Intracanalicular Vestibular Schwannoma: A Systematic Review and Meta-analysis of Therapeutics Outcomes

*†Marina Neves Cavada, ‡Michael Fook-Ho Lee, *||¶**Nicholas Emmanuel Jufas, *§Richard John Harvey, and *||¶**Nirmal P. Patel

*Department of Otolaryngology, Head and Neck Surgery, Faculty of Medicine and Health Sciences, Macquarie University; †Sydney Adventist Hospital; ‡Department of Otolaryngology, Head and Neck Surgery, Westmead Hospital; §Rhinology and Skull Base Research Group, Applied Medical Research Centre, University of New South Wales; ||Kolling Deafness Research Centre, University of Sydney & Macquarie University; ¶Department of Otolaryngology, Head and Neck Surgery, Royal North Shore Hospital; and **Discipline of Surgery, Sydney Medical School, University of Sydney, Sydney, NSW, Australia

Objective: To perform a systematic review and meta-analysis summarizing the current evidence on the management of intracanalicular vestibular schwannoma.
Data Sources: Embase (1947–), Medline (1946–), Cochrane library (1947–), Scopus (2010–), and CINAHL (1961–) were searched from 1969 to October 5, 2019 (50 years).
Study Selection: A search strategy was performed to identify patients with vestibular schwannoma confined to the internal auditory canal without extension to the cerebellopontine angle. Studies with patients aged less than 18, Neurofibromatosis type 2, revision cases, and non-English language were excluded.
Data Extraction: A standardized collection sheet was used for the extracted data and a quality assessment was performed using the Newcastle-Ottawa Scale with the comparability criterion omitted.
Data Synthesis: Seventy-one studies were included with 24 on observation, 14 on radiotherapy, and 34 on surgery. The primary outcome was serviceable hearing preservation. Secondary outcomes were preservation of facial nerve function, growth, involution, and dizziness. Sub-analysis on the type of surgery and type of radiotherapy were performed. Excel 2016 with MIX 2.0 Pro add-on package was used to analyze the data and create forest plots. Data were presented in proportion with a 95% confidence interval.
Conclusions: Serviceable hearing was observed in 31% of patients after observation, 56% after radiotherapy, and 51% after surgical treatment with mean follow-up time of 4.04 years, 4.92 years, and 2.23 years, respectively. Facial nerve function was found to be best preserved in both observation and radiotherapy groups. Vestibular schwannoma growth occurred in 33% of patients under observation. Involution occurred in 2% of patients under observation and in 38% after radiotherapy. **Key Words:** Acoustic neuroma—Acoustic tumor—Vestibular schwannoma.

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Vestibular schwannoma (VS) is defined as intracanalicular when it is limited to the internal auditory canal (1). The mean diameter of the tumor at diagnosis has decreased from 30 mm in 1979 to 10 mm in 2008, most likely from an increase in magnetic resonance imaging (MRI) availability (2,3). Cases that are exclusively intracanalicular have demonstrated a 25% increase in incidence, during this time period (3).

Three modalities of treatment are available for intracanalicular vestibular schwannoma (ICVS) including observation, stereotactic radiotherapy, and microsurgery (1,4). Since ICVS typically has gradual growth, conservative management with periodic imaging and audiogram follow-up has been advocated as an alternative to avoid complications related to other treatment options (1,2). However, controversies have arisen due to concerns regarding hearing deterioration and the risk of tumor growth (1). Therefore, some authors have reported a preference for microsurgery or stereotactic radiotherapy to preserve long-term serviceable hearing (1). Long-term treatment outcome goals are tumor control, preservation of cranial nerve function, including functional hearing and balance, as well as the maintenance of quality of life (2,4).

This work aims to perform a meta-analysis and systematic review of the current evidence regarding the management of ICVS. The primary outcome assessed was serviceable hearing preservation and secondary outcomes included facial nerve function preservation, tumor growth, tumor involution, and dizziness.

Address correspondence and reprint requests to Marina Neves Cavada, M.D., Sydney Adventist Hospital, 185 Fox Valley Rd, Wahroonga, Sydney, NSW 2076, Australia; E-mail: marinacavada@gmail.com
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MATERIALS AND METHODS

A systematic review was performed to identify patients with ICVS managed under observation, radiotherapy, or surgery. This review was performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (5) and registered in the International Prospective Register of Systematic Reviews (PROSPERO) database (6) (registration number CRD42018091862). Methods from the Cochrane Handbook for Systematic Reviews of interventions were followed (7).

Search Strategy

A systematic electronic search was performed on Embase (1947–), Medline (1946–), Cochrane library (1999–), Scopus (2010–), and CINAHL (–1961) from 1969 to October 5, 2019. A search strategy was designed for each database (Appendix 1, http://links.lww.com/MAO/B131) to identify all the studies on VS. Search terms included vestibular schwannoma, acoustic neuroma, acoustic tumor, and acoustic tumour. The target population was patients with VS confined to the internal auditory canal without extension to the cerebellopontine angle (CPA). A citation search was performed from the included studies.

Eligibility Criteria

The inclusion criteria were patients with ICVS not extending to CPA managed by observation, radiotherapy, or surgery. Studies were excluded if they had patients with neurofibromatosis type 2, previous treatment received, lesions partially removed, age under 18 or were case series with less than five cases. Studies including both ICVS and lesions extending to CPA had only ICVS data extracted. Non-English literature was also excluded. The studies in which ICVS data were impossible to extract or had the same database were excluded from the meta-analysis. Reviews, guidelines, letters, and editorials with no original data were excluded as well as cadaveric or animal studies.

Study Selection

The search results were reviewed by two authors (M.C. and M.L.) and selected according to the eligibility criteria. Initially the duplicates were removed followed by the processes of title screening and abstract review. The full texts of the selected abstracts were analyzed. A third or fourth review (N.P. and N.J.) discussed any disagreement between the first two reviewers. If necessary, e-mails were sent to corresponding authors requesting essential information and data for analysis.

Data Extraction and Quality Assessment

Data extraction was performed on an Excel standardized collection sheet. The publication information, surname of the first author and publication year, study design, number of patients, intervention, outcomes measures, mean follow-up, and baseline serviceable hearing were recorded. The quality of the studies and the risk of bias including baseline hearing level, duration of follow-up, year of study, type of surgical approach, and technique and dose of radiotherapy were assessed by two authors (M.C. and M.L.) with the Newcastle–Ottawa Scale (NOS) (8) (Table 1). Comparability criterion was omitted and follow-up was considered adequate if it was for longer than 6 months. The NOS is a star system for non-randomized studies. A study is judged on three broad perspectives: the selection of the study, the comparability of the groups that have been omitted in this study, and the ascertainment of the outcome of interest. Selection assessment includes representativeness of the selected cohort, ascertainment of the exposure, and demonstration of the outcome of interest. Outcome category includes assessment of the outcome, the length of the follow-up, and the adequacy of the follow-up. Each high-quality choice receives a star, and thus, is graded from zero to six stars when omitting the comparability criterion and zero to eight stars when the comparability is required in the case of cohort studies.

Primary and Secondary Outcomes

The primary outcome was serviceable hearing preservation defined as The American Academy of Otolaryngology and Head and Neck (AAO-HNS) (9) hearing classification class A/B or Gardner–Robertson (GR) (10) class I/II. The secondary outcomes were preservation of facial nerve (FN) function defined as the House–Brackmann (11) grade I/II; growth, which was defined positive if above 1 mm per year; involution, which was defined as any reduction in the size of the tumors for patients treated with observation or radiotherapy; recurrence in those treated with surgery; and dizziness after surgery assessed through the Dizziness Handicap Inventory (DHI) scores that range from 0 to 100 and correlated to patient's perception of their vestibular symptoms. Dizziness was assessed only in the surgery arm because there were no data available on dizziness in ICVS patients in observation and radiotherapy studies. Subanalyses on serviceable hearing preservation by type of surgery including retrosigmoid approach (RSA) and middle fossa approach (MFA); type of radiotherapy including Gamma Knife radiosurgery (GKRS) and linear accelerator (LINAC) and FN function after surgery were performed.

