Intraoperative facial motor evoked potential monitoring for pontine cavernous malformation resection

Clinical article

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Abstract

Objective. To predict postoperative facial nerve function during pontine cavernous malformation surgery by facial motor evoked potential (FMEP).

Methods. From 2008 to 2017, 10 patients with pontine cavernous malformation underwent total resection surgery by the trans-fourth ventricular floor approach with FMEP monitoring. House-Brackmann (HB) and Karnofsky Performance Scale (KPS) score were obtained pre- and postoperatively. The surgeries were performed via two safe entry zones into the brainstem: suprafacial triangle and infrafacial triangle. Six patients were operated on using the suprafacial triangle approach, and four patients were operated on using the infrafacial triangle approach. A cranial peg screw electrode was used to deliver electrical stimulation for FMEP by a train of 4 or 5 pulse anodal constant current stimulation. FMEP was recorded from needle electrodes on the ipsilateral face muscles, and monitored throughout surgery by using threshold-level stimulation method.

Results. FMEPs were recorded and analyzed in all patients, except in two patients operated on with the infrafacial triangle approach who already had severe facial palsy preoperatively. Warning signs appeared in all the patients operated on with the suprafacial approach. However, after halting the procedures temporarily, FMEP findings during operation showed recovery of the thresholds. FMEPs in patients operated on using the infrafacial approach were stable during the surgery. HB scores unchanged postoperatively in all patients. Postoperative KPS scores improved in three patients, decreased in one, and remained same in six.

Conclusions. FMEP can be used to monitor facial nerve function during surgery of pontine cavernous malformation, especially in the suprafacial approach.

Introduction

Surgery for a pontine cavernous malformation is a challenging procedure due to important anatomical structures are densely located in a narrow area. Multiple surgical approaches to resect this precariously located lesion have been described before.[9,10,12] Kyoshima et, al. introduced suprafacial and infrafacial triangle as safe entry zones to access brainstem lesions by a suboccipital approach via fourth ventricular floor (Figure 1).[12] In suprafacial triangle, medial border is medial longitudinal fascicle, caudal border is facial colliculus, and lateral border is cerebellar peduncle. In infrafacial triangle, medial border is medial longitudinal fascicle, caudal border is stria medullares, and lateral border is facial colliculus. [3,12] Cavernous malformations in the pontine area are classically approached by this transventricular route.[6]

Despite advancement in surgical techniques, surgery for brainstem cavernous malformation, especially pontine cavernous malformation still harbors risks to structures in fourth ventricular floor such as VI,VII, and VIII cranial nerves nuclei and fasciculi.[12] Facial, extraocular muscle (EOM), lower cranial nerve palsies, ataxia and others have been reported as complications. [12,15]

Intraoprerative motor evoked potential (MEP) allows preservation of motor pathway during surgery, and has been routinely used in neurosurgical procedures.[2,5,16,18] Although MEP has been used mainly to assess corticospinal tracts function, recent development make them possible to monitor facial motor pathway. [1,2,5,7,16-18] In this study, we performed recording of FMEP (FMEP) during pontine cavernous malformation surgery via the trans-fourth ventricular floor to predict the facial function.

Material and methods

From January 2008 to September 2017, we operated on 28 patients with brainstem cavernous malformation in Shinshu University Hospital. Among these patients, ten patients with pontine cavernous malformation underwent total resection by a trans-fourth ventricular floor approach. FMEPs were measured and monitored in these patients. Six patients were operated on using the suprafacial triangle approach, and four patients were operated on using the infrafacial triangle approach.

The operations were performed in the Concorde position.[11] One patient (Table 1; patient no. 10) underwent an intentional staged surgery.[14] Facial nerve examination with House-Brackmann scale, and other cranial nerves functions were assessed pre-and postoperatively at discharge. Karnofsky Performance Scale (KPS) score was obtained prior to the surgery and during a 6-month follow-up. Anesthetic and FMEP monitoring procedures were conducted according to previous methods described by Goto, et al. [8]

Patients were given general anesthesia by propofol injection. Neuromuscular blocking agent was used up to intubation. Following intubation, neuromuscular blockade agent and inhalational anesthesia were not given to the patients. Constant infusion of propofol (100 to 300 mg/kg/min) was used to maintain the sedation. Induction of narcosis was given by either constant infusion or intermittent bolus. Nitrous oxide (<50%) was also given in most cases.

Suboccipital craniotomies were performed, and the fourth ventricular floor was accessed by using a transcerebellomedullary fissure approach.[13] After reaching the fourth ventricular floor, brainstem mapping was performed to identify the facial colliculus. Cathodal stimulation by a ball electrode elicited the evoked facial electromyography (EMG). The stimulation was given with frequency of 4 Hz, duration of 0.2 mS, and with current less than 1 mA. The Pyoktanin Blue ® dye (Merck, Germany) was used to mark the margin of the facial colliculus.

