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Malignant transformation of a vestibular schwannoma to malignant peripheral nerve sheath tumor 10 years after Gamma Knife Surgery: Case report

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ABSTRACT

Background and importance: Malignant transformation of vestibular schwannoma (VS) after Gamma Knife Surgery (GKS) was extremely rare, but potentially serious complication leading to poor prognosis. Small number cases have been reported but they are limited to single case report.

Clinical presentation: This article presents a case of a cerebellopontine angle tumor in a 54-year-old man who had right-sided hearing disturbance which lasted for 11 years. The patient underwent tumor resection via retrosigmoid approach in May 2004 at another hospital, and subtotal removal was achieved. Pathological diagnosis was vestibular schwannoma (VS). One year later, Gamma Knife Surgery (GKS) was performed for residual tumor control. Two years after GKS, the patient was referred to our hospital and second surgical resection was performed, subtotal tumor removal was achieved and pathology showed VS. Clinical and radiological follow up were performed every 6 months. In April 2014, deterioration on clinical symptom appeared and the tumor had grown, and therefore third tumor resection via retrosigmoid approach was performed.

Conclusion: Subtotal removal was achieved and pathology showed malignant peripheral nerve sheath tumor (MPNST). Although this case is rare, malignant transformation of VS after GKS should keep in mind when treating VS.

1. Background and importance

Malignant tumor of the vestibular nerve is extremely rare, and malignant transformation of a previously diagnosed vestibular schwannoma is even more rarely, small number of cases has been reported in the literature so far [1,2,3,4,5,6,7,8,9]. Controversies about the ideal management for small- to median-sized vestibular schwannomas (VS), Gamma Knife radiosurgery has become more popular during the last decade, and promising clinical results have been reported [10]. In this report, we describe a case of malignant transformation of VS to malignant peripheral nerve sheath tumor (MPNST) with glandular differentiation 10 years after radiosurgery performed on the residual tumor after primary resection.

2. Clinical presentation

2.1. History and examination

This 54-year-old right-handed man without a familial history of neurofibromatosis, presented with a 11-year history of right hearing impairment and vertigo. Neurological examination demonstrated right hearing disturbance with a pure tone audiometry of 58.5 dB.

2.2. Radiological finding

Initial MR image, axial GD-enhanced T1-weighted MR image demonstrating a heterogeneous enhancing right cerebellopontine angle

Abbreviations: VS, vestibular schwannoma; MPNST, malignant peripheral nerve sheath tumor; GKS, Gamma Knife radiosurgery

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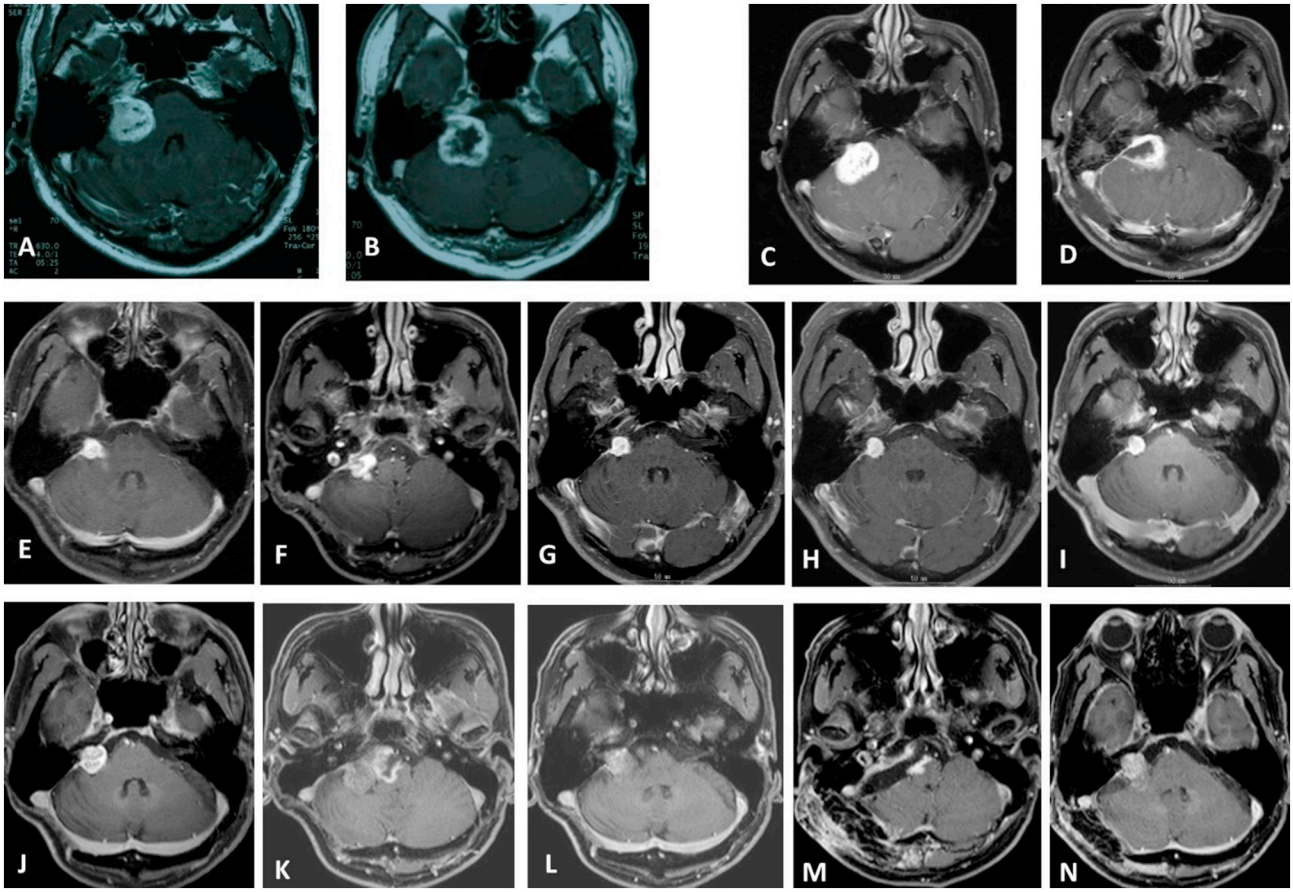

