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Subclassification of Koos grade 4 vestibular schwannoma: insights into tumor morphology for predicting postoperative facial nerve function

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OBJECTIVE Koos grade 4 vestibular schwannoma (KG4VS) is a large tumor that causes brainstem displacement and is generally considered a candidate for surgery. Few studies have examined the relationship between morphological differences in KG4VS other than tumor size and postoperative facial nerve function. The authors have developed a landmark-based subclassification of KG4VS that provides insights into the morphology of this tumor and can predict the risk of facial nerve injury during microsurgery. The aims of this study were to morphologically verify the validity of this subclassification and to clarify the relationship of the position of the center of the vestibular schwannoma within the cerebellopontine angle (CPA) cistern on preoperative MR images to postoperative facial nerve function in patients who underwent microsurgical resection of a vestibular schwannoma.

METHODS In this paper, the authors classified KG4VSs into two subtypes according to the position of the center of the KG4VS within the CPA cistern relative to the perpendicular bisector of the porus acusticus internus, which was the landmark for the subclassification. KG4VSs with ventral centers to the landmark were classified as type 4V, and those with dorsal centers as type 4D. The clinical impact of this subclassification on short- and long-term postoperative facial nerve function was analyzed.

RESULTS In this study, the authors retrospectively reviewed patients with vestibular schwannoma who were treated surgically via a retrosigmoid approach between January 2010 and March 2020. Of the 107 patients with KG4VS who met the inclusion criteria, 45 (42.1%) were classified as having type 4V (KG4VSs with centers ventral to the perpendicular bisector of the porous acusticus internus) and 62 (57.9%) as having type 4D (those with centers dorsal to the perpendicular bisector). Ventral extension to the perpendicular bisector of the porus acusticus internus was significantly greater in the type 4V group than in the type 4D group ($p < 0.001$), although there was no significant difference in the maximal ventrodorsal diameter. The rate of preservation of favorable facial nerve function (House-Brackmann grades I and II) was significantly lower in the type 4V group than in the type 4D group in terms of both short-term (46.7% vs 85.5%, $p < 0.001$) and long-term (82.9% vs 96.7%, $p = 0.001$) outcomes. Type 4V had a significantly negative impact on short-term (OR 7.67, 95% CI 2.90–20.3; $p < 0.001$) and long-term (OR 6.05, 95% CI 1.04–35.0; $p = 0.045$) facial nerve function after surgery when age, tumor size, and presence of a fundal fluid cap were taken into account.

CONCLUSIONS The authors have delineated two different morphological subtypes of KG4VS. This subclassification could predict short- and long-term facial nerve function after microsurgical resection of KG4VS via the retrosigmoid approach. The risk of postoperative facial palsy when attempting total resection is greater for type 4V than for type 4D. This classification into types 4V and 4D could help to predict the risk of facial nerve injury and generate more individualized surgical strategies for KG4VSs with better facial nerve outcomes.

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KEYWORDS vestibular schwannoma; retrosigmoid approach; facial nerve function; Koos grade; tumor

ABBREVIATIONS CPA = cerebellopontine angle; HB = House-Brackmann; IAC = internal auditory canal; KG4VS = Koos grade 4 VS; VS = vestibular schwannoma.

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Management options for vestibular schwannoma (VS), the most common benign tumor in the cerebellopontine angle (CPA), include observational wait and scan, microsurgical resection, and/or stereotactic radiosurgery.[1] The goals of these treatments for VS are to achieve tumor control and to preserve neurological function.[2] Although resection is the only curative option, it may place the facial nerve at greater risk of injury than the other treatment options.[1,3,4] In the modern era, there have been remarkable improvements in the outcomes of not only microsurgery for VS but also stereotactic radiosurgery.[1,5–8] Therefore, the surgical strategy has been shifting to less radical resection with the aim of optimal preservation of facial nerve function, that is, subtotal resection followed by stereotactic radiosurgery or stereotactic radiosurgery without resection.[9–13] However, these strategies require ongoing attention to regrowth from the residual tumor over time, especially in younger patients, because of insufficient knowledge about the long-term prognosis.[14–17] The ability to predict the difficulty of preserving facial nerve function in advance of surgery would be clinically worthwhile when planning appropriate treatment strategies, selecting appropriate candidates for surgery when aiming for complete resection, and counseling patients before treatment. We have previously reported that the presence of a fundal fluid cap on preoperative MRI, that is, CSF in the lateral end of a VS within the internal auditory canal (IAC), predicts long-term facial nerve function after resection of VS.[18] However, this alone is insufficient to predict the risk of facial nerve injury during resection of the extrameatal components, which represent the majority of large VSs.

There is a general consensus that tumor size is a predictor of facial nerve function after resection of VS.[19,20] The Koos classification system for VS has been widely used and has been a reliable grading scale based on the extrameatal extent of the tumor.[21,22] Unquestionably, patients with Koos grade 4 VS (KG4VS), which is a large tumor that causes brainstem displacement, are candidates for surgery. In theory, a KG4VS is associated with a greater risk of postoperative facial palsy than a lower-grade VS. However, the Koos classification cannot predict postoperative facial nerve function.[23] The mechanism underpinning this discrepancy might be morphological differences within KG4VSs other than tumor size. Several studies have found that a greater extension and proportion of the tumor anterior to the IAC are negative predictors of postoperative facial nerve function.[24,25]

For a KG4VS with more ventral than dorsal extension relative to the IAC, the center of the tumor would be more ventral than the IAC. Accordingly, we hypothesized that facial nerve function after VS resection would be worse in patients with KG4VS in whom the center of the tumor within the CPA cistern is ventral to the IAC than in those with KG4VS in whom the center of the tumor within the CPA cistern is dorsal to the IAC. We proposed a landmark-based subclassification of KG4VS based on our hypothesis, bringing insights into tumor morphology to make the most of the Koos classification and to predict the risk of facial nerve injury during microsurgery. The aims of this study were to morphologically verify the validity of the subclassification of KG4VS and to clarify the relationship between our subclassification of KG4VS on preoperative MR images and postoperative facial nerve function in patients who underwent microsurgical resection of VS.

Methods

Study Patients

In this study, we retrospectively reviewed 195 consecutive patients with VS who were treated surgically via a retrosigmoid approach by the same senior skull base neurosurgeon (E.K.) at our institution between January 2010 and March 2020. The following inclusion criteria were applied: newly diagnosed sporadic VS without neoadjuvant stereotactic radiosurgery; age ≥ 18 years; postoperative follow-up duration ≥ 1 month; and KG4VS determined by two investigators (Y.F. and Y.U.) in agreement. Twenty-eight patients were excluded because of neurofibromatosis type 2 (n = 13), recurrence (n = 7), stereotactic radiosurgery performed before surgery (n = 5), age < 18 years (n = 2), and loss to follow-up within 1 month after surgery (n = 1), as were 60 patients with Koos grade ≤ 3 (grade 1, n = 2; grade 2, n = 24; grade 3, n = 34). Supplemental Fig. 1 shows the patient selection process.

