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Abstract: Background: Preserving the facial nerve (FN) in patients undergoing acoustic neuroma (AN) surgery requires confirmation of its anatomical location and course.
Objective: To investigate the variation in the course of the FN, its adhesion to tumors, and the relationship between such adhesions and postoperative facial palsy.
Methods: Subjects were 356 patients who underwent AN surgery for whom the course of the FN could be confirmed. Patients were classified into six groups according to the FN course: (1) ventro-central surface of the tumor (VCe); (2) ventro-rostral (VR); (3) ventro-caudal (VCa); (4) rostral (R); (5) caudal (C); and (6) dorsal (D). The relationship between the course and tumor size, nerve adhesion to tumors, and postoperative FN function was investigated.
Results: The FN course was VCe in 185 cases, VR in 137, VCa in 19, R in 10, C in 4, and D in one. Regarding tumor size, for tumors □1.5 cm the VCe pattern was most common. For tumors □1.5 cm, the proportion of VR increased, and in tumors >3 cm, an increased proportion of patients had severely distorted courses. No significant difference was observed between course patterns of the FN in terms of postoperative FN function, but for tumors □3 cm there was an increasing tendency for the FN to adhere strongly to the tumor capsule, and postoperative facial palsy was more severe in patients with stronger adhesions.
Conclusions: The VCe pattern was most common for small tumors. Adhesion to the tumor capsule was most strongly associated with postoperative FN palsy.

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May 13, 2011

Nelson M. Oyesiku, MD, PhD, FACS
Editor-in-Chief
Neurosurgery

Dear Dr. Oyesiku:

Enclosed please find a copy of our manuscript entitled, "Evaluation of variations in the course of the facial nerve, nerve adhesion to tumors, and postoperative facial palsy in acoustic neuroma: A retrospective study of 356 cases" which we would like to submit for publication in ***Neurosurgery***.

In this study, we present the results of an investigation of the relationship between course of the facial nerve and adhesion of this nerve to tumors, and that between such adhesions and postoperative facial palsy in patients undergoing acoustic neuroma surgery. We believe that our study would be of interest to the readers of your journal because when performing acoustic neuroma surgery, attempts should be made to preserve hearing acuity and to accurately identify the course of the facial nerve in order to preserve its function.

The work presented herein is original, has not been previously published in whole or in part, and is not under consideration for publication at any other journal. Each author has contributed significantly to the research presented herein, has reviewed the final version of the manuscript and approved this submission.

We would like to thank you in advance for considering this manuscript. Please feel free to contact me if you have any questions or require further information.

Sincerely,

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*Title Page

Evaluation of variation in the course of the facial nerve, nerve adhesion to tumors, and postoperative facial palsy in acoustic neuroma: A retrospective study of 356 cases

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Results: The FN course was VCe in 185 cases, VR in 137, VCa in 19, R in 10, C in 4, and D in one. Regarding tumor size, for tumors <1.5 cm the VCe pattern was most common. For tumors ≥1.5 cm, the proportion of VR increased, and in tumors >3 cm, an increased proportion of patients had severely distorted courses. No significant difference was observed between course patterns of the FN in terms of postoperative FN function, but for tumors >3 cm there was an increasing tendency for the FN to adhere strongly to the tumor capsule, and postoperative facial palsy was more severe in patients with stronger adhesions.

Conclusions: The VCe pattern was most common for small tumors. Adhesion to the tumor capsule was most strongly associated with postoperative FN palsy.