Fig. 1. A. Initial MR image on April 2004, axial Gd-enhanced T1-weighted MR image demonstrating a heterogeneous enhancing right cerebellopontine angle tumor. B. Axial Gd-enhanced T1-weighted MR image on August 2005 1 year after first operation, and before SRS. C. Preoperative axial Gd-enhanced T1-weighted MR image on May 2007, for second surgical resection. D. Postoperative axial Gd-enhanced T1-weighted MR image 1 month after second surgical resection. E. Follow up axial Gd-enhanced T1-weighted MR image on May 2008. F. Follow up axial Gd-enhanced T1-weighted MR image on November 2009. G. Follow up axial Gd-enhanced T1-weighted MR image on November 2010. H. Follow up axial Gd-enhanced T1-weighted MR image on November 2011. I. Follow up axial Gd-enhanced T1-weighted MR image on November 2012. J. Follow up axial Gd-enhanced T1-weighted MR image on November 2013 showed tumor start to growth. K and L. Axial Gd-enhanced T1-weighted MR image on April 2014 demonstrating a heterogeneous enhancing, compression to the brain stem was showed, third surgical resection was performed. M and N. Follow up axial Gd-enhanced T1-weighted MR image two months after 3rd surgical resection.

tumor, tumor invaded to the right internal auditory canal (IAC), vestibular schwannoma was suspected.

2.3. Operation

In May 2004, right retrosigmoid approach was used to re-sect the tumor. Intraoperatively the tumor was solid and relatively vascular rich, and easy to bleed, tumor was resected partially (Fig. 1A–B) and GKS (Fig. 2) was performed on August 2005 to control residual tumor on that time. In May 2007, the patient was referred to our hospital and second surgical resection was performed, some tumor capsules were left behind because of arachnoid membrane had unclear margin and severe adhesion with cranial nerve (CN). 7, CN. 8, and lower cranial nerve (Fig. 1C–D). The patient was followed with serial brain MRI every 6 months (Fig. 1E–I), and initially the residual tumor was stable in size. In November 2013, routine follow-up MRI showed that tumor started to grow (Fig. 1J). In April 2014, progressive headache, vertigo and nausea developed, and MRI showed that tumor mass had grown. In June 2014 (Fig. 1K–L), subtotal tumor resection was performed, and operative finding showed that tumor had two parts namely one part has a soft content and relatively easy to resect, and the other part with elastic and fibrous tissue, in which the arachnoid membrane had unclear margin and severe adhesion with CN. 7, CN. 8, and lower cranial nerve. Both second and third surgeries of this case were done by one neurosurgeon.

2.4. Pathological findings

First pathological analysis in May 2004 (Fig. 3) showed Antoni A type and Antoni B type, of spindle cells with oval nuclear, nuclear palisading, and no evidence of malignancy. These pathological finding were consistent with vestibular schwannoma. Second pathological analysis in June 2007 (Fig. 4) showed homogeneous proliferation of spindle cells, Antoni A type and Antoni B type, no nuclear palisading, no necrosis, and second pathological analysis was also consistent with vestibular schwannoma. In additional, proliferation of eosinophilic spindle cell, perivascular high cellularity (condensation), increased nuclear chromatin, and mitosis were seen in all fields, and glandular structure were the results of third pathological analysis in June 2014 (Fig. 5). Immunohistochemistry analysis showed S-100(+), CAM5.2(+/−), p53(+/−), CD56(+), CD34(−), desmin(−), myogenin(−), MyoD1(−) α-actin(−), bcl-2(−), MIC-2(−) (spindel cells), CEA(+), and chromogranin A (glands). Third pathological analysis was consistent with malignant peripheral nerve sheath tumor (MPNST) with glandular differentiation.

2.5. Follow up

After malignancy was confirmed for this patient, we selected intensity-modulated radiation therapy (IMRT) with maximal dose 50 Gy.

