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Awake craniotomy for auditory brainstem implant in patients with neurofibromatosis type 2: Four case reports

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Abstract

BACKGROUND

The auditory brainstem implant (ABI) is a significant treatment to restore hearing sensations for neurofibromatosis type 2 (NF2) patients. However, there is no ideal method in assisting the placement of ABIs. In this case series, intraoperative cochlear nucleus mapping was performed in awake craniotomy to help guide the placement of the electrode array.

CASE SUMMARY

We applied the asleep-awake-asleep technique for awake craniotomy and hearing test *via* the retrosigmoid approach for acoustic neuroma resections and ABIs, using mechanical ventilation with a laryngeal mask during the asleep phases, utilizing a ropivacaine-based regional anesthesia, and sevoflurane combined with propofol/remifentanyl as the sedative/analgesic agents in four NF2 patients. ABI electrode arrays were placed in the awake phase with successful intraoperative hearing tests in three patients. There was one uncooperative patient whose awake hearing test needed to be aborted. In all cases, tumor resection and ABI were performed safely. Satisfactory electrode effectiveness was achieved in awake ABI placement.

CONCLUSION

This case series suggests that awake craniotomy with an intraoperative hearing test for ABI placement is safe and well tolerated. Awake craniotomy is beneficial for improving the accuracy of ABI electrode placement and meanwhile reduces non-auditory side effects.

Key Words: Awake craniotomy; Neurofibromatosis type 2; Auditory brainstem implant; Hearing test; Case report

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Core Tip: The auditory brainstem implant (ABI) is a significantly beneficial treatment to restore hearing sensations for neurofibromatosis type 2 (NF2) patients. However, there is no ideal method in assisting the placement of ABI. The asleep-awake-asleep technique was applied for awake craniotomy and hearing test *via* the retrosigmoid approach for acoustic neuromas resections and ABI in four NF2 patients. ABI electrode arrays were placed in the awake phase with successful intraoperative hearing tests in three patients. There was one uncooperative patient whose awake hearing test needed to be aborted due to her restlessness. In all cases, tumor resection and ABI were performed safely. The awake craniotomy is beneficial to improve the accuracy of electrode placement in the ABI and meanwhile reduces non-auditory side effects.

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INTRODUCTION

Neurofibromatosis type 2 (NF2) is an autosomal dominant disorder characterized by the development of bilateral vestibular nerve schwannomas. Progressive growth or neurosurgical removal of bilateral tumors often damages the cochlear nerve, causing hearing impairment. The auditory brainstem implant (ABI) guided by evoked auditory brainstem responses (EABRs) was developed to restore hearing sensations for NF2 patients. However, since the postoperative effect of ABIs is variable and complicated, the value of the EABRs as a tool for assisting placement of ABIs becomes disputable[1]. In this report, awake craniotomy was performed after acoustic neuroma removal so that cochlear nucleus mapping could be pursued to secure the accuracy of electrode array placement.

CASE PRESENTATION

Chief complaints

Case 1: A 43-year-old female presented with a chief complaint of tinnitus in left ear for 3 years (Table 1).

Case 2: A 31-year-old male presented with a chief complaint of visual obscuration for 1 mo.

Case 3: A 38-year-old male presented with a chief complaint of tinnitus in left ear for 12 years, hearing loss in left ear for 4 years, and hearing loss in right ear for 1 year.

Case 4: A 24-year-old female presented with a chief complaint of ptosis in right eye and hearing loss in both ears for 6 years.

History of present illness

Case 1: Patient's symptom started 3 years ago and had not been a good attention. Her mother was diagnosed with NF2 3 mo ago and the patient performed Magnetic resonance image (MRI) scan showed bilateral vestibular nerve schwannomas.

Case 2: Fundus examination was performed by an outside hospital and showed papilloedema. MRI demonstrated bilateral vestibular nerve schwannomas and left-sided lesions at the C3-C4 and C6-C7 intervertebral foraminal areas. The patient was diagnosed with NF2 and visited our hospital for surgical treatment.