The study was approved by the Kobe University Hospital Institutional Review Board and was conducted in accordance with institutional and national ethics guidelines and the Declaration of Helsinki. The need for informed consent was waived in view of the retrospective observational nature of the research.

Subclassification of KG4VS

In total, 107 KG4VSs were classified into two types according to the position of the center of the VS within the CPA cistern on preoperative MR images. For subclassification, we designated the perpendicular bisector of the porus acusticus internus, which was perpendicular to the petrous edge, as the landmark for subclassification of KG4VS. The center of the VS was defined as the intersection of the maximum ventrodorsal diameter parallel to the petrous edge and the maximal mediolateral diameter parallel to the perpendicular bisector of the porus acusticus internus (Fig. 1A). Finally, KG4VSs with centers that were ventral to the perpendicular bisector of the porus acusticus internus were classified as type 4V (Fig. 1B and C), and those with centers that were dorsal to the perpendicular bisector of the porus acusticus internus were classified as type 4D (Fig. 1D and E).

Clinical Analysis

To clarify the clinical differences between the subtypes of KG4VS, we first compared the following baseline characteristics: age, sex, tumor laterality, tumor size (maximum CPA[26]), findings on preoperative MR images (fundal fluid cap,[18] fluid cystic change, and a high jugular bulb), response on intraoperative facial nerve monitoring, adhesion between the tumor and facial nerve, facial nerve displacement pattern (rostroventral, central-ventral, caudoventral, or dorsal), fanning of the facial nerve, nerve of origin of the tumor, extent of resection (total, complete removal; near total, only a small remnant on the facial nerve

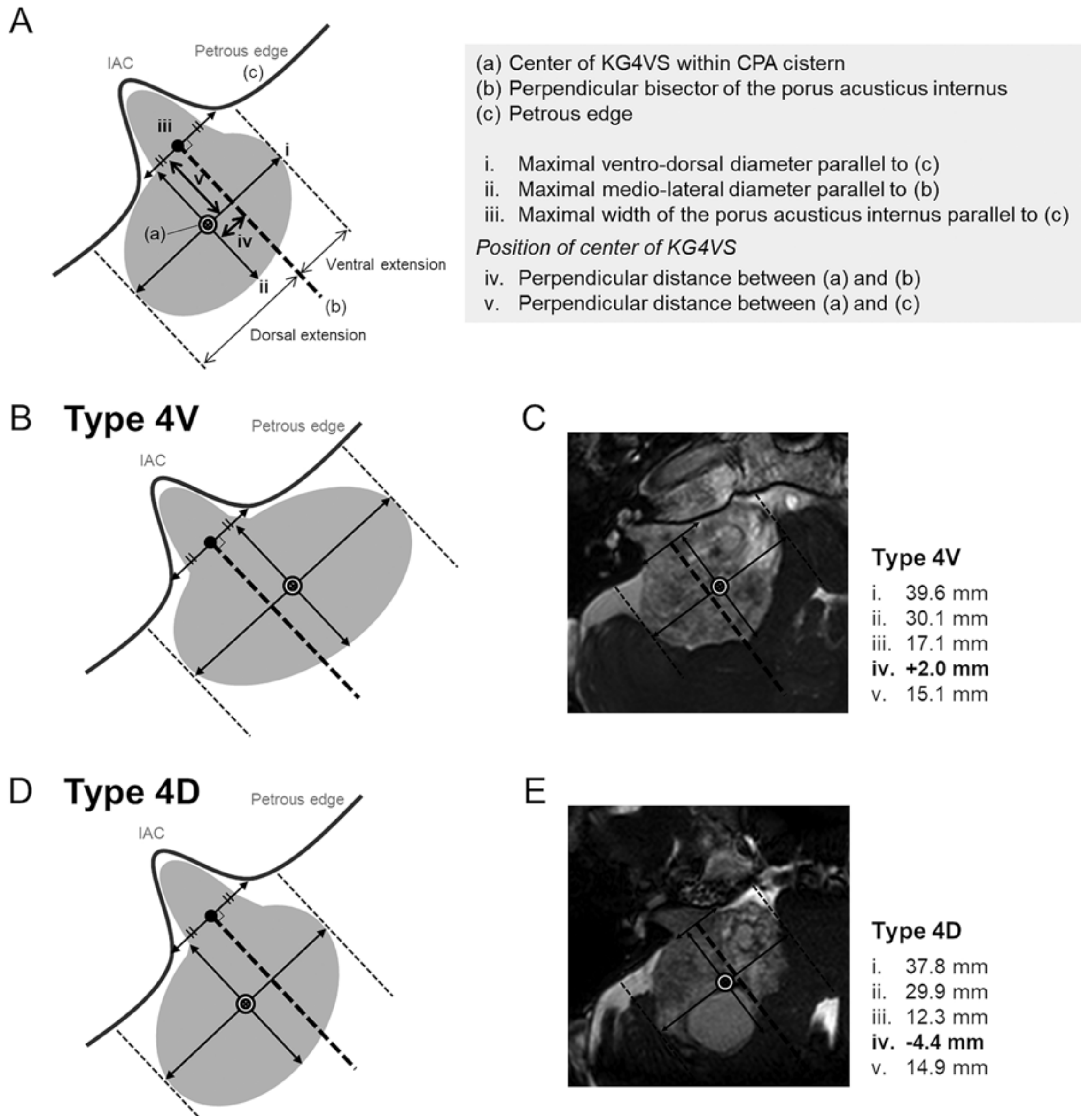

FIG. 1. Subclassification of KG4VSs. **A:** Schematic illustration of a CPA demonstrating each landmark (*a–c*) and showing how to measure each parameter (*i–v*; ventral extension, dorsal extension). **B and C:** Schematic illustration (B) and preoperative axial contrast-enhanced T2-weighted balanced fast field-echo image (C) showing representative type 4V cases. **D and E:** Schematic illustration (D) and preoperative axial contrast-enhanced T2-weighted balanced fast field-echo image (E) showing representative type 4D cases. The parameter values are presented in panels C and E.

under the microscope; or subtotal, remnant detectable on MR images), operation time, postoperative hearing status, postoperative hydrocephalus requiring ventriculoperitoneal shunt, and postoperative adjuvant stereotactic radiosurgery. Second, we retrospectively assessed the postoperative function of the facial nerve (House-Brackmann [HB] grade[27]) recorded at 1 month as the short-term outcome and at 24 months as the long-term outcome for both subtypes of KG4VS. Finally, we assessed the clinical significance of KG4VS subtype as a predictor of short- and long-term facial nerve function after surgery. For the purposes of this study, favorable facial nerve function was defined as HB grades I and II and unfavorable facial nerve function as HB grades ≥ III.

