Original Article

Brainstem auditory evoked potential combined with high resolution cranial base CT can optimize the diagnosis of auditory nerve injury

Hua Gu, Xing-Ming Zhong[*], Yi-Qi Wang, Jian-Guo Yang, Yong Cai

Department of Emergency and Department of Neurosurgery, The First People's Hospital of Huzhou, First Affiliated Hospital of Huzhou Normal University, Huzhou, 313000, Zhejiang Province, China

ARTICLE INFO

ABSTRACT

Purpose: Auditory nerve injury is one of the most common nerve injury complications of skull base fractures. However, there is currently a lack of auxiliary examination methods for its direct diagnosis. The purpose of this study was to find a more efficient and accurate means of diagnosis for auditory nerve injury.

Methods: Through retrospectively analyzing the results of brainstem auditory evoked potential (BAEP) and high-resolution CT (HRCT) in 37 patients with hearing impairment following trauma from January 1, 2018 to July 31, 2020, the role of the two inspection methods in the diagnosis of auditory nerve injury was studied. Inclusion criteria were patient had a clear history of trauma and unilateral hearing impairment after trauma; while exclusion criteria were: (1) severe patient with a Glasgow coma scale score ≤5 because these patients were classified as severe head injury and admitted to the intensive care unit, (2) patient in the subacute stage admitted 72 h after trauma, and (3) patient with prior hearing impairment before trauma. According to Goodman's classification of hearing impairment, the patients were divided into low/medium/severe injury groups. In addition, patients were divided into HRCT-positive and negative groups for further investigation with their BAEP results. The positive rates of BEAP for each group were observed, and the results were analyzed by Chi-square test ($p < 0.05$, regarded as statistical difference).

Results: A total of 37 patients were included, including 21 males and 16 females. All of them were hospitalized patients with GCS score of 6–15 at the time of admission. The BAEP positive rate in the medium and severe injury group was 100%, which was significantly higher than that in the low injury group (27.27%) ($p < 0.01$). The rate of BEAP positivity was significantly higher in the HRCT-positive group (20/30, 66.7%) than in the HRCT-negative group (1/7, 14.3%) ($p < 0.05$). Twenty patients (54.05%) were both positive for BEAP and HRCT test, and considered to have auditory nerve damage. Six patients (16.22%) were both negative for BEAP and HRCT test, and 10 patients (27.03%) were BAEP-negative but HRCT-positive: all the 16 patients were considered as non-neurological injury. The rest 1 case (2.70%) was BAEP-positive but HRCT-negative, which we speculate may have auditory nerve concussion.

Conclusion: By way of BAEP combining with skull base HRCT, we may improve the accuracy of the diagnosis of auditory nerve injury. Such a diagnostic strategy may be beneficial to guiding treatment plans and evaluating prognosis.

© 2021 Chinese Medical Association. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

Hearing impairment is one of the common complications in patients with skull base fractures. Due to the close relationship among tympanum, inner ear, acoustical ossicle and auditory nerve, especially the anatomical location of the middle skull base, hearing impairment is more common in fractures of the middle skull base.[1]

* Corresponding author.
E-mail address: zhongxingming@126.com (X.-M. Zhong).
Peer review under responsibility of Chinese Medical Association.

Hearing impairment after trauma can be divided into auditory nerve injury and non-neurological injury according to the pathogenesis. The main causes of non-neurological injury include tympanic membrane damage, tympanic effusion and acoustical ossicle fracture, etc. Patients with such injuries can usually get good functional recovery after symptomatic treatment. However, the hearing impairment caused by auditory nerve injury often has poor prognosis, and currently lacks effective rehabilitation treatment.[2] Targeted treatment should be carried out as soon as possible to minimize functional loss.