Case 3: 12 years ago, the patient went to another hospital due to tinnitus in left ear. He was diagnosed with neurogenic tinnitus and was administered neurotrophic treatment without improvement. He developed progressive hearing loss in left ear 4 years ago and hearing loss in right ear 1 year ago. He was diagnosed with NF2 based on an MRI

Table 1 Patient characteristics and demographic data

Case	Age (yr)	Sex	BMI (kg/m ²)	Preoperative hearing status	Comorbidities	Surgical side
1	43	F	20	Severe hearing loss in left and mild in right	None	Left
2	31	M	26	Complete hearing loss in left ear and profound hearing loss in right	Left-sided lesions at the C3-C4 and C6-C7 intervertebral foraminal areas, 14 years after resection of cervical spinal schwannomas	Left
3	38	M	25	Bilateral total deafness	Total deafness	Left
4	24	F	17	Complete hearing loss in right ear and severe hearing loss in right ear	Anxiety	Right

BMI: Body mass index.

scan.

Case 4: Patient's symptoms started 6 years ago. MRI was performed by an outside hospital and showed bilateral vestibular nerve schwannomas. The patient was diagnosed with NF2. She accepted MRI examination at intervals without treatment. Hearing loss had been worsening gradually.

History of past illness

Cases 1, 3, and 4: The patient had a free previous medical history.

Case 2: The patient underwent resection of cervical spinal schwannomas 14 years ago.

Personal and family history

Case 1: The patient admitted a family history of NF2 associated with mother.

Case 2: The patient's maternal grandfather, mother and two aunts on my mother's side were diagnosed NF2 successively.

Cases 3 and 4: The patient denied a family history of NF2.

Physical examination

Case 1: The patient had severe hearing loss in left ear and mild in right ear (Table 1).

Case 2: The patient had complete hearing loss in left ear and profound hearing loss in right ear.

Case 3: The patient had complete hearing loss in both ears

Case 4: The patient had total hearing loss in right ear and severe hearing loss in right ear and suffered from anxiety.

Laboratory examinations

Routine laboratory tests revealed no remarkable abnormality in the four patients.

Imaging examinations

MRI showed bilateral vestibular nerve schwannomas in four patients (Figure 1).

FINAL DIAGNOSIS

Cases 1-4: All patients were diagnosed with NF2.

TREATMENT

The procedures for the surgery and hearing tests in this case series have been published previously[2]. In this report, we present further details on anesthesia management. During preoperative consultation, we clearly outlined for the patient what to