Morphological Analysis

To clarify the morphological differences between the subtypes of KG4VS, we compared the following parameters: maximal ventrodorsal diameter parallel to the petrous edge, ventral extension to the perpendicular bisector of the porus acusticus internus, dorsal extension to the perpendicular bisector of the porus acusticus internus, maximal mediolateral diameter parallel to the perpendicular bisector of the porus acusticus internus, maximal width of the porus acusticus internus parallel to the petrous edge, perpendicular distance between the center of the VS and the perpendicular bisector of the porus acusticus internus, and perpendicular distance between the center of the VS and the petrous edge. All parameters were measured by the same neurosurgeon (Y.F.) on a representative axial slice showing the cochlea and semicircular canals on contrast-enhanced T2-weighted balanced fast field-echo images and confirmed by a second neurosurgeon (Y.U.). Figure 1A shows how each parameter was measured.

As reported previously, routine examinations for VS at our institution are performed using a 3T MR scanner (Achieva, Philips Medical Systems) and include T2-weighted images with 3D driven equilibrium (fast spin-echo sequence) for evaluation of the IAC up to the fundus and T2-weighted balanced fast field-echo images (gradient-echo sequence) before and after intravenous injection of a gadolinium contrast agent (Magnescope, 0.2 ml/kg, Guerbet) for evaluation of the CPA cistern.[18] The anterior commissure–posterior commissure line, which is widely accepted as the standard for clinical brain MRI, was adopted as a reference line for axial MR images.

Surgical Techniques Used for KG4VS

We performed neuromonitoring-guided resection of KG4VS using a retrosigmoid approach in a consistent manner.[18,28] The patient was placed in the park-bench position. A linear postauricular incision (length 10 cm) and suboccipital craniectomy (4 × 4 cm) were performed without decompression of the foramen magnum. The craniectomy size was always the same, regardless of tumor size. The tumor was removed microsurgically while monitoring the facial nerve using an NIM-Neuro 3.0 nerve monitoring system (Xomed, Medtronic). The IAC was drilled to remove the tumor filling the IAC. When the preoperative image showed a high jugular bulb, it was skeletonized and pushed down to get direct access to the IAC.

Our surgical policy for KG4VS is to remove the maximum amount of tumor possible with preservation of facial nerve function. Preservation of facial nerve function is prioritized over total resection in the following situations: poor recognition of the facial nerve due to heavy bleeding from the tumor, difficulty in securing a safe peeling plane on the facial nerve because of strong adhesion with the tumor, and a decreased response at the root exit zone on facial nerve monitoring.

Statistical Analysis

The clinical and morphological characteristics were compared between the groups using Fisher's exact test for categorical variables and the Mann-Whitney U-test for nonparametric variables. Univariate logistic regression analysis was performed to determine whether any of the preoperative factors, including the KG4VS subtype, were significantly associated with short- and long-term facial nerve function after resection of VS. Subsequent multivariate logistic regression analyses were performed with adjustment using all standard preoperative factors (age, tumor size, presence of a fundal fluid cap, subtype of KG4VS) and variables that were statistically significant ($p < 0.05$) in the univariate analyses. Odds ratios were calculated with their corresponding 95% CIs. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University), which is a graphical user interface for R (The R Foundation for Statistical Computing). A two-sided p value < 0.05 was considered statistically significant.[29]

Results

Clinical Characteristics

Investigated in this study were 107 patients with KG4VS who met the inclusion criteria. According to the preoperative MRI findings, 45 patients (42.1%; 20 men, 25 women; median age 51.0 [IQR 42.0–59.0] years) had type 4V and 62 (57.9%; 17 men, 45 women; median age 47.5 [IQR 36.5–61.8] years) had type 4D KG4VSs. The median preoperative tumor size (maximum CPA) was 33.0 (IQR 28.0–38.0) mm for type 4V and 30.0 (IQR 25.0–37.5) mm for type 4D. The baseline patient and tumor characteristics are summarized according to KG4VS subtype in Table 1. There was no statistically significant between-group difference in any characteristic except for a higher incidence of a decreased response on intraoperative facial nerve monitoring ($p = 0.027$) and in the facial nerve displacement pattern ($p = 0.011$) for type 4V. Overall, the facial nerve in 106 patients (99.1%) was displaced ventrally (rostroventral, 41.1%; central-ventral, 52.3%; caudoventral, 5.6%; dorsal, 0.9%). The most common displacement pattern was rostroventral for type 4V and central-ventral for type 4D.

Morphological Characteristics

The morphological characteristics are summarized according to subtype of KG4VS in Table 2. Although there was no statistically significant between-group difference in maximal ventrodorsal diameter, ventral extension was significantly greater in type 4V than in type 4D (17.7 [IQR 14.4–21.3] mm vs 12.3 [IQR 9.3–15.0] mm, $p < 0.001$) and dorsal extension was significantly smaller in type 4V than in type 4D (13.5 [IQR 11.1–16.8] mm vs 15.8 [IQR 12.4–20.6] mm, $p = 0.021$) (Fig. 2A–C). The maximum mediolateral diameter was significantly larger in type 4V than in type 4D (25.0 [IQR 19.9–27.8] mm vs 21.2 [IQR 16.9–25.7] mm, $p = 0.019$). There was no significant between-group difference in maximal width of the porus acusticus internus.

The median center of type 4V KG4VSs was located 1.9 (IQR 0.9–2.6) mm ventrally from the perpendicular bisector of the porus acusticus internus and 12.5 (IQR 9.9–13.9) mm from the petrous edge. However, the center of type 4D was located 1.6 (IQR 0.8–3.0) mm dorsally from the perpendicular bisector of the porus acusticus internus and 10.6 (IQR 8.4–12.9) mm from the petrous edge. The center was significantly farther from the petrous edge in type 4V than in type 4D ($p = 0.019$). Representative cases for both subtypes are shown in Fig. 1. The distributions of the position of the center of the KG4VS within the CPA cistern in all cases in both subtypes of KG4VS are shown in Fig. 2D.

