

VESTIBOLOGY

Vestibular assessment in patients with vestibular schwannomas: what really matters?

Valutazione della funzione vestibolare nei pazienti affetti da Schwannomi vestibolari: cosa conta realmente?

R. TEGGI¹, A. FRANZIN², G. SPATOLA², N. BOARI², P. PICOZZI², M. BAILO², L.O. PICCIONI¹, F. GAGLIARDI², P. MORTINI², M. BUSSI¹

¹ Department of ENT, San Raffaele Scientific Institute, Milan, Italy, ² Department of Neurosurgery and Radiosurgery, San Raffaele Scientific Institute, Milan, Italy

SUMMARY

Vestibular function is often underdiagnosed in vestibular schwannomas (VS). To evaluate it in a selected group of patients harbouring vestibular schwannomas, 64 patients were included in this study, recruited between March 2008 and June 2011 at our institution. All patients underwent Gd-enhanced MRI and complete neurotological evaluation before gamma knife surgery. Morphological measurements included Koos Classification and quantification of internal acoustic canal filling in length and diameter. Cochlear and vestibular functions were assessed considering pure tone and speech audiometry, bedside examination and caloric test by videonystagmography. A statistical analysis was performed to find possible correlations between morphological and cochleovestibular data. Patients with a higher intracanalicular length (ICL, mean value 8.59 and median 8.8 mm) of the tumour presented a higher value of UW than the subgroup with a lower length ($51.9 \pm 24.3\%$ and $38.8 \pm 18.1\%$ respectively, $p = 0.04$), while no difference was detected for pure tone audiometry (PTA) values (50.9 ± 22.3 db and 51.1 ± 28.9 db respectively). Patients with a higher ICL also presented a higher rate of positive HIT (88% and 60% respectively, $p = 0.006$). Patients with a higher value of intracanalicular diameter (ICD, mean value 5.22 and median 5.15 mm) demonstrated higher values of UW ($50.2 \pm 29.1\%$ and $39.3 \pm 21\%$ respectively, $p = 0.03$), but not different PTA (50.2 ± 29.1 db and 51.9 ± 29.9 db respectively). Finally, patients with a positive head impulse test (HIT) demonstrated significantly higher values of unilateral weakness (UW) ($p = 0.001$). Vestibular disorders are probably underdiagnosed in patients with VS. ICL and ICD seem to be the main parameters that correlate with vestibular function. Also, in case of small intracanalicular T1 VS a slight increase of these variables can result in significant vestibular impairment. The data reported in the present study are not inconsistent with the possibility of proactive treatment of patients with VS.

KEY WORDS: Vestibular Schwannomas • Vestibular tests • Hearing loss • Gamma-Knife • Radiosurgery

RIASSUNTO

La funzionalità vestibolare è ad oggi poco studiata nei pazienti affetti da Schwannomi Vestibolari ed i deficit vestibolari spesso sottovalutati. Allo scopo di valutare tale funzione, sessantaquattro pazienti affetti da Schwannomi Vestibolari sono stati inclusi nel lavoro, reclutati tra marzo 2008 e giugno 2011 presso il nostro ospedale. Tutti i pazienti hanno eseguito una RMN encefalo con contrasto ed una valutazione cocleo-vestibolare completa prima del trattamento con Gamma-Knife. Le misurazioni morfologiche comprendevano la classificazione secondo Koos e la quantificazione della lunghezza e diametro intracanalare della lesione. La valutazione cocleo-vestibolare è stata effettuata con una audiometria tonale e vocale ed una valutazione vestibolare completa con videonistagmografia e stimolazione calorica. Una analisi statistica è stata condotta per valutare possibili correlazioni tra i dati morfologici della lesione ed i reperti cocleo-vestibolari. I pazienti con una maggiore estensione in lunghezza della lesione all'interno del canale (media 8,59, mediana 8,8 millimetri) presentavano più elevati valori di Preponderanza Labirintica alla prova termica ($51,9$ e $38,8$ rispettivamente, $p = 0,04$), mentre nessuna differenza è stata trovata relativamente alla perdita uditiva all'esame audiometrico tonale ($50,9$ db e $51,1$ db rispettivamente). I pazienti con maggiore estensione intracanalare in lunghezza presentavano anche una più alta percentuale di positività al test dell'Head Impulse (88% e 60% rispettivamente, $p = 0,006$). I pazienti con maggiore diametro intracanalare della lesione (media 5,22, mediana 5,15 millimetri) hanno evidenziato più alti valori di Preponderanza Labirintica al test calorico ($50,2$ e $39,3$ rispettivamente, $p = 0,03$) ma nessuna differenza di soglia uditiva ($50,2$ e $51,9$ rispettivamente). Per ultimo, i pazienti con Head Impulse positivo hanno evidenziato più alti valori di Preponderanza Labirintica ai test calorici ($p = 0,001$). I disordini vestibolari sono probabilmente sotto-diagnosticati nei pazienti affetti da Schwannoma dell'8° nc. La lunghezza ed il diametro della lesione entro il condotto uditivo interno sono risultati i principali parametri correlabili con il danno vestibolare. Anche in caso di piccole lesioni T1, un modesto incremento della lesione potrebbe inoltre determinare un significativo peggioramento della funzione vestibolare. Questi dati suggeriscono l'utilità di una terapia attiva anche in pazienti con lesioni di piccolo volume a decorso intracanalare.

