Review Article

Management of vestibular schwannomas: Current state of the art

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Abstract

Background: Vestibular schwannomas (VS) have always been a great challenge for neurosurgeons. The evolution of surgical management of VS is parallel of the history of the development of modern neurosurgery. Gamma knife surgery (GKS) is becoming a standard treatment for small or middle size VS while microsurgery remains the effective treatment of the large tumours. The combinations of the two techniques offer a big chance to preserve facial function in Koos IV VS.

Materiel and methods: The Marseille SRS experience includes 2150 patients, with more than 1000 patients having follow-up longer than 3 years. In this series the Koos classification was: stage I 9%, stage II 55.5%, stage III 287 31% and stage IV 4.5%. The average volume was 12.7 mm^3. Hearing was useful (Gardner and Robertson) before radiosurgery in 47% of the patients (subnormal in 20.3%).

Results: A long-term tumour control rate of 97%. Globally, a clinical trigeminal injury was observed in 0.6% of the patients and transient facial palsy lower than 1%. There was clearly a decrease of the incidence of neuropathies with time, and a probability of functional hearing preservation between 50 and 95%, depending on preoperative parameters, was achieved in this large series of patients treated by state-of-the-art GKS.

Other parameters such as long-term complications, type 2 neurofibromatosis, the influence of tumour characteristics and the treatment of the residual or recurrent VS after microsurgery are reviewed and detailed.

Conclusion: Today, strong evidence supports the superiority of GKS in terms of functional preservation and equal efficacy compared with microsurgical removal. Consequently, radiosurgery must be preferred as a first intention choice for young patients with few symptoms presenting with a small to middle size VS (Koos I to III). Only large Koos IV remained first line indication for microsurgery. The combined approach should provide these patients with a major reduction of risks, particularly in terms of rate of facial palsy. *(p1-10)*

Key words: *Acoustics, vestibular schwannomas, microsurgery and radiosurgery*

Introduction

Within the last three last decades, microsurgery and stereotactic radiosurgery (SRS) have become well established management options for vestibular schwannomas (VS). Advancement in the management of VS can be separated into three periods: the microsurgical pioneer period, the demonstration of SRS as a first line therapy for small and medium sized VS, and currently, a period of SRS maturity based on a large worldwide patient accrual. The Marseille SRS experience includes 2150 patients, with more than 1000 patients having follow-up longer than 3 years. A long-term tumour control rate of 97%, transient facial palsy lower than 1%, and a probability of functional hearing preservation between 50 and 95% was achieved in this large series of patients treated by state-of-the-art SRS.

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The Swedish experience

Vestibular schwannoma, initially termed acoustic neurinomas, arise from the schwann cells of the vestibular nerve instead of the cochlear nerve.[10] These benign tumours are surgically challenging lesions. The neurosurgical manage-

ment of VS began in the 20th century. Pioneers such as Dr. Harvey Cushing, operated on VS patients for survival enhancement. These patients had large tumours, presenting with cerebellopontine angle (CPA) clinical manifestations, and were diagnosed by internal auditory canal (IAC) enlargement on radiography.[1] The surgical approach performed was a retrosigmoid suboccipital approach. Between 1925 and 1950, other pioneers such as Dr. Walter Dandy were able to rely on ventriculography, angiography and pneumencephalography for radical removal of these tumours.[2]

In the second half of the 20th century, microsurgery and SRS were introduced in the management of VS. The micro-otoneurosurgical experience began in 1962 with surgeons such as Dr. W House, who developed a translabyrinthine approach for preservation of facial nerve function.[11] The availability of auditory evoked potentials (1970), computerized tomography (CT) scan (1973), and magnetic resonance imaging (MRI) (1982) have been major advances during this period. A shift to functional hearing and facial nerve preservation were the goals of surgical removal of VS after these advances.

Gamma knife SRS was first used in 1969 by Dr. Lars Leksell to treat VS.[13] Between 1968 and 1974, the first prototype of the gamma knife unit was initially designed for functional targeting.[14] This unit was used to treat 9 patients with VS, including one neurofibromatosis type 2 (NF2) patient. Stereotactic fixation and imaging localization (pneumoencephalography) were crude methods at this time. Dosimetry was manually calculated and the central maximum dose was high (50 - 100 Gy) while the minimum dose was very low. None of the patients developed facial weakness and one patient experienced transient facial hypoaesthesia. Tumour control was achieved in 4 patients with a marginal tumour dose between 2 and 35 Gy (less than 1 Gy for failed cases).[17]

A second Gamma knife unit (Elekta U model) was designed specifically for tumours (spherical focus; 2 collimators of 8 and 14 mm) and used between 1974 and 1987. Computerised tomography was incorporated into the first SRS computerized dose planning system in 1975. The first 11 patients treated with this system were administered high tumour marginal radiation doses (20 - 70 Gy). Post-operatively, these patients developed a high rate of facial weakness (45%) and hypoaesthesia (80%). Consequently, marginal doses were decreased to 8 Gy. Unfortunately, treatment patients failed at this lower dose. A higher radiation dose between 10 and 20 Gy (mean 16.5) was then used through 1987. No patients developed a facial palsy and a high rate of tumour control (92%) was achieved.