Therefore, in the face of patients with hearing impairment, it is necessary to distinguish auditory nerve injury from non-neurological injury. Currently, diagnosis of auditory nerve injury is mostly made based on clinical symptoms.[3] Relevant auxiliary examinations, such as electroaudiometry and pure tone threshold detection, can only provide indirect evidence of auditory nerve injury. And these examinations cannot effectively distinguish auditory nerve injury from hearing loss caused by non-nerve injury. As a result, the difficulty in diagnosis often leads to delayed treatment of auditory nerve injury, as well as confusion in medical and disability identification. Therefore, it is very urgent and necessary to find an effective auxiliary examination for a precise diagnosis of auditory nerve injury.

Brainstem auditory evoked potentials (BAEP) is a neuro-electrophysiological inspection technique for detecting auditory nerve function, which can be used to evaluate the function of each segment of brainstem auditory conduction pathway.[4] BAEP can detect abnormalities in cochlear nerve or brainstem related nuclear groups at early stage, and has high sensitivity and specificity for the diagnosis of auditory nerve injury.[5] At the same time, high-resolution computed tomography (HRCT), combined with the subsequent three-dimensional (3D) reconstruction of HRCT, can more intuitively show the fracture line of the skull base, which improves the diagnosis rate of skull base fractures.[6] Therefore, it is envisaged that BAEP combined with skull base HRCT can be used for differential diagnosis of patients with hearing impairment after trauma.

Methods

Clinical data and grouping

In this study, patients with hearing impairment after trauma admitted to our hospital from January 1, 2018 to July 31, 2020 were collected. Inclusion criteria were patient had (1) a clear history of trauma and (2) unilateral hearing impairment after the trauma. The diagnostic criteria for hearing impairment followed Goodman's standard, as shown in Table 1. Exclusion criteria were: (1) severe patient with Glasgow coma scale (GCS) score ≤5 because these patients are classified as severe head injury and admitted to the intensive care unit, (2) patient in the subacute stage admitted 72 h after trauma, and (3) patient with prior hearing impairment before trauma.

Table 1
Goodman's classification of hearing impairment.

Goodman's standard	dB HL (0.5/1.0/2.0 kHz)
Normal	<26
Mild	26–40
Moderate	41–55
Medium severe	56–70
Severe	71–90
Extremely severe	>91
Totally deaf	–

Based on Goodman's classification of hearing impairment, the patients were divided into three groups: mild + moderate into the low injury group, medium severe + severe into the medium injury group, and extremely severe + total deaf into the severe injury group. The sex ratio, mean age and GCS score of each group were statistically analyzed.

Hearing evaluation and related auxiliary examination

All patients with hearing impairment received pure tone hearing threshold and acoustic resistance examination during hospitalization, and the hearing evaluation criteria was according to the "Diagnostic Criteria and Curative Effect Classification Criteria for Sudden Hearing Loss" formulated by Otolaryngology Society of Chinese Medical Association, mainly based on Goodman hearing impairment grading scale.[7,8]

BAEP test

BAEP module of Medelec (Synergy Electromyography, Oxford, UK) was adopted for patient assessment: the needle electrode was placed in the central position of the cranial top, the reference electrode was placed in the mastoid process on the donor side, and the contralateral mastoid process was grounded. The stimulation sound is short, the stimulation frequency is 10 times/s, and the stimulation intensity is 60–120 dB HL.

We set the filtering parameters to be 30–3000 Hz and sampling time 10 ms. The recorded values included the latency, interperiod and waveforms of I, III and V waves.[9]

BAEP test of both the affected and healthy ears was detected in all patients within 2 weeks after trauma. The main monitoring indexes were the incubation period and amplitude of I, III and V waves, and the waveforms were drawn.

Skull base HRCT scan

The patient was in supine position with the head fixed. Spiral CT scan of the brain was conducted. The scanning range is from orbito-meatal line 2-cm to the top of the head and the lower edge of the sphenoid bone to the upper edge of the valley. The window width was selected as 2000 HU, and the window level was selected as 500 HU. The parameters of the spiral CT scanner were set as matrix 512 × 512 and pitch 0.1–1.0. The obtained data were automatically imported into the workstation for software analysis and 3D reconstruction.

