The ongoing discussion regarding optimal treatment strategies for VS has been focused on the wait-and-scan option, surgical removal, and radiotherapy. The pros and cons of surgery compared with radiotherapy have been discussed extensively. Refinements in surgical techniques, which in themselves add to the preservation of cranial nerve function, are seldom addressed in the current literature. In particular the facial nerve and its course with respect to tumor anatomy are rarely discussed, although these factors are certainly of prognostic import with regard to postoperative facial nerve function. In 2000 Sampath and colleagues published data from a major surgical study in which they particularly focused on the variations in the course of the facial nerve through the CPA, and thus provided invaluable information to surgeons with respect to both complete and curative tumor removal and preservation of cranial nerve function. In more than 95% of their 1022 cases, the facial nerve was identified on the ventral tumor surface. Most often, the nerve traced the middle and cranial ventral tumor surface, followed by a course on the uppermost pole in 14%. A dorsal route on the tumor surface facing the surgeon was described in 2.5% of the cases. Aberrant courses through the tumor, possibly indicating a facial nerve neuroma, were encountered in 3% of cases. The tumor completely enfolded the nerve in approximately 1% of cases and infiltrated the nerve sheath in 2.5% of cases. Other courses of the facial nerve have not been reported in the literature. The present study features an additional variant of the facial nerve course in VSs that has yet to be described in detail.

Clinical Material and Methods
Between 1996 and 2005, a consecutive series of 241 patients with VSs underwent surgery via the suboccipitotemporal approach. The diagnosis of VS was histologically confirmed in all cases. From operating records, intraoperative video recordings, and digital screenshot photography, we...
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identified 16 patients in whom a distinct splitting of the facial nerve could be documented (Table 1). The mean age in seven women and nine men was 45 years (range 28–74 years). All patients underwent preoperative MR imaging, and tumor size was calculated on axial T₁-weighted images with contrast enhancement and three-dimensional constructive interference in steady-state sequences. The mean intrameatal size was calculated as 3 mm (range 0–10 mm), with a mean extrameatal component of 24 mm (range 18–50 mm). On three-dimensional constructive interference in steady-state MR sequences, the fundus appeared obliterated by tumor in five cases and was free of tumor in 11 (Fig. 1).

Facial nerve function was assessed as House–Brackmann Grade I in nine patients, Grade II in six, and Grade III in one (Table 1). Patients with preoperative EMG evidence of facial nerve neuropathy had House–Brackmann Grade II function. Other cranial nerve deficits included a fifth cranial nerve hypesthesia in four patients. Lower cranial nerve deficits were documented in one patient before surgery.

Pure-tone audiometry and SD were evaluated in the Department of Otorhinolaryngology. Hearing was classified according to the American Academy of Otolaryngology–Head and Neck Surgery criteria (Classes A–D: A, PTA ≤ 30 dB and SD ≥ 70%; B, PTA > 30 dB and ≤ 50 dB and SD ≥ 50%; C, PTA > 50 dB and SD ≥ 50%; D, PTA at any level and SD < 50%). Note that we modified Class D to differentiate between patients with some preserved hearing (Class D) and those who have completely lost hearing (Class D surdity). Before surgery, Class A was documented in four patients, Class B in six, Class D with some residual hearing in five, and Class D with surdity in one. Brainstem auditory evoked potentials were monitored in the patients in whom hearing preservation was attempted. For facial nerve monitoring, intraoperative three-channel EMG recordings (nasalis, orbicularis oris, and orbicularis oculi muscles) were obtained. Other cranial motor nerves such as the motor root of the trigeminal nerve (masseter muscle) and the lower cranial nerves were also monitored. For each channel, a pair of electrodes 5 mm apart were inserted into the muscles. The details of both techniques have been published previously.6,23 Electrical stimulation was applied to the facial nerve by using a hand-held concentric bipolar probe (Inomed GmbH, Teningen, Germany) connected to a constant-current stimulator (Neurosign 100; Magstim Co. Ltd., Whitland, United Kingdom). A stimulation intensity between 0.05 and 0.5 mA was selected together with a pulse width of 200 μsec and a stimulus frequency of 30 Hz. Using this technique, one can usually identify the facial nerve at the lowest stimulation intensities (0.05 mA) when the stimulator is positioned directly on the nerve.