PAROLE CHIAVE: Schwannomi 8° nervo cranico • Test vestibolari • Ipoacusia • Gamma-Knife • Radiocirurgia

Introduction

Vestibular schwannomas (VS) are extra-axial, slow-growing benign lesions arising from the vestibular nerve. Usually the VS originates in the distal neurilemmal portion of the nerve at, or close to, the neurilemmal glial junction¹. The median age at diagnosis is 50 years and appears in a sporadic unilateral form in the majority of cases (95%), with an incidence of about 1/100,000 per year, without any sexual prevalence^{2,3}. When bilateral, it is often linked to a neurofibromatosis type 2, an autosomal dominant tumour-suppressor syndrome characterised by schwannomas, meningiomas and ependymomas that develop throughout the central and peripheral nervous systems^{4,5}. They represent more than 90% of all cerebellopontine angle lesions. In 25%-45% of cases schwannomas occur in head and neck region⁶.

In the last decades, with the widespread availability of MRI, the incidental diagnoses of VS has increased, while the size of newly diagnosed VS has progressively decreased. Despite the anatomical origin, many patients with VS complain of hearing loss^{7,8}, but only a few experience vestibular symptoms⁹. Many studies have demonstrated the correlation between tumour size and functional hearing^{10,11}, but the correlation between tumour extension and vestibular symptoms has still not been clarified.

In previous studies, tumour size has been demonstrated to have a correlation with caloric responses and vestibular evoked myogenic potentials (VEMPs), and above all with ocular VEMPs^{12,13}, although in patients with VS within the internal acoustic canal neither the nerve origin of the tumour nor tumour size show clear correlation with the results of these tests¹⁴. In fact, the absence of caloric responses and VEMPs from one side may be predictive of a tumour size > of 2.5 cm¹⁵.

Three options have been proposed for VS:

Surgical treatment may be considered^{16,17}, although according to some authors intervention may be associated with several complications¹⁸;

A radiosurgical approach may be alternatively taken^{19,20}; according to the recent guidelines for the treatment of VS approved by the International RadioSurgery Association (IRSA)²¹, stereotactic radio-surgical treatment with gamma knife (GKS) is indicated in tumours smaller than 3 cm in diameter without brainstem distortion, post-surgical residual even larger than 3 cm and growing intracanalicular tumours. Recent studies reported a tumour growth control rate after GKS treatment of 93-100%^{22,23};

Since most VS have a slow growth rate, management with a "wait and see" policy has been proposed^{24,25}.

Some authors underline that when surgery is needed after radiosurgery, the risk of facial nerve palsy is increased²⁶. Audiometric exam, rather than vestibular assessment, is at present mainly considered in therapeutic decision. The

present study aims to evaluate vestibular function in a selected group of patients eligible for GKS for VS.

Materials and methods

Patient population

Between March 2008 and June 2011, 240 patients underwent GKS for VS at the Neurosurgical Department of San Raffaele Hospital in Milan. All patients were eligible for GKS according to IRSA Guidelines.