Statistical analysis

All data of this study were accurately input into SPSS 18.0 software for corresponding statistical analysis. One-way analysis of variance (ANOVA) was used for comparison between groups of continuous data, and Chi-square test was used for counting data. A $p < 0.05$ was regarded as statistical difference.

Ethical approval

This study has been reviewed by the Ethics Review Committee of Huzhou First People's Hospital (approval No. 2018033), and has not adversely affected the rights or interests of patients, nor disclosed the privacy and identity information of patients.

Results

General information and grouping

A total of 37 patients were included, including 21 males and 16 females. All of them were hospitalized patients with GCS score of 6–15 at the time of admission. All of them complained of hearing impairment at admission or during hospitalization. Although some patients have consciousness disorder at admission, their consciousness was restored enough to be evaluated at the time of hearing assessment. Grouping was achieved based on Goodman's standard (Table 2). Five patients had other nerve injuries such as peripheral facial paralysis, optic nerve injury, oculomotor nerve injury and other nerve injury.

HRCT positive rate of skull base detection

All the 37 patients with hearing impairment underwent HRCT 3D reconstruction examination of the skull base within 1 week after injury (Fig. 1), which showed positive results in 30 patients (81.08%): 26 with simple middle skull base fracture, and 4 with middle and posterior skull base fracture. Among them, there were 11 cases of sphenoid bone and sphenoid wing fractures, 17 temporal petrosal fractures, 22 mastoid process fractures and 4 occipital bone fractures. The most common fracture types were mastoid process fracture (59.46%) and temporal petrosal fracture (45.95%).

BAEP test

The detection results were abnormal in 21 cases (56.76%), including 8 cases of mixed damage and 13 cases of peripheral damage. Among the abnormal cases, 21 cases (100%) had abnormal latency and amplitude of I wave; 6 cases (28.57%) had abnormal latency and amplitude of III wave; and 5 cases (23.81%) had abnormal latency and amplitude of V wave (Fig. 2).

The positive rate of BAEP test and the distribution of abnormal waveforms in the three groups were analyzed. The BAEP positive rate in the medium and severe injury group was 100%, which was significantly higher than that in the low injury group (27.27%, $p < 0.01$). The proportion of abnormal III and V waves in medium to severe injury groups (66.67%, 66.67%) was significantly higher than that in low injury group (4.55%, 0, $p < 0.01$) (Table 3)

Correlation analysis of HRCT and BAEP results

To further investigate the two diagnosis methods, patients were divided into HRCT positive group ($n = 30$, confirmed by skull base fracture line on HRCT images) and HRCT negative group ($n = 7$). The positive rate of BAEP in the two groups was counted; and the correlation between the two methods was analyzed by four-grid Chi-square test (Table 4).

The results showed that there were 20 patients with double positivity (both BEAP and HRCT positivity), accounting for 54.05%, and these patients were considered as confirmed patients with auditory nerve injury. There were 6 double-negative patients (16.22%), and 10 BAEP-negative patients with HRCT positivity. These two types of patients were considered as non-neurological injury patients. The rest one patient (2.70%) was BAEP-positive but HRCT-negative, which we think may be auditory nerve concussion. The rate of BEAP positivity (20/30, 66.7%) was significantly higher in the HRCT-positive group than in the negative group (1/7, 14.3%) ($\chi^2 = 6.3450$, $p = 0.0118$).

Discussion

Auditory nerve injury is one of the most common complications of cranial nerve injury, most frequently associated with middle and posterior skull base fracture. The incidence of skull base fracture combined with auditory nerve injury has been reported to be about 8%.[10] The results of this study suggest that BAEP test combined with HRCT scan of the skull base may be helpful in the diagnosis of auditory nerve injury. It also provides an optional diagnostic strategy to distinguish auditory nerve injury from other causes in patients with post-traumatic hearing impairment.