Key Words: Acoustic neuromas, Facial nerve, Retrosigmoid approach

Running title: Course of the facial nerve

Introduction

The goals of acoustic neuroma surgery are safe tumor resection, hearing preservation, and preservation of facial nerve function. In recent years, operative results reported by expert skull base teams working with innovative microsurgical instruments have improved markedly, with the incidence of facial nerve palsy being only a few percent. In general, during acoustic neuroma surgery, surgeons proceed with removal while confirming the position of the facial nerve, the course of which is known to vary according to factors such as tumor size, site of origin, and degree of adhesion. As accurate preoperative assessment of the anatomical location and course of the facial nerve is difficult even with current advances in imaging technology, the only method currently available is confirmation under a microscope with repeated intraoperative facial nerve stimulation. In this study, we investigated the association between facial nerve course patterns in acoustic neuroma, adhesion to tumors, and postoperative facial palsy.

Material and Methods

Subjects were 356 patients undergoing surgery for acoustic neuroma via the retrosigmoid approach between April 2002 and December 2010 (160 women and 196 men; mean age, 59.1 years; mean tumor size, 19.8 mm).

In all cases, we attempted total or near-total removal of the tumor, and facial nerves were anatomically preserved. All procedures were performed by expert neurosurgical teams with intraoperative facial nerve monitoring and intraoperative auditory brain stem response monitoring for hearing preservation.

The data obtained included patient age, tumor size (evaluated as the largest transverse diameter on enhanced magnetic resonance images), pre- and postoperative facial nerve function, and extent of adhesions between the facial nerve and the tumor.

We classified the course of the facial nerve into 6 patterns according to its path on the surface of the tumor: ventro-central (VCe), ventro-rostral (VR), ventro-caudal (VCa), rostral (R), caudal (C), and dorsal (D) patterns (Figure 1).

All 356 patients exhibited normal (grade 1) facial function preoperatively. In addition, the facial nerve was anatomically preserved after surgery in all cases. Facial nerve outcome was reported on the House-Brackmann scale,[1] and the results are recorded as early (approximately 2 weeks after surgery) and late (8 to 12 months after surgery).

Adhesion between the tumor and the facial nerve was evaluated during the procedure by the operating surgeon. In patients with severe adhesion, it was difficult to separate the facial nerve from the tumor capsule with blunt dissection, and sharp dissection with scissors was required.

Results

The course of the facial nerve

The VCe pattern, i.e., that in which the facial nerve ran ventrally and centrally over the tumor surface, accounted for 185/356 cases (52.0%), the largest proportion of cases overall, followed by VR in 137 cases (38.5%), VCa in 19 (5.3%), R in 10 (2.8%), C in 4 (1.1%), and D in 1 (0.3%) (Table 1). Categorized by tumor size, for tumors <1.5 cm the pattern was VCe in 77/98 cases (78.6%) and VR in 21 (21.4%); for tumors of 1.5–3 cm the pattern was VCe in 90/195 cases (46.2%), VR in 89 (45.6%), VCa in 11 (5.6%), R in 3 (1.5%), C in 1 (0.5%), and D in 1 (0.5%), while for tumors >3.0 cm the pattern was VCe in 18/63 cases (28.6%), VR in 27 (42.9%), VCa in 8 (12.7%), R in 7 (11.1%), and C in 3 (4.8%). That is, for tumors <1.5 cm the VCe pattern was most common, accounting for nearly 80% of cases. For tumors ≥1.5 cm the proportion of VR rose, and once tumor size exceeded 3 cm, there was an increase in the proportion of patients with severely distorted courses, such as the R pattern in which the nerve runs across the upper peak of the tumor or the VCa and C patterns in which it runs along the caudal side. In one patient (tumor size 2.4 cm), the course ran entirely along the dorsal side.