In all cases, Gd-enhanced MRI and complete otolaryngological evaluation before GKS treatment were performed. Exclusion criteria were:

- no detectable hearing before treatment;
- type 2 neurofibromatosis;
- bilateral tumours;
- Koos T4b stage;
- previous therapy on the targeted tumour;
- evidence of chronic otitis media and/or previous surgery of the middle ear;
- therapies with ototoxic drugs and/or chemotherapy;
- other lifetime vestibular disorders, with particular attention to Ménière's disease and CNS disorders.

Moreover, patients were asked to avoid consumption of any sedative drugs within the 24 hours before examination. According to these criteria, 64 patients were selected and included in the study: 42 women (66%) and 22 men (34%) with a mean age of 54.5 years (median 55.5 years, range 19-81 years). Thirty-five patients (55%) had right sided VS, and 29 (45%) left sided VS. Demographic data are summarised in Table I.

Evaluation of tumour size

Tumour volume, internal acoustic canal filling (in length and diameter) and Koos classification were assessed on MRI (Magnetom Vision model, Siemens; 1.5 Tesla) performed before GKS. The MRI imaging sequences were gadolinium contrast enhanced axial and coronal T1-weighted (2 mm thickness without gap, TR = 650, TE = 14, matrix 512 x 512 and double acquisition), 3D-CISS (reconstructed to 1.2 mm thickness without gap, TR = 4000, TE = 250, matrix 512 x 512) and axial T2 weighted (2 mm thickness without gap, TR = 3000, TE = 120, matrix 512 x 512).

The tumour volume varied between 0.01 and 9.4 ml (mean 1.34 ± 0.22 ml, median 0.73 ml). The mean intracanalicular length (ICL) was 8.59 mm (median 8.8 range 2.8-13.4 mm), and mean intracanalicular diameter (ICD) was 5.22 mm (median 5.2 range 1.1-10.8 mm). According to Koos classification, 11 lesions were stage T1, 8 stage T2, 15 stage T3a, 20 stage T3b and 10 stage T4a; no patients with 4th ventricle obstruction (Koos stage T4b) were included. Morphologic data are summarised in Table II.

Table I. Patient population.

Characteristic	# patients (%)
Sex	
Male	22 (34)
Female	42 (66)
Side	
Right	35 (55)
Left	29 (64)
Koos tumour stage	
T1	11 (17)
T2	8 (13)
T3a	15 (23)
T3b	20 (31)
T4a	10 (16)

Table II. Morphological data of lesions.

	Age y \pm SD	ICL mm \pm SD	ICD mm \pm SD	Volume ml \pm SD
Koos 1 (n=11)	51 \pm 15	8.2 \pm 1.9	4.7 \pm 1.5	0.12 \pm 0.08
Koos 2 (n=8)	47 \pm 19	9.4 \pm 2.2	5.6 \pm 1.2	0.53 \pm 0.34
Koos 3A (n=15)	55 \pm 9	7 \pm 2.5	4.9 \pm 1.6	1.3 \pm 1
Koos 3B (n=20)	55 \pm 13	9.6 \pm 2.5	5.1 \pm 1.8	2.7 \pm 2.6
Koos 4 (n=10)	57 \pm 16	8.3 \pm 2.8	5.6 \pm 1.8	4.8 \pm 2.9

ICD = intracanalicular diameter, ICL = intracanalicular length, y = years.

Cochlear and vestibular assessment

Cochlear and vestibular assessments were performed by a senior neurotologist and included:

- Clinical history for the age of onset of cochlear symptoms, presence of previous episodes of rotational vertigo and sensation of unsteadiness or imbalance.
- Pure tone audiometry for frequencies between 250 Hz and 8000 Hz; the exam was performed in a quiet room with a half octave precision. The pure-tone average (PTA) was calculated as the mean of 0.5, 1, 2, and 3 kHz thresholds.
- Speech audiometry was performed in silence, scoring by phonemes correctly repeated at several suprathreshold intensities. The CD contained phonetically balanced disyllabic lists commonly used for adult clinical testing. Speech discrimination score (SDS) was assessed; SDS was defined as the percentage of words correctly identified.
- Evaluation of vestibular system function performed by videonystagmography using the VO25 VNG system (Interacoustics, Assens, Denmark); the full vestibular examination included a study of spontaneous nystagmus, post head shaking test (HST), head impulse test (HIT) and hyperventilation tests.