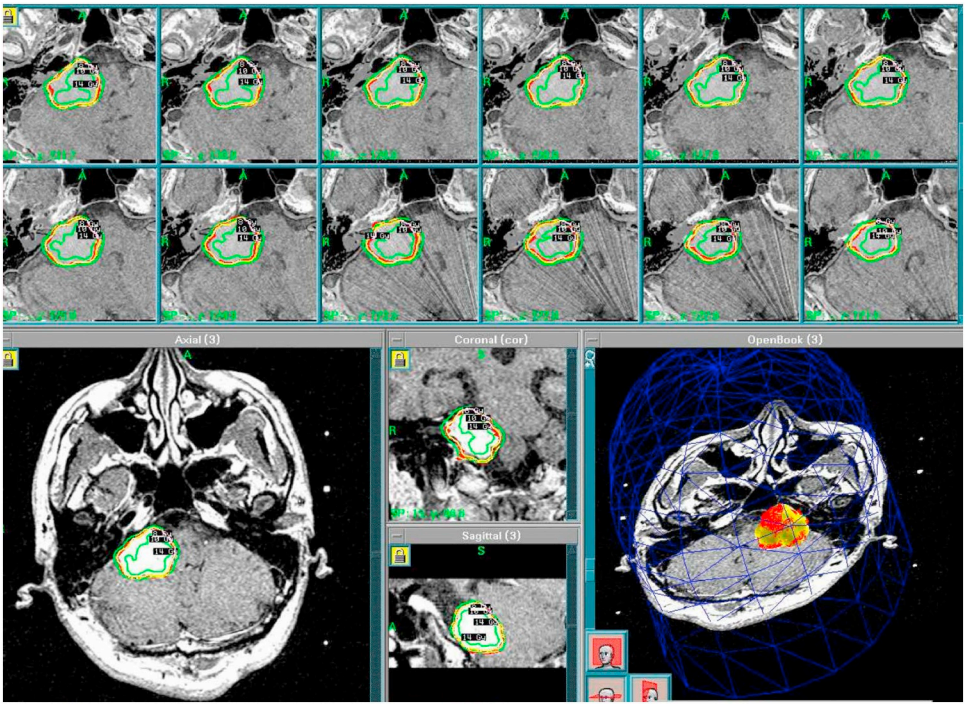

Fig. 2. Treatment plan of Gamma Knife radiosurgery. The tumor was treated with prescribed dose of 10 Gy (50% isodose).

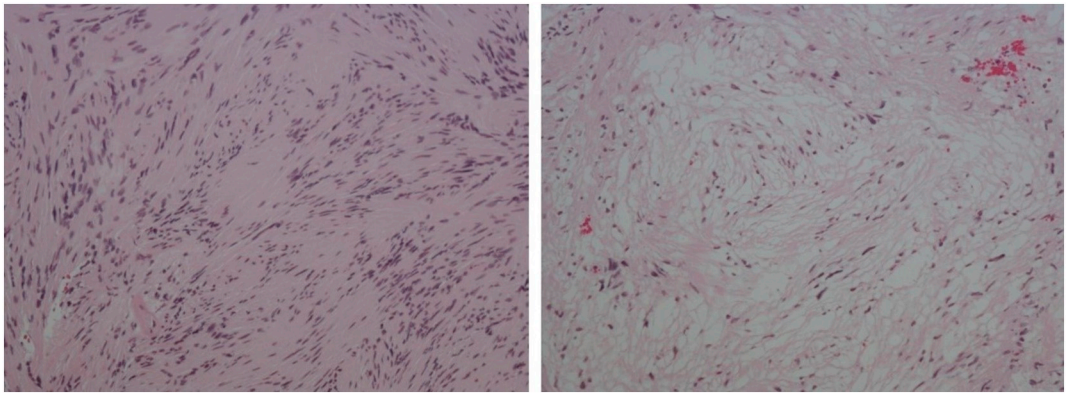

Fig. 3. First pathological analysis shows: Antoni A type and Antoni B type, spindle cells with oval nuclear, nuclear palisading, and no evidence of malignancy, pathological analysis was consistent with vestibular schwannoma.

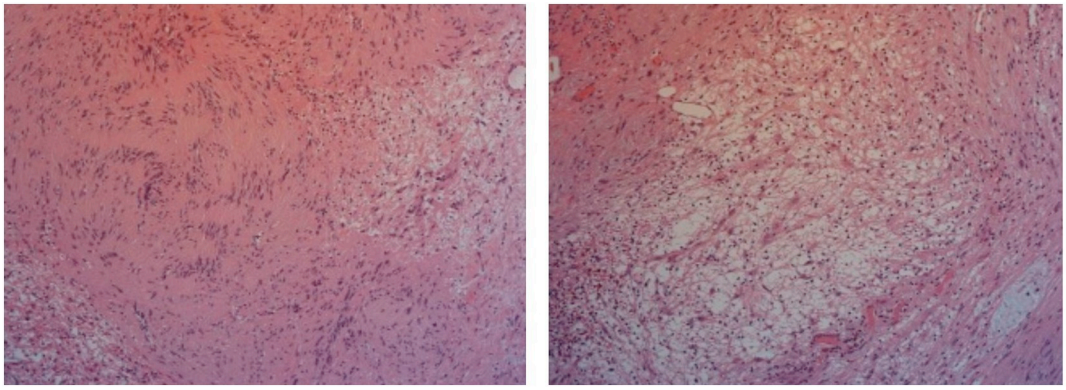

Fig. 4. Second pathological analysis shows: homogeneous proliferation of spindle cells, Antoni A type and Antoni B type, no nuclear palisading, no necrosis, pathological analysis confirmed with vestibular schwannoma.