Thinnest part of the fourth ventricular floor was checked by judging from bulging and discoloration on the fourth ventricular floor. Navigation system was used to check whole of the lesion. Depending on the location of lesion, as shown in Figure 2, suprafacial of infrafacial triangle was entered. If the facial colliculus was located relatively lower to the lesion, the suprafacial triangle was chosen, and vice versa.

FMEP was recorded by using Neuropack MEB 2216 (Nihonkohden Co. Ltd., Tokyo, Japan) monitoring device. A cranial peg screw electrode was used to deliver electrical stimulation for FMEP, and a pair of scalp corkscrew electrodes were used to stimulate upper extremity MEP. The ipsilateral corkscrew was chosen as cathode, and the contralateral corkscrew was the anode.

The scalp corkscrew electrodes were placed bilaterally at C3', and C4', which each can be located 7 cm lateral from the midline on the line between Cz' (2 cm caudal from Cz) and midpoint of the zygomatic arch (Figure 3). The cranial peg screw electrode was placed in contralateral side within the line mentioned before, between C3' or C4' and imaginary sylvian fissure which was measured 6 cm above the external auditory canal from the external angle of eyelid.

Transcranial electrical stimulation was delivered by a train of 4 or 5 pulse anodal constant current stimulation (mA) with duration of each stimulus was 0.2 or 0.3 milliseconds, and an initial interstimulus interval of 1.7 to 2.0 milliseconds. A pair of needle electrodes were used to record compound muscle action potential (CMAP). Recording electrodes for FMEP were placed frontalis, orbicularis oculi,and orbicularis muscle on the ipsilateral face, and recording electrodes for upper extremity MEP were placed on bilateral abductor pollicis brevis (APB) muscle. The intensity of stimulus was keeped below 100 mA. Signals were amplified and filtered (20 to 2000 Hz) before display.

FMEP monitoring was done by using threshold-level stimulation method. A threshold response was defined by any evoked muscle response that exceed ~20 μV in peak-to-peak amplitude and that had appropriate response latency (e.g., latency to orbicularis oris was ~15 to 20 milliseconds and latency to APB was ~20 to 25 milliseconds). Confirmation regarding the response was evoked by the motor pathway was performed by observing disappearance of the response when the train times of pulse stimulus decreased.

FMEP thresholds were recorded at the start (initial threshold), the end (final threshold), and at multiple interval throughout the surgery. If surgical manipulation was performed around the course of the facial nerve, FMEP was measured frequently at every a few seconds. When MEP thresholds or MEP amplitude increased after surgical manipulation, it meant "warning sign" was issued. When this occured, the surgeon temporarily stopped maneuvering, and waited for a while or performed procedures at a different site when technical error or anesthetic factor were excluded as the cause of MEP attenuation.

After the MEP monitoring returned normal, removal procedures were resumed. Depending on the severity of the damage, threshold recovered to its initial threshold or remained increased throughout the surgery. When the FMEP threshold unchanged throughout the surgery, the threshold pattern was regarded as stable. The diagram of the FMEP pattern is shown in Figure 4. Initial and final FMEP threshold difference was calculated as a percentage.

FMEP was used to decide whether complete lesion resection could be carried away or not. Total resection could be performed if FMEP threshold remain stable throughout operation. Total resection was determined by the intraoperative surgeon's impression, and would be confirmed by postoperative MRI. If FMEP warning sign did not disappeared, despite any effort had been made to relieve FMEP disturbance, and further tumor removal would increased FMEP threshold even more, the surgery would be stopped.

Case illustration

A previously healthy 19-year-old woman presented with headache, dysarthria, ataxia, and mild right hemiparesis, which was noted when she was playing a piano. Radiological imaging showed a large mass including hemorrhages in the left pons (Figure 5A), suspecting cavernous nalformation. Initially, she was treated conservatively, but as the symptoms progressed and the lesion enlarged because of repeated hemorrhage, she was referred to our hospital for surgery.

Trans-fourth ventricular floor approach with suprafacial triangle route was taken. The initial FMEP threshold was 45 mA. After the facial colliculus was mapped (Figure 5C), the lesion was approached from just above the facial colliculus. Eventually the lesion was dissected with precautions, especially at the dorsal caudal site. The FMEP threshold increased (alarm sign) at this point (Figure 5D). Maneuvering this site was stopped temporarily until FMEP threshold recovered. FMEP threshold remained stable throughout the rest of the procedure. Final FMEP threshold was 45 mA. Postoperative radiological imaging demonstrated total resection of tumor (Figure 5B) and the patient showed no apparent facial paresis and motor weakness.