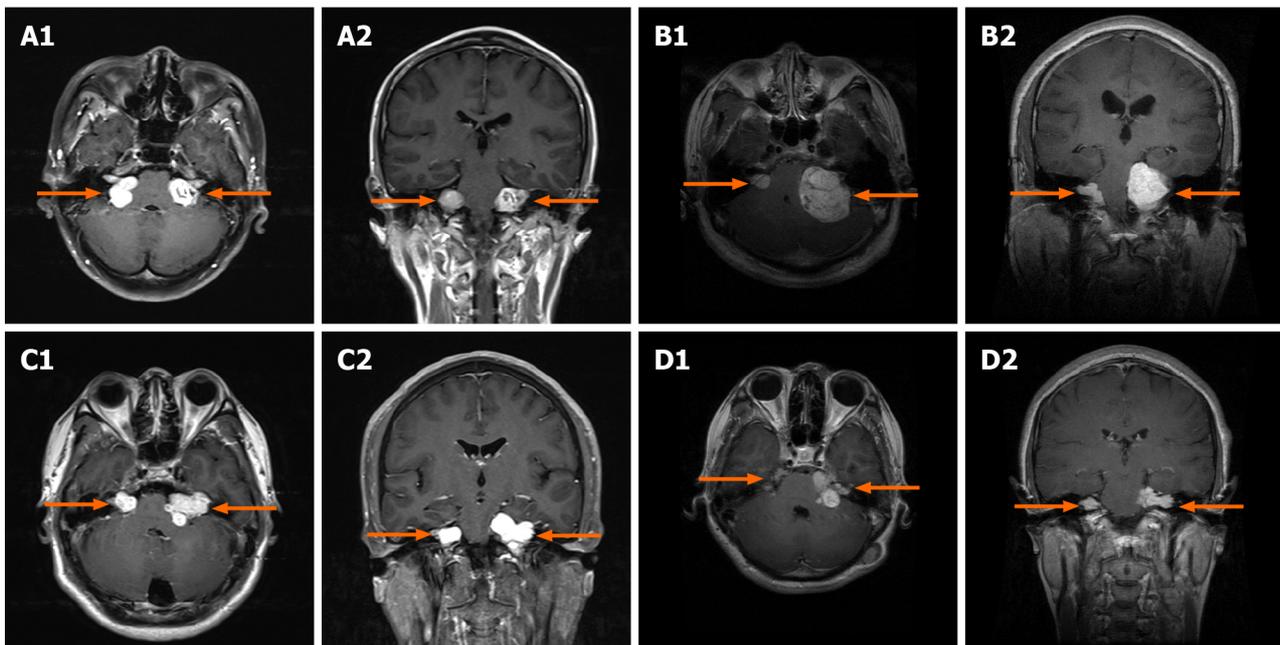


Figure 1 Magnetic resonance images before surgery of 4 patients demonstrate bilateral vestibular nerve schwannomas (orange arrow).

A1 and A2: Case 1; B1 and B2: Case 2; C1 and C2: Case 3; D1 and D2: Case 4.

expect during the procedure, including the varying states of sedation and awareness, the positioning, the possible discomfort, and the testing process. A trustful, solid relationship between the patients and anesthesiologists had been established prior to the procedure.

The first awake phase

After the patient entered the operating room, electrocardiography, noninvasive blood pressure, body temperature, oxygen saturation and bispectral index (BIS) were monitored. General anesthesia was induced with propofol using a targeted controlled infusion technique. Subsequently, a laryngeal mask airway (LMA) was inserted followed by mechanical ventilation and maintenance with 0.5-0.7 minimum alveolar concentration (MAC) sevoflurane combined with propofol 0.5-1.5 $\mu\text{g}/\text{mL}$ and remifentanyl 0.02-0.10 $\mu\text{g}/\text{kg}/\text{min}$. Ropivacaine (0.5%) was used for auriculotemporal nerve and cervical plexus block along the side to be operated on. Pin sites were infiltrated with 0.5% ropivacaine. Patients were positioned laterally at 90 degrees and secured in a Mayfield head holder without jaw adduction (Figure 2). The Bair Hugger warming units were used intraoperatively to maintain a comfortable body temperature in the range of 36-37 $^{\circ}\text{C}$. Ropivacaine (0.5%) was infiltrated in the incision. Cottonoids soaked with 1% lidocaine were applied to cover the dura flap. Three to four hours later, when the tumor was almost resected, inhalant sevoflurane was discontinued, and the propofol infusion rate was increased to 2.0-2.5 $\mu\text{g}/\text{mL}$.

The awake phase

Once adequate hemostasis was achieved and the electrode array was placed, all the anesthetic agents were discontinued. LMA was removed when the patient's respiration recovered. Sevoflurane was washed out (end tidal concentration < 0.1). When the patient was fully awake and engaged in cooperation, a wake-up hearing test was performed. The target blood concentration of propofol at that time was 0.5-0.6 $\mu\text{g}/\text{mL}$ (Table 2). Propofol was continuously infused at this concentration to maintain an appropriate level of consciousness for ongoing hearing tests in the awake phase.