The powerful Elekta B Gamma knife model was introduced in 1988 along with the Elekta G stereotactic frame (1987). Magnetic resonance imaging was coupled to SRS planning in 1989. Freshly loaded with new cobalt sources, the B unit was able to achieve a much higher dose rate than prior units. Despite using the same marginal dose as before, the rate of facial palsy increased to 27%. As a result, in 1989, the tumour marginal dose was lowered by G. Noren to 12 Gy (10 Gy for large and 14 Gy for small lesions).[17] A high level of functional hearing preservation (75%), absent facial palsy, and a high rate of tumour control (97%) was achieved.

The Pittsburgh experience

No group has contributed more to the evaluation and administration of SRS in the management of VS than Drs. L Dade Lunsford, Doug Kondziolka and John Flickinger from the University of Pittsburgh. Since 1987, when the University of Pittsburgh acquired the first gamma knife unit in North America, this team has treated thousands of patients and published numerous manuscripts on the management of VSs. This group has established optimal treatment parameters for tumour control of VSs in combination with hearing and facial nerve preservation. Dr. Lunsford et al, have confirmed the importance of G. Noren's policy of "low irradiation doses which are therapeutically effective".[5] They have demonstrated the impact of technical advances in the improvement of clinical results.[7] Flickinger, et al recently reviewed their series of 313 patients presenting with previously untreated unilateral VS who underwent SRS (with 12 - 13 Gy margin) between 1991 and 2001.[6] The actuarial six-year resection-free tumour control rate was 98.6%. The six-year actuarial rates for preserved facial nerve function, trigeminal nerve function, and hearing were 100%, 95.6 ± 1.8%, 78.6 ± 5.1%. Dr. Lunsford's team was the first to prospectively demonstrate the advantage (in term of functional outcome) of SRS over microsurgery in the management of VS.[20]

The Marseille experience

In 1992, SRS was incorporated into VS management in Marseille. A strong otoneurosurgical team already present, provided for a comprehensive and successful programme in the management of VSs. Between 1973 and 2004, a total of 2577 VSs have been surgically resected or treated by SRS in Marseille. Surgical resections include translabyrinthine, middle fossa and retrosigmoid/suboccipital approaches. Approximately 1500 patients have been treated with SRS using the gamma knife. All patients have been evaluated prospectively. Three major technical advances have clearly influenced our practice. The availability of high resolution stereotactic MRI, workstations to select the dose and treatment plan (Gamma Plan) and the installation of the robotic APS system have allowed our group to achieve more conformal and selective dose planning.[7,22] The

average number of isocentres used in 1992 was less than 5 and more than 15 in 2003 with the APS system.[23] Consequently, if we consider the first 100 patients of our experience representing our learning curve, 4 treatment periods can be defined. The rate of transient facial palsy and hemifacial spasm for VS patients treated by our group was, 3 and 3% during the first phase (June 1992 - December 1994; 100 pts), 1.4 and 2.8% during the second period (December 1994 - July 1997; 212 pts), 0.55 and 0.83% during the third period (July 1997 - May 2000; 360 pts), and 0 and 0% during the last period (May 2000 - January 2002; 258 pts), respectively. Only patients with greater than 2 years of follow-up were included in our series.[21]

Radiosurgical procedure

The procedure on the day of gamma knife surgery (GKS) treatment was started with application of the Leksell stereotactic frame (Elekta Instrument AB, Stockholm, Sweden) to the patient's head after induction of local anaesthesia. After the frame fixation, MR and CT imaging were used for dose planning with Leksell Gamma Plan (Elekta Instrument AB). The MR images were calibrated before examination and verified by comparison with the CT images for each patient. Gadolinium-enhanced axial T1-weighted MR images were acquired in 1 mm slices images, axial CISS images and axial Gd-enhanced CISS images in 0.5 mm. All of the imaging data were then fused with 0.2 mm axial CT bone windows scans and uploaded to Gamma Plan for dose planning in order to minimize magnetic distortion errors. Magnetic resonance CISS images provide excellent visualization of the structures in the pontocerebellar cistern and were particularly useful in allowing us to distinguish among the tumour, facial nerve, and acoustic nerve. Gadolinium-enhanced CISS images, on the other hand, demonstrate tumour and peritumoural cranial nerves very clearly and allow a good definition of the relationship between the tumour and the brainstem in Koos III and IV vestibular schwannomas. Fusing the CT and CISS images provides an even clearer view of the anatomical structures of the fundus of the IAM.

Dosimetry planning is certainly the most typical neuro-surgical instant in the radiosurgical procedure for the treatment of VS. Indeed, it is a key-moment in which the therapeutical choices will have a major influence on the clinical results, in terms of efficacy and safety. Multiple isocentres with different collimator sizes were chosen.

The theoretical aim was to deliver a dose of 12 Gy at the maximal (50%). However, the maximal dose was determined by integrating the measured dose to tumour coverage, conformity, selectivity, homogeneous intratumoural dose administration, and prevention of excessive irradiation of adjacent structures such as the cochlea taking in consideration the grading of hearing of the patient (Gardner Robertson classification) the day of the treatment. Leksell Gamma knife (Model B, Elekta Instrument AB) treatment proceeded according to routines of the department, and the patients were discharged within 12 hours after radiosurgery. All procedures were performed by the same neurosurgeon (Fig. 1).