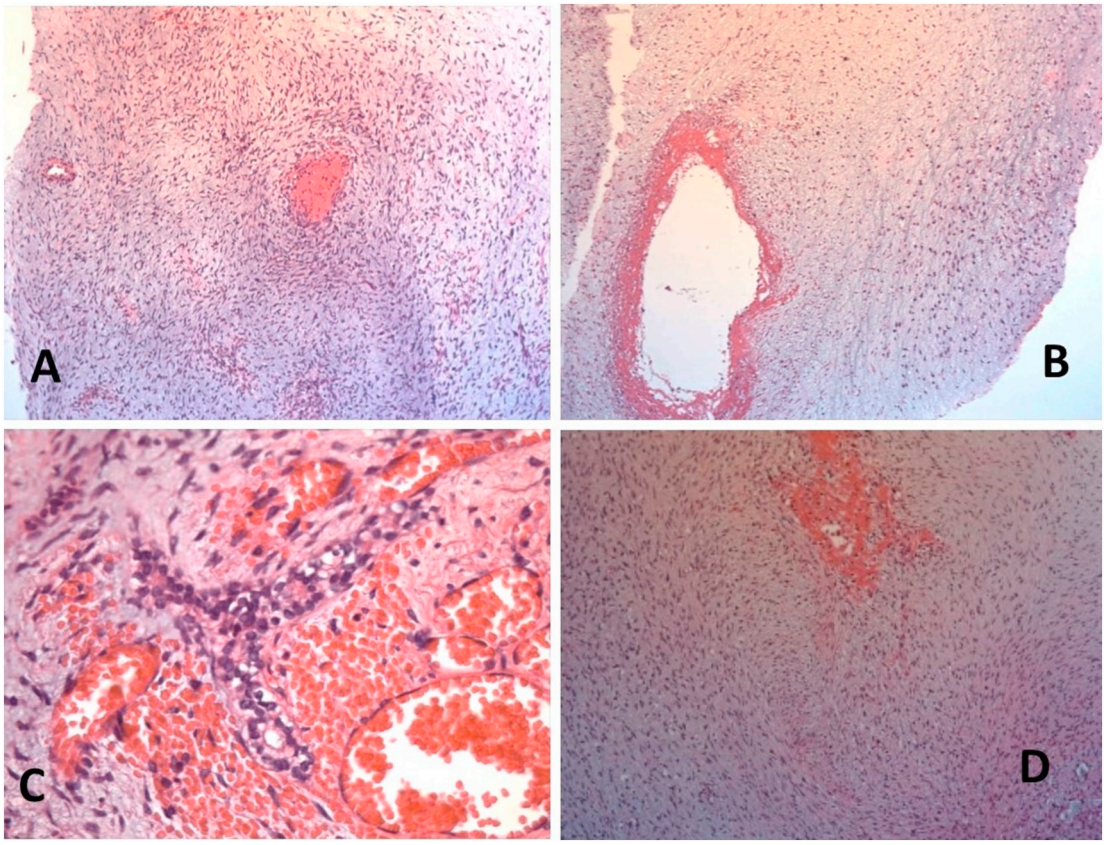

Fig. 5. Third pathological analysis shows: proliferation of eosinophilic spindle cell, perivascular accentuation (A), nuclear chromatin are increase, mitosis are seen in all field, necrotic area (B) and glandular structure (C), pathological analysis consistent with malignant peripheral nerve sheath tumor (MPNST) with glandular differentiation.

Since we submitted this paper, the patient is still undergoing follow up in outpatient clinic.

3. Discussion

Vestibular schwannomas are benign tumors arising from the eighth cranial nerve. Malignant of the eighth cranial nerve is extremely rare, and to our knowledge, 20 cases of primary malignant have been reported since 1983 to 2014 [2,11,12,13,14,15,16,17,18,19,20,21,22,23]. The transformation of a benign tumor to a sarcoma like MPNST in the absence of underlying neurofibromatosis is also rare. Rarely, vestibular schwannoma undergo a malignant transformation [9]. Hasegawa et al., reported an expected incidence of malignant transformation after radiation to be approximately 0.3% [24]. We found only 2 cases of malignant transformation of vestibular schwannoma with no predisposing factors for malignant transformation such as neurofibromatosis or previous radiation (Table 1).

Although there is an ongoing debate about the ideal management for small- to median-sized VS, the goal for treatment of VS includes long-term tumor control, preservation of facial, vestibulocochlear, and trigeminal nerve function [8]. GKS has become more popular during the last decade, and promising clinical results have been reported. Lee et al., long-term (average 36 months, range 1–110 months) tumor control rate among 195 patients was 96.8% [10]. Hasegawa et al., the actuarial 10-year facial nerve preservation rate was 97% in the high marginal dose group (> 13 Gy) and 100% in the low marginal dose group (≤ 13 Gy) [16]. However, the risk of radiation-induced malignancy after this modality is largely unknown [1]. On the other side, complete tumor resection is the gold standard therapy to prevent a second salvage surgery which will be much more difficult with a high morbidity rate and to avoid the risk of malignant tumor transformation [25].

We carefully reviewed literature concerning malignant transformation of VS after GKS. Cahan and Woodward modified criteria to define malignant transformation of VS after GKS. These criteria are [26,27,28]: (1) There must have been microscopic or roentgenographic evidence of the non-malignant nature of the initial condition, (2) Irradiation must have been given and malignancy subsequently developed must have arisen in the area included within the radiotherapeutic beam, (3) A relatively long, asymptomatic latent period must have elapsed after irradiation, (4) Malignancy must have been proved

Table 1
Reported cases of histology malignant transformation of VS without the use of GKS.