TABLE 1. Clinical characteristics of KG4VS stratified by subtype

	Total No. of Patients (n = 107)	KG4VS Subtype		p Value
		Type 4V (n = 45)	Type 4D (n = 62)	
Age, yrs	51.0 (39.0–60.5)	51.0 (42.0–59.0)	47.5 (36.5–61.8)	0.574
Sex				0.099
Male	37 (34.6)	20 (44.4)	17 (27.4)	
Female	70 (65.4)	25 (55.6)	45 (72.6)	
Tumor laterality				0.696
Rt	45 (42.1)	20 (44.4)	25 (40.3)	
Lt	62 (57.9)	25 (55.6)	37 (59.7)	
Preop tumor size				
Maximum CPA, mm	31.0 (25.0–38.0)	33.0 (28.0–38.0)	30.0 (25.0–37.5)	0.190
Preop MRI findings				
Fundal fluid cap	76 (71.0)	31 (68.9)	45 (72.6)	0.829
Cystic change	36 (33.6)	18 (40.0)	18 (29.0)	0.301
High jugular bulb	9 (8.4)	5 (11.1)	4 (6.5)	0.488
Extent of resection				0.081
Total	51 (47.7)	16 (35.6)	35 (56.5)	
Near total	37 (34.6)	18 (40.0)	19 (30.6)	
Subtotal	19 (17.8)	11 (24.4)	8 (12.9)	
Decrease in response on intraop facial nerve monitoring	16 (15.0)	11 (24.4)	5 (8.1)	0.027
Strong adhesion btwn tumor & facial nerve	69 (64.5)	33 (73.3)	36 (58.1)	0.152
Facial nerve displacement pattern				0.011
Rostroventral	44 (41.1)	25 (55.6)	19 (30.6)	
Central-ventral	56 (52.3)	16 (35.6)	40 (64.5)	
Caudoventral	6 (5.6)	3 (6.7)	3 (4.8)	
Dorsal	1 (0.9)	1 (2.2)	0 (0)	
Fanning of facial nerve*	84 (79.2)	35 (77.8)	49 (80.3)	0.811
Origin of tumor				0.806
Superior vestibular nerve	37 (34.6)	14 (31.1)	23 (37.1)	
Inferior vestibular nerve	53 (49.5)	24 (53.3)	29 (46.8)	
Unidentified	17 (15.9)	7 (15.6)	10 (16.1)	
Op time, hrs	5.6 (4.6–7.0)	6.3 (4.7–7.2)	5.3 (4.5–6.9)	0.115
Postop hearing loss	93 (86.9)	42 (93.3)	51 (82.3)	0.146
Postop hydrocephalus requiring VPS op	1 (0.9)	0 (0)	1 (1.6)	>0.999
Postop adjuvant SRS	3 (2.8)	1 (2.2)	2 (3.2)	>0.999

SRS = stereotactic radiosurgery; VPS = ventriculoperitoneal shunt.
Values are reported as median (IQR) or as number of patients (%).
* One patient in the type 4D group lacked data.

Postoperative Facial Nerve Function

No patient had facial nerve paralysis in either group preoperatively. Overall, the facial nerve was morphologically preserved in 106 patients (99.1%), with the exception of 1 patient with type 4V.

Figure 3 left shows the short-term facial nerve outcome. Facial nerve function 1 month after surgery was unfavorable in 24 patients (53.3%) with type 4V and in 9 patients (14.5%) with type 4D; the between-group difference was significant ($p < 0.001$). Figure 3 right shows the long-term outcome in 101 patients (type 4V, n = 41; type 4D, n = 60). Facial nerve function at 24 months after surgery was unfavorable in 7 patients (17.1%) with type 4V. In contrast, only 2 patients (3.3%) with type 4D had unfavorable facial nerve function 24 months after surgery; this rate was significantly lower than that in the group with type 4V ($p = 0.001$).

Predictors of Short-Term Postoperative Facial Nerve Function

In univariate analyses, only type 4V (OR 6.73, 95% CI 2.69–16.9; $p < 0.001$) was a significant predictor of an unfavorable facial nerve outcome at 1 month after surgery (Table 3). No other feature was associated with facial nerve function at 1 month after surgery (Supplemental Table 1).

TABLE 2. Morphological characteristics of KG4VS stratified by subtype

		KG4VS Subtype		
	Overall (n = 107)	Type 4V (n = 45)	Type 4D (n = 62)	p Value
i) Maximal ventrodorsal diameter, mm	30.0 (23.3 to 36.6)	31.1 (25.5 to 37.6)	28.7 (22.2 to 35.5)	0.121
Ventral extension, mm	14.4 (10.9 to 18.1)	17.7 (14.4 to 21.3)	12.3 (9.3 to 15.0)	<0.001
Dorsal extension, mm	14.3 (12.3 to 18.4)	13.5 (11.1 to 16.8)	15.8 (12.4 to 20.6)	0.021
ii) Maximal mediolat diameter, mm	22.8 (17.7 to 27.5)	25.0 (19.9 to 27.8)	21.2 (16.9 to 25.7)	0.019
iii) Maximal width of porus acusticus internus, mm	10.9 (8.6 to 12.6)	10.6 (8.8 to 12.4)	11.1 (8.6 to 12.8)	0.902
Position of center of KG4VS				
iv) Perpendicular distance from perpendicular bisector of porus acusticus internus, mm	–0.4 (–2.0 to 1.6)	1.9 (0.9 to 2.6)	–1.6 (–3.0 to –0.8)	<0.001
v) Perpendicular distance from parallel line to petrous edge, mm	11.4 (8.9 to 13.8)	12.5 (9.9 to 13.9)	10.6 (8.4 to 12.9)	0.019

Values are reported as median (IQR). Roman numerals in the left column correspond to those in Fig. 1A. For the perpendicular distance between the center of the KG4VS and the perpendicular bisector of the porus acusticus internus, the ventral side is represented by a positive value and the dorsal side by a negative value.