- Caloric stimulation according to Fitzgerald-Hallpike was performed using an Amplaid otocalorimeter. The authors used angular slow phase velocity (SPV), as calculated during 10 sec of culmination, as the single parameter of labyrinthine function during caloric tests: data were interpreted in terms of unilateral weakness (UW) according to Jongkees' formula.

According to the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) guidelines²⁷, hearing function was defined as class A (PTA < 30 dB and SDS > 70%), class B (PTA > 30 dB and < 50 dB and SDS > 50%), class C (PTA > 50 dB and SDS > 50%) or class D (PTA any level and SDS < 50%). Caloric vestibular function was defined as class A when UW was less than 25%, class B when between 25 and 50%, class C when between 50 and 75%, class D when UW exceeded 75%.

Statistical analysis

Continuously distributed variables were described as mean and standard deviation (SD), while median values and categorical variables were described by frequencies and percentages. The significance of any difference between groups was evaluated by a t-test for independent samples and analysis of variance (ANOVA) for repeated measures. Nominal data were compared by the chi-square test. The results were considered statistically significant for p values < 0.05.

Results

In this cohort, 18 subjects referred a previous episode of acute vertigo and 26 referred feeling unstable. Results of cochlear and vestibular findings differentiated for Koos classification are shown in Table III. Although patients with Koos 2 stage VS presented lower values of UW and PTA compared to other groups, no statistical difference was detected. Koos 4 patients referred a lower rate of lifetime rotational vertigo than other subjects. No difference was present for clinical history of imbalance.

HIT was positive in 8 subjects in Koos stage 1 (80%), 6 in Koos 2 (75%), 12 in Koos 3a (80%), 19 in Koos 3b (95%) and 7 in Koos 4a (60%). All subjects with a positive hyperventilation test also presented a positive HIT. Finally, the total population of patients with a positive HIT demonstrated higher values of UW (p = 0.001).

All vestibular and cochlear results were compared to the ICL and ICD. ICL values ranged between 2.8 and 13.4 mm (mean 8.59 \pm 2.65 mm) and the median was 8.8 mm. ICD values ranged between 1.1 and 10.8 mm (mean 5.22 \pm 1.68 mm) and the median was 5.15 mm. The subgroup of 30 patients with a higher ICL of the tumour presented a higher value of UW than the subgroup with a lower length (51.9 \pm 24.3% and 38.8 \pm 18.1% respectively, p = 0.04), while no difference was seen for PTA values (50.9 \pm 22.3 db and 51.1 \pm 28.9 db, respectively). Moreover, patients with a higher ICL also presented a higher rate

Table III. Cochlear and vestibular data.

	Vertigo	Imbalance	Mean PTA in decibel	Class of Hearing function	Class of vestibular function	UW%	Hypervent
Koos 1 (n = 11)	5 (45%)	5 (45%)	49 ± 27	A = 4 B = 1 C = 4 D = 2	A = 1 B = 3 C = 6 D = 1	52 ± 21	9 (82%)
Koos 2 (n = 8)	3 (37%)	4 (50%)	25 ± 13	A = 5 B = 2 C = 1	A = 4 B = 4	29 ± 14	4 (50%)
Koos 3A (n = 15)	4 (27%)	3 (20%)	60 ± 30	A = 3 B = 6 C = 3 D = 3	A = 2 B = 5 C = 4 D = 4	46 ± 27	11 (73%)
Koos 3B (n = 20)	6 (30%)	9 (45%)	57 ± 35	A = 4 B = 6 C = 6 D = 4	A = 2 B = 9 C = 5 D = 4	49 ± 25	16 (80%)
Koos 4A (n = 10)	1 (10%)	5 (50%)	55 ± 34	A = 2 B = 3 C = 3 D = 2	A = 1 B = 6 C = 1 D = 2	47 ± 30	7 (70%)

PTA = Pure tone average, UW = unilateral weakness.

of positive HIT (88% and 60% respectively, $p = 0.006$). No difference between the two groups was detected in the hyperventilation test (72% and 70% of subjects, respectively). Finally, the subgroup of 30 patients with a higher value of ICD demonstrated higher values of UW ($50.2 \pm 29.1\%$ and $39.3 \pm 21\%$ respectively, $p = 0.03$), but not different PTA (50.2 ± 29.1 db and 51.9 ± 29.9 db, respectively). No statistical difference for HIT was observed between these two groups (81% and 68%, respectively) and hyperventilation test (73% and 69%, respectively).