Statistical Analysis

Statistical analyses were performed using Excel 2016 (Microsoft, Redmond, WA) with a statistical add-on application package MIX 2.0 Pro (BiostatXL, 2016, CA) (12). Descriptive data were presented in percentages and proportions. Forest plots were visually inspected to investigate statistical heterogeneity. Heterogeneity across studies was assessed by means of I^2 statistic (7), which provides an estimate of the percentage of variation observed across studies due to heterogeneity rather than caused by chance, and p-value. A value of I^2 is more than or equal to 50% was taken to indicate significant heterogeneity. Data output was generated as a weighted proportion both within individual studies and as overall cumulative/summary proportion using a fixed effects model. The data were presented as a proportion with a 95% confidence interval. Statistical significance was determined at the $p < 0.05$.

RESULTS

Study Selection

The search strategy identified 6,574 studies, of which 1,741 were removed as duplicates. After screening titles, 3,572 articles were excluded. From a total of 1,261 abstracts screened, there were 814 full texts assessed. Of these, 105 were included in the systematic review and 71 were meta-analyzed. A PRISMA flow diagram is shown in Figure 1.

Included Studies

The studies included in this meta-analysis consisted mainly of case series (n = 69) and cohort (n = 2). Twenty-four studies with 2,077 patients were included in the observation arm, 14 studies with 366 patients were

TABLE 1. *Characteristics of included studies*

Observation Studies

Author	Year	Design	n	n (ICVS)	Primary Outcome	Secondary Outcome	Follow-up (Mean ± SD) (yr)	ICVS Baseline Serviceable Hearing (%)	Serviceable Hearing Preservation (%)
Rosenberg (13)	1993	Case series	23	5	Growth	–	4.30 ± 2.12	–	–
Charabi (14)	1999	Case series	40	40	SRT/SDS	Growth	3.60 ± 2.80	–	–
O'Reilly (15)	1999	Case series	44	20	Growth >1 mm/yr		7.00 ± 2.25	–	–
Massick (16)	2000	Case series	21	13	AAO-HNS	Growth >10%	3.80 ± 1.20	50.0	20.0
Raut (17)	2004	Case series	61	18	AAO-HNS	Growth >1 mm/yr	6.66 ± 3.79	–	–
Grayeli (18)	2005	Case series	693	114	HB	–	2.75 ± 2.18	–	–
Martin (19)	2008	Case series	167	91	AAO-HNS	HB	5.16 ± 1.58	–	–
Ferri (20)	2008	Case series	124	59	AAO-HNS	Growth ≥2 mm/yr	4.78 ± 3.66	–	–
Solares (21)	2008	Case series	110	32	Growth >2 mm/yr	–	2.62 ± 3.12	–	–
Godefroy (22)	2009	Case series	70	30	Growth >2 mm/yr	–	3.91 ± 4.00	–	–
Bakkouri (23)	2009	Case series	386	174	Growth >1 mm/yr	–	4.50 ± 2.00	–	–
Régis (24)	2010	Cohort	47	47	GR	Growth	3.65 ± 3.33	77.5	55.0
Suryanarayanan (25)	2010	Case series	490	155	Growth >1 mm/yr	–	3.60 ± 3.50	–	–
Pennings (26)	2011	Case series	47	47	AAO-HNS	Growth >2 mm/yr	3.60 ± 1.57	65.9	48.9
Moffat (27)	2012	Case series	381	238	Growth >2 mm/yr	–	4.20 ± 3.20	–	–
Lee (28)	2014	Case series	31	31	Consensus Meeting Guidelines		3.20 ± 1.50	38.7	19.3
Álvarez-Morujo (29)	2014	Case series	73	43	Growth >2 mm/yr	–	2.98 ± 4.75	–	–
Elliot (30)	2015	Case series	123	48	AAO-HNS	–	5.61 ± 2.66	100	60.4
Daultrey (31)	2016	Case series	555	256	Growth >1 mm/yr	–	–	–	–
Wolbers (32)	2016	Case series	155	80	Growth >2 mm/yr	–	4.05 ± 1.55	–	–
Kirchmann (33)	2017	Case series	156	156	AAO-HNS	Growth ≥2 mm/yr	9.50 ± 6.00	48.7	16
Younes (1)	2017	Case series	53	53	Consensus Meeting Guidelines	Growth ≥2 mm/yr	2.66 ± 1.00	–	–
Prasad (34)	2018	Case series	154	95	AAO-HNS	HB/Growth >1 mm/yr	3.07 ± 2.51	–	–
Lees (35)	2018	Case series	396	232	Growth ≥2 mm/yr	–	3.57 ± 1.07	–	–

Radiotherapy Studies

Author	Year	Design	n	n (ICVS)	Primary Outcome	Secondary Outcome	Intervention Type	Dose (mean ± SD) (Gy)	Follow-up (mean ± SD) (yr)	ICVS Baseline Serviceable Hearing (%)	Serviceable Hearing Preservation (%)
Vermeulen (36)	1998	Case series	54	14	HB	Growth	GKRS	16 ± 1.5	1.50 ± 0.79	–	–
Litvack (37)	2003	Case series	134	11	GR	HB/ Growth	GKRS	12 ± 0.6	2.64 ± 1.25	100	63.6
Weber (38)	2003	Case series	88	12	GR	HB	Proton beam	–	3.95 ± 1.88	–	–
Iwai (39)	2008	Case series	248	25	PTA	Growth	GKRS	–	7.41 ± 2.00	64	40.0
Lasak (40)	2008	Case series	33	10	AAO-HNS/GR	Growth	GKRS	25.9 ± 0.48	2.05 ± 1.15	–	–
Niranjan (41)	2008	Case series	96	96	AAO-HNS/GR		GKRS	12 ± 2.0	3.50 ± 2.75	82.2	56.2
Franzin (34)	2009	Case series	50	8	GR		GKRS	13 ± 1.0	3.20 ± 1.87	100	100
Régis (13)	2010	Case series	128	34	GR		GKRS	–	3.65 ± 3.33	100	76.4
Kim (42)	2013	Case series	728	60	GR	Growth	GKRS	12 ± 0.1	5.12 ± 0.27	100	56.6
Marston (43)	2016	Case series	68	9	AAO-HNS	Growth	GKRS	–	6.19 ± 2.77	–	–
Lin (44)	2017	Case series	100	19	AAO-HNS		GKRS	–	3.68 ± 1.75	100	15.7
Rues (4)	2017	Case series	49	49	GR	HB/Growth	LINAC/CK	12.6 ± 0.6	5.41 ± 4.89	65.3	51.0
Sauer (45)	2018	Case series	45	14	AAO-HNS	Growth	LINAC	–	2.16 ± 0.54	78.5	42.8
Tang (46)	2018	Case series	58	5	GR	HB	GKRS	6.7 ± 0.1	2.16 ± 1.06	100	100