All patients were placed in a modified prone position, except one patient with a giant tumor who was placed in a semisitting position, and surgery was performed via a suboccipital lateral approach. Four patients underwent osteoplastic trephination. The IAC was opened in all but two cases (Fig. 1). Meatal sealing was achieved with a fibrin-soaked collagen sponge (Nycomed, Unterschleissheim, Germany) in seven cases; muscle or fat patches were applied to the posterior wall of the IAC by using fibrin sealant in seven patients. Based on either intraoperative brainstem auditory evoked potential patterns indicating a risk for delayed hearing loss or EMG recordings revealing A trains, which are highly specific for the deterioration of facial nerve function, 11 patients received vasoactive medication to improve microcirculation.25 The 10-day treatment regimen involved the intravenous administration of nimodipine (15–30 μg/kg/hr; Bayer, Leverkusen, Germany), which was started at the end of the surgical procedure. In addition, a nimodipine-soaked Gelfoam pack (dilution 1:19 with 0.9% NaCl solution) was applied locally on the exposed cranial nerves when tumor removal was complete. Hydroxyethyl starch (6%, maximum 2 × 500 ml/day; Baxter, Unterschleissheim, Germany) was started 24 hours after surgery to achieve hemodilution.28

One year later, all patients underwent reevaluation including MR imaging studies with and without contrast enhancement. In one patient who had undergone surgery in 2005, the follow-up period was 6 months. The mean follow-up period was 30 months (range 6–68 months). Facial nerve EMG was performed in selected cases. In patients in whom hearing was preserved, PTA and SD were evaluated in the Department of Otorhinolaryngology.

Results

Tumor Removal

In all but two patients, tumor removal was complete. In one patient, a small capsule remnant (2 × 3 mm) adherent to the facial nerve within its course through the CPA was not resected, but its presence could not be confirmed on follow-up contrast-enhanced MR imaging. In another patient, who had neurofibromatosis Type 2 and a giant tumor (55 mm) on one side and a small intracanalicular neuroma on the other, the IAC intentionally was not opened, leaving tumor remnants lateral to the porus acusticus.

Facial Nerve

In all 16 patients, distinct splitting of the facial nerve from the root exit zone to the porus acusticus was seen during the surgical procedure (Fig. 2) and verified by selective electrical stimulation and three-channel EMG recordings (Figs. 3 and 4). A major portion of the facial nerve was located on the middle or lower portion of the anterior tumor capsule, crossing the CPA in the most typical fashion (Figs. 2 and 5). Electrical stimulation revealed EMG activity in all three facial nerve branches (nasalis, orbicularis oris, and orbicularis oculi muscles; Fig. 3). In all but two patients the smaller portion of the nerve coursed parallel to the brainstem toward the cranial pole of the tumor, crossing the CPA on the cranial anterior tumor capsule either posterior or anterior to the trigeminal nerve and rejoining the major portion of the nerve anterior to the porus acusticus. In one case realignment was observed within the CPA approximately 10 mm lateral to the porus acusticus (Fig. 5). In the second case realignment was documented immediately distal (5 mm) to the facial nerve exit zone. On electrical stimulation at the lowest intensities (bipolar constant-current 0.05 mA), the smaller nerve portion revealed responses selectively from the orbicularis oris muscle either alone or from the nasalis muscle as well. In all cases the two portions were separated immediately distally to the exit zone of the facial nerve (Fig. 6). There was no noticeable spreading of either portion (Figs. 2 and 5). The area of realignment medial and
anterior to the porus acusticus showed the most pronounced adhesions between the nerve and the tumor capsule and proved difficult to dissect. Although the latencies and amplitudes of the EMG responses were not systematically evaluated, differences in the latencies or amplitudes of the two nerve portions were not demonstrated (Figs. 3 and 4).

After surgery facial nerve function deteriorated in most patients, although both portions of the facial nerve were anatomically preserved in all 16 patients. On intraoperative EMG monitoring, corresponding A trains were recorded in eight patients. Intraoperative EMG data could not be analyzed in two patients because of incomplete data storage.

Given that the evaluation of postoperative facial nerve function was strictly based on the House–Brackmann scale, no information regarding selective paresis of the orbicularis oris muscle could be obtained from the available records. According to the lowest House–Brackmann scores during the immediate postoperative period, deficits did not occur in three patients (Grade I), were mild in one (Grade II), and were moderate in five (Grade III). Pronounced facial nerve deficits were documented in the remaining patients: House–Brackmann Grade IV function in five patients and Grades V and VI function in one patient each. Long-term results showed marked improvement in facial nerve function 12 months postsurgery. On follow up seven patients had Grade I function; five, Grade II; and three, Grade III. One patient suffered from a persistent, complete palsy (Table 1).

One patient suffered from delayed facial nerve paresis, although immediately after the surgical procedure no facial nerve deficit had been apparent. This patient was treated with a 10-day course of intravenous hydroxyethyl starch and nimodipine. After terminating this treatment, facial nerve function deteriorated to House–Brackmann Grade III. After resuming treatment, facial nerve function recovered to House–Brackmann Grade II. Six months later facial nerve function had improved to House–Brackmann Grade I (Table 1).

### Tumor Origin

In four cases the inferior vestibular nerve was identified as the origin of the tumor. In six cases the superior vestibular nerve was assumed to be the site of tumor origin. In the remaining six cases including the two patients in whom the IAC had not been drilled, the tumor origin could not be identified.

