Preoperative Imaging and Microscopic Navigation During Surgery Can Avoid Unnecessarily Opening the Mastoid Air Cells Through Craniotomy Using the Retrosigmoid Approach

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■ OBJECTIVE: **To analyze treatment of microvascular decompression using the retrosigmoid approach (RA) in primary trigeminal neuralgia and hemifacial spasm using preoperative images combined with intraoperative microscopic navigation to avoid unnecessarily opening the mastoid air cells (MACs).**

■ METHODS: **Ten patients with primary trigeminal neuralgia and 20 patients with hemifacial spasm (test group) were treated using RA for microvascular decompression. Preoperative head magnetic resonance angiography and temporal bone computed tomography were performed and the images registered using SPM12 and fused with MRIcron to determine the relationship between MACs and sigmoid sinuses. An O-arm was used for navigation, and the transverse sigmoid sinus was projected under a microscope to guide RA. A control group comprised 139 patients who had the same surgical procedure as the test group but without image processing or intraoperative navigation.**

■ RESULTS: **The relationship between MACs and the ipsilateral sigmoid sinus was classified as follows: I, MACs did not exceed the lateral edge of the ipsilateral sigmoid sinus (10/60); II, MACs exceeded the ipsilateral lateral edge of the sigmoid sinus but did not exceed the medial edge (42/60); and III, MACs exceeded the medial edge of the ipsilateral sigmoid sinus (8/60). Test and control groups showed significant differences in the incidences of opening MACs (*P* = 0.003). There was no cerebrospinal fluid leakage or scalp and intracranial infection at follow-up.**

■ CONCLUSIONS: **Image processing and intraoperative microscopic navigation can avoid unnecessarily opening MACs and might reduce postoperative cerebrospinal leakage and scalp infection after RA craniotomy.**

INTRODUCTION

The retrosigmoid approach (RA) is a routine surgical approach used to treat cranial nerve microvascular decompression (MVD), cerebellopontine angle tumors, and other similar conditions; however, infringement of and opening the mastoid air cells (MACs) are risk factors that could lead to cerebrospinal fluid (CSF) leakage and scalp infection.[1-3] This study analyzed 10 cases of primary trigeminal neuralgia (PTN) and 20 cases of hemifacial spasm (HFS) that were treated for MVD using RA. Head magnetic resonance angiography (MRA) and temporal bone computed tomography (CT) images were registered and fused before surgery to analyze the relationship between MACs and the sigmoid sinuses and were combined with intraoperative microscopic navigation to evaluate their value in avoiding unnecessarily opening MACs and preventing postoperative CSF leakage and scalp infection.

Key words
- Mastoid air cells
- Microscopic navigation
- Preoperative imaging
- Retrosigmoid approach

Abbreviations and Acronyms
CSF: Cerebrospinal fluid
CT: Computed tomography
e-Thrive: Enhanced T1 high resolution isotropic volume excitation
HFS: Hemifacial spasm
MACs: Mastoid air cells
MRA: Magnetic resonance angiography
MVD: Microvascular decompression
PTN: Primary trigeminal neuralgia
RA: Retrosigmoid approach
TSSJ: Transverse and sigmoid sinuses junction

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Table 1. Demographic and Clinical Data of Test Group and Control Group

	Test Group			Control Group		
	PTN (*n* = 10)	HFS (*n* = 20)	All Patients (*n* = 30)	PTN (*n* = 53)	HFS (*n* = 86)	All Patients (*n* = 139)
Sex						
Male	4 (40)	11 (55)	15 (50)	28 (52.8)	44 (51.2)	72 (51.8)
Female	6 (60)	9 (45)	15 (50)	25 (47.2)	42 (48.8)	67 (48.2)
Age, years	45.7 (31—60)	40.3 (22—62)	42.1 (22—62)	51.3 (31—68)	37.2 (21—60)	42.6 (21—68)
Follow-up time, months	3.5 (1—6)	3.9 (1—6)	3.8 (1—6)	14.8 (8—20)	15.1 (8—20)	14.9 (8—20)
Duration of symptoms, years	11.4 (1—20)	7.5 (2—15)	8.8 (1—20)	13.2 (1—25)	8.1 (2—18)	9.4 (1—25)
Side of surgery						
Left	6 (60)	12 (60)	18 (60)	35 (66.0)	46 (53.5)	81 (58.3)
Right	4 (40)	8 (40)	12 (40)	18 (34.0)	40 (46.5)	58 (41.7)

Values are presented as number (%) or median (range).
PTN, primary trigeminal neuralgia; HFS, hemifacial spasm.