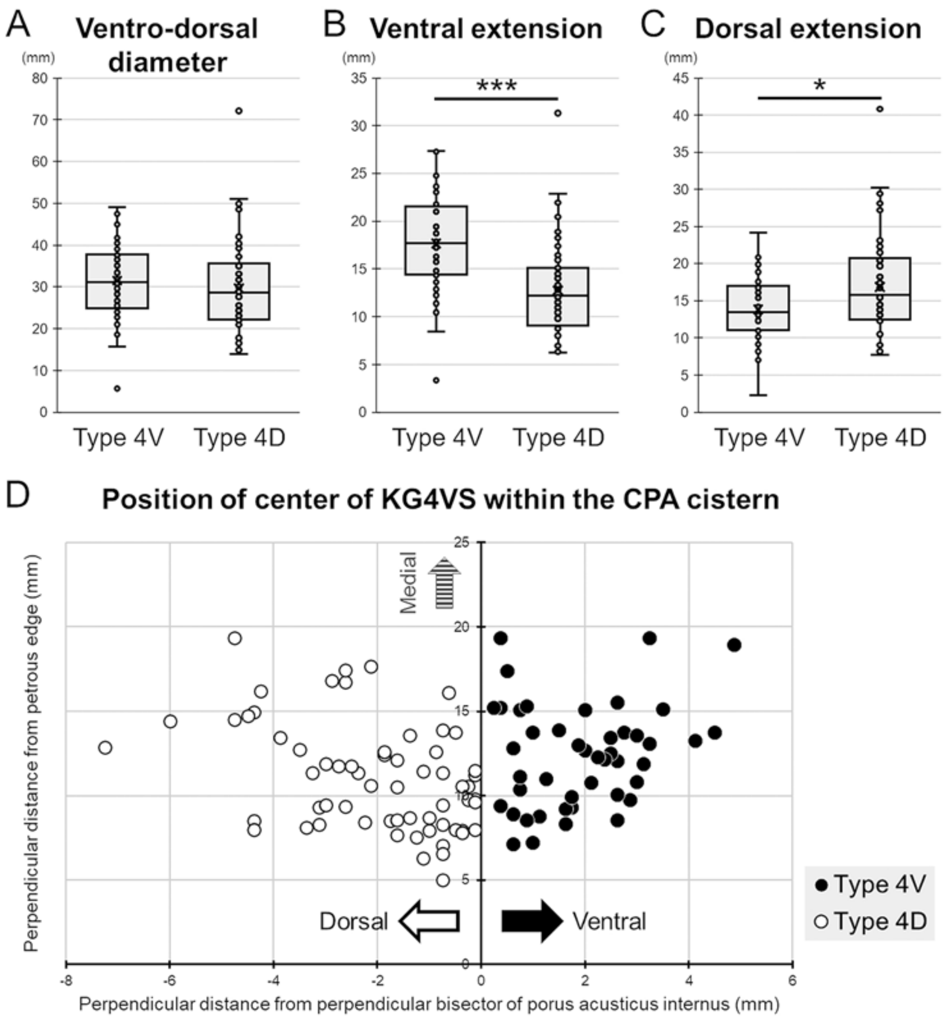

FIG. 2. A–C: Box plots showing the difference in maximal ventrodorsal diameter (A), ventral extension (B), and dorsal extension (C) between the subtypes of KG4VS. The *circles* represent the cases, the *horizontal lines* the median, and the *boxes* the IQR. *p < 0.05; ***p < 0.001. **D:** Scatterplot showing distributions of the position of the center of KG4VS within the CPA cistern in all cases for both subtypes of KG4VS. *Black* represents type 4V, and *white* represents type 4D. In terms of the perpendicular distance from the perpendicular bisector of the porus acusticus internus, the ventral side is represented by a positive value, and the dorsal side by a negative value.

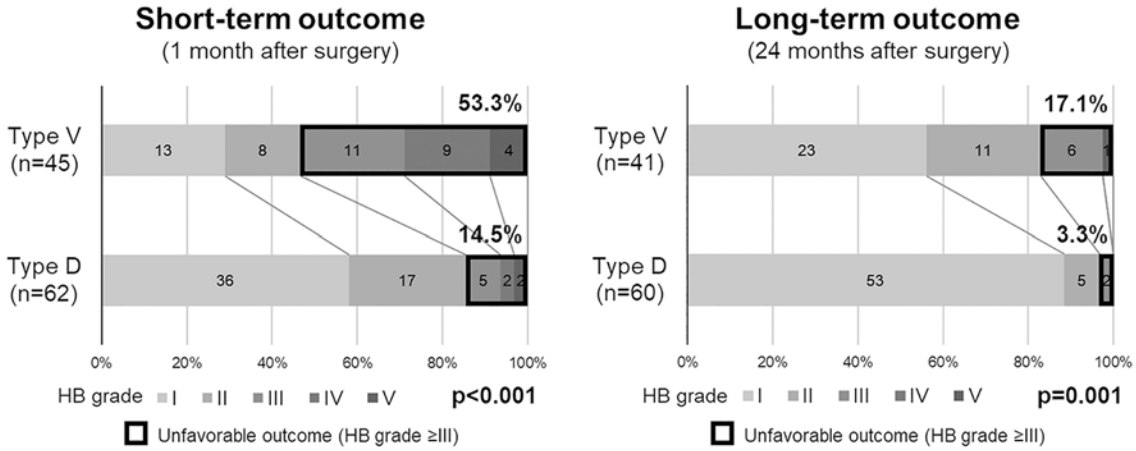

FIG. 3. Bar graphs showing the short-term (*left*) and long-term (*right*) postoperative facial nerve outcomes for both subtypes of KG4VS. The graphs show the number of patients with each HB grade. The percentages represent the proportion with an unfavorable facial nerve outcome (HB grades ≥ III). Significance values are listed below the graph.

In multivariate analysis with adjustment for age, tumor size, presence of a fundal fluid cap, and subtype of KG4VS, type 4V (OR 7.67, 95% CI 2.90–20.3; $p < 0.001$) remained a significant independent predictor of an unfavorable facial nerve outcome at 1 month after surgery (Table 3).

Predictors of Long-Term Postoperative Facial Nerve Function

In univariate analyses, tumor size > 40 mm (OR 5.25, 95% CI 1.10–25.1; $p = 0.038$), absence of a fundal fluid cap (OR 11.8, 95% CI 2.28–61.3; $p = 0.003$), and type 4V (OR 5.97, 95% CI 1.17–30.4; $p = 0.031$) were significant predictors of an unfavorable facial nerve outcome at 24 months after surgery (Table 4). No other feature was associated with long-term facial nerve function after surgery (Supplemental Table 2).

In multivariate analysis with adjustment for age, tumor size, presence of a fundal fluid cap, and subtype of KG4VS, type 4V (OR 6.05, 95% CI 1.04–35.0; $p = 0.045$) remained a significant independent predictor of an unfavorable facial nerve outcome at 24 months after surgery together with the absence of a fundal fluid cap (OR 10.6, 95% CI 1.89–59.8; $p = 0.007$) (Table 4).

Discussion

Postoperative facial nerve dysfunction has a devastating impact on the quality of life in patients with VS.[28,30–32] Therefore, preservation of facial nerve function is a priority in resection of VS. Preoperative prediction of postoperative facial nerve function using a simple method would enable more appropriate decision-making regarding the treatment strategy for patients with VS. We propose a novel landmark-based subclassification of KG4VS, which is generally considered a candidate for surgery, according to the relative relationship between the center of the VS and the porus acusticus internus for prediction of postoperative facial nerve function. In our series, in which total resection was attempted in all cases, type 4V had a significantly negative prognostic impact on short- and long-term facial nerve outcomes after resection of KG4VS via the retrosigmoid approach.