Surgery Studies

Author	Year	Design	n	n (ICVS)	Primary Outcome	Secondary Outcome	Type	Follow-up (Mean ± SD) (yr)	ICVS Baseline Serviceable Hearing (%)	Serviceable Hearing Preservation (%)
Kanzaki (47)	1991	Case series	131	13	HB	–	EMFA	–	–	–
Goel (48)	1992	Case series	42	6	GR	–	RSA	2.36 ± 1.18	100.0	66.6
Haines (49)	1993	Case series	119	12	GR	HB	MFA/PFA	–	91.6	83.3
Brookes (50)	1994	case series	24	5	PTA/SDS	HB	PFA	–	100.0	60.0
Wiegand (51)	1996	Case series	1579	62	HB	–	MFA/TLA/PFA	–	–	–
Kanzaki (52)	1997	Case series	28	10	AAO-HNS	–	MFA	4.80 ± 1.75	100.0	40.0
Schwartz (53)	1998	Case series	50	12	HB/QOL	–	SOA/TLA/MFA	1.92 ± 0.91	–	–
Irving (54)	1998	Case series	98	42	AAO-HNS	HB	MFA/RSA	0.83 ± 0.73	100.0	61.1
Ishikawa (55)	1998	Case series	43	5	PTA/SDS	HB	MFA	–	40.0	20.0
Kumon (56)	2000	Case series	53	15	AAO-HNS	HB	MFA	3.75 ± 0.75	86.6	66.6
Staecker (57)	2000	Case series	30	30	AAO-HNS	HB	MFA/RSA	–	93.3	50.0
Møller (58)	2000	Case series	100	14	HB	–	TLA/SOA	–	–	–
Gjurić (59)	2001	Case series	735	162	AAO-HNS	HB	EMFA	–	70.3	43.8
Magnan (60)	2002	Case series	119	20	AAO-HNS	HB	RSA	–	–	–
Darrouzet (61)	2004	Case series	400	39	AAO-HNS	HB	TLA/WRLA/SOA	5.83 ± 4.16	–	–
Mangham (62)	2004	Case series	73	73	AAO-HNS	HB	RSA/MFA	–	69.0	49.2
Colletti (63)	2005	Case series	70	70	AAO-HNS	HB	MFA/RSA	–	100.0	45.7
Tufarelli (64)	2006	Case series	386	52	DHI	-	MFA/RLA/RSA/ TCA/TLA	4.01 ± 2.40	–	-
Godefroy (65)	2007	Case series	18	18	DHI		TLA	–	–	–
Bernat (66)	2010	Case series	120	13	HB	–	MFA/TLA/ TOA	–	–	–
Yamakami (67)	2010	Case series	22	5	AAO-HNS	–	RSA	4.78 ± 2.27	100.0	60.0
Ammar (68)	2011	Case series	1722	200	HB	–	ETLA	-	-	-
Freitas (69)	2012	Case series	176	94	AAO-HNS	HB	MFA/RSA	-	-	-
Springborg (70)	2012	Case series	1244	13	HB	–	TLA	-	-	-
Bento (71)	2012	Case series	825	189	AAO-HNS	HB	RLA	-	-	-
Mazzoni (72)	2012	Case series	200	25	AAO-HNS	–	RSA	7.50 ± 3.75	100.0	72.7
Nguyen (73)	2012	Case series	379	53	AAO-HNS	–	RSA	–	100.0	75.4
Rinaldi (74)	2013	Case series	66	6	HB	–	TLA/ RLA/ RSA/ MFA	1.58 ± 1.75	–	–
Aihara (75)	2015	Case series	48	48	AAO-HNS	–	MFA	–	97.9	70.8
Raheja (76)	2016	Case series	78	78	AAO-HNS	HB	MFA	1.25 ± 2.74	81.6	63.3
Samii (77)	2017	Cohort	19	19	HC	HB/DHI	RSA	–	68.4	52.6
Marchioni (78)	2018	Case series	49	20	AAO-HNS	HB	ETTA	1.15 ± 14.75	–	–
Dandinarasaiah (79)	2018	Case series	1983	155	HB		ETLA	–	–	–
Moon (80)	2018	Case series	7	5	GR	SF-36	ETTA	1.07 ± 0.20	–	–

AAO-HNS indicates American Academy of Otolaryngology–Head and Neck Surgery; CK, CyberKnife; DHI, Dizziness Handicap Inventory; EMFA, enlarged middle cranial fossa approach; ETLA, enlarged translabyrinthine approach; GKRS, Gamma knife radiosurgery; GR, Gardner–Robertson hearing class; Gy, Grays; HB, House–Brackmann; HC, Hannover classification; ICVS, Intracanalicular vestibular schwannoma; LINAC, linear accelerator; MFA, middle cranial fossa approach; PFA, posterior fossa approach; PTA, pure tone audiometry; QOL, quality of life; RLA, retrolabyrinthine approach; RSA, retrosigmoid approach; SD, standard deviation; SDS, speech discrimination score; SOA, suboccipital approach; SRT, speech recognition threshold; TCA, transcochlear approach; TLA, translabyrinthine approach; TOA, transotic approach; TTEA, totally transcanal endoscopic approach; WRLA, widened retrolabyrinthine approach.

included in the radiotherapy arm, and 34 studies with 1,583 patients in the surgery arm (Table 2). One of the cohort studies (24) was included in both the observation and the radiotherapy arms.

Population

The majority of the studies included patients with vestibular schwannoma located in the internal auditory canal and extending to CPA (n = 58). The minority of the studies (n = 13) (26,33,36,39,41,42,49,63,75,77) were exclusively on ICVS.

Quality Assessment

According to NOS, from the 69 case series, one (1.4%) had a total of three stars, 16 (22.5%) had a total of 4 stars, 22 (30.9%) scored 5 stars, and 30 (42.2%) scored six stars. From the two cohort studies, one scored six stars and the other one eight stars out of 8-item criteria. Studies

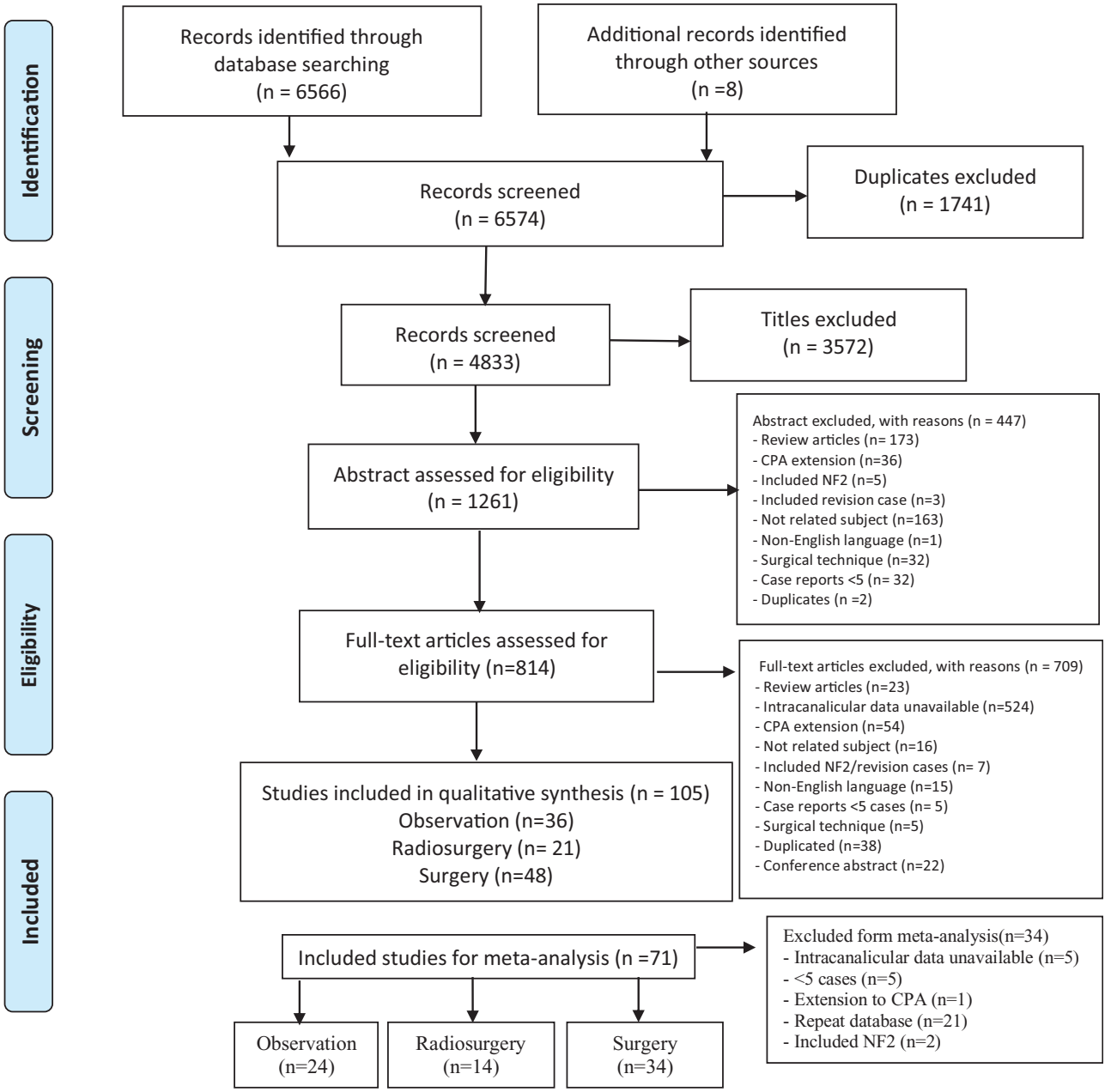

FIG. 1. PRISMA flowchart of the study selection process. PRISMA indicates Preferred Reporting Items for Systematic Reviews and Meta-analyses.

scoring less than four stars were considered to have a higher risk of bias. Sixty-nine studies (97.1%) had an adequate representativeness in their selection of the patients. The ascertainment of exposure was adequate in 100% of the included studies. The outcome of interest was present in 55 studies (77.4%). The assessment of outcome was appropriate in 100% of the studies. Fifty-three studies (74.6%) had an adequate length of follow-up. Fifty-one studies (71.8%) had an adequacy of follow-up. From the two cohort studies, one had an adequate selection of the non-exposed group and comparability (Table 1).