Facial nerve outcome (late) according to the House-Brackmann scale

Table 2 shows facial nerve function according to the House-Brackmann scale[1] for each facial nerve course pattern at late follow-up examination (8-12 months). Grade 1 patients comprised 131 cases (70.8%) of VCe, 99 (72.3%) of VR, 15 (78.9%) of VCa, 8 (80.0%) of R, and 2 (50.0%) of C; Grade 2 patients comprised 40 cases (21.6%) of VCe, 31 (22.6%) of VR, 1 (5.3%) of VCa, 1 and (10.0%) of R; Grade 3 patients comprised 9 cases (4.9%) of VCe, 5 (3.6%) of VR, 2 (10.5%) of VCa, 1 (10.0%) of R, 2 (50.0%) of C, and 1 (100%) of D; and Grade 4 patients comprised 5 cases (2.7%) of VCe, 2 (1.5%) of VR, and 1 (5.3%) of VCa. If we exclude patterns C and D, which were seen in only small numbers of patients, there were no major differences in outcome for different facial nerve course patterns in terms of postoperative facial nerve function.

Adhesion between the tumor and the facial nerve

Table 3 shows the presence or absence of adhesion between the tumor capsule and the facial nerve in terms of course pattern and tumor size. Adhesion was present in 22 cases (28.6%) of VCe and 8 (38.1%) of VR for tumors <1.5 cm; 49 cases (54.4%) of VCe, 49 (55.1%) of VR, 3 (27.3%) of VCa, 2 (66.7%) of R, 1 (100%) of C, and 1 (100%) of D for tumors 1.5–3.0 cm; and 14 cases (77.8%) of VCe, 22 (81.5%) of VR, 5 (62.5%) of VCa, 6 (85.7%) of R, and 2 (66.7%) of C for tumors >3.0 cm. There were no major differences between VCe, VR, and VCa in terms of extent of adhesion, but adhesion was frequent in cases of R, C, and D, courses that ran in an extremely distorted pattern. Adhesion was more frequent for larger tumors in all course patterns.

The site of strongest adhesion was in the region of the entrance to the internal auditory canal in all course patterns.

Postoperative facial nerve function and tumor adhesion to the facial nerve

A comparison of postoperative facial nerve function in relation to the presence or absence of tumor adhesion showed that adhesion had a significant effect on facial nerve preservation outcomes (Table 4). In some cases, the facial nerve was embedded within the tumor capsule, resulting in a higher rate of postoperative facial palsy.

Changes in facial nerve morphology

When the tumor was larger than 3.0 cm, the facial nerve tended to become thinned and flattened, and to adhere to the tumor capsule more strongly.

Discussion

The goals of acoustic neuroma surgery are safe, accurate, and complete tumor resection, hearing preservation, and facial nerve preservation.[2-8] In order to accomplish microsurgical total tumor resection with curative intent in patients without any complications, surgeons must have a detailed understanding of temporal bone and cerebellopontine angle anatomy and employ precise and sophisticated micro-technical skills, as well as abundant clinical experience.[9-11] In recent years, operative results reported by expert skull base teams working with innovative microsurgical instruments have improved markedly, with the incidence of facial nerve palsy being only a few percent.[12,13] Normally, hearing impairment is the primary complaint in acoustic neuroma, with preoperative facial nerve palsy hardly ever present, meaning that preservation of this function requires the most care.

In general, during acoustic neuroma surgery, resection proceeds while confirming the position of the facial nerve, the course of which is known to vary according to factors such as tumor size, site of origin, and degree of adhesion. Accurate preoperative assessment of the anatomical location and course of the facial nerve is difficult even with the current rapid development of imaging technologies such as MRI. Particularly with large tumors the facial nerve can be compressed and flattened into a thin structure that adheres strongly to the tumor capsule, and sometimes even becomes infiltrated or enfolded into the tumor. Because this makes it difficult to confirm the course accurately, even under a microscope, the only method currently available is cautious confirmation of its course with repeated intraoperative facial nerve stimulation while removing the tumor. We performed frequent intraoperative facial nerve stimulation,[14] identifying the root exit zone of the facial nerve at the earliest possible stage and placing the electrode for continuous stimulation monitoring at that point during tumor removal surgery.