Results

Ten patients with pontine cavernous malformation underwent surgeries with FMEP recording in this study.. . The intraoperative FMEP findings and outcomes of surgeries, including extent of resection, KPS, facial nerve, other cranial nerve, and tracts function examination are presented in Table 1. Seven patients were women, mean age was 38.7 years. Six patients were operated on via the suprafacial triangle approach, another four with the infrafacial triangle approach (one patient underwent staged surgery). Total tumor resection was achieved, and confirmed with postoperative MRI in all patients.

HB scores were obtained before and just after operation. As shown in Table 1, pre- and postoperative HB score remained same in all patients. Seven patients have HB scores of 1, others were 2, 4, and 5, respectively. KPS score was obtained before surgery and during a six-month follow-up. KPS score improved in three patients, decreased in one patient, and remained same in six patients.

We attempted to obtain FMEP recording in all the patients. FMEPs were sucessfully recorded in all patients operated on via the suprafacial triangle approach. On the other hand, in two patients with the infrafacial triangle approach, FMEP recordings were not obtained even stimulation intensity was increased to 100 mA (Table 1: patient no. 7 and no. 8). These patients had already demonstrated severe facial palsy preoperatively (HB scores of 4 and 5).

In patients operated on with suprafacial triangle approach, the mean initial thereshold was 63 ± 14 mA, and the mean final threshold was 68 ± 14 mA. The average difference between the initial and final thresholds was 9 ± 11%. In two patients operated on with infrafacial triangle approach, who had successful FMEP recording (Table 1; patients no. 9 & 10), initial thresholds were 60 mA and 82 mA (3% of threshold difference), and final thresholds were 62 mA and 84 mA (2% of threshold difference), respectively.

Warning signs appeared in 6 patients who underwent the suprafacial triangle approach surgery and did not appear in 2 patients who underwent infrafacial approach. In the suprafacial triangle approach, warning signs appeared when the facial colliculus was compressed during the surgical intervention. The warning signs disappeared following cessation of the compression, and final FMEP thresholds recovered in these patients. FMEP were stable in patients operated on with the infrafacial triangle approach.

Discussion

FMEP may be considered the most promising method in facial nerve monitoring because it outweigh limitations of previous methods.[1,5] It is possible to be performed for the duration of surgery without hindering the procedures.[16] Proximal facial nerve also not required to be located for the stimulation of facial motor pathway in FMEP, thus make it useful when proximal stimulation is difficult to perform. In addition, FMEP supports identification of free-running electromyogram's waveforms.[11]

Although FMEP has been demonstrated successfully for intraoperative facial nerve monitoring, warning sign's criteria remains undefined until now, thus preventing it's widespread uses.[1,2] Usually, decrease in the ratio of final and baseline amplitude below 50% is used as a warning sign of ongoing central motor pathway damage. FMEP final and baseline threshold ratio has been reported as a good predictive value to assess postoperative facial nerve function.[2,7]. On the other hand, Fukuda and others reported some false positive and negative findings.[2,5,7] Fukuda et al. pointed that within 30% of patients who had at least 50% amplitude reduction or even full preservation of FMEP showed mild postoperative facial palsy.[7]

Another method to measure FMEP function during operations is a threshold-level stimulation method. Calancie et al. showed that stimulation threshold of MEP significantly increased minutes to even hours before the muscle stopped responding to stimulations in numerous instances of total MEP loss.[4] Thus, the threshold-level stimulation method is more sensitive to detect impending motoric deterioration, and give warning to surgeons earlier.[4] Watanabe et al. reported that the threshold-level stimulation method successfully detected warning signs and used to alleviate motor deterioration in cerebral and spinal surgeries.[17]

There is few literature on the application of FMEP on patients with pontine lesions. Most researches on the use of FMEP were performed on vestibular schwannoma patients.[1,5,7] Unlike in a vestibular schwannoma, in a surgery for pontine lesion, proximal stimulation is difficult to perform, because the lesion usually locates proximal to the stimulation site. Application of FMEP on pontine cavernous malformation surgeries gives facial nerve function to the surgeons in more reliable way intraoperatively.

In this study, the FMEP was more useful for patients operated on via the suprafacial triangle approach than for patients operated on via the infrafacial triangle approach. FMEP showed warning sign in all patients operated on via the suprafacial triangle approach, then showed recovery of MEP stimulation threshold after halting the procedures and waiting for weaning of insults to the nerve. On the other hand, it was stable in the infrafacial triangle approach. The facial colliculus is likely to be compressed at a time of removing a lesion, by caudal brainstem retraction in the suprafacial triangle approach . In the infrafacial triangle approach, the facial colliculus is not likely to be compressed as the procedures is carried out caudal to the facial colliculus.