Morphological Features of KG4VS

As reported in previous morphological studies,[33–35] a larger VS (i.e., one with a higher Koos grade) tends to have greater ventral extension. In most of the previous studies, the dimensions of the tumor were measured anterior or posterior to the IAC axis. However, various morphological measurement methods were used. Furthermore, evaluations based only on actual values measured could not take into account individual morphological differences in the petrous bone and the posterior fossa.[36–38] Therefore, we

TABLE 3. Results of univariate and multivariate analyses of potential predictors of unfavorable facial nerve function at 1 month after surgery as the short-term outcome

	Univariate Analysis			Multivariate Analysis		
Factor	OR	95% CI	p Value	OR	95% CI	p Value
Age, yrs	0.98	0.96–1.01	0.243	0.98	0.94–1.01	0.158
Tumor size (maximum CPA): >40 vs ≤40 mm	1.71	0.50–5.84	0.393	1.57	0.37–6.68	0.538
Fundal fluid cap: absent vs present	2.02	0.84–4.86	0.116	1.95	0.72–5.30	0.166
KG4VS subtype: 4V vs 4D	6.73	2.69–16.9	<0.001	7.67	2.90–20.3	<0.001

TABLE 4. Results of univariate and multivariate analyses of potential predictors of unfavorable facial nerve function at 24 months after surgery as the long-term outcome

Factor	Univariate Analysis			Multivariate Analysis		
	OR	95% CI	p Value	OR	95% CI	p Value
Age, yrs	1.00	0.95–1.04	0.822	1.00	0.95–1.06	0.979
Tumor size (maximum CPA): >40 vs ≤40 mm	5.25	1.10–25.1	0.038	4.03	0.61–26.5	0.147
Fundal fluid cap: absent vs present	11.8	2.28–61.3	0.003	10.6	1.89–59.8	0.007
KG4VS subtype: 4V vs 4D	5.97	1.17–30.4	0.031	6.05	1.04–35.0	0.045

developed a simple subclassification that focuses on the relative relationship between the center of the VS and the perpendicular bisector of the porus acusticus internus. In this study, we identified morphological differences other than tumor size within the same grade of KG4VS and successfully delineated two distinctly different subtypes of KG4VS, namely, type 4V and type 4D.

We classified 42.1% of our patients as having type 4V and 57.9% as having type 4D. The center of type 4V was located ventrally to the perpendicular bisector of the porus acusticus internus and farther from the petrous edge than was type 4D. Consistent with our hypothesis, ventral extension was significantly greater in type 4V than in type 4D, although there was no significant difference in the maximal ventrodorsal diameter. Furthermore, the maximal mediolateral diameter was larger in type 4V than in type 4D. These morphological findings suggest that type 4V is a subtype of KG4VS with greater ventral and medial extension. Moreover, our morphological findings based on actual values measured indicate that our landmark-based subclassification of KG4VS is valid.

Postoperative Facial Nerve Function Based on Subclassification of KG4VS

It has been unclear why the Koos classification cannot predict postoperative facial nerve function even though tumor size is generally considered to be a predictor of facial nerve function after resection of VS.[19,20,23] To answer this question, we focused on the abovementioned morphological differences within KG4VS and proposed a subclassification system. This study has successfully demonstrated that our subclassification can predict short- and long-term facial nerve function after resection of KG4VS via the retrosigmoid approach. Hobson et al. put forward a hypothesis similar to ours and evaluated 127 patients who underwent resection of large (≥ 25 mm) VSs mainly via the translabyrinthine approach.[33] They found that a large proportion of tumors posterior to the IAC axis had a high likelihood of good short- and long-term facial nerve outcomes. Moreover, both Wong et al. and Perkins et al. reported worsened facial nerve function in patients with tumors that were larger and in those with greater anterior extension.[34,39] These studies showed that greater ventral tumor extension was associated with unfavorable postoperative facial nerve function based on actual measurements, but no clear criteria were given. Our present study has resolved this issue.

We performed KG4VS resection guided by intraoperative facial nerve monitoring using consistent procedures and intraoperative judgment. Overall, we achieved favorable facial nerve function (HB grade I or II) in 69.2% of patients at 1 month postoperatively and in 91.1% at 24 months postoperatively, which is satisfactory when compared with previous reports.[3,19,40] However, the short- and long-term rates of preservation of favorable facial nerve function were significantly lower for type 4V (46.7% at 1 month postoperatively and 82.9% at 24 months postoperatively) than for type 4D (85.5% and 96.7%, respectively). We identified morphological subtypes of KG4VS with a different prognosis in terms of facial nerve function even when tumor size within the KG4VS was taken into account. Interestingly, the incidence of a decreased response on intraoperative facial nerve monitoring was significantly higher for type 4V (24.4%) than for type 4D (8.1%), leading to a low rate of total resection in our patients with type 4V. The anatomical location of the facial nerve might help to explain why type 4V is likely to have an unfavorable facial nerve outcome after resection of VS via the retrosigmoid approach. The facial nerve is located in the anterior superior quadrant of the IAC and generally lies ventrally to a VS.[41,42] Therefore, the facial nerve fibers in type 4V are more strongly stretched at the exit of the porus acusticus internus and over the ventral tumor surface than are those in type 4D. The facial nerve was lacerated intraoperatively at the exit of the porus acusticus internus in 1 patient with type 4V in our case series, which is consistent with this hypothesis. Furthermore, the rostroventral facial nerve displacement pattern is generally related to poor facial nerve outcomes.[43] Our intraoperative finding that the rostroventral displacement pattern was significantly more common in type 4V further explains the relationship between our subclassification and postoperative facial nerve function. These features could potentially make the facial nerve more vulnerable to mechanical injury during microsurgery in patients with type 4V KG4VS (Fig. 4).

Like the KG4VS subtype, the fundal fluid cap also contributes to long-term postoperative facial nerve function. Our proposed subclassification targets the risk of facial nerve injury during resection of tumor components within the CPA cistern, which accounts for the majority of KG4VS tumors. However, the fundal fluid cap targets the risk of facial nerve injury during resection of tumor components within the IAC.[18] The difference in the rate of preservation of favorable facial nerve function was obvious in our case series when this combination of radiographic features was

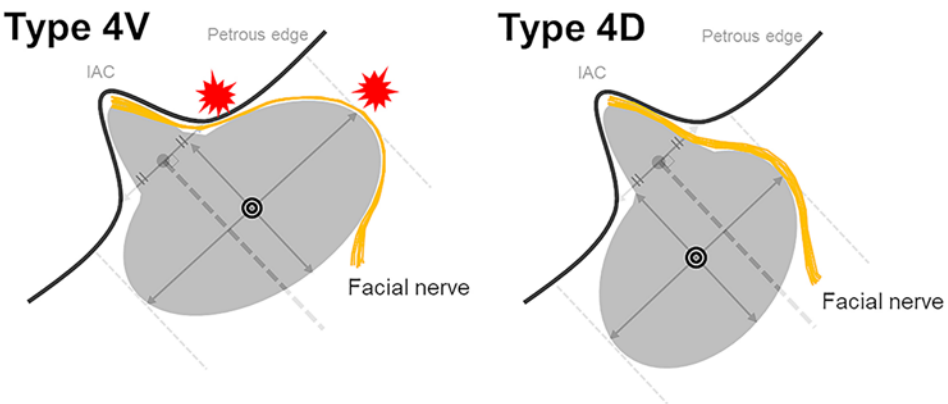

FIG. 4. Schematic illustration of both subtypes of KG4VS with a facial nerve demonstrating our hypothesis regarding why an unfavorable facial nerve outcome can be predicted for type 4V after VS surgery. The facial nerve fibers in type 4V are more strongly stretched at the exit of the porus acusticus internus and over the ventral tumor surface (*left*). These features could potentially make the facial nerve more vulnerable to mechanical injury during microsurgery, as indicated by the *red areas*. Conversely, the stretching of the facial nerve fibers in type 4D are milder than that in type 4V and there would be a greater likelihood of a favorable postoperative facial nerve outcome (*right*).