Discussion

Since VS originates from the vestibular nerve, a deficit of vestibular function should always be observed²⁸; nonetheless, vestibular impairments are rarely studied in preoperative workup, and most patients came to diagnosis because of hearing loss confirmed by audiometric exam. According to previous studies, the degree of the vestibular deficit correlates with both tumour size and growth rate²⁹. In our sample, only 18 subjects referred a previous episode of acute vertigo; in contrast, only 10 patients had normal vestibular assessment (15%; 1 subject in T1 stage, 4 in T2, 3 in T3a and 2 in T3b). Our data are in agreement with previously published data concerning vestibular abnormalities in patients with VS, reporting normal vestibular function in only 14% of cases. It should be also considered that only 26 subjects (40%) in our cohort referred imbalance; in our opinion, central compensation processes in slowly decreasing vestibular function may explain the significant difference with the rate of subjects presenting UW at caloric tests.

At present, the HIT proposed by Halmagyi and Curthois is widely used to detect vestibular peripheral hypofunction³⁰; hyperventilation, on the other hand, is an increasingly used bedside test and alkalosis provoked by the manoeuvre can produce a nystagmus normally beating towards the healthy side, probably disrupting central compensation. In our series, the hyperventilation test was positive in 73% of patients, while other authors reported a positive result in up to 91.7% of cases³¹⁻³³; in particular, we found no statistical difference in test responses between patients with higher or lower ICL /ICD. Moreover, according to some authors, caloric responses are well correlated with intraoperative findings and provide predictive factors for facial palsy and hearing outcome³⁴. The loss of vestibular function has been correlated with tumour size, although it is not strictly associated with a deterioration of the quality of life assessed with the Dizziness Handicap Inventory questionnaire¹⁰.

Another previous study reported a higher incidence of vertigo in patients with small and medium size VS compared to patients harbouring larger tumours (> 4 cm)³⁵; in the present series, vestibular function correlated with the ICL and ICD of VS rather than with tumour volume or Koos stage. A possible explanation for this finding may be that the main mechanism of nerve injury is related to its compression inside the internal acoustic canal. On these bases, some authors proposed clinical intervention, such as vestibular rehabilitation in all patients with VS, and especially in subjects treated with surgical intervention or GKS³⁶.

Some authors advocate a wait-and-see strategy, especially for T1 stage VS, and focusing attention on tumour growth and hearing function^{24,25,37}. On the other hand, other dem-

onstrated that the wait-and-see policy exposes patients to a high risk of tumour growth and hearing loss. Both events may occur independently in the mid-term period³⁸. To the best of our knowledge, nothing has been published on vestibular function in patients proposed for wait-and-see policy. The results of this study showed that vestibular function is more influenced by ICL and ICD, rather than by total tumour volume. Consequently, it is likely that a slight increase in ICL or ICD may produce alteration in the HIT and caloric responses, reflecting a poorer result in terms of vestibular function even after successful therapy at later times. It should be also considered that previous studies reported tumour growth control in 98% of patients treated with GKS, possibly avoiding a further increase in ICL and ICD with the possibility of hearing and vestibular preservation¹⁹. The data reported in the present study support the possibility of proactive GKS treatment even in patients harbouring small T1 VS. Nevertheless, a prospective study analyzing data on vestibular function after GKS is needed to confirm this possibility.

Conclusions

Vestibular disorders are probably underdiagnosed in patients with VS, and complete vestibular assessment should always be performed. ICL and ICD seem to be the main parameters that correlate with vestibular function even in patients harbouring small intracanalicular VS. Particular attention should be given to ICL and ICD in small T1 VS, in which even a slight increase of these variables can affect vestibular function. The data from the present study support the role of proactive treatment even in these patients. Nevertheless, a prospective study analysing data on vestibular function after GKS is needed to confirm this possibility.