Author	Age/sex	NF2	Initial surgery	Initial histology	Repeated surgery	Repeated histology	Latent period (months)	Survival (months)
McLean et al. [3]	75/M	No	GTR	VS	GTR	Malignant spindle cell	12	2
Son et al. [5]	33/F	No	GTR	VS	GTR	Malignant schwannoma	2	NA

Median survival was 7 months (2–12 months). M, male; F, female; VS, vestibular schwannoma; GTR, gross total resection; NF2, neurofibromatosis type 2; NA, not available.

Table 2
Group 1, reported cases of malignancy of VS related to GKS as a first line therapy.

Author	Age/sex	NF2	Symptom	Initial histology	Definitive GKS dose	Surgical resection	Histology	Latent period (months)	Survival (months)
Kurita (in Bary et al., and Comey et al.) [28,29]	26/F	No	Decreases hearing	No	17 Gy	STR	MVS	72	3
Noren et al. [33]	18/F	Yes	Decreased hearing, tinnitus	No	20 Gy	NA	Triton	60	NA
Comey et al. [30]	44/M	No	1 year right ear tinnitus and hearing loss	No	14.36 Gy	STR	MTT	60	12
Bari et al. [28]	28/F	Yes	Decreased hearing, numbness left face	No	15 Gy,	GTR	MVS	42	10
Lee et al. [10]	46/F	NA	Ataxia, facial palsy	No	12 Gy	STR	MPNST	72	8
Husseini et al. [32]	15/M	Yes	Mild sensorineural hearing loss	No	13.5 Gy	GTR	MPNST	24	3
Schmitt et al. [26]	51/M	No	2.5 years unilateral hearing loss	No	12 Gy	STR	UHGPS	84	7
Milligan et al. [40]	59/M	NA	NA	No	NA	STR	Pleomorphic sarcoma	74	3
Kuzmik et al. [41]	73/F	No	Mild hearing loss	No	13 Gy	GTR	Poorly differentiated MPNST	5	2

Median latency period for group 1 was 60 months (range 5–84 months), and median survival was 5 months (range 2–12 months). M, male; F, female; VS, vestibular schwannoma; MVS, malignant vestibular schwannoma; MPNST, malignant peripheral nerve sheath tumor; MTT, malignant triton tumor; UHGPS, undifferentiated high-grade pleomorphic sarcoma; GTR, gross total resection; STR, subtotal resection; NF2, neurofibromatosis type 2; SRS, stereotactic radiosurgery; NA, not available.

Table 3
Group 2, reported cases malignant transformation related SRS which are fits to Cahan's criteria.

Author	Age/sex	NF2	Symptom	Initial surgery	Initial hystology	GKS dose	Repeated surgery	Final histology	Latent time (months)	Survival (months)
Pollock et al. [42]	NA	NA	NA	NA	VS	12 Gy	STR	MTT	NA	NA
Hanabusa et al. [2]	51/F	No	1 year progressive hearing disturbance	STR	VS	15 Gy	STR	Sarcomatous change	24	6
Shin et al. [4]	26/F	No	Gradual hearing loss	STR	VS	17 Gy	STR	MPNST	72	10
Rompaey et al. [43]	53/F	No	Dizziness and vertigo	STR	VS	12 Gy	Autopsy	MVS	96	< 1
Demetriades et al. [1]	27/M	No	Facial numbness and balance disturbance	STR	VS	15 Gy	GTR	MPNST	120	4
Yang et al. [9]	74/M	No	Dizziness, ataxia, facial palsy, hoarseness, difficult swallowing	GTR	VS	12.5 Gy	GTR	Undifferentiated sarcoma	156	12
Akamatsu et al. [44]	67/F	No	Hearing disturbance	STR	VS	12 Gy	GTR	MPNST	76	NA
Yanamadala et al. [8]	46/F	No	Decreased hearing, facial palsy, decreased sensation on face	STR	VS	14 Gy	STR	MPNST	48	11
Hasegawa et al. [31]	56/F	No	NA	STR	VS	12,7 Gy	STR	MPNST	66	13
Present case	54/M	No	Decreased hearing, vertigo	STR	VS	10 Gy	STR	MPNST	122	Undergoing follow up

Median latency period for this group 76 months (range 24–156 months), and median survival was 10 months (range 1–13 months). M, male; F, female; BVS, benign vestibular schwannoma; MVS, malignant vestibular schwannoma; MPNST, malignant peripheral nerve sheath tumor; MTT, malignant triton tumor; GTR, gross total resection; STR, subtotal resection; NF2, neurofibromatosis type 2; SRS, stereotactic radiosurgery; NA, not available.

histologically. (5) The patient has no genetic predisposition to cancer.

A few authors reported malignancy of VS after GKS as first line treatment or as adjuvant treatment [1,4,6,7,8,9,24,27,29,30,31]. Those Cahan's criteria are difficult to apply because malignant transformation of VS could not be proven histologically (Table 2). Malignant transformation could only be strictly confirmed if pathology was available prior to radiation [28,30]. We reviewed cases in literature and divided them to 2 groups; group 1 (Table 2) are cases of malignancy of VS related to GKS as a first line therapy, and group 2 (Table 3) are cases malignant transformation related to GKS which are suitable to Cahan's criteria. We exclude primary malignant VS, malignancy developed outside radiotherapeutic beam, and other types of radiation therapy.