Hearing Assessment

The AAO-HNS hearing classification was used in 32 studies whereas the GR scale was used in 12 studies. Some studies used both classifications (n = 2) and other studies used speech recognition threshold (SRT) and speech discrimination scores (SDS) (n = 1), pure-tone average (PTA) and SDS (n = 2), PTA only (n = 1), Consensus Meeting guidelines (24) (n = 2), Modified Sanna classification (n = 1), and Hannover classification (25) (n = 1) (Table 2).

The baseline serviceable hearing in the observation group was 65% (95%CI 0.59–0.70), ultimately 31% of

TABLE 2. *Characteristics of included studies*

Newcastle-Ottawa Scale			Selection				Comparability	Outcome			Total
Author	Year	Study Design	Represen-tativeness	Selection of Non-exposed	Ascertain-ment of Exposure	Demonstrate the Outcome of Interest	Compara-bility	Assessment of Outcome	follow Up	Adequate Follow Up of Cohorts	Total
Kanzaki (47)	1991	Case series	*		*			*		*	****
Goel (48)	1992	Case series	*		*	*		*			****
Rosenberg (13)	1993	Case series			*	*		*		*	****
Haines (49)	1993	Case series	*		*	*		*			****
Brookes (50)	1994	Case series	*		*			*	*	*	*****
Wiegand (51)	1996	Case series	*		*			*	*		****
Kanzaki (52)	1997	Case series	*		*	*		*	*	*	******
Vermeulen (36)	1998	Case series	*		*			*		*	****
Schwartz (53)	1998	Case series	*		*			*	*	*	*****
Irving (54)	1998	Case series	*		*	*		*			****
Ishikawa (55)	1998	Case series	*		*	*		*	*		*****
Charabi (14)	1999	Case series	*		*	*		*	*		*****
O'Reilly (15)	1999	Case series	*		*	*		*	*	*	******
Massick (16)	2000	Case series	*		*	*		*	*	*	******
Kumon (56)	2000	Case series	*		*	*		*	*	*	******
Staecker (57)	2000	Case series	*		*	*		*			****
Møller (58)	2000	Case series	*		*			*			***
Gjurić (59)	2001	Case series	*		*	*		*	*	*	******
Magnan (60)	2002	Case series	*		*			*	*	*	*****
Litvack (37)	2003	Case series	*		*	*		*	*		*****
Weber (38)	2003	Case series	*		*			*	*		****
Raut (17)	2004	Case series	*		*	*		*	*	*	******
Darrouzet (61)	2004	Case series	*		*			*	*	*	*****
Mangham (62)	2004	Case series	*		*	*		*		*	*****
Grayeli (18)	2005	Case series	*		*			*		*	****
Colletti (63)	2005	Case series	*		*	*		*	*	*	*****
Tufarelli (64)	2006	Case series	*		*			*	*	*	*****
Godefroy (65)	2007	Case series	*		*	*		*	*		*****
Ferri (20)	2008	Case series	*		*	*		*	*		*****
Solares (21)	2008	Case series	*		*	*		*	*		*****
Martin (19)	2008	Case series	*		*	*		*	*		*****
Iwai (39)	2008	Case series	*		*	*		*	*	*	******
Lasak (40)	2008	Case series	*		*	*		*	*	*	******
Niranjan (41)	2008	Case series	*		*	*		*	*	*	******
Bakkouri (23)	2009	Case series	*		*	*		*	*	*	******
Godefroy (22)	2009	Case series	*		*			*	*	*	*****
Franzin (81)	2009	Case series	*		*	*		*	*	*	******
Régis (24)	2010	Cohort	*		*	*		*	*	*	******
Suryanarayanan (25)	2010	Case series	*		*	*		*	*	*	******
Bernat (66)	2010	Case series	*		*	*		*			****
Yamakami (67)	2010	Case series	*		*	*		*	*	*	******
Pennings (26)	2011	Case series	*		*	*		*	*	*	******
Ammar (68)	2011	Case series	*		*			*	*	*	*****
Moffat (27)	2012	Case series	*		*			*	*	*	*****
Mazzoni (72)	2012	Case series	*		*	*		*	*	*	******
Freitas (69)	2012	Case series	*		*	*		*	*	*	******
Springborg (70)	2012	Case series	*		*	*		*	*	*	******
Bento (71)	2012	Case series	*		*	*		*	*	*	******
Nguyen (73)	2012	Case series	*		*	*		*			****
Kim (42)	2013	Case series	*		*	*		*	*	*	******
Rinaldi (74)	2013	Case series	*		*	*		*	*	*	******
Lee (28)	2014	Case series	*		*	*		*	*	*	******
Álvarez-Morujo (29)	2014	Case series	*		*	*		*	*	*	******
Elliott (30)	2015	Case series	*		*	*		*		*	*****
Aihara (75)	2015	Case series	*		*	*		*			****

TABLE 2 (*Continued*)

Newcastle-Ottawa Scale			Selection				Comparability	Outcome			Total
Author	Year	Study Design	Represen-tativeness	Selection of Non-exposed	Ascertain-ment of Exposure	Demonstrate the Outcome of Interest	Compara-bility	Assessment of Outcome	follow Up	Adequate Follow Up of Cohorts	Total
Daultrey (31)	2016	Case series	*		*	*		*			****
Wolbers (32)	2016	Case series	*		*	*		*	*	*	******
Marston (43)	2016	Case series	*		*	*		*	*	*	******
Raheja (76)	2016	Case series	*		*	*		*			****
Kirchmann (33)	2017	Case series	*		*	*		*	*	*	******
Younes (1)	2017	Case series	*		*			*	*	*	*****
Lin (44)	2017	Case series	*		*	*		*	*	*	******
Rueß (4)	2017	Case series	*		*	*		*		*	*****
Samii (77)	2017	Cohort	*	*	*	*	*	*	*	*	********
Prasad (34)	2018	Case series	*		*			*	*	*	*****
Lees (35)	2018	Case series	*		*	*		*	*	*	******
Sauer (45)	2018	Case series	*		*	*		*	*	*	******
Tang (46)	2018	Case series	*		*	*		*			****
Marchioni (78)	2018	Case series	*		*	*		*	*	*	******
Dandinarasaiah (79)	2018	Case series	*		*	*		*	*	*	******
Moon (80)	2018	Case series			*	*		*	*	*	*****

this group preserved serviceable hearing ($I^2 = 91\%$) with a mean follow-up of 4.04 years (95%CI 3.78–4.31). In the patients who received radiotherapy, baseline serviceable hearing was 91% (95%CI 0.88–0.95), 56% ultimately preserved serviceable hearing ($I^2 = 77\%$) with a mean follow-up of 4.89 years (95%CI 4.83–4.99). In patients treated surgically, baseline serviceable hearing was 88% (95%CI 0.84–0.91), 51% ultimately preserved serviceable hearing ($I^2 = 80\%$) with a mean follow-up of 2.23 years (95%CI 2.01–2.45). Serviceable hearing preservation was similar between the retrosigmoid and middle fossa approach (56% versus 53%, $p = 0.66$) as well as LINAC and Gamma Knife (60% versus 58%, $p = 0.82$).

Facial Nerve Assessment

All the included studies assessed FN function according to the House–Brackmann (HB) grading score. FN function was preserved in all of the patients under observation ($I^2 = 0\%$) with a mean follow-up of 4.28 years (95%CI 4.10–4.46). In the radiotherapy arm, even though one study had four cases with permanent facial neuropathy (HB > I/II), the summary of the proportion of patients showed 0% of facial neuropathy in patients receiving radiotherapy ($I^2 = 45\%$) with a mean follow-up of 2.59 years (95%CI 2.40–2.78), respectively, while 95% of patients had an acceptable facial function after surgery ($I^2 = 61.8\%$) with mean follow-up of 1.44 years (95%CI 1.33 to –1.56). Higher values of preservation of FN function were found in patients who were treated via RSA (99% versus 89%, $p < 0.01$) (Fig. 2).

Growth and Involution

Growth was defined as more than 2 mm/yr in 12 studies, more than 1 mm/yr in 6 studies, and above 10% of the baseline size in one study. Two studies did not clarify their definition for growth. Growth was observed in 33% of the patients under observation ($I^2 = 96\%$) with a mean follow-up of 3.78 years (95%CI 3.69–3.87) and in 3% of the patients who received radiotherapy ($I^2 = 53\%$) with a mean follow-up of 2.61 years (95%CI 2.42–2.80) (Table 3).