With respect to facial nerve course patterns, in our series, courses crossing the ventro-central surface accounted for around 80% of cases for small acoustic neuromas of <1.5 cm. In contrast, for tumors measuring between 1.5-3 cm, the frequency of VCe was very similar to that of VR (46.2% vs. VR in 45.6%), and for tumors >3.0 cm the course had shifted to the ventro-rostral surface in many cases, with VCe accounting for 28.6% of cases and VR for 42.9%. In this series, a course across the dorsal portion of the tumor was seen in only one patient (0.3%).

Sampath *et al*.[15] analyzed microanatomical variations in the location of the facial nerves for 1006 cases of acoustic neuromas categorized by size but with measurements 1.0 cm larger than our classification (Group I: smaller than 2.5 cm; Group II: between 2.5 cm and 4.0 cm; and Group III: larger than 4.0 cm). In their patients, the facial nerve most commonly ran across the anterior middle third of the tumor (corresponding to VCe in our classification); this pattern was seen in 40.0% of cases in Group I, 40.2% in Group II, and 39.8% in Group III, followed by the anterior superior third (corresponding to VR) in 33.5% of cases in Group I, 33.2% in Group II, and 32.7% in Group III, and the posterior location (corresponding to D) in 1.6% of cases in Group I, 2.5% in Group II, and 2.6% in Group III. There were no differences in course frequency between different sizes of tumor.

In a study of 163 cases of acoustic neuroma, Bae *et al*.[16] categorized facial nerve course patterns into four groups: (1) the ventral and superior surface of the tumor (corresponding to VR in our classification), (2) the ventral and central surface (corresponding to VCe), (3) the ventral and inferior surface (corresponding to VCa), and (4) the dorsal surface (corresponding to D). They found that the course ran across the ventral and superior surface in 55.8% of cases, the ventral and central surface in 35.0%, the ventral and inferior surface in 8.6%, and the dorsal surface in 0.6%. For tumors of <2 cm diameter, the ventral and central surface pattern was most common, occurring in 65.2% of cases, whereas for tumors of diameter >2 cm the ventral and superior surface was most common, occurring in 59.3%. As in our series, the course increasingly shifted to the rostral side with increasing tumor size. With the retrosigmoid approach, Rand *et al*.[17,18] reported that the dorsal pattern with the nerve running on the operator's side of the tumor was present in 7-9% of cases.

However, for this type of pattern, Sampath *et al*.[15] reported a frequency of 1.6-2.6% and Bae *et al*.[16] noted one of 0.6%, and this pattern was also extremely rare in our series, seen in only one case (0.3%).

If the small number of cases with patterns C and D is excluded, there was no difference with respect to postoperative facial nerve function between VCe, VR, VCa, and R, and around 90% of patients were Grade 2 on the House-Brackmann scale after 8-12 months. When the facial nerve is located on the dorsal aspect of the tumor, however, tumor resection is performed across the facial nerve from the start, meaning that postoperative palsy (Grade 3) occurs more easily due to excessive manipulation of the nerve.

With respect to adhesion of the facial nerve to the tumor, there were no major differences between VCe, VR, and VCa in terms of course pattern, but adhesion was frequent in cases of R, C, and D, courses that ran in an extremely distorted pattern. Adhesion was more frequent for larger tumors in all course patterns, with stronger pressure from the tumor on the nerve resulting in it becoming morphologically stretched and flattened, with a higher chance of adhering strongly to the tumor capsule and even becoming incorporated within the tumor in some cases. Sampath *et al*.[15] reported that "the facial nerve passed through the tumor itself (infiltrating tumor or enfolded by tumor)" in around 3% of cases, but unlike our series, this was not related to tumor size. The site of strongest adhesion was in the region of the internal acoustic foramen in all course patterns, and as there was a tendency for longer latency and smaller amplitude during continuous stimulation monitoring for resections in this area, this location is regarded as having the highest risk of causing facial nerve damage. Accordingly, in recent cases, we have been performing subtotal removal if there is severe adhesion between the facial nerve and the tumor, leaving part of the tumor capsule along the course of the facial nerve, with the goal of facial nerve preservation.