Abbreviations

VS:	Vestibular Schwannomas
GKS:	Gamma Knife
HIT:	Head Impulse Test
UW:	Unilateral Weakness
PTA:	Pure Tone Audiometry
ICD:	Intracanalicular Diameter
ICL:	Intracanalicular Length
SDS:	Speech Discrimination Score

References

- 1 Roche PH, Bouvier C, Chinot O, et al. *Genesis and biology of vestibular schwannomas*. *Prog Neurol Surg* 2008;21:24-31.
- 2 Propp JM, McCarthy BJ, Davis FG, et al. *Descriptive epidemiology of vestibular schwannomas*. *Neuro Oncol* 2006;8:1-11.
- 3 Tos M, Stangerup SE, Caye-Thomasen P, et al. *What is the real incidence of vestibular schwannoma?* *Arch Otolaryngol Head Neck Surg* 2004;130:216-20.
- 4 Blakeley J. *Development of drug treatments for neurofibromatosis type 2-associated vestibular schwannoma*. *Curr Opin Otolaryngol Head Neck Surg* 2012;20:372-9.
- 5 Barbara M, Ronchetti F, Manni V, et al. *Double localization of a unilateral sporadic vestibular schwannoma*. *Acta Otorhinolaryngol Ital* 2008;28:34-7.
- 6 Iaconi P, Faggioni M, De Bartolomeis C, et al. *Cervical sympathetic chain schwannoma: a case report*. *Acta Otorhinolaryngol Ital* 2012;32:133-6.
- 7 Ginzkey C, Scheich M, Harnisch W, et al. *Outcome on hearing and facial nerve function in microsurgical treatment of small vestibular schwannoma via the middle cranial fossa approach*. *Eur Arch Otolaryngol* 2013;270:1209-16.
- 8 Ragab A, Emara A, Shouker M, et al. *Prospective evaluation of the clinical profile and referral pattern differences of vestibular schwannomas and other cerebellopontine angle tumors*. *Otol Neurotol* 2012;33:863-7.
- 9 Wackym PA, Hannley MT, Runge-Samuelson CL, et al. *Gamma Knife surgery of vestibular schwannomas: longitudinal changes in vestibular function and measurement of the Dizziness Handicap Inventory*. *J Neurosurg* 2008;109 (Suppl):137-43.
- 10 Wagner JN, Glaser M, Wowra B, et al. *Vestibular function and quality of life in vestibular schwannoma: does size matter?* *Front Neurol* 2011;2:e55.
- 11 Montaguti M, Bergonzoni C, Zanetti MA, et al. *Comparative evaluation of ABR abnormalities in patients with and without neurinoma of VIII cranial nerve*. *Acta Otorhinolaryngol Ital* 2007;27:68-72.
- 12 Ushio M, Iwasaki S, Chihara Y, et al. *Is the nerve origin of the vestibular schwannoma correlated with vestibular evoked myogenic potential, caloric test, and auditory brainstem response?* *Acta Otolaryngol* 2009;129:1095-100.
- 13 Huang CH, Wang SJ, Young YH. *Correlation between caloric and ocular vestibular evoked myogenic potential test results*. *Acta Otolaryngol* 2012;132:160-6.
- 14 Day AS, Wang CT, Chen CN, et al. *Correlating the cochleovestibular deficits with tumor size of acoustic neuroma*. *Acta Otolaryngol* 2008;128:756-60.
- 15 Demonte F, Gidley PW. *Hearing preservation surgery for vestibular schwannoma: experience with the middle fossa approach*. *Neurosurg Focus* 2012;33:e10.
- 16 Mazzoni A, Biroli F, Foresti C, et al. *Hearing preservation surgery in acoustic neuroma. Slow progress and new strategies*. *Acta Otorhinolaryngol Ital* 2011;31:76-84.
- 17 Mazzoni A, Zanoletti E, Calabrese V. *Hearing preservation surgery in acoustic neuroma: long-term results*. *Acta Otorhinolaryngol Ital* 2012;32:98-102.
- 18 Ansari SF, Terry C, Cohen-Gadol AA. *Surgery for vestibular schwannomas: a systematic review of complications by approach*. *Neurosurg Focus* 2012;33:e14.
- 19 Franzin A, Spatola G, Serra C, et al. *Evaluation of hearing function after gamma knife surgery of vestibular schwannomas*. *Neurosurg Focus* 2009;27:e3.
- 20 Mulder JJ, Kaanders JH, van Overbeeke JJ, et al. *Radiation therapy for vestibular schwannomas*. *Curr Opin Otolaryngol Head Neck Surg* 2012;20:367-71.
- 21 IRSA: *Stereotactic radiosurgery for patients with vestibular schwannoma*. 2006.