The definition of involution was not specified by any study. Involution was reported in 2% of the patients under observation ($I^2 = 32\%$) and 38% of the patients receiving radiotherapy ($I^2 = 91\%$) with a mean follow-up of 3.29 years (95%CI 3.09–3.48) and 2.99 years (95%CI 2.76–3.21), respectively.

Recurrence

Recurrence was not reported by any of the studies included in the surgery arm ($I^2 = 0\%$) with a mean follow-up of 3.00 years (95%CI 2.70–3.30).

Dizziness

The DHI scores were reported in three studies in the surgery arm with a mean of 11.42 (8.95; 13.89).

DISCUSSION

Introduction and Tumor Definition

There is still much debate on the management of ICVS. Some authors opt for microsurgery or radiotherapy when hearing is still serviceable (24,37,42,44,46,48,50,52, 54,63,67,72,81), others favor observation as first-line management, reserving other treatments for growing tumors, aggravating symptoms, and/or patient preferences (1,16,26,28,30,33,82). In this study, even the definition of ICVS was varied. The KOOS classification was used for several studies (1,24,45,46,61,78,80,81), however, highlighting the heterogeneity in the data, some articles used different guidelines or definitions to determine an

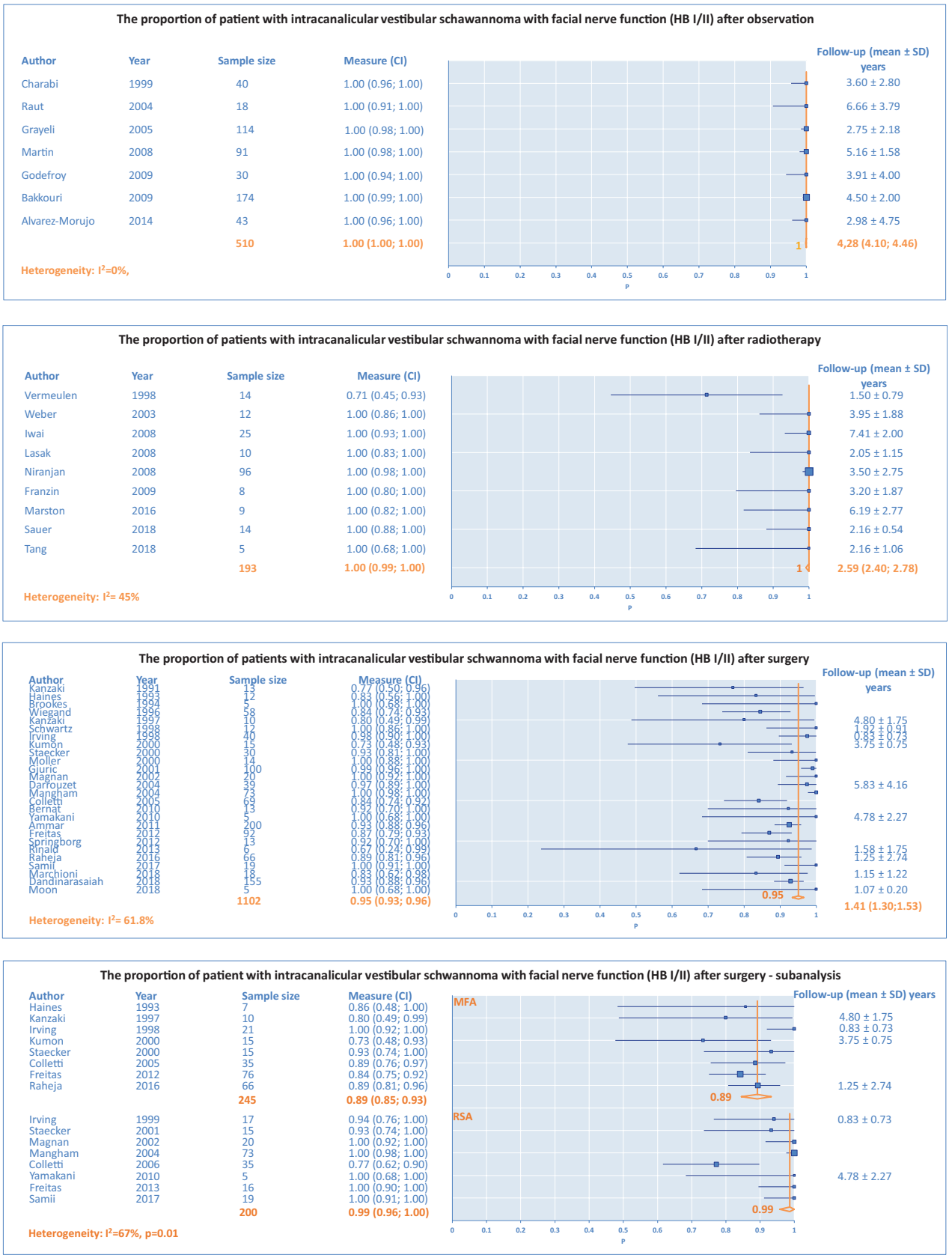

FIG. 2. Forest plot of the proportion of patients with intracanalicular vestibular schwannoma with facial nerve function (HB I/II) after (*A*) observation, (*B*) radiotherapy, (*C*) surgery; and (*D*) sub-analysis of facial nerve function after surgery.

TABLE 3. *Summary of primary and secondary outcomes and the heterogeneity associated with the findings*

	Weighted Average	I^2
Serviceable hearing preservation (AAO-HNS A/B or GR I/II)		
Observation	31%	91%
Radiotherapy	56%	77%
Surgery	51%	80%
Facial nerve function (HBI/II)		
Observation	100%	0%
Radiotherapy	100%	45%
Surgery	95%	62%
Growth		
Observation	33%	96%
Radiotherapy	3%	53%
Involution		
Observation	2%	32%
Radiotherapy	38%	91%
Recurrence		
Surgery	0%	0%
Dizziness		
Dizziness Handicap Inventory	11.42 ± 1.23	0%

AAO-HNS indicates American Academy of Otolaryngology and Head and Neck; GR, Gardner–Robertson.

''intracanalicular'' tumor. Some defined it as tumors contained within the internal auditory meatus (IAM) but others include lesions extending to CPA which were excluded from this analysis. Others have subclassified ICVS in stage IA, IB, and IC, according to its location in the IAM (2).

Hearing Preservation

Hearing loss is the most frequent initial symptom in ICVS (1,4,24,36,42). A recent study demonstrated that 32.5% presented hearing loss as a primary clinical manifestation and a sudden hearing loss in 7.5% of those patients (1). However, a study demonstrated that ICVS can grow without affecting the hearing level, and conversely, patients' hearing can deteriorate without tumor growth (1). In this regard, a cohort of patients with ICVS indicated that normal SDS at diagnosis had a significantly smaller risk of subsequent loss of pure tone/hearing and speech discrimination under observation (83). Additionally, PTA deterioration was significantly higher in patients with growing tumors (mean PTA increase, 3.8 versus 1.5-dB HL/yr; $p < 0.001$) (33).

The annual hearing decrease rate (AHDR) is an alternative measure of hearing deterioration, which represents the number of decibels lost per year (dB/yr). A study found a mean AHDR of 3.5 dB/yr in the tumor ear compared with 0.9 dB/yr on the contralateral side (2). In ICVS, AHDR is associated with tumor growth, helping facilitate management decisions (2). As observed in this meta-analysis, multiple studies included patients who had already had their hearing affected, which influenced the baseline serviceable hearing of some studies and analysis. Serviceable hearing preservation for the observation group was 31% with a mean follow-up of 4.04 years (3.78; 4.31) but heterogeneity was high ($I^2 = 91\%$).

In terms of hearing preservation after RT, rates ranging from 50 to75% are consistently reported. Transient volume expansion (TVE), defined as a volume expansion of more than or equal to 20% compared with the initial tumor volume within a year of RT, seems to be the strongest indicator of hearing deterioration after RT for ICVS (42). Several factors, such as TVE; patient age; baseline hearing status; radiation dose to the cochlear nucleus, nerve, or cochlea itself; and marginal dose prescribed to tumors, have been suggested as possible prognostic factors for hearing outcomes after RT (42).

It is important to be aware of the continued risk of hearing decline with time following radiotherapy. A study with RT of ICVS demonstrated serviceable hearing preservation rates of 70% in the first year, 63% in the second year, and 55% in the fifth year after radiotherapy (42). Another study also showed declined in hearing preservation from 79% at 2 years to 60% at 5 years (24). The mechanism of the continued decline that occurs after RT is still unknown and, unfortunately, majority of studies have a follow-up period shorter than 10 years which affects the analysis of long-term hearing preservation rate.