Efficacy of radiosurgery

In order to better define the accuracy and efficacy of SRS, we have systematically evaluated the morphologic imaging changes of tumours treated between July 1992 and January 2002 by the otoneurosurgical group of the Timone Hospital in Marseille.[4] Evaluation of MRI performed before and after SRS (intervals of 6 months, 1, 2, 3, 5, 7 and 10 years) have been reviewed. Systematic measurements have been performed on all tumours treated. Preoperatively, 129 patients presented with progressive tumours. At the time of SRS, the median tumour volume was 732 mm^3 (mean 1346; range 20 - 14405). According to the Koos topographical classification, there were 80 stage I, 538 stage II, 322 stage III, and 56 stage IV cases. Loss of central enhancement was visible on postoperative MRI at 6 months and/or 1 year in 45.5% patients. In 64% of these patients, loss of the central contrast enhancement occurred. A significant increase in tumour size was recorded in 15% of the patients. In 3% of the patients, progression led to a second procedure, either resection or a second SRS procedure. We have defined failure as continuous tumour progression after 3 years from treatment (SRS). Tumour control was achieved in 97% of cases. Since the natural history of the VSs include growth of 2 mm/ year, our results confirm the efficacy of SRS (Fig. 2).

Hearing preservation

In spite of the technical advances in microsurgery, the majority of VS patients who undergo surgical resection, loose functional hearing. In our SRS experience, 175 patients, with a VS and functional preoperative hearing (Gardner and Robertson 1 or 2), were initially treated with SRS. These patients all had follow-up longer than 3 years.[9] Hearing preservation after SRS was 60% for all patients. Univariate and multivariate analysis have revealed parameters which influence the probability of functional hearing preservation at 3 years. These parameters include: a limited hearing loss (Gardner and Robertson stage 1), the presence of a tinnitus, younger age of the patient, and small lesion size. Functional hearing preservation at 3 years is 77.8% in patients with stage 1 hearing, 80% in patients with tinnitus as a first symptom, and 95% when the patient has both stage 1 hearing and tinnitus. In these patients, the probability of functional hearing preservation at 5 years is 84%.[9]

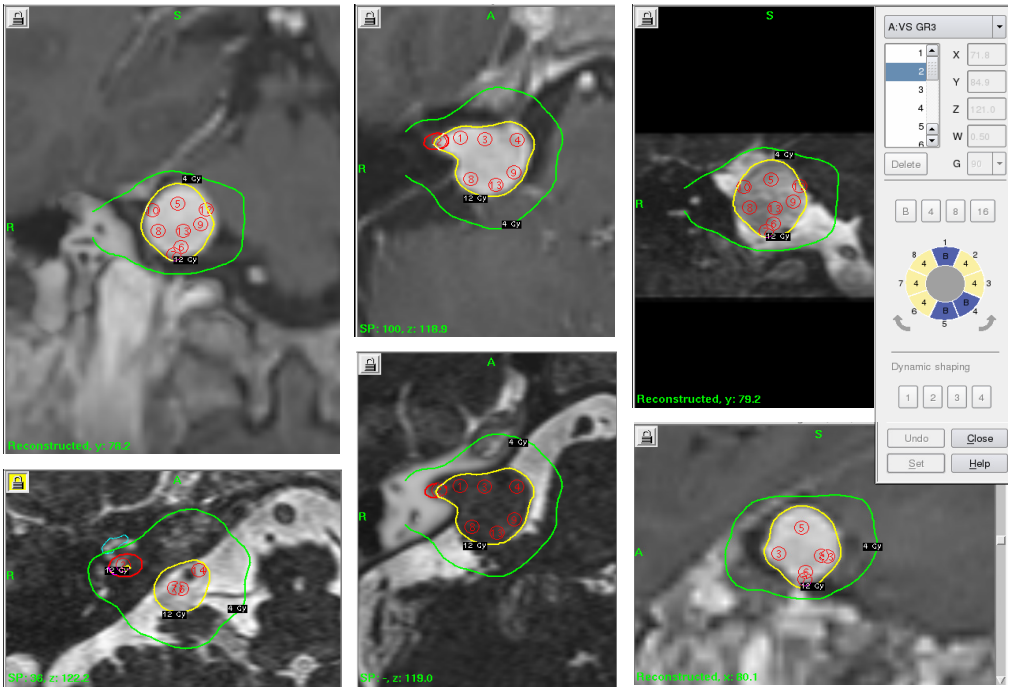
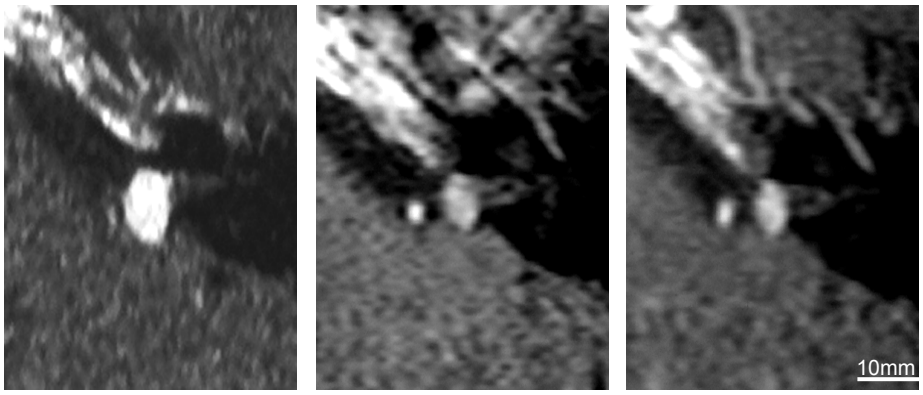
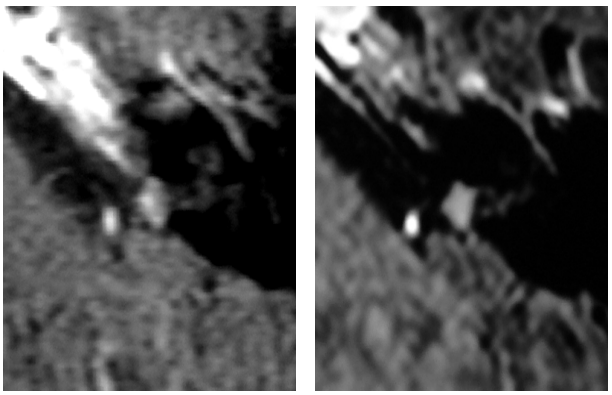