Conclusions

When performing acoustic neuroma surgery, attempts should be made to preserve hearing acuity and to accurately identify the course of the facial nerve in order to preserve its function. Since it remains difficult to accurately identify the course of the facial nerve on preoperative images, surgical manipulation must be performed carefully and precisely, using appropriate measures as such frequent intraoperative nerve stimulation and continuous stimulation monitoring.

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Legends to Figure and Tables

Figure 1

Illustration showing our classification of facial nerve course patterns in acoustic neuroma. (1) ventro-central surface of the tumor (VCe); (2) ventro-rostral surface (VR); (3) ventro-caudal surface (VCa); (4) rostral surface (R); (5) caudal surface (C); and (6) dorsal surface (D).

Table 1

Facial nerve course patterns by tumor size.

Table 2

Postoperative facial nerve outcome (late) according to the House-Brackmann scale for each facial nerve course pattern.

Table 3

Presence of adhesions and postoperative facial nerve palsy in relation to tumor size and facial nerve course patterns.

Table 4

Presence of adhesions and postoperative facial nerve palsy.

Figure
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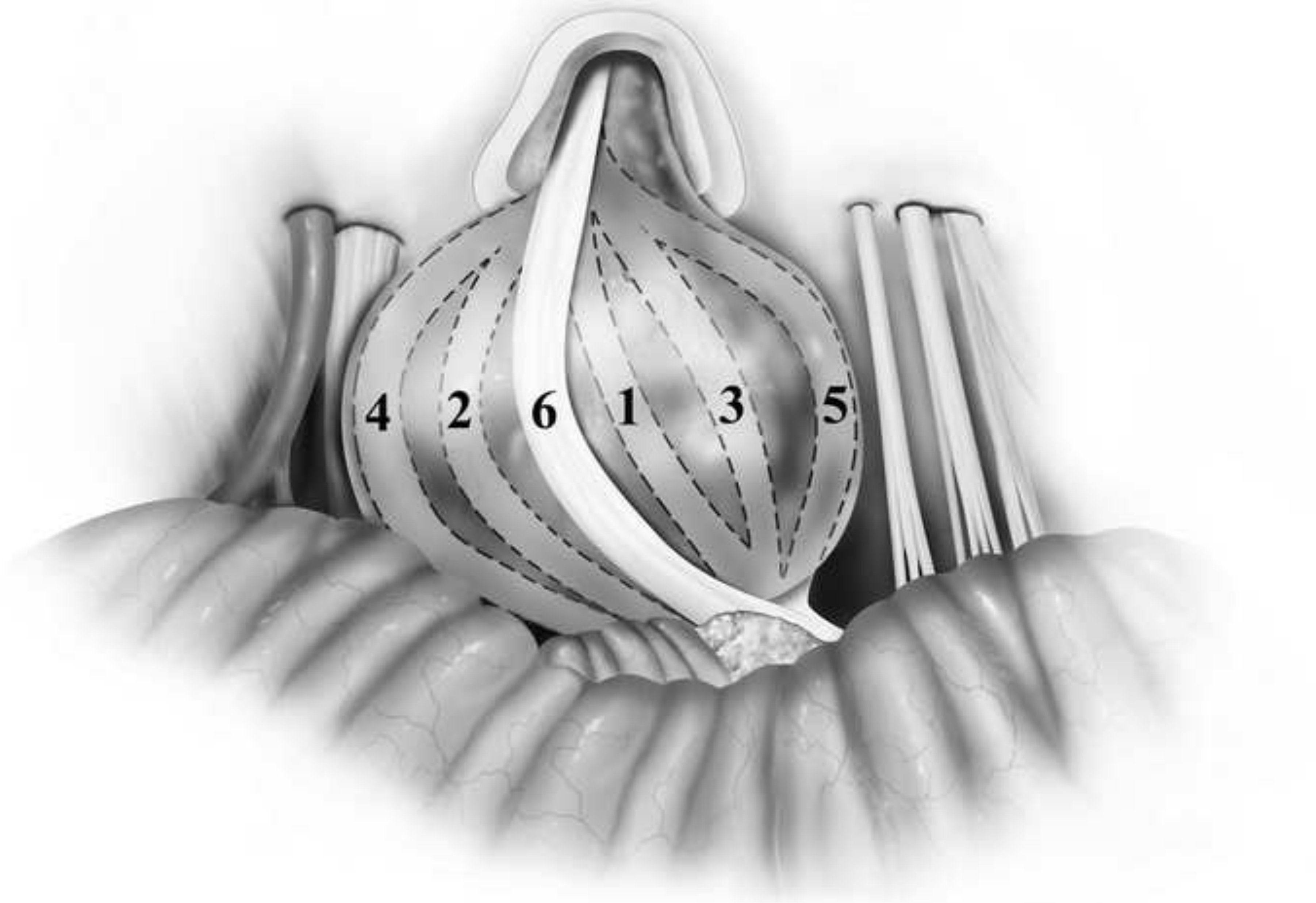