According to this subgroup, nine cases included into Group 1 (Table 2). Three cases reported by Noren et al., Bari et al. and Husseini et al. had a predisposition to neurofibromatosis 2 (NF2) [29,32,33]. NF2 is an autosomal dominant disease which is characterized by tumors on the vestibular. NF2 patients who have received radiotherapy had a 14-fold increased risk of developing malignant brain tumors (The incidence was 10% in irradiated patients compared to 0.7% in non-irradiated patients) [34].

Ten cases including the present case were classified into group 2 (Table 3). Median latency period for this group was 76 months (range 24–156 months), and median survival was 10 months (range 1–13 months).

Our case definitely involved the transformation of a VS after GKS, as confirmed by multiple histopathology analyses. Two previous histopathology analyses showed benign VS, and last histopathology analysis showed malignancy (MPNST). In our case, MIB-1 index was 4%, Ki-67 staining index can be used as an index of regrowth rate in partially or subtotally removed acoustic neurinomas [35,36]. MIB-1 index > 2% was significant correlation with tumor double time (TDT) [36].

Group 1 and Group 2 presented relatively long period latency. Hasegawa et al. demonstrated that the actuarial 5- and ≥10-year progression-free survival were 93% and 92%, respectively [24]. Murphy et al. explained that 117 patients in whom data were analysed from January 1997 to February 2003 imaging-documented tumor progression were present in 8 patients (7.8%) [37]. Some previous cases reported that they had a short latent period after GKS. In those cases, it may have been malignant component existed before GKS. We only found 2 publications which reported spontaneous malignant transformation VS (Table 1), but in a case reported by McLean et al., primary resection pathology showed a VS, but signs of malignant degeneration were present in a small portion of the tumor, and relatively short period of latency [3]. We assumed that primary malignant VS was also possible for this patient, it showed that spontaneous malignant transformation as a natural caused for VS are extremely rare. The presence of the latency period at least suggests that radiation therapy is effective in controlling otherwise large and symptomatic benign conditions with high morbidity [28]. Our case latent period was 122 months, this long silent period most likely as benign behaviour.

The mechanisms by which radiation may induce malignancy are still unclear. After radiation exposure, there are two possible outcomes. One is the deterministic effect, which has a threshold of dose and a severity of the effects which are dose related. And another possible outcome is called stochastic effect, which is carcinogenesis, and hereditary effect is one of example for this category. An advanced conformal radiation technique, such as GKS can deliver high radiation dose to tumor with lower dose to normal tissue. This might reduce only the deterministic effect, but the effect to the stochastic is still unknown [38]. The occurrence rate of secondary neoplasm due to GKS is low, but high single doses delivered during GKS preferentially lead to cytotoxicity over mutagenicity. It may explain why VS, which traditionally treated with lower doses are associated with greater rates of secondary neoplasms [39].

Previous literature showed a median survival in all groups were < 12 months. This suggests that malignant transformation after radiation may be become more aggressive subset compared to other etiologies of MPNST or secondary tumor [28]. Poor prognosis and relatively short survival rate make management after malignant transformation related to radiosurgery so challenging. Several combinations such as surgical resection, radiosurgery, and chemotherapy have been used to control malignant vestibular nerve tumors. Chen et al., suggested that aggressive resection of intracranial MPNST including surrounding tissue such as muscle, fat, dura, and bone which demonstrated evidence of tumor invasion and dysfunctional cranial nerve. Preservation of CN should only be considered when CN is compressed but not invaded by tumor. The residual tumor should be left if adherent to brain stem, main vessel, or other vital structures [12]. Husseini et al., stated that complete surgical resection of VS was more difficult after radiotherapy with relatively poor facial nerve outcomes and nearly impossible hearing preservation [25]. The discussion regarding the most effective treatment to extend survival will continue to develop as more data become available [28].

By many published results, it is proven that GKS is an effective and non-invasive technique for VS, especially small sized tumors with satisfactory tumor control rate, but radiation therapy should not be considered as an optional treatment of VS without a clear and documented evidence of tumor growth. Hasegawa et al., explained that Gamma Knife Surgery (GKS) has been a safe and effective treatment for VS for longer than 10 years [24].The patients should be made aware of its complications and risks of failure, especially in young patients and NF2 cases [25].

4. Conclusion

The question of malignant transformation related to radiosurgery is difficult to answer due to small numbers and limited to single case report, relatively most of the cases followed < 10 years. The risk of malignant transformation following radiosurgery in vestibular schwannoma seems to be extremely low, but potentially serious, therefore we suggest that patients should be informed the possibility of this complication before GKS. As long term effects of therapy are not fully understood, radiosurgery should be used with caution, especially in young individual. Radiation-induced malignancy takes place after a sufficient latency period, and therefore long term follow up is highly recommended in all cases which treated by radiosurgery.

Statement of ethics

Patient consent was obtained regarding the usage of patient data, and the patient accepted the terms and regulations under the hospital ethics committee.

Disclosure statement

The authors report no conflicts of interest concerning the materials or methods used in this study or the findings specified in this paper. No funding was received for this study.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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References

[1] A.K. Demetriades, N. Saunders, P. Rose, C. Fisher, J. Rowe, R. Tranter, C. Hardwidge, Malignant transformation of acoustic neuroma/vestibular schwannoma 10 years after Gamma Knife stereotactic radiosurgery, Skull Base 20 (2010) 381–387.