Awake craniotomy with well-placed electrodes and a successful intraoperative hearing test was achieved in 3 patients (Cases 1, 2, and 3). It took 41-65 min (mean, 55 min) for the patients to regain consciousness and 47-70 min (mean, 61 min) for them to fully cooperate after anesthetics were discontinued (Table 2). Case 4 was considered uncooperative and in a state of agitation when the plasma concentration of propofol decreased to 0.5 $\mu\text{g}/\text{mL}$ and the BIS increased to 85. The patient's status was not improved after sufentanil 3 μg was administered. Thus, the awake procedure was aborted to ensure the safety of this patient. The ABI electrode was placed with the

Table 2 Summary of intraoperative anesthetic management of awake craniotomy

Case	Duration of the first phase (min)	The interval of time between discontinuation and eye opening (min)	The interval of time between discontinuation and full cooperation (min)	The plasma propofol awakening concentration ($\mu\text{g/mL}$)	Duration of hearing test (min)
1	336	41	47	0.6	56
2	354	60	65	0.6	77
3	367	65	70	0.5	62

**Figure 2** Intraoperative position and the incision line of case 3.

guidance of EABRs under general anesthesia.

The second asleep stage

At the end of the hearing test, general anesthesia was induced. The LMA was inserted followed by mechanical ventilation. Anesthesia was maintained with propofol 2.5-3 $\mu\text{g/mL}$ and remifentanyl 0.05-0.1 $\mu\text{g/kg/min}$. Four patients recovered smoothly after the surgery and were transferred to the intensive care unit.

OUTCOME AND FOLLOW-UP

The median duration of surgery in the first asleep stage was 347 min (330-367 min) (Table 2). There were no cardiovascular or respiratory adverse events in any of the 4 patients. No instances of intraoperative seizures, brain swelling or bleeding were observed during the awake phase. Case 3 reported nausea and received ondansetron 4mg and methylprednisolone 40mg without improvement (Table 3). The hearing test showed that the placement of the ABI electrode array over the cochlear nucleus was suboptimal. The position of the electrode was therefore adjusted, and the patient reported no further discomfort. Case 2 reported neck pain, which was considered to be caused by the tumor and surgical history of the cervical spinal cord (Table 3). The pain was relieved with flurbiprofen 50 mg.

Case 1: ABI implanted was not switched on because she had functional hearing in her right ear. Cases 2 and 3: They used ABI daily and showed an obvious improvement in speech recognition scores in lip reading combined with ABIs after 1 year. Case 4: ABI implanted was not switched on because she had functional hearing in her left ear.

DISCUSSION

We successfully performed an asleep-awake-asleep technique for ABI surgery following acoustic neuroma resections *via* the retrosigmoid approach in three NF2

Table 3 Intraoperative adverse events

Case	Adverse events during wake-up hearing test	Treatment measures
1	No event	No event
2	Neck pain	Flurbiprofen 50 mg
3	Nausea and vomiting	Ondansetron 4 mg, methylprednisolone 40 mg and adjusting the position of electrode array
4	Agitation	Aborting the awake surgery

patients. Awake craniotomy is usually performed to maximize resection of tumors near the eloquent area[3,4]. It can reduce anesthetic interference with brain mapping [5]. Awake craniotomy for posterior fossa surgery reminds a number of significant challenges for the anesthesiologist. Posterior fossa procedure is more commonly performed in the three-quarter prone or prone with jaw adduction and head rotation position, which provide superior surgical exposure. However, it is difficult to get access to the airway and to communicate with patient in this position. Furthermore, sudden alterations of the cardiovascular and respiratory systems may occur during or after brainstem manipulation with surgery in the posterior fossa surgery. Moreover, patients must keep quiet completely during brainstem manipulation.

Shinoura *et al*[6] published a report in relation to awake craniotomy during vestibular schwannoma surgery to preserve hearing in 2017. There are several noteworthy differences between the present report and Shinoura's report regarding surgery and anesthesia technique usage. First, an awake hearing test was performed after the removal of the tumor. Consequently, the duration of the first asleep phase was far longer than awake tumor resection and the total consumption of analgesics and sedatives increased dramatically. Second, NF2 patient usually encounters different degrees of hearing loss, which increases the difficulty of patient's cooperation. For the patient who had no useful hearing, a communication method was designed preoperatively for use during in the awake phase; for example, this method included patting the patient's face slightly as a signal to open the eyes and writing notes for the patient to read when awake. Moreover, suboptimal placement of the electrode array may result in the stimulation of non-auditory structures in the brainstem, causing non-auditory side effects (NASEs), such as dizziness, tingling sensations, nausea and vomiting. In our report, patients were positioned laterally at 90° during surgery, instead of in the park-bench position, which facilitated airway management and made it convenient for anesthesiologists to observe and deal with various events, especially when NASEs or other complications occurred.