Table1

TABLE 1

Facial nerve course patterns by tumor size.

Tumor size (cm)	No. of patients	Course of facial nerve					
		VCe	VR	VCa	R	C	D
< 1.5	98	77(78.6%)	21(21.4%)	0	0	0	0
1.5-3.0	195	90(46.2%)	89(45.6%)	11(5.6%)	3(1.5%)	1(0.5%)	1(0.5%)
> 3.0	63	18(28.6%)	27(42.9%)	8(12.7%)	7(11.1%)	3(4.8%)	0
Total	356	185(52.0%)	137(38.5%)	19(5.3%)	10(2.8%)	4(1.1%)	1(0.3%)

*VCe: ventro-central pattern, VR: ventro-rostral pattern, VCa: ventro-caudal pattern, C: caudal pattern, R: rostral pattern, D: dorsal pattern

Table2

TABLE 2

Postoperative facial nerve outcome (late) according to the House-Brackmann scale for each facial nerve course pattern.

Grade	Course of facial nerve					
	VCe	VR	VCa	R	C	D
1	131(70.8%)	99(72.3%)	15(78.9%)	8(80.0%)	2(50.0%)	0
2	40(21.6%)	31(22.6%)	1(5.3%)	1(10.0%)	0	0
3	9(4.9%)	5(3.6%)	2(10.5%)	1(10.0%)	2(50.0%)	1(100%)
4	5(2.7%)	2(1.5%)	1(5.3%)	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
Total	185	137	19	10	4	1

Table3

TABLE 3

Presence of adhesions and postoperative facial nerve palsy in relation to tumor size and facial nerve course patterns.

	Course of facial nerve					
Tumor size (cm)	VCe	VR	VCa	R	C	D
< 1.5	22/77(28.6%)	8/21(38.1%)	0	0	0	0
1.5-3.0	49/90(54.4%)	49/89(55.1%)	3/11(27.3%)	2/3(66.7%)	1/1(100%)	1/1(100%)
> 3.0	14/18(77.8%)	22/27(81.5%)	5/8(62.5%)	6/7(85.7%)	2/3(66.7%)	0
Total	85/185(45.9%)	79/137(57.7%)	8/19(42.1%)	8/10(80.0%)	3/4(75.0%)	1/1(100%)

Table4

TABLE 4

Presence of adhesions and postoperative facial nerve palsy.

	Postop Grade				
	1	2	3	4	5
Adhesion (+)	113(44.3%)	47(64.4%)	16(80.0%)	8(100.0%)	0
Adhesion (-)	142(55.7%)	26(35.6%)	4(20.0%)	0	0
Total	255	73	20	8	0

*According to the House-Brackmann grading system