MEP disturbances can be caused by various mechanisms. MEP amplitude can reduced by motor neuron trauma, ischemia, stretching, and pressure during surgery.[1] Muscle relaxant, depth of anesthesia, stimulation failure, scalp edema can also influence MEP recording.[1,2] Based on our experiences, FMEP transient attenuation might occur by compression. In case of direct injury, the FMEP will attenuate permanently. Most importantly, by utilizing the intraoperative MEP monitoring, a surgeon can understand what types of procedure which might cause MEP attenuation. When the MEP does not attenuate the surgeon can perform his/her procedure more confidently.

Difficulties in analyzing the electrophysiological finding often arise during FMEP monitoring. Damage due to mechanical manipulations, delayed ischemic injury or postoperative delayed palsy cannot be predicted. Peripheral seventh nerve can be stimulated directly without activating facial motor pathway from cerebral cortex because location stimulation is near to the recording electrodes.[2,5,7,8] Temporalis muscle contraction also can be elicited directly by transcranial electrical stimulation.[8] To avoid this current spread issue, it has been suggested to put stimulating electrodes on Cz, although stimulation intensity may needs to be stronger to stimulate the facial motor cortex. [2,5,7,8]

Beside the use of intraoperative FMEP in resection of pontine lesion, surgical approach need to be thoroughly planned by considering avalaible routes to resect the lesion safely. Access to pontine lesion generally recommended from area which bulging of the lesion is visible, or adjacent surface of the lesion.[14] Trans-fourth ventricular floor approach is indicated when the lesion is located dorsally near or protruding to the fourth ventricular floor under above-mentioned brainstem mapping and/or monitoring is available, although it has been described by some authors that lateral suboccipital retrosigmoid approach via the cerebellar peduncle for dorsal pontine surgery reduces manipulation of structures in the fourth ventricular floor.[3,10] Brainstem vascularization does not comes from fourth ventricular floor surface, but from perforating arteries on it's ventral or lateral side, and upper motor neuron part of facial motor pathway located in ventrolateral part of the pons.[12] These anatomic considerations made fourth ventricular floor approach has an advantage over the lateral suboccipital retrosigmoid approach.

Surgery by trans fourth ventricular approach in dorsal pontine region harbor risks of compromising the function of external ocular muscle (EOM) by injury to medial longitudinal fascicle (MLF), and nucleus of abducens nerve, facial sensorymotor impairment from damage to trigeminal nuclei, and lower cranial nerve palsy.[12, 15] To minimize harms to fouth ventricular floor structures in suprafacaial triangle approach by retraction, medial and caudal retraction should be avoided because of possibility to cause abducens nerve palsy, while in infracial triangle approach, brainstem retraction is possible only laterally, and the surgery should not extend over the caudal edge of the striae medullares to avoid damaging nuclei of the lower cranial nerves.[12]

Conclusion

FMEP can be used to monitor facial nerve function during surgery of pontine cavernous malformation, especially in the suprafacial approach. Measuring the FMEP using a threshold-level stimulation method is useful to detect and alleviate warning signs throughout surgery.

Disclosures

The authors do not have any conflict of interest concerning the materials or methods used in this study or the findings specified in this manuscript.

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FIGURE LEGENDS

Figure 1 Schematic drawing of suprafacial and infrafacial triangle in the floor of the fourth ventricle. Figure was featured in Kyoshima K, Kobayashi S, Gibo H, Kuroyanagi T: A study of safe entry zones via the floor of the fourth ventricle for brain-stem lesions. J Neurosurg 78(6)**:** 987-993, 1993, copyright The Journal of Neurosurgery Publishing Group. Published with permission. Reprinted with permission from Kyoshima, K., et al. A study of safe entry zones via the floor of the fourth ventricle for. brain-stem lesions. *Journal of Neurosurgery 78*: 987–993, 1993.

Figure 2 Lateral illustration of the brainstem on (A) suprafacial and (B) infrafacial triangle approaches. *Arrows* depict direction of surgical approach.

Figure 3 (A) Illustration depicting the placement of stimulating scalp corkscrew electrode and cranial peg-screw electrode. (B) Photo showing a peg-screw electrode (arrow) connected to the electrical stimulator (asterisk) placed on the patient's head.

Figure 4 Threshold pattern of the FMEP. **A** Stable: FMEP threshold increased gradually but regarded as stable because of no sudden increase in threshold was observed throughout surgery. **B** Warning sign: There was sudden increase in the threshold during surgery that associated with the surgical intervention. **C** Recovered: Threshold recovered to initial threshold and remained stable until the end of the surgery. **D** Not recovered: The threshold was increased, but not recovered to the initial threshold throughout the surgery.