Figure 1 - Dose planning images obtained for GKS of a right Koos stage III VS, using CISS, CISS with contrast and 3D T1 sequences, and the corresponding sequences fused with CT

Figure 2 - Follow-up imaging of a left Koos stage II VS



GKS (01/98) 36 Months 59 Months



83 Months 119 Months

Figure 2a - Size of the tumour on (from left to right) the day of treatment, then 36 months, 59 months, 83 months and 119 months after GKRS.

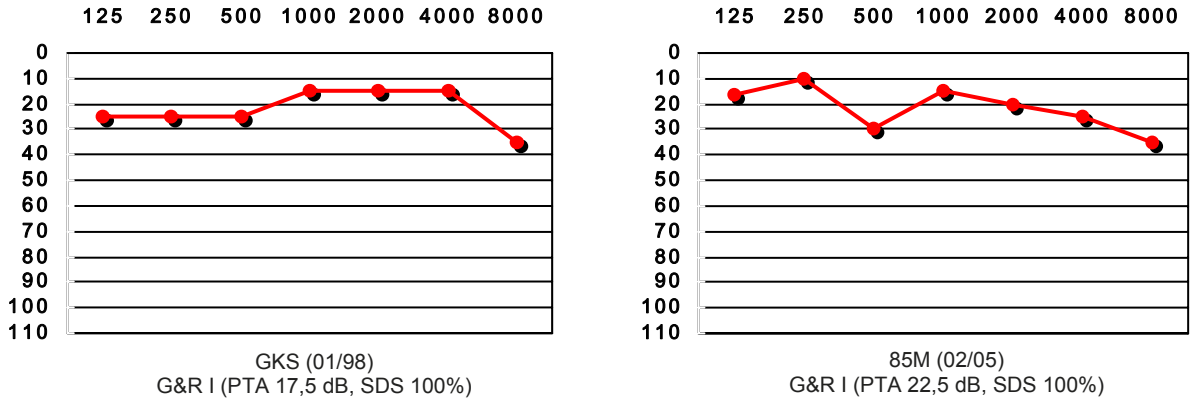


Figure 2b - Audiometry curves demonstrating excellent hearing preservation

Cochlear structures can be exposed to intolerable doses of radiation, especially when the tumour extends deeply into the IAC. Because of the correlation between irradiation of the cochlea and hearing outcome after radiosurgery, we define systematically the volume of the cochlea, and measure the dose of radiation delivered during the planning. The threshold dose to the cochlea is 4 Gy.[26]

Facial nerve preservation

Facial palsy is very rare (less than 1%) in our SRS management of VSs. Our results coincide with the Pittsburgh and Rhode Island experiences.[21] Schwannomas originating from the facial nerve itself are more prone to interfere with facial motor function. Surgical resection of VII nerve schwannomas implies a higher risk of facial palsy after surgery. Due to the paucity of facial palsy after SRS of VSs, the use of SRS may be rational in this difficult group of patients.[15] Among the 1000 schwannomas of the CPA treated by SRS in Marseille between July 1992 and March 2003, 9 have been diagnosed as originating from the VII nerve. Criterion for diagnosis was the involvement of the second or third portion of the VII nerve (7 patients) and/or intraoperative demonstration during a previous surgical resection (2 patients). Facial palsy occurring within 18 months of VS radiosurgery was determined in patients with more than 2 years of follow-up (8 patients). Four patients had previous facial paresis. Normal motor facial function was observed in 2 patients prior to SRS (House-Brackmann grade 2 in 6 patients; grade 3 in one patient). Follow-up ranged from 2 - 7 years in all patients. No patient developed worsening facial palsy while 2 patients had improvement in their preoperative facial palsy. Our results confirm the leading role of SRS in the management of VS in combination with facial nerve preservation.