[2] K. Hanabusa, A. Morikawa, T. Murata, W. Taki, Acoustic neuroma with malignant transformation: case report, J. Neurosurg. 95 (2001) 518–521.

[3] C.A. McLean, J.D. Laidlaw, D.S. Brownbill, M.F. Gonzales, Recurrence of acoustic neurilemoma as a malignant spindle-cell neoplasm. Case report, J. Neurosurg. 73 (1990) 946–950.

[4] M. Shin, K. Ueki, H. Kurita, T. Kirino, Malignant transformation of a vestibular schwannoma after Gamma Knife radiosurgery, Lancet 360 (2012) 309–310.

[5] E.I. Son, I.M. Kim, S.P. Kim, Vestibular schwanoma with malignant transformation: a case report, J. Korean Med. Sci. 16 (2001) 817–821.

[6] J. Thomsen, F. Mirz, R. Wetke, J. Astrup, M.B. Moller, E. Nielsen, Intracranial sarcoma in a patient with neurofibromatosis type 2 treated with Gamma Knife radiosurgery for vestibular schwannoma, Am. J. Otolaryngol. 21 (2000) 364–370.

[7] J.S. Wilkinson, H. Reid, G.R. Armstrong, Malignant transformation of a recurrent vestibular schwannoma, J. Clin. Pathol. 57 (2004) 109–110.

[8] V. Yanamadala, R.W. Williamson, D.J. Fusco, J. Eschbacher, P. Weisskopf, R.W. Porter, Malignant transformation of a vestibular schwannoma after Gamma Knife radiosurgery, World Neurosurgery. 79 (2013) 593[e1]–593[e8].

[9] T. Yang, J. Rockhill, D.E. Born, L.N. Sekhar, A case of high-grade undifferentiated sarcoma after surgical resection and stereotactic radiosurgery of a vestibular schwannoma, Skull Base 20 (2010) 179–183.

[10] C.C. Lee, Y.S. Yen, D.H. Pan, W.Y. Chung, H.M. Wu, W.Y. Guo, Delayed microsurgery for vestibular schwannoma after Gamma Knife radiosurgery, J. Neuro-Oncol. 98 (2010) 203–212.

[11] P.V. Best, Malignant triton tumour in the cerebellopontine angle. Report of a case, Acta Neuropathol. 74 (1987) 92–96.

[12] L. Chen, Y. Mao, H. Chen, L.F. Zhou, Diagnosis and management of intracranial malignant peripheral nerve sheath tumors, Neurosurgery 62 (2008) 825–832.

[13] D.K. Dastur, G. Sinh, S.K. Pandkya, Melanotic tumor of the acoustic nerve, J. Neurosurg. 27 (1967) 166–170.

[14] L.F. Gonzalez, G.P. Lekovic, J. Eschbacher, S. Coons, R.F. Spetzler, A true malignant schwannoma of the eighth cranial nerve: case report, Neurosurgery 61 (2007) E421–E422.

[15] B. Gruber, L. Petchenik, M. Williams, C. Thomas, M.G. Luken, Malignant vestibular schwannoma, Skull base surgery 4 (4) (1994) 227–231.

[16] M.H. Schulman, K. Welch, R. Strand, J.I. Ordia, Acoustic neuromas in children, Am. J. Neuroradiol. 7 (1986) 519–521.

[17] M. Kudo, M. Matsumoto, H. Terao, Malignant nerve sheath tumor of acoustic nerve, Archives of Pathology & Laboratory Medicine Online 107 (1983) 293–297.

[18] M. Maeda, T. Jozaki, S. Baba, H. Muro, H. Shirasawa, T. Ichihashi, Malignant nerve sheath tumor with rhabdomyoblastic differentiation arising from the acoustic nerve, Acta Pathol. Jpn. 43 (1993) 198–203.

[19] M. Matsumoto, Y. Sakata, K. Sanpei, A. Onagi, H. Terao, M. Kudo, Malignant schwannoma of acoustic nerve: a case report, No Shinkei Geka 18 (1990) 59–62.

[20] R.T. Miller, H. Sarikaya, A. Sos, Melanotic schwannoma of the acoustic nerve, Archives of Pathology & Laboratory Medicine Online 110 (1986) 153–154.

[21] R.E. Mrak, S. Flanigan, C.L. Collins, Malignant acoustic schwannoma, Archives of Pathology & Laboratory Medicine Online 118 (1994) 557–561.

[22] T. Saito, S. Oki, T. Mikami, Malignant peripheral nerve sheath tumor with divergent cartilage differentiation from the acoustic nerve: case report, Nō to shinkei 52 (2000) 734–739.

[23] B.W. Scheithauer, S. Erdogan, F.J. Rodriguez, Malignant peripheral nerve sheath tumors of cranial nerves and intracranial contents: a clinicopathologic study of 17 cases, Am. J. Surg. Pathol. 33 (2009) 325–338.

[24] A.T. Husseini, E. Piccirillo, A. Taibah, T. Almuatir, G. Sequino, M. Samma, Salvage surgery of vestibular schwannoma after failed radiotherapy: the Gruppo Otologico experience and review of the literature, American Journal of Otolaryngology-Head and Neck Medicine and Surgery 34 (2013) 107–114.