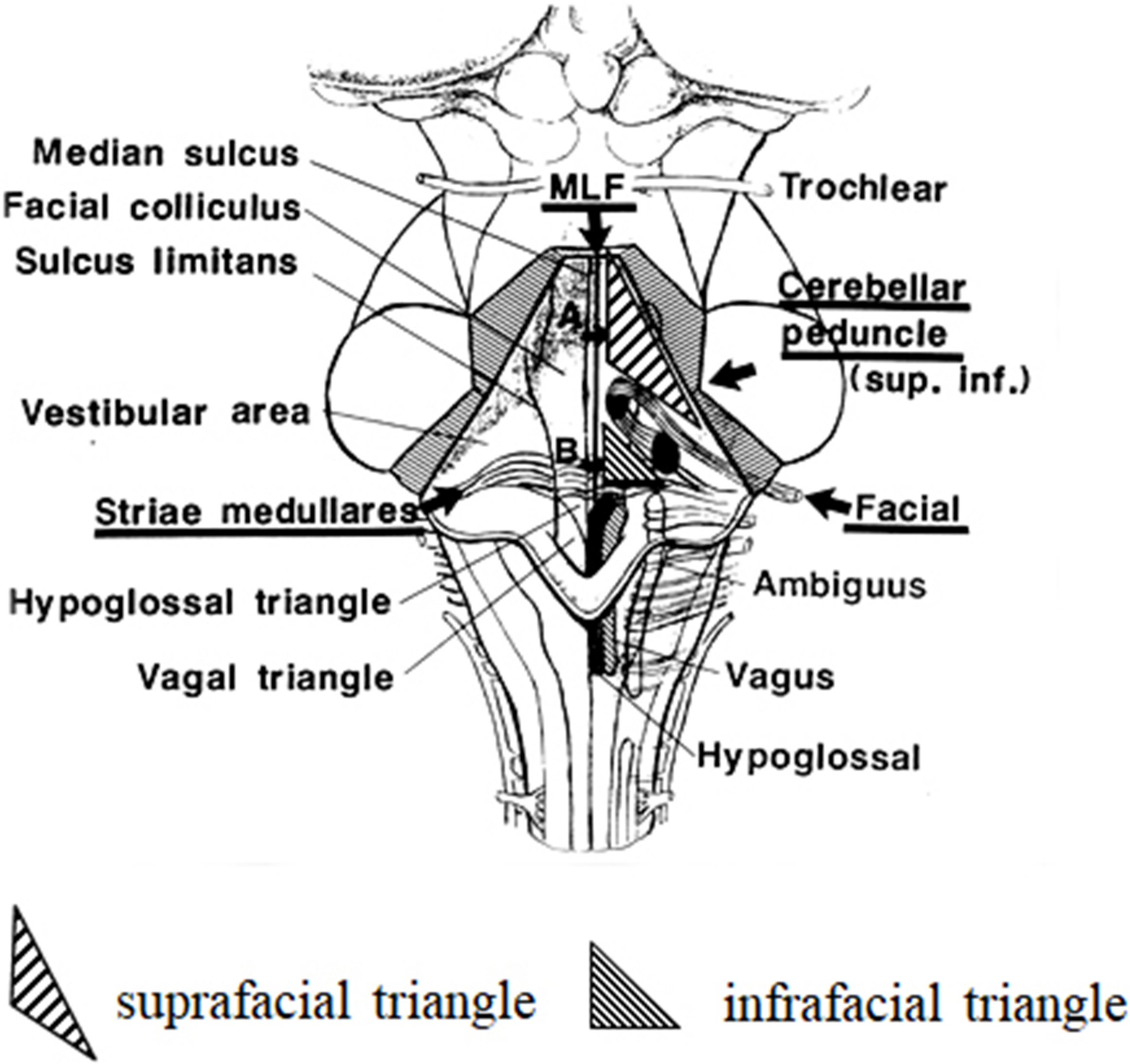
Figure 5 (A) Preoperative T2-weighted axial MRI demonstrating a cavernous lesion with hematoma in the pons. (B) Postoperative T2-weighted axial image showing removal of the lesion. (C) Intraoperative photograph during facial colliculus mapping in the fourth ventricular floor using a ball electrode (*large arrow). Arrowheads*: midline, *small arrows*: stria medullaris (D) FMEP reading during tumor resection by using anodal stimulation with current of 45-60 mA, 5 pulse stimulus train, duration of 0.3 milliseconds. Above channel is the baseline recording, and bellow channel demonstrating warning sign (*circle*).