Nervus intermedius dysfunction

The impact of radiosurgery on the facial nerve and nervus intermedius has recently been reported.[32] Due to the dual role of the facial nerve and the nervus intermedius in the mechanical protection of the eye, VS management can interfere with visual function. We have sought to evaluate and compare the impact of microsurgery or SRS on eye function. A functional questionnaire evaluating patient complaints related to the eye was sent to 100 patients who underwent SRS three years prior. Another questionnaire was sent to a group of 100 patients who underwent surgical resection. A Schirmer test was performed before radiosurgery and 2 years after SRS in 46 patients. The incidence of a dry and burning eye was much higher in patients who underwent surgical resection of their VS (57/99 patients), while no patients reported a dry and burning eye in the SRS group. The presence of a permanent facial deficit was reported by the majority of patients who underwent surgical resection (57/99 patients). In patients from both groups with no facial palsy, a dry eye was reported in 8/63 after SRS and 7/42 after surgical resection. Patients reported a burning eye in 9/63 after SRS and 9/42 after surgical resection. As a result, 15% of patients with no facial palsy present with possible injury of the intermedius nerve. When no permanent facial palsy is observed, a crocodile tear syndrome occurs predominantly after surgical resection (4/42 versus 1/63; $p = 0.07$). This could suggest an early lesion of cranial nerve VII and nervus intermedius and subsequent abnormal regrowth. The only patient reporting a crocodile tear syndrome after SRS presented transiently with a slight deficit of the orbicularis muscle. In the absence of facial palsy, a weeping eye was reported more frequently after surgical resection (16/42 versus 9/63; $p = 0.01$). This leads us to suspect a subclinical injury of the VII nerve. Of patients with a Schirmer test prior to SRS and 2 years after, 28.3% had improvement, 56.5% had a stable test, and 15.2% worsened. This study was the first to demonstrate that radiosurgery can induce nervus intermedius injury in a

small percentage of cases (15%). Symptoms related to the eye either due to the injury of the nervus intermedius and/or the VII nerve are much more frequent after surgical resection than after SRS. We believe evaluation of the lacrymal function must be part of the systematic evaluation of radiosurgery studies involving VSs.[32]

Vestibular symptoms

The influence of radiosurgery on vestibular symptoms is poorly understood. Our comparative study of the functional outcome of patients treated by SRS versus surgical resection have globally shown no superiority of one technique over the other for imbalance and vertigo.[24] The probability to observe a worsening at 3 years was 22% for microsurgery and 26% for radiosurgery.[24] However the systematic study of imbalance in our patients has revealed the improvement in postural orientation and stability after SRS.

We have recently reported the study of postural, vestibular dependent performances in 218 patients before and after SRS.[18] Subjects were asked to stand at ease on a static dynamometric foot-plate, gazing at a fixed point (EO condition) or stand with their eyes closed (EC condition). Statokinesigrams were registered during two consecutive sessions of 51.2 seconds, under EO and EC conditions. These sessions were performed the before (J - 1), and after (J + 1) irradiation; others were performed later (J + 1 to 5 years; n = 37). Centre of pressure, mediolateral (X), and sagittal (Y) positions were quantified every 100 ms. Mean Xm session value (with SD) was said a personal parameter for left or right body inclination. Area S for 90% of the XY successive placements of the C of P observed during a session was said an index for 2D postural sway. Before irradiation Grand average the 218 personal Xm mean values has evidenced a statistically significant body inclination toward the affected side, however under EC condition only. The day after irradiation a significant reduction of the Grand mean value of body inclination was observed. Statistics of paired Xm confirmed this trend toward usual symmetry. The day after stereo-irradiation averaging areas S of ellipses has indicated a shift of instability toward normality. For the two parameters, the pseudo-Romberg ratios (performance EC/performance EO) have indicated that a special visual contribution to balance control is present under vestibular nerve tumour (here I and II grades). The relative importance of this visual support reduced shortly after ionizing treatment. Because the radiation is neither noxious nor excitatory we think such a rapid recovery due to some recovery of vestibular nerve afferent conduction, and a rapid neural reprogramming of the balance control. These attractive results call for vestibular deeper investigations.

Hydrocephalus (HCP)

Obstructive HCP in association with a VS is a well known phenomenon. In order to investigate whether SRS contributes to HCP, we studied our own series of patients.[28] Among the 1000 patients treated at the Timone Hospital using SRS between July 1992 and January 2002, 43 patients displayed HCP. Thirty-two patients displayed HCP prior to treatment (group A) and 11 after treatment (group B). Age at the time of treatment (median age of 70 year in A and B) and tumour volume were higher than for the entire treated population. Following radiosurgery, 75% of the patients from group A did not require a shunting device whereas all the patients from group B required a shunt. Three patients had tumour progression requiring surgery. Occurrence of de novo HCP was a rare event (1%) that required a shunt early after radiosurgery, at a mean interval of 14.8 months. Results from this study suggest that radiosurgery is not responsible for a significant increase in the risk of HCP developing. We can postulate that SRS might provide a protective influence on HCP progression since the number of pre-existing patients with HCP which required a shunt was small.[28]

Microsurgery after radiosurgery

One of the primary criticisms of VS radiosurgery is the increased risk of microsurgery morbidity in those patients with tumour progression after SRS. We have recently reviewed our experience with patients who have undergone surgical resection after failed SRS.[27] From July 1992 to December 2000, 25 out of 1000 patients underwent a second procedure after SRS failure. Excluding NF2 patients, 21 patients underwent surgical resection. In order to analyse the potential difficulties encountered during surgical resection, a questionnaire was sent to the primary surgeon.