Table 2
Grouping and general statistics of the included 37 patients with hearing impairment.

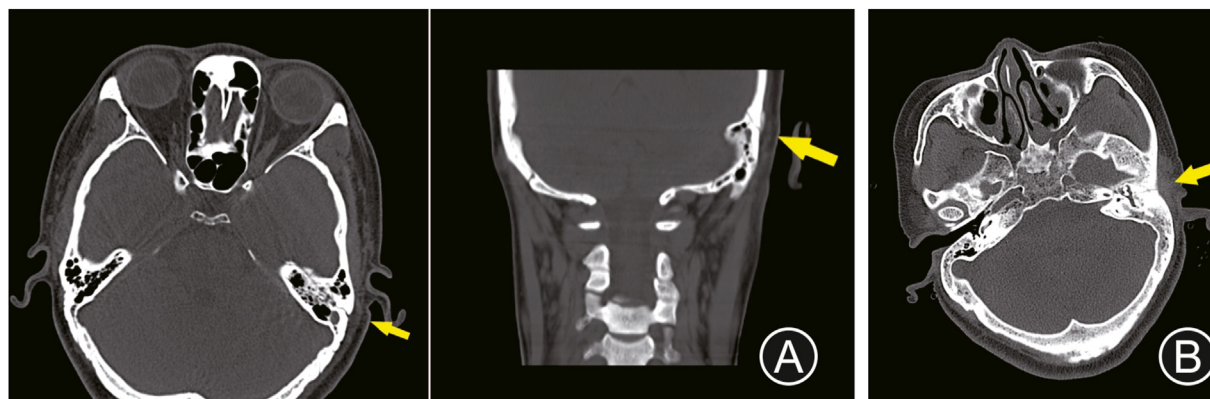| Groups	n	Sex ratio (M/F)	Mean age (years)	Mean Glasgow coma scale	No. of cases with other cranial nerve injuries
Low injury	22	14/8	44.4	13.45	2
Medium injury	9	4/5	43.0	12.44	2
Severe injury	6	3/3	47.2	13.00	1
Total	37	21/16	44.5	13.14	5

Fig. 1. Two typical cases. (A) High-resolution CT image of a case with base skull fracture. The left temporal bone fracture involves the mastoid and external auditory canal wall. The arrow shows the fracture line (axial, coronal); (B) High-resolution CT image of another case. The arrow shows the fracture line of the external auditory canal wall.

Patients with post-traumatic hearing impairment are often complicated with cerebrospinal fluid otoorrhea and tympanic membrane damage. The causes of early hearing loss are complex, including auditory nerve damage, tympanic membrane damage, tympanic fluid effusion, acoustical ossicle fracture and other non-neurological injuries.[11] In this study, BAEP, a neurophysiological examination, identified different causes of hearing impairment among 37 patients into auditory nerve injury and non-neurological injury. There were 20 patients with double positive BAEP and HRCT, and such patients were considered as auditory nerve injury, which was mainly caused by directly nerve injury or fracture compression. There were 10 patients who were positive for HRCT but negative for BAEP, and 6 patients who were negative for both BAEP and HRCT. The hearing loss in these patients may be caused by non-neurological causes, for such cases lack definite evidence of neu-roelectrophysiological damage. HRCT result of 1 patient showed no definite skull base fracture but positive BAEP. The pathogenesis of this patient may be related to auditory nerve concussion or axonal injury, and similar case has been reported in other literatures.[12]