Table 1

Pontine cavernous malformation surgeries and facial MEP monitoring via the fourth ventricular floor approach

No.	Age (years)	Sex	Approach	Resection	Facial MEP finding	Initial threshold (mA)	Final threshold (mA)	Change (%)	HB		EOM disturbance		Lower cranial nerve disturbance		Motor extremity deficit		KPS	
									Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	32	Woman	Suprafacial	Total	Recovered	83	85	3	1	1	+	++	-	-	+	+	80	80
2	18	Woman	Suprafacial	Total	Recovered	45	45	0	1	1	+	-	-	-	+	-	70	90
3	38	Woman	Suprafacial	Total	Recovered	52	60	15	1	1	-	-	-	-	-	-	90	90
4	57	Man	Suprafacial	Total	Recovered	75	70	-7	1	1	+	++	+++	++	+++	+++	40	40
5	32	Man	Suprafacial	Total	Recovered	65	80	23	2	2	+++	++	+++	+	+++	+	30	80
6	54	Woman	Suprafacial	Total	Recovered	60	70	17	1	1	++	+	-	-	-	-	80	80
7	24	Woman	Infrafacial	Total	-	Over 100	Over 100	-	5	5	++	+++	-	-	-	-	60	60
8	39	Man	Infrafacial	Total	-	Over 100	Over 100	-	4	4	++	++	++	+	++	+	50	80
9	54	Woman	Infrafacial	Total	Stable	60	62	3	1	1	+	++	-	-	+	+	90	80
10	39	Woman	Infrafacial	Total	Stable	82	84	2	1	1	+	+	-	-	+	+	80	80