The mean interval between radiosurgery and surgical resection was 36 months, ranging from 10 to 83 months. The mean increase in volume was 559% (range 37 to 3036%, median 160%). Evaluation by the Koos staging system revealed 8 stage II, 10 stage III, 2 stage IV tumours. Patients underwent surgical resection for radiographic tumour progression in 7 cases and for clinico-radiological progression in 13 cases. In 9 cases, the surgeon reported unusual difficulty related to adhesion of the tumour to neurovascular structures. Tumour removal was complete in 14 cases, near total in 4 cases, and subtotal in 2 cases. One case of venous infarction occurred following surgical resection associated with hemiparesis and aphasia which gradually recovered. At last follow-up, facial nerve function was near normal (House-Brackmann grade I, II) in 10 cases while 7 cases had grade III, and 3 cases had grade IV and V function. We recommend that surgical resection of a progressive VS after SRS be performed after a sufficient follow-up period. Our results conclude that surgical resection may be more problematic and facial

nerve preservation might be impaired by radiosurgery in half of our cases. However, these results do not support a change in our decision making of radiosurgical treatment of small to medium size VS.[27]

Long-term complications

The use of SRS for many benign tumours has increased significantly over the last two decades. The long-term potential carcinogenic risk of SRS was not evaluated until recently. The definition of radio-induced tumours is based on the criteria by Cahan: the tumour must occur in a previously irradiated field, after a long time interval from irradiation, and must be pathologically different from the primary tumour and not present at the time of irradiation. In addition, the patient must not have a genetic predisposition for the tumour. A low dose of radiation, such as 1 Gy, has been associated with second tumour formation and a relative risk between 1.57 and 8.75. This relative risk increases to 18.4 for an interval time between 20 and 25 years. Radiation-associated tumour incidence is linked to different factors such as age and individual genetic susceptibility. At this time, three radiation-associated gliomas and five malignant VSs have been reported in the literature. Moreover, these second tumours do not meet all the Cahan criteria. We have reported two cases from our radiosurgical experience to discuss these points.[16] Long-term follow-up, ranging from 5 to 30 years, is needed to observe the crude incidence of radiation-induced tumours. The relative risk is estimated less than 1 per 1000 and must be reported to each patient prior to any radiosurgical procedure.

Comparison to microsurgery

In a comparison of 110 VSs surgically resected and 97 treated by SRS, a lower rate of facial palsy and a higher probability of functional hearing preservation were both achieved after SRS.[24] All patients had Koos stage II - II tumours with a minimum follow-up of 4 years.

NF2

Neurofibromatosis type 2 was present in 37 patients (50 VS treated by SRS) among the VS patients treated in Marseille between July 1992 and January 2002.[31] Prior to SRS treatment, surgical resection was performed on 16 patients. Tumour volumes ranged from 120 to 14405 mm^3 (mean 3468 mm^3) at the time of treatment. Twelve tumours were categorized as Koos stage IV. Median clinical and radiological follow-up was 62 months and ranged from 27 to 123 months. The 5 and 10-year actuarial survival rates were 90 and 85%, respectively. The 5-year actuarial survival rate without hearing decrement was 36% in patients with useful hearing (Gardner I and II) at the time of treatment. Severe phenotype of the disease ($p = 0.05$) and dose (> 12 Gy) delivered to the tumour margin ($p = 0.032$) correlated with hearing deterioration in a univariate analysis. Permanent facial nerve palsy occurred in 2%. These results confirm SRS is a valuable alternative treatment for NF2 patients with VSs. However, SRS does not provide the same level of tumour control and hearing preservation in comparison to treatment of patients with sporadic VSs. These results may improve with early treatment of NF2 VSs with SRS.

Stereotactic radiosurgery indications

Small and middle sized VS in young patients with few symptoms are the best candidates for radiosurgery. Patients with Koos stage II and III tumours are good candidates as well. Intracanalicular, cystic, previously resected, and Koos stage IV tumours may be candidates as well.

Intracanalicular schwannomas

Originally, Koos class I tumours, until 1999, were considered for radiosurgery only in cases of tumour progression at our institution. Our retrospective analysis of tumour growth rate, functional hearing preservation, and patients requesting radiosurgery have led us to modify our practice. Patients treated by SRS have a higher probability of functional hearing preservation.[25] Consequently, patients presenting with a stage I lesion and functional hearing are now considered for radiosurgery at our institution in the absence of tumour progression.

Large VS

Surgical resection and facial nerve preservation is reserved for large tumours. In a small number of patients, microsurgery is not warranted because of contralateral deafness or the presence of comorbidities. We have analyzed our results of SRS treatment of large VS.[30] Between July 1992 and December 2000, we treated 50 patients harbouring large VSs, defined as Koos stage IV. Follow-up data was available for 44 patients, including 12 NF2 patients. Mean age at the time of treatment was 43.5 years (range 14 - 84 years), mean diameter of the tumour was 18 mm (12 - 30), and the mean volume was 4301 cubic millimeters (1340 - 11405). Gamma knife treatment was undertaken utilizing an average of 13.4 isocentres (4 - 48) and a dose of 10.2 Gy at the tumour margin (8 - 14). Median follow-up of patients was 45.5 months (range 24 - 108 months). Tumour control was 69% (interval confidence 52 - 83%) and 3 patients had surgical resection because of tumour progression. Statistical analysis revealed the tumour volume correlated with SRS failure in a uni- and multivariate model ($p = 0.027$). No brainstem complication was observed in any patient. No facial nerve deterioration was found and useful hearing preservation was obtained in 12 out of 20 cases (60%). These results suggest that in a highly selected subgroup of large VSs, radiosurgery can be a potential alternative to open surgery, particularly if hearing preservation is pursued.