considered. Facial nerve function was preserved in 88.9% of patients (40/45) at 1 month postoperatively and in 97.8% (44/45) at 24 months postoperatively when the KG4VS was type 4D with a fundal fluid cap. In contrast, facial nerve function was preserved in 35.7% of patients (5/14) at 1 month postoperatively and in 53.8% (7/13) at 24 months postoperatively when the KG4VS was type 4V without a fundal fluid cap. Our findings suggest that these two independent radiographic features (subclassification of KG4VS and fundal fluid cap) could be used together in advance of surgery to predict facial nerve function after resection of KG4VS via the retrosigmoid approach.

Limitations

Our study has three main limitations. First, it was conducted at a single institution with a small sample and had a retrospective design. Therefore, we cannot exclude the possibility of bias in the study population. However, of all the morphological studies that have examined facial nerve function after resection of KG4VS via the retrosigmoid approach, ours is based on the largest number of patients to date. Second, we used only the retrosigmoid approach for resection of VS. Our surgical strategy has always been to attempt total resection for KG4VS while preserving facial nerve function. Therefore, an effect of differences in surgical approach and surgical strategy between centers on postoperative facial nerve function cannot be excluded. Based on our findings, intentional near-total resection or subtotal resection followed by stereotactic radiosurgery might be the preferable surgical goal for type 4V KG4VSs. However, the clinical applicability of our proposed subclassification of KG4VS for patients treated by other surgical strategies, including other surgical approaches, requires further investigation. Finally, the subclassification did not take into account 3D morphological differences. Our proposed subclassification is based on 2D analysis and is designed to be simple and easy for clinicians to use. However, future investigations that include 3D analysis might reveal unresolved issues.

Conclusions

This paper describes the development and validation of a novel landmark-based subclassification of KG4VS according to the relative relationship between the center of the VS and the porus acusticus internus that can be used to predict facial nerve function after surgery. This subclassification can delineate two distinctly different morphological subtypes of KG4VS and predict short- and long-term facial nerve function after microsurgical resection of KG4VS via the retrosigmoid approach. The risk of postoperative facial palsy is greater for type 4V than for type 4D when attempting total resection. The distinction between types 4V and 4D could help to predict the risk of facial nerve injury and generate more individualized surgical strategies for KG4VSs with better facial nerve outcomes.

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References

1. Carlson ML, Link MJ. Vestibular schwannomas. *N Engl J Med*. 2021;384(14):1335-1348.
2. Goldbrunner R, Weller M, Regis J, et al. EANO guideline on the diagnosis and treatment of vestibular schwannoma. *Neuro Oncol*. 2020;22(1):31-45.
3. Samii M, Gerganov VM, Samii A. Functional outcome after complete surgical removal of giant vestibular schwannomas. *J Neurosurg*. 2010;112(4):860-867.
4. Seol HJ, Kim CH, Park CK, et al. Optimal extent of resection in vestibular schwannoma surgery: relationship to recurrence and facial nerve preservation. *Neurol Med Chir (Tokyo)*. 2006;46(4):176-181.