(-)= no impairment, (+) = mild impairment, (++) = moderate impairment, (+++) = severe impairment, HB= House-Brackmann , EOM= Extra Ocular Muscle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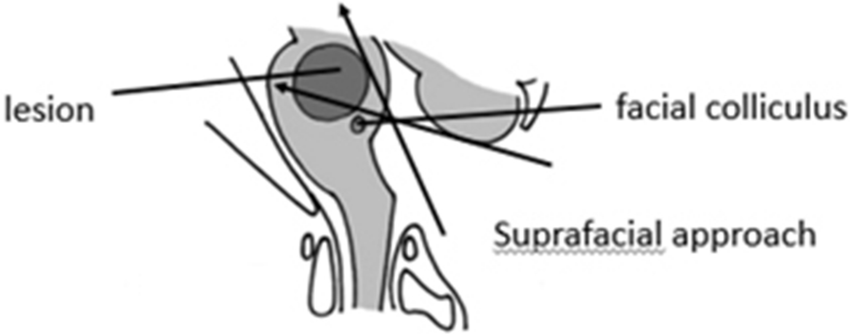
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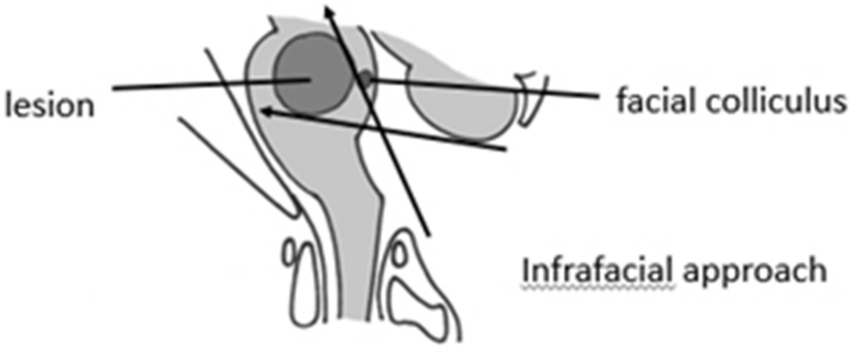