BAEP is characterized by small physiological variation, reliable reaction and high accuracy of the latency of each wave. Secondly, the body state has little influence on the reaction, which is rarely interfered by the outside world and can be constantly induced. Therefore, BAEP detection, especially the relative ratio of the affected ear to the healthy ear, has obvious advantages in the specificity of the diagnosis of auditory nerve injury. The I wave originated from the extracranial segment of the auditory nerve, which is mainly a segment of the nerve in the temporal bone near the cochlear ganglion. The III wave usually originates from the olivary nucleus near the pons. The V wave originated from the midbrain part of the quadriassic inferior colliculus.[9] Therefore, abnormalities in the latency and amplitude of the I wave are
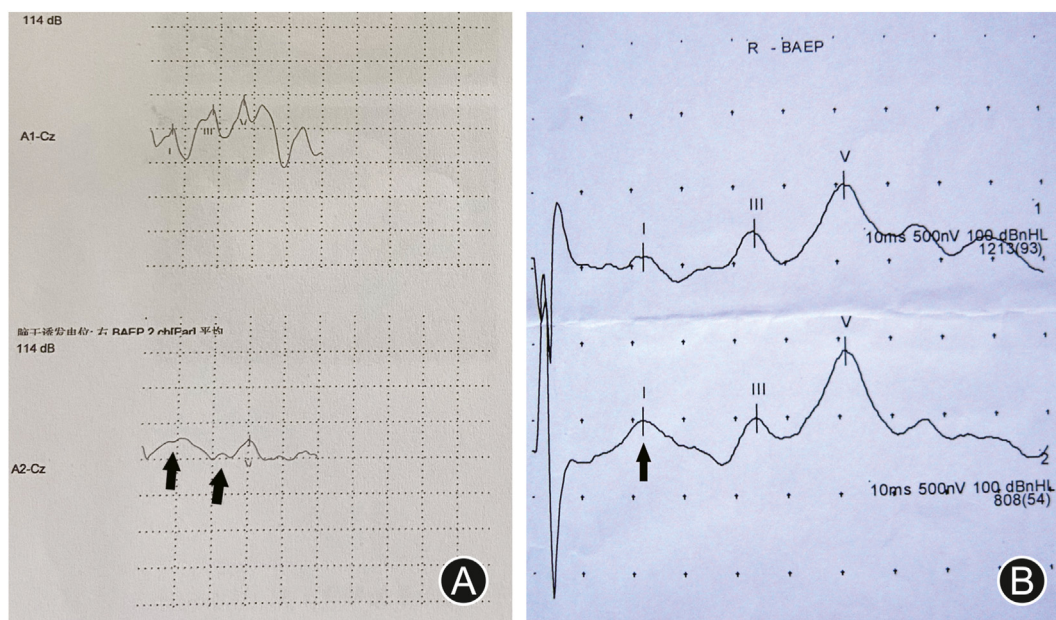

Fig. 2. BAEP test. (A) The BAEP results of a patient with hearing impairment on the right: The arrows show prolonged latency and decreased amplitude of wave I and wave III, suggesting mixed damage; (B) The BAEP results of another patient with left hearing impairment: The arrow shows prolonged latency and decreased amplitude of wave I, and well differentiated wave III and wave V, suggesting peripheral nerve injury. BAEP:brainstem auditory evoked potential.

Table 3
Statistical results of BAEP test and Goodman's injury level of 37 patients with hearing impairment.

Groups	Total	BAEP positive	Wave I positive	Wave III positive	Wave V positive
Low injury	22	6	6	1	0
Medium injury	9	9	9	1	1
Severe injury	6	6	6	4	4
Total	37	21	21	6	5
χ^2 value	/	19.22077	19.22077	13.6183	17.9861
p value	/	<0.001	<0.001	0.0011	<0.001

Table 4
Comparative results of HRCT and BAEP of 37 patients with hearing impairment.

Groups	BAEP negative	BAEP positive	Total
HRCT positive	10 (non-neurological injury)	20 (auditory nerve injury)	30
HRCT negative	6 (non-neurological injury)	1 (auditory nerve concussion)	7
Total	16	21	37
$\chi 2$ value		6.3450	
p value		0.0118	

generally considered to be peripheral nerve damage, while the III and V waves anomalies point to central damage.