- ²² Chung WY, Liu KD, Shiau CY, et al. *Gamma knife surgery for vestibular schwannoma: 10-year experience of 195 cases*. J Neurosurg 2005;102:87-96.
- ²³ Yomo S, Carron R, Thomassin JM, et al. *Longitudinal analysis of hearing before and after radiosurgery for vestibular schwannoma*. J Neurosurg 2012;117:877-85.
- ²⁴ Bakkouri WE, Kania RE, Guichard JP, et al. *Conservative management of 386 cases of unilateral vestibular schwannoma: tumor growth and consequences for treatment*. J Neurosurg 2009;110:662-9.
- ²⁵ Godefroy WP, Kaptein AA, Vogel JJ, et al. *Conservative treatment of vestibular schwannoma: a follow-up study on clinical and quality-of-life outcome*. Otol Neurotol 2009;30:968-74.
- ²⁶ Falcioni M, Piccioni LO, Taibah A, et al. *Treatment of residual acoustic neurinomas*. Acta Otorhinolaryngol Ital 2000;20:151-8.
- ²⁷ *Committee on Hearing and Equilibrium guidelines for the evaluation of hearing preservation in acoustic neuroma (vestibular schwannoma)*. American Academy of Otolaryngology-Head and Neck Surgery Foundation, INC. Otolaryngol Head Neck Surg 1995;113:179-80.
- ²⁸ Erickson LS, Sorenson GD, McGavran MH. *A review of 140 acoustic neurinomas (neurilemmoma)*. Laryngoscope 1965;75:601-27.
- ²⁹ Stipkovits EM, Van Dijk JE, Graamans K. *Electronystagmographic changes in patients with unilateral vestibular schwannomas in relation to tumor progression and central compensation*. Eur Arch Otorhinolaryngol 1999;256:173-6.
- ³⁰ Black RA, Halmagyi GM, Thurtell MJ, et al. *The active head-impulse test in unilateral peripheral vestibulopathy*. Arch Neurol 2005;62:290-3.
- ³¹ Califano L, Melillo MG, Vassallo A, et al. *Hyperventilation-induced nystagmus in a large series of vestibular patients*. Acta Otorhinolaryngol Ital 2011;31:17-26.
- ³² Bance ML, O'Driscoll M, Patel N, et al. *Vestibular disease unmasked by hyperventilation*. Laryngoscope 1998;108:610-4.
- ³³ Minor LB, Haslwanter T, Straumann D, et al. *Hyperventilation-induced nystagmus in patients with vestibular schwannoma*. Neurology 1999;53:2158-68.
- ³⁴ Tringali S, Charpiot A, Ould MB, et al. *Characteristics of 629 vestibular schwannomas according to preoperative caloric responses*. Otol Neurotol 2010;31:467-72.
- ³⁵ Heerma H, Braun V, Richter HP. *Effect of microneurosurgical operation in acoustic neurinoma on symptoms of vertigo and tinnitus*. Hno 2000;48:372-7.
- ³⁶ Wackym PA, Hannley MT, Runge-Samuels CL, et al. *Gamma knife surgery of vestibular schwannomas: longitudinal changes in vestibular function and measurement of the Dizziness Handicap Inventory*. J Neurosurg 2008;109:137-43.
- ³⁷ Hughes M, Skilbeck C, Saeed S, et al. *Expectant management of vestibular schwannoma: a retrospective multivariate analysis of tumor growth and outcome*. Skull Base 2011;21:295-302.
- ³⁸ Regis J, Carron R, Park MC, et al. *Wait-and-see strategy compared with proactive gamma knife surgery in patients with intracanalicular vestibular schwannomas*. J Neurosurg 2010;113:105-11.

Received: May 22, 2013 - Accepted: September 23, 2013

Address for correspondence: Roberto Teggi, Department of ENT, San Raffaele Scientific Institute, via Olgettina 60, 20132 Milan, Italy. Tel. +39 02 26433522. Fax +39 02 26433508. E-mail: teggi.roberto@hsr.it