In terms of surgical management, the MFA and RSA represent the two most common options for ICVS (84,85). These techniques are an alternative for durable hearing preservation in patients with a small tumor size (<1.5 cm) and good preoperative hearing (84,86,87). Conversely, the trans-labyrinthine approach represents an alternative in cases of profound hearing loss and intractable imbalance (77).

Classically both MCF and RSA are thought to be less amenable to hearing preservation if the tumor is more lateral in the IAC. With this work once again the data is very heterogenous to draw conclusions, with some work showing worse hearing (50) and others not finding any significant difference in hearing preservation and fundal extension (75). One study comparing the two approaches demonstrated when the distance from the IAC fundus was 3 mm or less, the MFA afforded significantly better hearing results than the RSA (60% versus 44%, $p < 0.05$) (63).

Anatomical changes to the IAM on preoperative Computed Tomography (CT) may affect hearing outcome. A study on ICVS suggested that enlargement of the IAM on coronal reconstruction images before surgery can predict hearing loss using the MFA, it was found that inferior enlargement of IAC was an independent predictor of hearing outcomes (odds ratio 32.0, 95%CI 4.2–783.6, $p < 0.01$) (75). However, another study found that IAC enlargement greater than 7 mm had higher hearing preservation after the RSA approach ($p < 0.05$) (63).

Facial Nerve Function

The major counter argument for surgery in ICVS management is potential injury to the FN. In this meta-analysis the reported FN injury rates were 0% in both observation and RT arms and 5% after surgery. The analysis of RT should be interpreted with caution as one of the studies had few cases of facial neuropathy, however it was not reflected in the summary of the proportion

of patients with facial function HB I/II after RT. The FN has been considered at higher risk during the MFA compared with other routes because after exposure of the IAC in the MFA, the FN is immediately visualized as it occupies the anterosuperior portion of the IAC fundus. It therefore may be damaged during the surgical maneuvers as it requires to be displaced during tumor removal. However, one study found no difference in FN function between MFA and RSA approaches in ICVS at 1 year postsurgery (63). Another study on ICVS reported four cases of facial dysfunction early after RSA, but they all improved within 1 year (HB I/II) (77). This meta-analysis revealed higher values of preservation of FN function in patients who were treated via RSA compared with MFA (99% versus 89%, $p < 0.01$).

Growth

The main concerns of opting for observation with ICVS are tumor growth and hearing loss. Several studies have analyzed ICVS growth following management by watchful waiting (1,14–16,20–28,31–35). In this regard, an annual enlargement of the tumor diameter of 1 to 2 mm has been commonly observed; however, lesions with a faster growth rate are rare (2). This meta-analysis observed that 33% of the patients with ICVS had growth under observation, but the heterogeneity among the studies was high ($I^2 = 96\%$).

Dizziness

Intractable dizziness is commonly cited as an indication for surgery in ICVS (77). Dizziness is the second most common presenting symptom in ICVS and the DHI scores has been used to gain a more detailed assessment of functional, emotional, and physical deficits that emerge as secondary issues in balance problems or vertigo (77). In this meta-analysis, three surgery studies (64,65,77) provided continuous data on DHI showing an overall improvement of balance after surgery. One of these studies, which included patients with disabling vestibular symptoms kanzaki grade IV (88) and DHI more than or equal to 54 (66.3 ± 10), demonstrated durable and improving DHI and quality of life scores over time at 3 weeks (DHI 31.05 ± 12), 3 months (DHI 9.8 ± 10.5), and 1 year after surgery (DHI 4.3 ± 8.0) (23). The second study also included patients with Kanzaki grade IV (DHI 51.3 ± 13.1) and showed no significant change in DHI at 3 months (38.1 ± 9.1) and a significant reduction in DHI after 12 months (DHI 19.4 ± 9.5). The third study, showed that patients with ICVS had significantly lower DHI postoperatively than patients with extracanalicular VS (34). However, some authors think that there is insufficient evidence to support either surgical resection or RT for treatment of preoperative balance problems (89).

Radiotherapy Dose and Side Effects

Radiotherapy has been considered as an alternative first-line treatment for small and growing ICVS as it has been demonstrated to achieve tumor control rates between 91 and 100% (4). One study recommended the use of less than 13 Gy for single-fraction RT doses to facilitate hearing preservation and to minimize the onset of new or deterioration of preexisting cranial nerve deficits (84). The RT studies included in this meta-analysis used a mean dose of 11.7 Gy (95%CI 11.68–11.73) (4,36,37,40–42,46,81). Side effects were reported by some of the included RT studies. One study that used GKRS at a dose of 16 ± 1.5 Grays (Gy) revealed that facial neuropathy occurred in six (43%) patients, of which three resolved or improved; trigeminal neuropathy occurred in three (21%) patients concurrently with facial neuropathy of HB III or greater, two of them resolved within 1 week; four (29%) patients had a new and acute onset of vertigo, and three (21%) patients presented with intermittent tinnitus (36). Similarly, a study using LINAC at a dose of 12.6 ± 0.6 Gy, new transient or permanent symptoms were reported in nine cases (18%) (vertigo n = 2, imbalance n = 4, CN VII paralysis n = 2, facial hemispasm n = 1) (4). However, another RT study showed a trend toward a higher incidence of late facial neuropathy in VS with extracanalicular extension, as no patient with only an ICVS developed FN dysfunction (38).

Limitations

Several limitations of the present study must be noted. The major limitation is that only unpaired studies were used in this meta-analysis which may under or overestimate the report effects, thus, caution should be used to interpret the findings. Additionally, there was a marked heterogeneity in the pooled data and only English language studies were included. Furthermore, the classification of definition of ICVS, growth, follow up, hearing analysis, radiation methods, and doses often varied. Also, continuous data were rarely reported for absolute growth rate (mm/yr) and hearing levels (PTA dB).

Surgical studies are inherently flawed due to the method of surgery varying from institutions. One disappointing aspect of the surgical data was that many studies did not provide the length of the follow-up. One of the main arguments for surgery in the management of ICVS is the maintenance of durable hearing. This was not answered with the presented meta-analysis as the mean surgical follow up time was only 2.23 years.

CONCLUSION

The management of intracanalicular vestibular schwannoma should be individualized and take into consideration initial presentation, progress of symptoms, patient comorbidities, and preferences. In this meta-analysis, serviceable hearing was observed in 31% of the patients after observation (mean follow up 4.04 yr), 56% after radiotherapy (mean follow up 4.92 yr), and 51% after surgical treatment (mean follow-up 2.23 yr). Facial nerve function was best preserved via observation and radiotherapy. Vestibular schwannoma growth occurred in 33% of the patients under observation while involution occurred in 2% of the patients under observation and in 38% on radiotherapy.