Patients need to understand the risk of SRS failure is much greater when large VSs are treated.[30]

Cystic vestibular schwannomas

Cystic VSs are a well defined subgroup of patients that historically have a poor outcome after microsurgical resection. These patients are considered poor candidates for radiosurgery based on Pendl's report of a high SRS failure rate.[19] Among the 1000 consecutive patients treated by SRS in Marseille between July 1992 and January 2002, 54 patients had cystic tumours at the time of treatment.[3] The median follow-up for this group of patients was 26 months (mean 33 mos.; range 6-90 months). A failure rate of 6.4% resulted in microsurgical tumour removal in two patients and repeat SRS in 1 patient. No patients developed a facial palsy. Two patients developed transient facial hypaesthesia. Among the 32 patients with functional hearing at the time of SRS, 53% had preserved hearing at 3 years follow-up. In summary, SRS treatment failure was higher in patients harbouring cystic tumours in comparison to patients with solid tumours (93.6% versus 98%).

Residual or recurrent VS after microsurgical resection

Significant morbidity is expected after a second microsurgical procedure for recurrent or growing residual VS. Among the first 1000 VSs treated by SRS in Marseille, 60 patients (including 12 NF2 patients) underwent radiosurgical treatment after one or more surgical resection attempts. There were 27 residual and 19 recurrent VSs. The mean interval of time between surgical removal and radiosurgery was 71.5 months (range 1.8 - 127.8 months). Difficulty with radiosurgery planning occurred with 12 patients due to problematic target identification. Median follow-up for these patients was 51.6 months. Four out of 58 patients (7%, CI 1.9 - 16.7) were considered treatment failures. Statistical evaluation failed to identify significant parameters influencing failure. Facial and trigeminal nerve function was not impaired in any patient. One patient developed a radiation-induced pontine injury responsible for lower cranial nerve deficits. Our results confirm SRS is an acceptable treatment alternative for patients that have undergone prior surgical resection.[29]

Planned combined surgical resection and GKS

Large vestibular schwannomas can be effectively treated by deliberate combination of subtotal microsurgical removal under neurophysiological control followed with gamma knife radiosurgery of the remnant. This two-fold therapeutic method seems to give an excellent functional outcome and high rate of tumoural control. Iwai, et al previously reported on a series of patients with large vestibular schwannomas who were treated using a combined surgical and radiosurgical approach.[12] The results obtained in the later series were encouraging, since the rate of facial nerve preservation was 85.7%, and an excellent rate of tumoural control was achieved. Since 2000, we adopted this strategy in our department, a small series was already evaluated, the average maximum diameter of the tumour was 40 mm (35 - 45 mm). At the time of radiosurgery the treatment size became 18 mm (9 - 20 mm). The mean peripheral dose administered was 11.8 Gy (range 11 - 13 Gy), and the mean dose administered in the centre of the tumour was 23.75 Gy (22 - 26 Gy). The mean follow-up period was 46 months after radiosurgery. Tumour control rate was 100%, excellent facial nerve function (House-Brackmann Grade I or II) was preserved in 87.5% instead of 50% with a radical removal (Fig. 3).[8]

Conclusion

We have evaluated the outcome results of our prospective series of patients with vestibular schwannomas treated by gamma knife SRS. Between July 1992 and March 2001, 1000 patients with VSs have been treated consecutively in Marseille Timone University Hospital. Patients without NF2 and tumours originating from the facial nerve represented a total of 927 patients (414 males and 513 females). According to the Koos classification, 77 patients had stage I, 520 stage II, 287 stage III, and 42 patients had stage IV tumours. Average tumour volume was 12.7 mm^3. Hearing prior to radiosurgery was useful, according to the Gardner and Robertson classification, in 47% of the patients. Tumour control at last follow-up was 97%. Trigeminal nerve injury was reported in 0.6% of the patients while 1.3% developed a facial palsy. Among the last 258 patients treated by SRS, no patient has developed a facial palsy. The rate of functional hearing preservation for patients with class I hearing was 77.8% at 3 years and 47.6% for class II hearing. In patients initially presenting with tinnitus, this rate of functional hearing preservation increased to 95%.

Based on our results and others, SRS may be superior to VS surgical resection in terms of cranial nerve preservation while equal in efficacy. Radiosurgery should be the preferred treatment modality for young patients with few symptoms presenting with small to medium sized VSs (Koos stage I - III). Determination of the potential long-term complications and mechanisms of action of radiosurgery should be future goals as the paradigm of SRS evolves.