[25] W.G. Cahan, H.Q. Woodard, N.L. Higinbotham, F.W. Stewart, B.L. Coley, Sarcoma arising in irradiated bone. Report of eleven cases, Cancer 1 (1) (2006) 3–29.

[26] W.R. Schmitt, M.L. Carlson, C. Giannini, C.L. Driscoll, M.J. Link, Radiation-induced sarcoma in a large vestibular schwannoma following stereotactic radiosurgery: case report, Neurosurgery 68 (2011) E840–E846.

[27] M. Zhang, S.D. Chang, Outcomes following malignant degeneration of benign vestibular schwannomas after stereotactic radiosurgery, World Neurosurgery 82 (2014) 346–349.

[28] M.E. Bari, D.M. Forster, A.A. Kemeny, L. Walton, D. Hardy, J.R. Anderson, Malignancy in a vestibular schwannoma: report of a case with central neurofibromatosis, treated by both stereotactic radiosurgery and surgical excision, with a review of the literature, Br. J. Neurosurg. 16 (2002) 284–289.

[29] C.H. Comey, M.R. McLaughlin, H.D. Jho, A.J. Martinez, L.D. Lunsford, Death from a malignant cerebellopontine angle triton tumor despite stereotactic radiosurgery: case report, J. Neurosurg. 89 (1998) 653–658.

[30] T. Hasegawa, S. Fujitani, S. Katsumata, Y. Kida, M. Yoshimoto, J. Koike, Stereotactic radiosurgery for vestibular schwannomas: analysis of 317 patients followed more than 5 years, Neurosurgery 57 (2005) 257–265.

[31] T. Hasegawa, Y. Kida, T. Kato, H. Iizuka, S. Kuramitsu, T. Yamamoto, Long term safety and efficacy of stereotactic radiosurgery for vestibular schwannoma: evaluation of 440 patients more than 10 years after treatment with Gamma Knife surgery, J. Neurosurg. 118 (2013) 557–565.

[32] A.T. Husseini, E. Piccirillo, A. Taibah, C. Paties, R. Rizzoli, M. Sanna, Malignancy in vestibular schwannoma after stereotactic radiotherapy: a case report and review of the literature, Laryngoscope 121 (2011) 923–928.

[33] G. Noren, Long-term complications following Gamma Knife radiosurgery of vestibular schwannomas, Stereotact. Funct. Neurosurg. 70 (1998) 65–73.

[34] M. Fukuda, M. Oishi, T. Hiraishi, M. Natsumeda, Y. Fujii, Clinicopathological factors related to regrowth of vestibular schwannoma after incomplete resection, J. Neurosurg. 114 (2011) 1224–1231.

[35] M.E. Baser, D.G. Evans, R.K. Jackler, E. Sujansky, A. Rubenstein, Neurofbromatosis 2, radiosurgery and malignant nervous system tumours, Br. J. Cancer 82 (2000) 998.

[36] M. Yokoyama, M. Matsuda, S. Naksu, M. Nakajima, J. Handa, Clinical significance of Ki-67 staining index in acoustic neurinoma, Neurol. Med. Chir. 36 (1996) 698–702.

[37] E.S. Murphy, G.H. Barnett, M.A. Vogelbaum, G. Neyman, G.H. Stevens, B.H. Cohen, P. Elson, A.D. Vassil, J.H. Suh, Long-term outcomes of Gamma Knife radiosurgery in patients with vestibular schwannomas, J. Neurosurg. 114 (2011) 432–440.

[38] P. Puataweepong, T. Janwityanujit, N. Larbcharoensub, M. Dhanachal, Radiation-induced peripheral malignant nerve sheath tumor arising from vestibular schwannoma after linac-based stereotactic radiation therapy: a case report and review of literatures, Hindawi Publishing Corporation 2012 (2012) 6, https://doi.org/10.1155/2012/648191 (648191).

[39] T.R. Patel, V.L.S. Chiang, Secondary neoplasms after stereotactic radiosurgery, World Neurosurgery 81 (2014) 594–599.

[40] B.D. Milligan, B.E. Pollock, R.L. Foote, M.J. Link, Long term tumor control and cranial nerve outcomes following Gamma Knife surgery for larger-volume vestibular schwannomas, J. Neurosurg. 116 (2012) 598–604.

[41] G.A. Kuzmik, E.M. Michaelides, V.L. Chiang, Y. Nonaka, T. Fukushima, A.O. Vortmeyer, Rapidly progressive epitheloid malignant peripheral nerve sheath tumor of the vestibular nerve, Otology & Neurotology 34 (2013) 1739–1742.

[42] B.E. Pollock, L.D. Lunsford, D. Kondziolka, R. Sekula, B.R. Subach, R.L. Foote, Vestibular schwannoma management. Part II. Failed radiosurgery and the role of delayed microsurgery, J. Neurosurg. 89 (1998) 949–955.

[43] V.K. Rompaey, A. Michotte, B. Ampe, Malignant transformation of a vestibular schwannoma after radiosurgery, Surg. Neurol. 71 (2009) 145.

[44] Y. Akamatsu, K. Murakami, M. Watanabe, H. Jokura, T. Tominaga, Malignant peripheral nerve sheath tumor arising from benign vestibular schwannoma treated by Gamma Knife radiosurgery after two previous surgeries: a case report with surgical and pathological observations, World Neurosurgery 73 (2010) 751–754.