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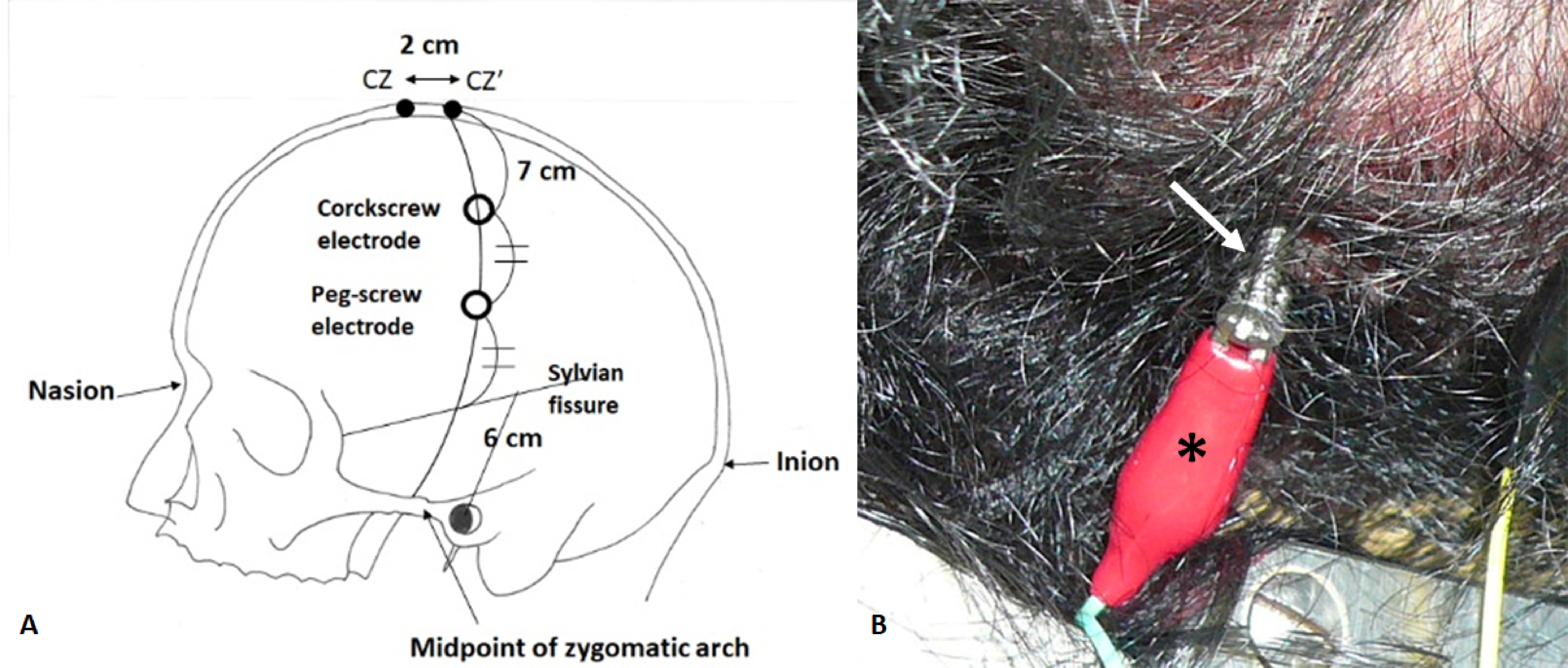
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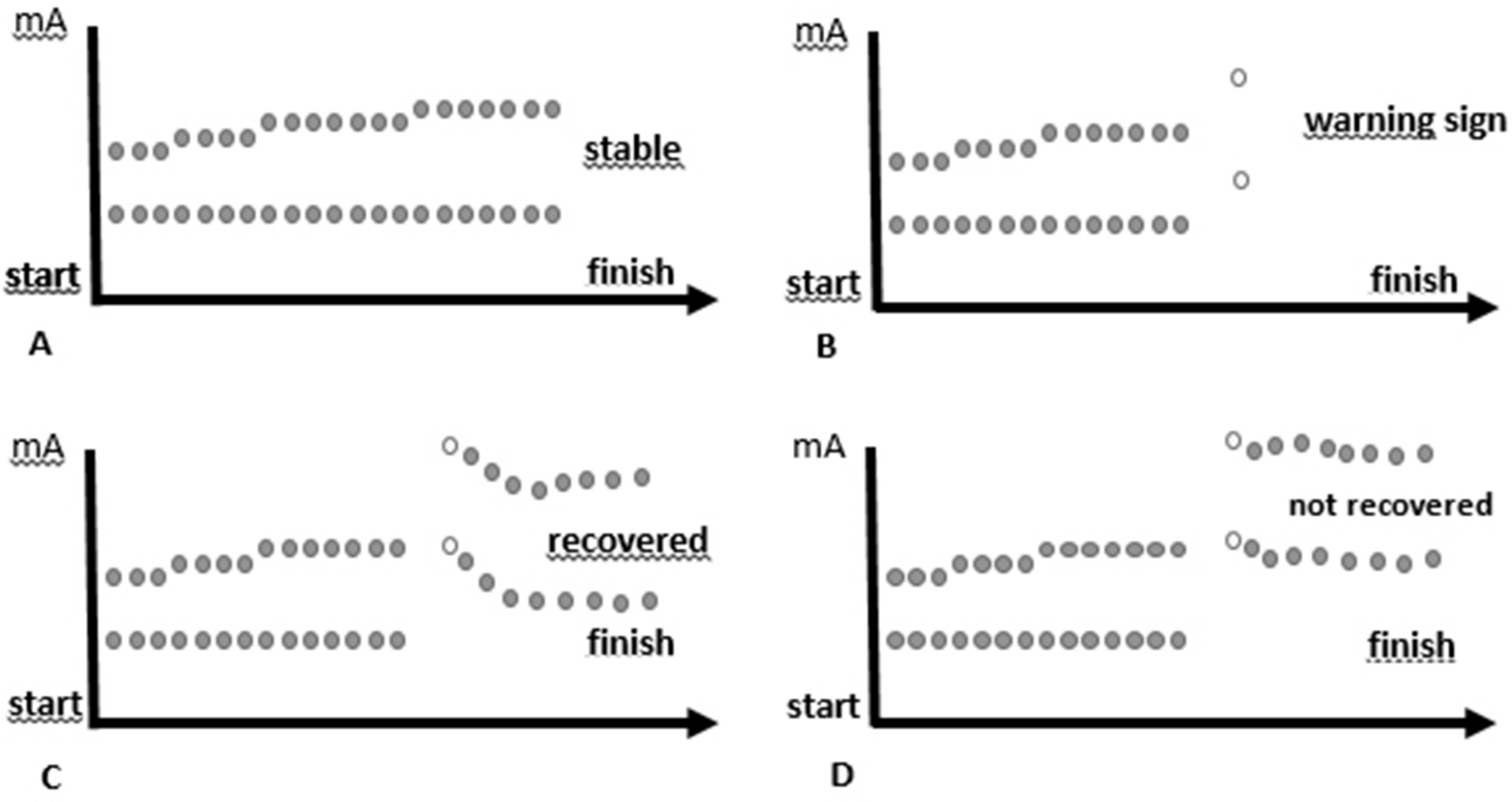
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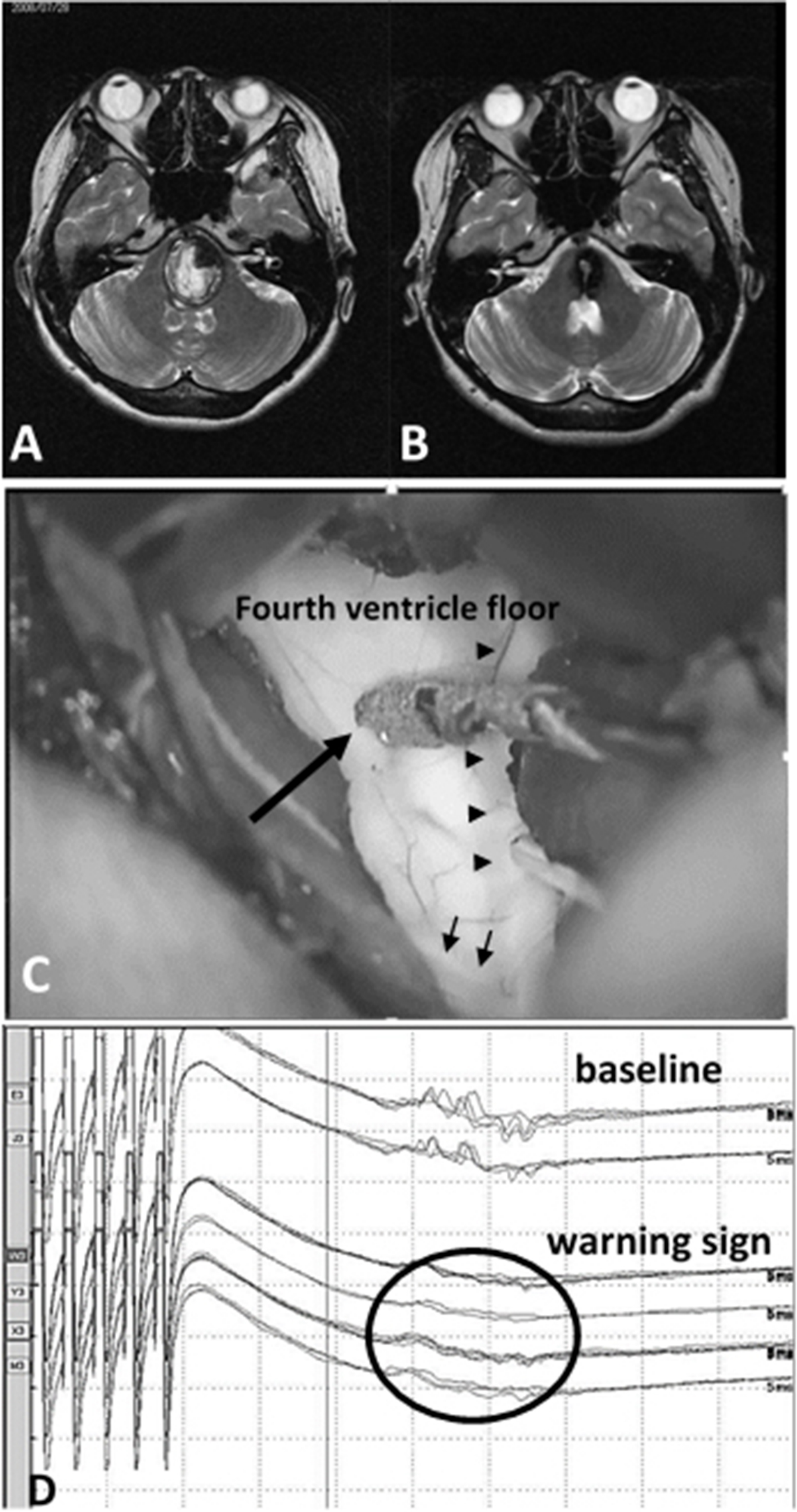
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