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REFERENCES

1. Younes EMM, Bachelard-Serra M, Jaloux L, Salburgo F, Lavieille JP. Intracanalicular vestibular schwannomas: initial clinical manifestation, imaging classification, and risk stratification for management proposal. *Otol Neurotol* 2017;38:1345–50.
2. van Linge ABG, Wieringa MH, Goedegebure A. Hearing loss progresses faster in patients with growing intracanalicular vestibular schwannomas. *Otol Neurotol* 2016;37:1441–8.
3. Stangerup SE, Toss M, Thomsen J, Caye-Thomasen P. True incidence of vestibular schwannoma? *Neurosurgery* 2010;67:1335–40.
4. Rues DPL, Grau S, Hamisch C, et al. Long-term follow-up after stereotactic radiosurgery of intracanalicular acoustic neurinoma. *Radiat Oncol* 2017;12:68.
5. Moher DLA, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;6:e1000097.
6. PROSPERO - international prospective register of systematic reviews. https://www.crd.york.ac.uk/prospero/
7. Higgins J, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA, editors. Cochrane Handbook for Systematic Reviews of Interventions version 6.0. (updated July 2019).
8. Wells GA, Shea B, O'Connell D, et al. The Newcastle–Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Available at: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed March 30, 2020.
9. American Academy of Otolaryngology Head and Neck Surgery Foundation, Inc. Committee on Hearing and Equilibrium Guidelines for the evaluation of hearing preservation in acoustic neuroma (vestibular schwannoma). *Otolaryngol Head Neck Surg* 1995;113:179–80.
10. Gardner GRJ. Hearing preservation in unilateral acoustic neuroma surgery. *Ann Otol Rhinol Laryngol* 1988;97:55–66.
11. House JW, Brackman DE. Facial nerve grading system. *Otolaryngol Head Neck Surg* 1985;93:146–7.
12. Bax L. Mix 2.0 - Professional software for meta-analysis in Excel, Version 2.015. BiostatXL, 2016. Available at: https://www.meta-analysis-made-easy.com.
13. Rosenberg SI, Silverstein H, Gordon MA, et al. A comparison of growth rates of acoustic neuromas: Nonsurgical patients vs. subtotal resection. *Otolaryngol Head Neck Surg* 1993;109:482–7.
14. Charabi S, Thomsen J, Tos M, et al. Management of intrameatal vestibular schwannoma Microsurgery, radiosurgery or 'wait and scan'. *Acta Oto-Laryngol* 1999;119:796–800.
15. O'Reilly B, Murray CD, Hadley DM. The conservative management of acoustic neuroma:a review of forty-four patients with magnetic resonance imaging. *Clin Otolaryngol* 2000;25:93–7.
16. Massick DD, Welling DB, Dodson EE, et al. Tumor growth and audiometric change in vestibular schwannomas managed conservatively. *Laryngoscope* 2000;110:1843–949.
17. Raut VV, Walsh RM, Bath AP, et al. Conservative management of vestibular schwannomas - Second review of a prospective longitudinal study. *Clin Otolaryngol Allied Sci* 2004;29:505–14.
18. Grayeli AB, Kalamarides M, Ferrary E, et al. Conservative management versus surgery for small vestibular schwannomas. *Acta Oto-Laryngol* 2005;125:1063–8.
19. Martin TPC, Tzifa K, Kowalski C, Holder RL, et al. Conservative versus primary surgical treatment of acoustic neuromas: A comparison of rates of facial nerve and hearing preservation. *Clin Otolaryngol* 2008;33:228–35.
20. Ferri GG, Modugno GC, Pirodda A, et al. Conservative management of vestibular schwannomas: an effective strategy. *Laryngoscope* 2008;118:951–7.
21. Solares CA, Panizza B. Vestibular schwannoma: an understanding of growth should influence management decisions. *Otol Neurotol* 2008;29:829–34.
22. Godefroy WP, Kaptein AA, Vogel JJ, van der Mey AG. Conservative treatment of vestibular schwannoma: a follow-up study on clinical and quality-of-life outcome. *Otol Neurotol* 2009;30:968–74.
23. Bakkouri WE, Kania RE, Guichard JP. Conservative management of 386 cases of unilateral vestibular schwannoma: tumor growth and consequences for treatment. *J Neurosurg* 2009;110:662–9.
24. Regis J, Carron R, Park MC, et al. Wait-and-see strategy compared with proactive GammaKnife surgery in patients with intracanalicular vestibular schwannomas. *J Neurosurg* 2010;113 (suppl):105–11.
25. Suryanarayanan R, Ramsden RT, Saeed SR, et al. Vestibular schwannoma: role of conservative management. *J Laryngol Otol* 2010;124:251–7.
26. Pennings RJ, Morris DP, Clarke L, et al. Natural history of hearing deterioration in intracanalicular vestibular schwannoma. *Neurosurgery* 2011;68:68–77.
27. Moffat DA, Kasbekar A, Axon PR, Lloyd SK. Growth characteristics of vestibular schwannomas. *Otol Neurotol* 2012;33:1053–8.
28. Lee JD, Park MK, Kim JS, Cho YS. The factors associated with tumor stability observed with conservative management of intracanalicular vestibular schwannoma. *Otol Neurotol* 2014;35:918–21.
29. Alvarez-Morujo RJGO, Alvarez-Palacios I, Martin-Oviedo C, Scola-Yurrita B, Aristegui-Ruiz MA. Conservative management of vestibular schwannoma. *Acta Otorrinolaringol Esp* 2014;65:275–82.
30. Elliott A, Hebb AL, Walling S, Morris DP, Bance M. Hearing preservation in vestibular schwannoma management. *Am J Otolaryngol* 2015;36:526–34.
31. Daultrey CRJ, Rainsbury JW, Irving RM. Size as a risk factor for growth in conservatively managed vestibular schwannomas: The Birmingham Experience. *Otolaryngol Clin North Am* 2016;49:1291–5.
32. Wolbers JG, Dallenga AHG, van Linge A, et al. Identifying at diagnosis the vestibular schwannomas at low risk of growth in a long-term retrospective cohort. *Clin Otolaryngol* 2016;41:788–92.
33. Kirchmann M, Karnov K, Hansen S, et al. Ten-year follow-up on tumor growth and hearing in patients observed with an intracanalicular vestibular schwannoma. *Neurosurgery* 2017;80:49–56.
34. Prasad SC, Patnaik U, Grinblat G, et al. Decision making in the wait-and-scan approach for vestibular schwannomas: is there a price to pay in terms of hearing, facial nerve, and overall outcomes? *Neurosurgery* 2018;83:858–70.
35. Lees KA, Tombers NM, Link MJ, et al. Natural history of sporadic vestibular schwannoma: a volumetric study of tumor growth. *Otolaryngol Head Neck Surg* 2018;159:535–42.
36. Vermeulen S, Young R, Posewitz A, et al. Stereotactic radiosurgery toxicity in the treatment of intracanalicular acoustic neuromas: the Seattle Northwest gamma knife experience. *Stereotact Funct Neurosurg* 1998;70 (suppl):80–7.
37. Litvack ZN, Noren G, Chougule PB, Zheng Z. Preservation of functional hearing after gamma knife surgery for vestibular schwannoma. *Neurosurg Focus* 2003;14:e3.
38. Weber DC, Chan AW, Bussiere MR, et al. Proton beam radiosurgery for vestibular schwannoma: tumor control and cranial nerve toxicity. *Neurosurgery* 2003;53:577–88.
39. Iwai Y, Yamanaka K, Kubo T, Aiba T. Gamma knife radiosurgery for intracanalicular acoustic neuromas. *J Clin Neurosci* 2008;15:993–7.
40. Lasak JM, Klish D, Kryzer TC, et al. Gamma knife radiosurgery for vestibular schwannoma: early hearing outcomes and evaluation of the cochlear dose. *Otol Neurotol* 2008;29:1179–86.
41. Niranjan A, Mathieu D, Flickinger JC, Kondziolka D, Lunsford LD. Hearing preservation after intracanalicular vestibular schwannoma radiosurgery. *Neurosurgery* 2008;63:1054–62.
42. Kim YH, Kim DG, Han JH, et al. Hearing outcomes after stereotactic radiosurgery for unilateral intracanalicular vestibular schwannomas: implication of transient volume expansion. *Int J Radiat Oncol Biol Phys* 2013;85:61–7.
43. Marston AP, Jacob JT, Carlson ML, Pollock BE, Driscoll CLW, Link MJ. Pretreatment growth rate as a predictor of tumor control following Gamma Knife radiosurgery for sporadic vestibular schwannoma. *J Neurosurgery* 2017;127:380–7.