### Cochlear Nerve Function

Preservation of cochlear nerve function was attempted in...
all 15 patients with preoperative hearing, regardless of the hearing class. Hearing was preserved in four patients after the surgical procedure: in one patient, SD was documented as Class D (<50%); in two patients, Class B; and in one patient, Class C. In this latter patient preoperative hearing levels were preserved.

On long-term follow up, three additional patients showed slight hearing recovery from complete deafness. These patients had received hydroxyethyl starch and nimodipine after surgery. Long-term results revealed a hearing Class D with measurable but less than 50% SD in four patients and good, serviceable hearing in three patients, that is, Class B hearing in two and Class C hearing in one patient. The remaining patients were deaf (Table 1).

**Postprocedural Complications**

Postoperative complications occurred in five patients: meningitis in one, pneumonia in one, and cerebrospinal fluid fistula in three. One patient with preexisting lower cranial nerve deficits and a giant tumor required a transient tracheostomy. Two patients required permanent shunts because of persistent hydrocephalus. Cranial nerve deficits other than those caused by the facial and cochlear nerves resolved in all patients. There were no deaths among the patients in this study.

**Discussion**

The preservation of socially acceptable facial nerve function is the key concern for most patients suffering from VSs. Treatment options are critically evaluated by patients based on whether the risks involve little or no facial nerve dysfunction. Particularly large tumors, for which surgery remains the treatment of choice, carry considerable risks for postoperative deterioration of facial nerve function. The fact that surgical considerations focus on this issue is illustrated by the most recently advocated strategies aiming at subtotal resection, followed by adjuvant postoperative radiotherapy.
During the surgical procedure, intraoperative localization of the facial nerve by direct electrical stimulation and continuous monitoring of EMG activity has become part of the surgeon’s efforts to minimize the risk of persistent facial nerve deficits. The use of various techniques such as F-wave recordings,\(^1\) the calculation of proximal–distal EMG amplitude ratios,\(^2\) or multiple-channel EMG monitoring\(^3,4\) also support such efforts. With regard to continuous monitoring, the detection of a specific EMG A-train pattern, which carries high sensitivity and high specificity for facial nerve paresis, alerts the surgeon to potentially dangerous maneuvers.\(^5,6\) Advances in recording techniques such as multichannel recordings of various facial muscles have enabled identification of the split facial nerve phenomenon in medial VSs.\(^7\) Instead of two-channel referential recordings, a three-channel recording setup was used (nasalis, orbicularis oris, and orbicularis oculi muscles). A pseudobipolar recording setup with two recording electrodes 5 mm apart was utilized. With this particular setup, it was possible to identify from a series of 241 surgically treated VSs 16 cases with distinct splitting of the facial nerve as it coursed through the CPA.

In all cases the major branch of the facial nerve was identified on the anterior middle or lower tumor capsule, taking an expected course through the CPA on the ventral tumor surface (Figs. 2 and 5). The smaller branch always separated at the root exit zone (Fig. 6), taking an anterior direction parallel to the brainstem toward the cranial pole of the tumor. At the level of the fifth cranial nerve exit zone, this branch crossed the CPA on the cranial tumor capsule either superior or inferior to the trigeminal nerve and rejoined the major portion of the nerve immediately anterior to the porus acusticus (Figs. 2 and 5). At this level dissection proved most difficult because of strong adhesions between the two nerve portions and the tumor capsule. In all cases identification was documented by selective stimulation (Figs. 3 and 4). The described multichannel recording setup proved essential for selective identification of the two branches. The smaller aberrant portion was found exclusively to carry fibers to the orbicularis oris muscle (Fig. 4), whereas stimulation of the major portion could induce motor responses from all three branches of the nerve (Fig. 3).

Based on the topography of the smaller portion of the facial nerve and its proximity to the vestibulocochlear nerve at its root exit zone and according to the surgical observations of Koos, et al.,\(^10\) one can assume that these fibers represent the intermediate nerve. This nerve is rarely identified and preserved during removal of VSs and usually is not specifically assessed.\(^9,12,26\) Based on data from anatomical investigations, we know that the intermediate nerve cannot be separated from the vestibulocochlear nerve bundle within the CPA in 22% of cases and is adherent through most of its intracisternal course in 35% of cases.\(^22\) Rhoton and colleagues\(^23\) have reported on a root exit of the intermediate nerve together with the eighth cranial nerve fibers. They have also stated that its junction with the facial nerve fibers
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Fig. 5. Case 6. Photograph depicting a split facial nerve with realignment of the smaller portion approximately 10 mm lateral to the porus acusticus.

