 50% worse	6/7 stable	19.8/2
	Gerszten (25)		8/13 pain improved, 2 myelopathy improved Others; stable	All controlled	21.3 (Dmax)/single
	Murovic (7 PNST)	20	3 improved 2 stable 2 worse	3 decrease 1 stable 3 increase	25.07 (Dmax)

mo months, *Dmax* maximum radiation dose, *PNST* peripheral nerve sheath tumor

range in which the spinal cord resists 14 Gy of radiation has not been determined. When reported cases of radiation myelopathy produced in the course of spinal cord radiosurgery were reviewed, specific risk factors could not be

found. For the safe performance of radiosurgery for spinal lesions, it is recommended that the spinal cord volume receiving a radiation dose over 10 Gy (single session) should be less than 10% of exposed spinal cord volume

**Table 4** Summary of radiation myelopathy cases in benign spinal tumors which had Cyberknife radiosurgery

Age/sex (Ref.)	Tumor type	Location	Onset (mo)	Volume	RS dose/fx	Maximum spinal cord dose (Gy)	Maximum spinal cord BED <sub>3</sub> (Gy)	Volume of spinal cord > BED <sub>3</sub> (8 Gy) (cm <sup>3</sup> )
29/F [5]	mng	C7-T2	9	7.6	24/3	29.9	129.2	4.0
61/F [9]	sch	C6	12	4.5	20/1	8.5	32.6	0.1
25/M [9]	nf	C7	5	1.2	20/1	10	43.3	0.2
NM [9]	sch	Cervical	13	6.4	20/1	NM	NM	<0.2

mo months, RS radiosurgery, fx fractions, BED biological equivalent dose, NM not mentioned, Ref. reference, mng meningioma, sch schwannoma, nf neurofibroma

**Table 5** Summary of hemangioblastoma treatments

Age/sex	Location	Lesion volume (mm <sup>3</sup> )	Radiation dose (Gy)/fraction	Follow-up (months)	Image result	Clinical result
33/F	C2	357	33/5	72	Shrinkage	Asymptomatic
24/F	C1	34	33/5	64	Shrinkage	Asymptomatic
	C7	38	26/3	51	Shrinkage	Asymptomatic
	T11	549	31/5	57	Shrinkage	Gait improved
27/M	C1	81	23 (single)	48	Stable	Asymptomatic
22/F	C7	83	13 (single)	23	Shrinkage	Asymptomatic
	T10	173	24/3	23	Shrinkage	Stable
26/F	C1	706	23 (single)	61	Increased	Asymptomatic

[20]. However, analysis of our data shows that relatively larger amount of radiation had been delivered to a significant volume of spinal cord adjacent to tumor mass. From our data, the mean exposed spinal cord volume was 1.88 cm<sup>3</sup> and the mean spinal cord volume irradiated with over 10 Gy (single session,  $\alpha/\beta = 3$ ) was 0.4 cm<sup>3</sup>. Volume percent of exposed spinal cord irradiated over 10 Gy was 32.4%. This value is three times larger than that recommended by Ryu et al.. Based on this value, we decided during radiosurgery planning that spinal cord volume irradiated over 10 Gy should be less than 0.4 cm<sup>3</sup>.

The radiation tolerance of the spinal cord in spinal SRS is unknown, because of the scarcity of reported radiation myelopathy after radiosurgery (Table 4). Various spinal cord constraints exist. For example, the spinal cord limit for RTOG 0631 (spinal SBRT trial), from Ryu et al., is a V10 (volume of spinal cord receiving more than 10 Gy) of 10% of spinal cord volume defined as 6 mm above and below the radiosurgery target [20]. The trials of Yamada and Chang limit the spinal cord maximum dose (Dmax) to 14 and 10 Gy, respectively [21, 22]. RTOG 0618 (lung cancer SBRT trial) limits the cord to 18 Gy in three fractions (single fraction biologically effective dose of 11.3 Gy, by the LQ model,  $\alpha/\beta$  of 3). The radiation tolerance dose of the spinal cord which is applied in the performance of conventional radiotherapy is vague and variable. When combined analysis was performed on published data on the probability of myelopathy according

to radiation dose, the median tolerance dose of the cervical cord was estimated to be 69.4 Gy (95% confidence interval, 66.4–72.6). At 45 Gy, the probability of myelopathy is 0.03%; and at 50 Gy, 0.2%. The dose for 5% myelopathy is 59.3 Gy [23]. Nieder et al. investigated published data on human spinal cord re-irradiation tolerance [24]. They evaluated risk scores based on three variables; cumulative biological equivalent dose (BED), highest BED of all treatment series in a particular individual, and interval between two treatment courses. The risk of radiation myelopathy seems small when cumulative BED is less than 135.5 Gy<sub>2</sub>, the interval is not shorter than 6 months, and the dose of each course is <98 Gy<sub>2</sub>. The cumulative BED for which no case of radiation myelopathy has yet been reported is 120 Gy<sub>2</sub>. In the study by Sahgal et al. of SRS after conventional radiation therapy for spinal metastasis patients, median value of spinal cord volume irradiated over 8 Gy ranged from 0 to 28 cm<sup>3</sup> (mean, 0.3 cm<sup>3</sup>) for 22 patients [25]. At 10 months of follow-up (1–48 months) no myelopathy was reported.

Few reports are available about radiosurgical trials on spinal hemangioblastomas [9, 10, 16, 26]. In our study, a total of eight lesions of hemangioblastoma were treated in five patients. Among these, three patients had already had brain surgery because of Von Hippel–Lindau disease, so lesion volume was small (mean, 0.25 cm<sup>3</sup>). At 50 months follow-up, six lesions had decreased, one lesion had slightly increased, and one lesion showed no change in size

(Table 5). In the series of Moss et al. 16 hemangioblastomas were treated with the Cyberknife and the local control rate was 92% at 36 and 60 months [26]. In spinal cord hemangioblastomas, cystic lesions are often accompanied by solid masses. But radiosurgery was confined to the solid enhancing lesions only, without including the cyst wall. In two sporadic cases, hemangioblastoma showed cystic enlargement after radiosurgery [10, 16]. Hemangioblastoma is a pia-based intramedullary tumor which limits radiosurgery, because of a higher probability of spinal cord injury than extramedullary spinal tumors. With regard to intramedullary lesions, radiosurgery was rarely tried. The only result was reported by Stanford University Cyberknife Center after 15 arteriovenous malformations had been treated. In their series, they proposed 20 Gy in two fractions, which was proved to be safe on follow-up. It is recommended that radiosurgery is feasible for intramedullary lesion if the volume is less than 1.5 cm<sup>3</sup> [27].

## Conclusion

Clinical experience of spinal radiosurgery is accumulating. Although data for long-term efficacy are lacking, the result of radiosurgery for benign spinal tumors is promising. We have treated 30 benign spinal tumors using the Cyberknife, and most of the patients were satisfied with the final result. The overall tumor control rate was 90% and clinical symptoms mostly improved. Radiation tolerance of the spinal cord may be higher than we expected. Our data are a small addition that proves the safety and clinical effectiveness of spinal radiosurgery. Although the best treatment for benign spinal tumors is microsurgical resection, in selected cases, for example neurofibromatosis, recurrent tumors, multiple lesions, postoperative residual mass, and patients with high medical co-morbidities, SRS can be an alternative to microsurgical resection.

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