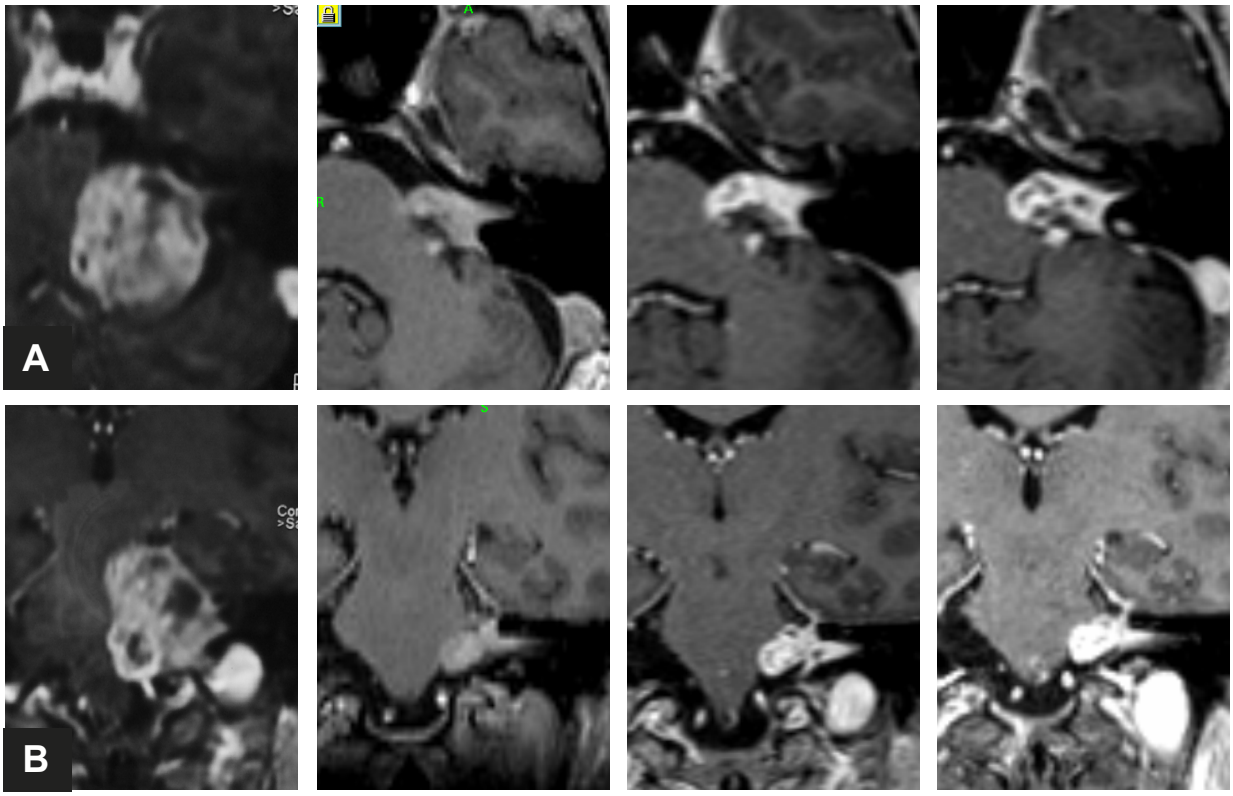


Figure 3 - Combined microsurgery and Gamma knife surgery – follow-up imaging of a left Koos stage IV VS. Axial and coronal T1 weighted MRI with contrast showing the tumour size (from left to right) preoperatively, on the day of GKRS with the residual fragment in contact with the facial nerve, and then the stability of the lesion at 6 and 24 months.

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Neuro-Radiological Quiz

What is your diagnosis?

Case history

45 year-old female known to have polycystic kidney disease presented with headache. No neurological deficit found.

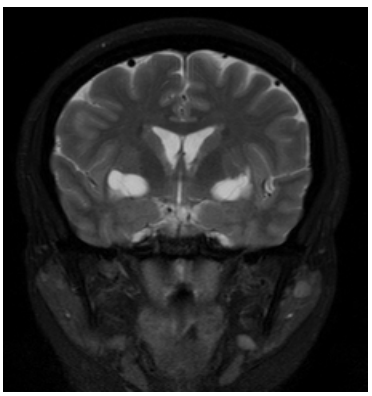

Figure 1 - Coronal T2

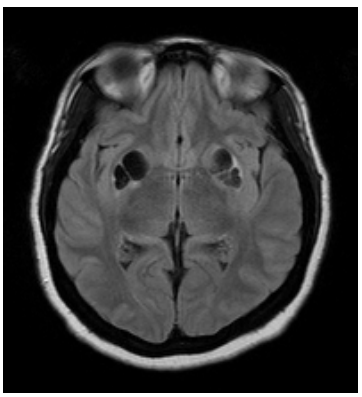

Figure 2 - Axial FLAIR

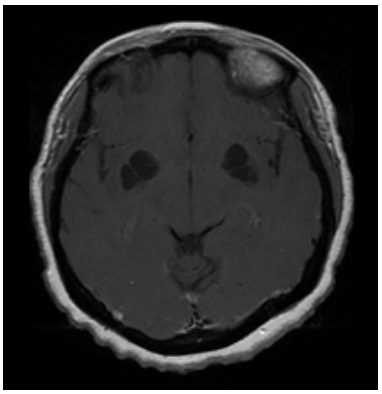

Figure 3 - Post contrast T1

Answer on page 120