Fig. 6. Case 13. Photograph, close-up view, showing the seventh cranial nerve root exit zone with distinct splitting. The preserved vestibulocochlear bundle is visible. VIII = eighth cranial nerve.

varies considerably from the seventh cranial nerve root exit zone to the IAC and usually can be found 5 mm proximal to the fundus within the IAC. In all 16 cases in the present study the junction was located medial and anterior to the porus acusticus. Note, however, that the anatomical distortion caused by the tumor must be taken into consideration.

The electrophysiological results with selective EMG responses from the two separate branches of the facial nerve at the lowest stimulation intensities (0.05 mA) using a bipolar constant-current technique clearly point to two separate bundles of the facial nerve (Figs. 3 and 4). Recently, Ashram, et al.,³ have published very similar electrophysiological observations with identification of two separate nerve branches. The smaller branch supplied fibers exclusively to the orbicularis oris muscle. These authors found longer latencies and smaller amplitudes for the smaller branch, which they attributed to the intermediate nerve. In our series we found no amplitude or latency differences on stimulation of the aberrant smaller branch compared with the main branch, although we did not investigate this issue systematically with supramaximal stimulation techniques. In addition we used bipolar constant-current stimulation compared with the monopolar constant-voltage stimulation used by Ashram and associates. It is not clear why electrical stimulation of the intermediate nerve should result in selective motor responses of the orbicularis oris muscle as discussed. The selectivity of the response supports the proposition of a topographical arrangement of facial nerve fibers already within the course of the nerve through the CPA.¹⁹

Regardless of terminology and interpretation, the surgical impact of our and Ashram and colleagues’ observations is similar and evident.

First, obtaining facial nerve responses from the orbicularis oris muscle on electrical stimulation at the cranial tumor capsule in the upper CPA encourages the surgeon to perform a more aggressive and time-saving dissection of other portions of the tumor capsule, because the facial nerve has been successfully identified. This technique could result in severe facial nerve damage if the major nerve portion is dissected.

Second, the adjacency of the trigeminal nerve’s course and that of the smaller portion of the facial nerve may cause misinterpretation of the EMG signals. The EMG responses obtained from the small and often initially invisible small facial nerve component in the upper CPA could be mistaken for motor responses from the trigeminal nerve, and thus mislead the surgeon and cause him or her to dissect the smaller portion of the facial nerve (Fig. 7). Differentiation between trigeminal and facial nerve responses based on the shape of the potentials is difficult when a two-channel recording setup is used for monitoring.

Third, a positive stimulation effect at two different sites (cranial tumor capsule and anterior tumor surface) may be interpreted as a spreading of the facial nerve on the tumor capsule, resulting in unnecessary tumor remnants.

In medial VSs, a split facial nerve has been observed in as many as two thirds of the cases. These lesions are defined by a primarily extrameatal tumor growth into the CPA. Their incidence varies from 1.3% with a strict definition of a normal IAC to 12% when the term is attributed to tumors that do not reach the fundus.¹¹,³⁰ It has been assumed that the primarily intracisternal growth pattern in this clinical entity is an anatomical condition of a split nerve course within the CPA.²⁷ This interpretation is supported by the fact that an atypical course of the facial nerve, compared with that in nonmedial tumors, was found in almost 50% of cases. In the present series a split facial nerve was not limited to medial VSs, given that the fundus was obliterated by tumor in five cases. The tumor origin does not seem to be important; in six of 10 cases with a clear tumor origin, the superior vestibular nerve was identified as the site of origin, compared with four cases in which the tumor originated from the inferior vestibular nerve. Most likely the multichannel EMG setup, with three channels for facial nerve monitoring and one channel for the trigeminal nerve, picks up an important prognostic phenomenon for facial nerve function, which in conventional one- or two-channel recordings is seldom observed and described. The clinical impact of these observations regarding facial nerve function is difficult to assess, because the established House–Brackmann scale does not.
differentiate between the three branches of the facial nerve. In this retrospective series isolated impairment of the orbicularis oris muscle branch was not specifically noted. Because we are more alert to this variation of the facial nerve course, we have seen this entity more frequently. In these cases we have seen a preponderance of paresis of the orbicularis oris muscle branch was not specifically noted. Be -

Conclusions

In VS surgery a distinct anatomical splitting of the facial nerve can be encountered. The surgeon finds a smaller component running parallel to the brainstem and the trigeminal nerve and a major component crossing the CPA on the ventral tumor surface. This phenomenon can be identified using intraoperative EMG recording. Electrophysiological monitoring should include complete coverage of all involved cranial motor nerves and all three branches of the facial nerve. A multichannel recording setup diminishes the risk of misinterpreting the EMG signals and will improve facial nerve outcome in VS surgery.

Dedication

This paper is dedicated to Rudolf Fahlbusch, M.D., chairman of the Department of Neurosurgery, University of Erlangen-Nuremberg, Germany, in honor of his 65th birthday.

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