5. Yeole U, Prabhuraj AR, Arivazhagan A, et al. Gamma knife radiosurgery for large vestibular schwannoma more than 10 cm^3: a single-center Indian study. *J Neurol Surg B Skull Base*. 2021;83(2 suppl 2):e343-e352.
6. Daoudi H, Lahlou G, Degos V, Sterkers O, Nguyen Y, Kalamarides M. Improving facial nerve outcome and hearing preservation by different degrees of vestibular schwannoma resection guided by intraoperative facial nerve electromyography. *Acta Neurochir (Wien)*. 2020;162(8):1983-1993.
7. Hasegawa T, Kida Y, Kato T, Iizuka H, Kuramitsu S, Yamamoto T. Long-term safety and efficacy of stereotactic radiosurgery for vestibular schwannomas: evaluation of 440 patients more than 10 years after treatment with Gamma Knife surgery. *J Neurosurg*. 2013;118(3):557-565.
8. Koerbel A, Gharabaghi A, Safavi-Abbasi S, Tatagiba M, Samii M. Evolution of vestibular schwannoma surgery: the long journey to current success. *Neurosurg Focus*. 2005; 18(4):e10.
9. Manzoor NF, Nassiri AM, Sherry AD, et al. Predictors of recurrence after sub-total or near-total resection of vestibular schwannoma: importance of tumor volume and ventral extension. *Otol Neurotol*. 2022;43(5):594-602.
10. Dumot C, Pikis S, Mantziaris G, et al. Stereotactic radiosurgery for Koos grade IV vestibular schwannoma in young patients: a multi-institutional study. *J Neurooncol*. 2022;160(1): 201-208.
11. Dhayalan D, Perry A, Graffeo CS, et al. Salvage radiosurgery following subtotal resection of vestibular schwannomas: does timing influence tumor control? *J Neurosurg*. 2022;138(2): 420-429.
12. Daniel RT, Tuleasca C, George M, et al. Preserving normal facial nerve function and improving hearing outcome in large vestibular schwannomas with a combined approach: planned subtotal resection followed by gamma knife radiosurgery. *Acta Neurochir (Wien)*. 2017;159(7):1197-1211.
13. Brokinkel B, Sauerland C, Holling M, et al. Gamma Knife radiosurgery following subtotal resection of vestibular schwannoma. *J Clin Neurosci*. 2014;21(12):2077-2082.
14. Zhang Z, Zhang D, Shi X, Tao B, Liu Y, Zhang J. A nomogram to predict recurrence-free survival following surgery for vestibular schwannoma. *Front Oncol*. 2022;12:838112.
15. Behling F, Bersali I, Santacroce A, et al. Transition of a vestibular schwannoma to a malignant peripheral nerve sheath tumor with loss of H3K27 trimethylation after radiosurgery—a case report and review of the literature. *Neurosurg Rev*. 2022;45(1):915-922.
16. Whitmeyer M, Brahimaj BC, Beer-Furlan A, et al. Resection of vestibular schwannomas after stereotactic radiosurgery: a systematic review. *J Neurosurg*. 2021;135(3):881-889.
17. Peker HO, Gok H, Altay T. Malignant transformation of vestibular schwannoma after stereotactic radiosurgery. *World Neurosurg*. 2019;124:81-83.
18. Fujita Y, Uozumi Y, Sasayama T, Kohmura E. Presence of a fundal fluid cap on preoperative magnetic resonance imaging may predict long-term facial nerve function after resection of vestibular schwannoma via the retrosigmoid approach. *J Neurosurg*. 2023;138(4):972-980.
19. Falcioni M, Fois P, Taibah A, Sanna M. Facial nerve function after vestibular schwannoma surgery. *J Neurosurg*. 2011; 115(4):820-826.
20. Sun Y, Yang J, Li T, Gao K, Tong X. Nomogram for predicting facial nerve outcomes after surgical resection of vestibular schwannoma. *Front Neurol*. 2022;12:817071.
21. Erickson NJ, Schmalz PGR, Agee BS, et al. Koos classification of vestibular schwannomas: a reliability study. *Neurosurgery*. 2019;85(3):409-414.
22. Koos WT, Day JD, Matula C, Levy DI. Neurotopographic considerations in the microsurgical treatment of small acoustic neurinomas. *J Neurosurg*. 1998;88(3):506-512.
23. Erickson NJ, Mooney JH, Walters BC, Agee B, Fisher WS. The validity of the Koos classification system with respect to facial nerve function. *Neurosurgery*. 2021;88(6):E523-E528.
24. Grahnke K, Garst JR, Martin B, Leonetti JP, Anderson DE. Prognostic indices for predicting facial nerve outcome following the resection of large acoustic neuromas. *J Neurol Surg B Skull Base*. 2017;78(6):454-460.
25. Sharma M, Sonig A, Ambekar S, Nanda A. Radiological and clinical factors predicting the facial nerve outcome following retrosigmoid approach for large vestibular schwannomas (VSs). *J Neurol Surg B Skull Base*. 2013;74(5):317-323.
26. Tanaka Y, Hongo K, Tada T, Kobayashi S. What is the best method for reporting tumor diameter in vestibular schwannoma? *Neurosurgery*. 2003;53(3):634-638.
27. House JW, Brackmann DE. Facial nerve grading system. *Otolaryngol Head Neck Surg*. 1985;93(2):146-147.
28. Fujita Y, Uozumi Y, Yamaguchi Y, Nakai T, Sasayama T, Kohmura E. Symptom-based opioid-free treatment for persistent postoperative headache after vestibular schwannoma resection via the retrosigmoid approach. *World Neurosurg*. 2022;162:e347-e357.
29. Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. *Bone Marrow Transplant*. 2013;48(3):452-458.
30. Carlson ML, Lohse CM, Link MJ, et al. Development and validation of a new disease-specific quality of life instrument for sporadic vestibular schwannoma: the Mayo Clinic Vestibular Schwannoma Quality of Life Index. *J Neurosurg*. 2023;138(4):981-991.
31. Carlson ML, Tveiten OV, Driscoll CL, et al. Long-term quality of life in patients with vestibular schwannoma: an international multicenter cross-sectional study comparing microsurgery, stereotactic radiosurgery, observation, and nontumor controls. *J Neurosurg*. 2015;122(4):833-842.
32. Walker DT, Hallam MJ, Ni Mhurchadha S, McCabe P, Nduka C. The psychosocial impact of facial palsy: our experience in one hundred and twenty six patients. *Clin Otolaryngol*. 2012; 37(6):474-477.
33. Hobson CE, Saliba J, Vorasubin N, Lyles RH, Mastrodimos B, Cueva RA. Vestibular schwannoma cerebellopontine angle position impacts facial outcome. *Laryngoscope*. 2022;132(5): 1093-1098.
34. Wong RH, Copeland WR, Jacob JT, et al. Anterior extension of tumor is as important as tumor size to facial nerve outcome and extent of resection for vestibular schwannomas. *J Neurol Surg B Skull Base*. 2017;78(6):473-480.
35. Gerganov VM, Klinge PM, Nouri M, Stieglitz L, Samii M, Samii A. Prognostic clinical and radiological parameters for immediate facial nerve function following vestibular schwannoma surgery. *Acta Neurochir (Wien)*. 2009;151(6):581-587.
36. Noureldine MHA, Aum D, Piper K, et al. Value of the petromeatal angle in predicting outcome of translabyrinthine resection of vestibular schwannomas. *Oper Neurosurg (Hagerstown)*. 2020;19(4):E370-E378.
37. Nishikawa M, Sakamoto H, Hakuba A, Nakanishi N, Inoue Y. Pathogenesis of Chiari malformation: a morphometric study of the posterior cranial fossa. *J Neurosurg*. 1997;86(1): 40-47.
38. Muren C. The internal acoustic meatus. Anatomic variations and relations to other temporal bone structures. *Acta Radiol Diagn (Stockh)*. 1986;27(5):505-512.
39. Perkins EL, Manzoor NF, Totten DJ, et al. The influence of extent of resection and tumor morphology on facial nerve outcomes following vestibular schwannoma surgery. *Otol Neurotol*. 2021;42(9):e1346-e1352.
40. Samii M, Gerganov V, Samii A. Improved preservation of hearing and facial nerve function in vestibular schwannoma surgery via the retrosigmoid approach in a series of 200 patients. *J Neurosurg*. 2006;105(4):527-535.

41. Mastronardi L, Cacciotti G, Roperto R, Di Scipio E, Tonelli MP, Carpineta E. Position and course of facial nerve and postoperative facial nerve results in vestibular schwannoma microsurgery. *World Neurosurg*. 2016;94:174-180.
42. Sampath P, Rini D, Long DM. Microanatomical variations in the cerebellopontine angle associated with vestibular schwannomas (acoustic neuromas): a retrospective study of 1006 consecutive cases. *J Neurosurg*. 2000;92(1):70-78.
43. Esquia-Medina GN, Grayeli AB, Ferrary E, et al. Do facial nerve displacement pattern and tumor adhesion influence the facial nerve outcome in vestibular schwannoma surgery? *Otol Neurotol*. 2009;30(3):392-397.

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Fujita. Acquisition of data: Fujita, Uozumi. Analysis and interpretation of data: Fujita, Uozumi. Drafting the article: Fujita. Critically revising the article: all authors. Reviewed submitted version of manuscript: Uozumi, Sasayama, Kohmura. Approved the final version of the manuscript on behalf of all authors: Fujita. Statistical analysis: Fujita, Uozumi. Administrative/technical/material support: Fujita. Study supervision: Sasayama, Kohmura.

Supplemental Information

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