This study found that in patients with skull base fracture complicated with hearing impairment, the positive rate of BEAP was 56.76% (21/37). Abnormal I wave was the most common in positive patients, and the positive rate of CT detection in patients with abnormal I wave was more than 95% (20/21), which was related to the direct or indirect injury of auditory nerve caused by skull base fracture. This also reveals that one of the main causes of hearing loss in patients with skull base fracture is peripheral auditory nerve fibers damage, which may be distinguished from hearing loss caused by other reasons. III and V wave damage was common in patients with severe hearing impairment, and the proportion of abnormal III and V wave in moderate and severe injury group (66.67%, 66.67%) was significantly higher than that in low injury group (4.55%, 0%). Because the III and V waves mainly point to the central region near the brainstem, it may be considered that some patients have central damage such as severe axonal injury.[12]

Meanwhile, in the 37 patients with hearing impairment, the positive rate of HRCT was as high as 81.08% (30/37). Through analysis, mastoid fracture (59.46%) and temporal bone rock fracture (45.95%) were the most common. Therefore, the fracture of the middle skull base is the most common fracture type of auditory nerve injury, and the possibility of combined auditory nerve injury should be considered in clinical patients with such skull base fractures. However, due to the complex skull base structure of the middle skull base, different bone thickness, overlapping blood vessels, nerves, muscles, blood, fat, gas and other tissues, and obvious image artifact interference, it is easy to form missed diagnosis in CT plain scan.[13] Because the thin layer has less overlapping structure and high spatial resolution of the image, HRCT scan can minimize the interference of partial volume effect.[14] Combined with the statistical results of this study, HRCT has obvious advantages in the diagnosis of mid-skull base fracture.

It is significant to define the causes of post-traumatic hearing impairment because patients with neurogenic injuries or non-neurogenic injuries have very different prognosis. Currently, the clinical diagnosis of cranial nerve injury still depends on clinical symptoms and CT scan of the skull base.[10] For example, patients with light hearing impairment are more likely to be diagnosed with non-neurogenic injury. However, our study demonstrates that more than a quarter of patients in "low injury group" still more likely to be diagnosed with nerve damage, who had positive of BEAP. Furthermore, imaging examinations of skull base fractures only provides indirect evidence of auditory nerve damage, such as fracture lines of middle skull base and internal auditory canal.[15] Therefore, the combination of HRCT and BAEP may provide an important basis to distinguish the causes of hearing impairment.

Nevertheless, the follow-up time of the cases in this study is short, and in particular, data on long-term hearing recovery of the hearing-impaired patients are not available. At the same time, the number of cases of auditory nerve injury collected is still relatively small, and the special case with positive BEAP but negative HRCT needs to be further expanded for clinical collection to find the internal pathophysiological mechanism.

In conclusion, the use of auditory evoked potential combined with skull base HRCT 3D reconstruction has a high accuracy in the diagnosis of skull base fracture complicated with auditory nerve injury, and can play an auxiliary role in judging the degree of hearing injury and hearing recovery of patients. It may provide more direct and accurate evidence for the diagnosis of patients with auditory nerve injury, and guidance of treatment and prognosis evaluation.

Ethical statement

This study has been reviewed by the Ethics Review Committee of Huzhou First People's Hospital (approval No. 2018033), and has not adversely affected the rights or interests of patients, nor disclosed the privacy and identity information of patients.

Declaration of competing interest

The authors declared no conflicts of interest.

Author contributions

Hua Gu designed this study and prepared the draft. Yi-Qi Wang and Jian-Guo Yang carried out the clinical diagnosis and treatment of the collected cases. Yong Cai was responsible for the collection and arrangement of medical records. Xing-Ming Zhong performed statistical analysis on the data.