Local anesthesia is the cornerstone of the awake craniotomy technique. The incision for acoustic neuroma resection and ABI surgery was entirely different from an incision for supratentorial tumor resection. On the operative side, the auriculotemporal nerve and cervical plexus were blocked with 0.5% ropivacaine. The anesthesia protocol for the pin sites, the incision, and the dura was similar to the protocol used in awake craniotomy for supratentorial mass lesions[7]. There was no increase in heart rate or blood pressure in any of the four patients during painful phases, and none of the patients experienced headache during the awake hearing test. No signs of cardiovascular or central nervous system toxicity were observed in any of the four patients.

A combination of propofol, remifentanyl, and sevoflurane was used for general anesthesia in the first asleep phase. The facial, glossopharyngeal and trigeminal nerves were monitored throughout the procedure to assist in the placement of the electrode array and avoid nerve injuries during acoustic neuroma resection. Sevoflurane was limited to 0.5 MAC during tumor resection in all 4 patients[8]. Cranial nerve EMG activity was recorded effectively in all patients.

In this case series, the interval between the discontinuation of the IV infusion and the moment of consciousness recovery was much longer than previously reported in awake craniotomy for supratentorial masses [55 min (41-65 min) *vs* 14 ± 6 min][9]. This was probably related to the fact that the duration of the first asleep phase was far longer [347 min (330-367 min) *vs* 98 ± 25 min][9]. The plasma propofol concentration upon awakening would be lower after long-term infusion than after short-term infusion[10]. This was consistent with what we observed in the present case series. The blood propofol concentration at awakening was 0.5-0.6 µg/mL in this case series. However, the mean target propofol concentration was 1.3 ± 0.4 µg/mL for a fully cooperative patient who underwent awake craniotomy for supratentorial tumors[9].

Despite receiving prophylactic anti-emetics, case 3 suffered from nausea and vomiting. Under this circumstance, it is worth mentioning that the hearing test showed that the placement of the ABI electrode array over the cochlear nucleus was suboptimal. The patient did not report any discomfort when the position of the electrode was adjusted. As a result, nausea and vomiting might be symptoms of NASEs in this patient.

Case 4 was uncooperative and agitated when she woke up from general anesthesia. This patient suffered from anxiety before surgery, although great efforts had been made to establish mutual trust. Anxiety might be the main reason for agitation in the awake phase[11]. Since awake craniotomy patients are liable to become anxious and stimulated, their attention and vigilance are critical to the success of the surgery. Therefore, to guarantee safety, the surgeon and anesthesiologist should seriously consider the risk of failure before planning an awake craniotomy for a patient with a severe anxiety disorder[12].

This case series demonstrated that the awake hearing test in ABI might increase the availability of electrodes and decrease patients' NASEs[2]. Two patients (cases 2 and 3) who used ABI daily showed an obvious improvement in speech recognition scores in lip reading combined with ABIs after 1 year, which was comparable to previously literature[13]. The other two patients (cases 1 and 4) still with functional hearing in the contralateral ear, ABI implanted was not switched on until hearing was lost in the contralateral ear. It has been reported in a previous study that for most patients, hearing will continuously improve after implantation[14]. More studies with long-term follow-up are expected to further investigate the potential benefits of awake craniotomy.

CONCLUSION

Our experiences suggested that awake craniotomy during ABI placement for NF2 patients was safe and mostly tolerated, and no obvious extra surgical risk was found due to awake craniotomy. This technique can potentially improve the accuracy of electrode positioning in the cochlear nucleus and reduce NASEs during surgery.

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