44. Lin RH, Wang TC, Lin CD, et al. Predictors of hearing outcomes following low-dose stereotactic radiosurgery in patients with vestibular schwannomas: a retrospective cohort review. *Clin Neurol Neurosurg* 2017;162:16–21.
45. Sauer JP, Kinfe TM, Pintea B, Schafer A, Bostrom JP. The impact of MRI steady-state sequences as an additional assessment modality in vestibular schwannoma patients after LINAC stereotactic radiotherapy or radiosurgery. *Strahlenther Onkol* 2018;194:1103–13.
46. Tang X, Zheng M, Tang H, et al. Hearing outcomes between multisession and single-session radiosurgery for vestibular schwannoma: a single center study. *Translat Cancer Res* 2018;7:1092–102.
47. Kanzaki J, Kunihiro T, O-uchi T, Shiobara R, Toya S. Preservation of facial nerve function in acoustic neuroma surgery by the extended middle cranial fossa approach. *Acta Oto-Laryngol* 1991;111:36–40.
48. Goel A, Sekhar LN, Langheinrich W, Kamerer D, Hirsch B. Late course of preserved hearing and tinnitus after acoustic neurilemoma surgery. *J Neurosurg* 1992;77:685–9.
49. Haines SJ, Levine SC. Intracanalicular acoustic neuroma: early surgery for preservation of hearing. *J Neurosurg* 1993;79:515–20.
50. Brookes GB, Woo J. Hearing preservation in acoustic neuroma surgery. *Clin Otolaryngol Allied Sci* 1994;19:204–14.
51. Wiegand DA, Ojemann RG, Fickel V. Surgical Tkeatment of Acoustic Neuroma (Vestibular Schwannoma) in the United States: Report from the Acoustic Neuroma Registry. *Laryngoscope* 1996;106:58–66.
52. Kanzaki J, Ogawa K, Inoue Y, Shiobara R. Hearing preservation surgery in acoustic neuroma patients with normal hearing. *Skull Base Surg* 1997;7:109–13.
53. Schwartz MS, Riddle S, Delashaw JB, Morgan MA, Kellogg JX, McMenomey SO. Quality of life following acoustic neuroma surgery. *Skull Base Surg* 1998;8:32.
54. Irving RM, Jackler RK, Pitts LH. Hearing preservation in patients undergoing vestibular schwannoma surgery: comparison of middle fossa and retrosigmoid approaches. *J Neurosurg* 1998;88:840–5.
55. Ishikawa K, Yasui N, Mineura K, Sasajima H, Togawa K. Significance of hearing preservation in acoustic neuroma surgery. *Acta Oto-Laryngol* 1998;118:16–9.
56. Kumon Y, Sakaki S, Kohno K, et al. Selection of surgical approaches for small acoustic neurinomas. *Surg Neurol* 2000;53:52–60.
57. Staecker H, Nadol JB Jr, Ojeman R, Ronner S, McKenna MJ. Hearing preservation in acoustic neuroma surgery: Middle fossa versus retrosigmoid approach. *American J Otol* 2000;21:399–404.
58. Møller P, Myrseth E, Pedersen PH, Larsen JL, Krakenes J, Moen G. Acoustic neuroma - Treatment modalities Surgery, gamma-knife or observation? *Acta Oto-Laryngol* 2000;120 (543):34–7.
59. Gjuric M, Wigand ME, Wolf SR. Enlarged middle fossa vestibular schwannoma surgery: experience with 735 cases. *Otol Neurotol* 2001;22:223–30.
60. Magnan J, Barbieri M, Mora R, et al. Retrosigmoid approach for small and medium-sized acoustic neuromas. *Otol Neurotol* 2002;23:141–5.
61. Darrouzet V, Martel J, Enée V, et al. Vestibular schwannoma surgery outcomes: our multidisciplinary experience in 400 cases over 17 years. *Laryngoscope* 2004;114:681–8.
62. Mangham CA. Retrosigmoid versus middle fossa surgery for small vestibular schwannomas. *Laryngoscope* 2004;114:1455–61.
63. Colletti V, Fiorino F. Is the middle fossa approach the treatment of choice for intracanalicular vestibular schwannoma? *Otolaryngol Head Neck Surg* 2005;132:459–66.
64. Tufarelli D, Meli A, Alesii A, et al. Quality of life after acoustic neuroma surgery. *Otol Neurotol* 2006;27:403–9.
65. Godefroy WP, Hastan D, van der Mey AG. Translabyrinthine surgery for disabling vertigo in vestibular schwannoma patients. *Clin Otolaryngol* 2007;32:167–72.
66. Bernat I, Grayeli AB, Esquia G, et al. Intraoperative electromyography and surgical observations as predictive factors of facial nerve outcome in vestibular schwannoma surgery. *Otol Neurotol* 2010;31:306–12.
67. Yamakami I, Yoshinori H, Saeki N, et al. Hearing preservation and intraoperative auditory brainstem response and cochlear nerve compound action potential monitoring in the removal of small acoustic neurinoma via the retrosigmoid approach. *J Neurol Neurosurg Psychiatry* 2009;80:218–27.
68. Ammar MB, Piccirillo E, Topsakal V, et al. Surgical results and technical refinements in translabyrinthine excision of vestibular schwannomas: the Gruppo Otologico experience. *Neurosurgery* 2012;70:1481–91.
69. De Freitas MR, Russo A, Sequino G, et al. Analysis of hearing preservation and facial nerve function for patients undergoing vestibular schwannoma surgery: The middle cranial fossa approach versus the retrosigmoid approach-personal experience and literature review. *Audiol Neurotol* 2012;17:71–81.
70. Springborg JB, Fugleholm K, Poulsgaard L, et al. Outcome after translabyrinthine surgery for vestibular schwannomas: Report on 1244 patients. *J Neurol Surg, Part B: Skull Base* 2012;73:168–74.
71. Bento RF, Pinna MH, De Brito Neto RV. Vestibular schwannoma: 825 cases from a 25-year experience. *Int Arch Otorhinolaryngol* 2012;16:466–75.
72. Mazzoni A, Zanoletti E, Calabrese V. Hearing preservation surgery in acoustic neuroma: long-term results. *Acta Otorhinolaryngol Ital* 2012;32:98–102.
73. Nguyen QT, Wu AP, Mastrodimos BJ, et al. Impact of fundal extension on hearing after surgery for vestibular schwannomas. *Otol Neurotol* 2012;33:455–8.
74. Rinaldi V, Casale M, Bressi F, et al. Facial nerve outcome after vestibular schwannoma surgery: our experience. *J Neurol Surg B* 2012;73:21–7.
75. Aihara N, Murakami S. Enlargement of the internal auditory canal and hearing preservation in the middle fossa approach for intracanalicular vestibular schwannomas. *World Neurosurg* 2015;84:21–2.
76. Raheja A, Bowers CA, Macdonald JD, et al. Middle fossa approach for vestibular schwannoma: good hearing and facial nerve outcomes with low morbidity. *World Neurosurg* 2016;92:37–46.
77. Samii M, Metwali H, Gerganov V. Efficacy of microsurgical tumor removal for treatment of patients with intracanalicular vestibular schwannoma presenting with disabling vestibular symptoms. *J Neurosurg* 2017;126:1514–9.
78. Marchioni D, Soloperto D, Masotto B, et al. Transcanal transpromontorial acoustic neuroma surgery: results and facial nerve outcomes. *Otol Neurotol* 2018;39:242–9.
79. Dandinarasaiah M, Prasad SC, Piccirillo E, et al. Facial nerve outcomes following total excision of vestibular schwannoma by the enlarged translabyrinthine approach. *Otol Neurotol* ;40:226–35.
80. Moon IS, Cha D, Nam SI, et al. The feasibility of a modified exclusive endoscopic transcanal transpromontorial approach for vestibular schwannomas. *J Neurol Surg B Skull Base* 2019;80:82–7.
81. Franzin A, Spatola G, Serra C, et al. Evaluation of hearing function after gamma knife surgery of vestibular schwannomas. *Neurosurg Focus* 2009;27:. E3.1 8.
82. Quesnel AM, McKenna MJ. Current strategies in management of intracanalicular vestibular schwannoma. *Curr Opin Otolaryngol Head Neck Surg* 2011;19:335–40.
83. Caye-Thomasen PDT, Hansen S, Stangerup SE, Thomsen J. Hearing in patients with intracanalicular vestibular schwannomas. *Audiol Neurootol* 2007;12:1–12.
84. Olson JJKS, Ryken TC. Congress of neurological surgeons systematic review and evidence-based guidelines on the treatment of adults with vestibular schwannomas: executive summary. *Neurosurgery* 2018;82:129–34.
85. Wick CC, Arnaoutakis D, Barnett SL, Rivas A, Isaacson B. Endoscopic transcanal transpromontorial approach for vestibular schwannoma resection: a case series. *Otol Neurotol* 2017;38:e490–4.
86. Quist TS, Givens DJ, Gurgel RK, Chamoun R, Shelton C. Hearing preservation after middle fossa vestibular schwannoma removal: are the results durable? *Otolaryngol Head Neck Surg* 2015;152:706–11.
87. Ahmed S, Arts HA, El-Kashlan H, et al. Immediate and long-term hearing outcomes with the middle cranial fossa approach for vestibular schwannoma resection. *Otol Neurotol* 2018;39:92–8.
88. Kanzaki J, Tos M, Sanna M, et al. New and modified reporting systems from the consensus meeting on systems for reporting results in vestibular schwannoma. *Otol Neurotol* 2003;24:642–8.
89. Hadjipanayis CG, Carlson ML, Link MJ, et al. Congress of neurological surgeons systematic review and evidence-based guidelines on surgical resection for the treatment of patients with vestibular schwannomas. *Neurosurgery* 2018;82:E40–43.