References

1. Faried A, Halim D, Widjaya IA, et al. Correlation between the skull base fracture and the incidence of intracranial hemorrhage in patients with traumatic brain injury. *Chin J Traumatol*. 2019;22:286–289. https://doi.org/10.1016/j.cjtee.2019.05.006.
2. Yang LH, Wang WF, Zhang SH, et al. Neuromuscular electrical stimulation on hearing loss caused by skull base fracture: a protocol for systematic review of randomized controlled trial. *Medicine (Baltim)*. 2019;98, e14650. https://doi.org/10.1097/MD.0000000000014650.
3. Yellinek S, Cohen A, Merkin V, et al. Clinical significance of skull base fracture in patients after traumatic brain injury. *J Clin Neurosci*. 2016;25:111–115. https://doi.org/10.1016/j.jocn.2015.10.012.
4. Joo BE, Park SK, Lee MH, et al. Significance of wave I loss of brainstem auditory evoked potentials during microvascular decompression surgery for hemifacial spasm. *Clin Neurophysiol*. 2020;131:809–815. https://doi.org/10.1016/j.clinph.2019.12.409.
5. Thirumala PD, Carnovale G, Habeych ME, et al. Diagnostic accuracy of brainstem auditory evoked potentials during microvascular decompression. *Neurology*. 2014;83:1747–1752. https://doi.org/10.1212/WNL.0000000000000961.
6. Ali QM, Dietrich B, Becker H. Patterns of skull base fracture: a three-dimensional computed tomographic study. *Neuroradiology*. 1994;36:622–624. https://doi.org/10.1007/BF00600424.
7. Humes LE. Examining the validity of the World Health Organization's long-standing hearing impairment grading system for unaided communication in age-related hearing loss. *Am J Audiol*. 2019;28:810–818. https://doi.org/10.1044/2018_AJA-HEAL18-18-0155.
8. Shen W, Dai H, Zhao FZ, et al. Observation on the efficacy of mecobalamin in the treatment of sudden deafness. *Chin J Otorhinolaryngology-Skull Base Surg*. 2000;6:35. https://doi.org/10.3969/j.issn.1007-1520.2000.01.021.
9. Loiselle DL, Nuwer MR. When should we warn the surgeon? Diagnosis-based warning criteria for BAEP monitoring. *Neurology*. 2005;65:1522–1523. https://doi.org/10.1212/01.wnl.0000187311.78352.56.
10. Jin H, Hou LJ. Research on craniocerebral trauma combined with cranial nerve injury. *J Int Neurol Neurosurg*. 2008;35:185–188. https://doi.org/10.3969/j.issn.1673-2642.2008.02.026.
11. Wang YQ, Zhong XM, Yang JG, et al. Changes in brainstem auditory evoked potentials in patients with skull base fractures and hearing impairment. *Chin Crit Care Med*. 2014;26:594. https://doi.org/10.3760/cma.j.issn.2095-4352.2014.08.015.
12. Pamuk AE, Pamuk G, Bajin MD, et al. Traumatic facial and vestibulocochlear nerve injury in the internal acoustic canal in the absence of a temporal bone fracture. *J Int Adv Otol*. 2018;14:330–333. https://doi.org/10.5152/iao.2018.4782.
13. Gudziol V, Marschke T, Reden J, et al. Impact of anterior skull base fracture on lateralized olfactory function. *Rhinology*. 2020;58:45–50. https://doi.org/10.4193/Rhin18.092.
14. Kuninaka H, Takahashi Y, Sano R, et al. Use of postmortem computed tomography angiography to detect vascular injuries accompanying skull base fracture. *Leg Med*. 2016;23:55–58. https://doi.org/10.1016/j.legalmed.2016.09.008.
15. Coello AF, Canals AG, Gonzalez JM, et al. Cranial nerve injury after minor head trauma. *J Neurosurg*. 2010;113:547–555. https://doi.org/10.3171/2010.6.JNS091620.