MATERIALS AND METHODS

Data Source

The study was approved by the Medical Ethics Committee of the Guangdong Second Provincial General Hospital. All patients provided signed consent forms before surgery. From January to June 2018, 10 patients with PTN and 20 patients with HFS were used as the test group and were treated for MVD using RA in the Department of Neurosurgery, Guangdong Second Provincial General Hospital. The age range of the 4 men and 6 women with

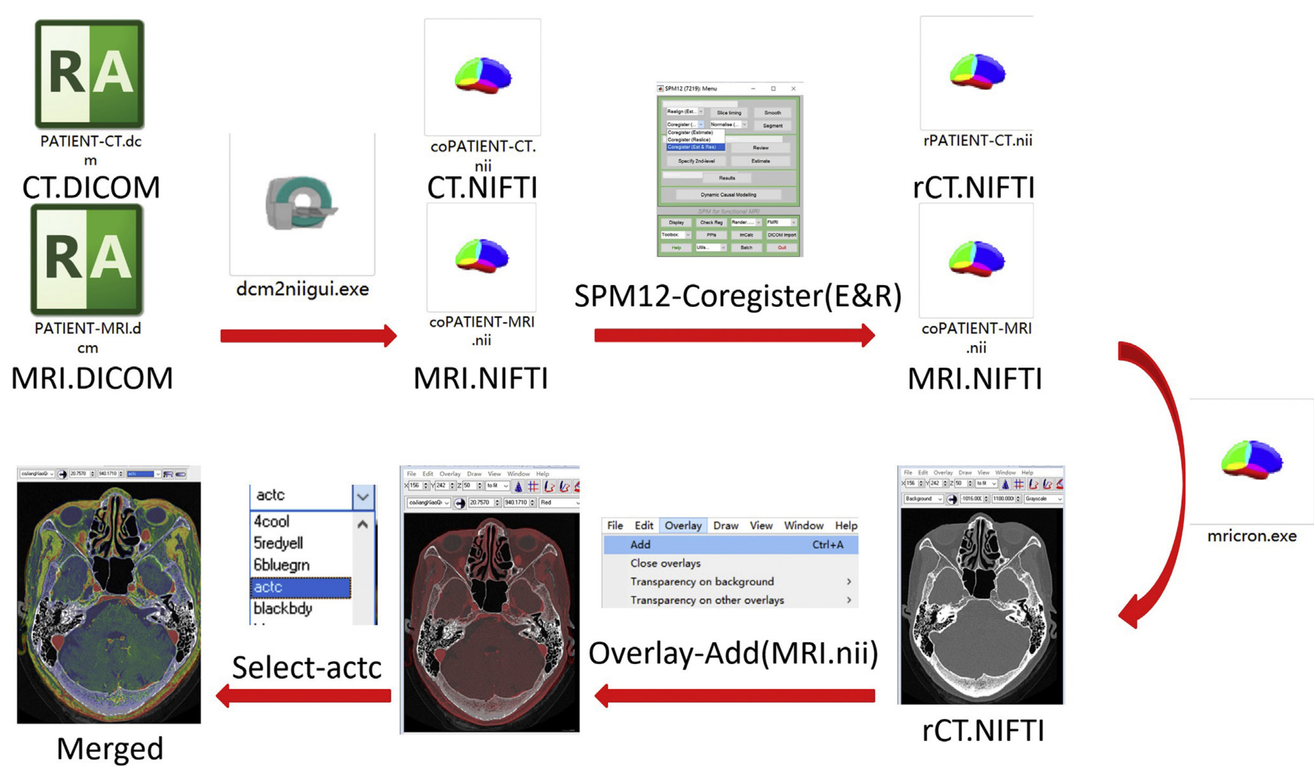

Figure 1. Steps of image registration and fusion.

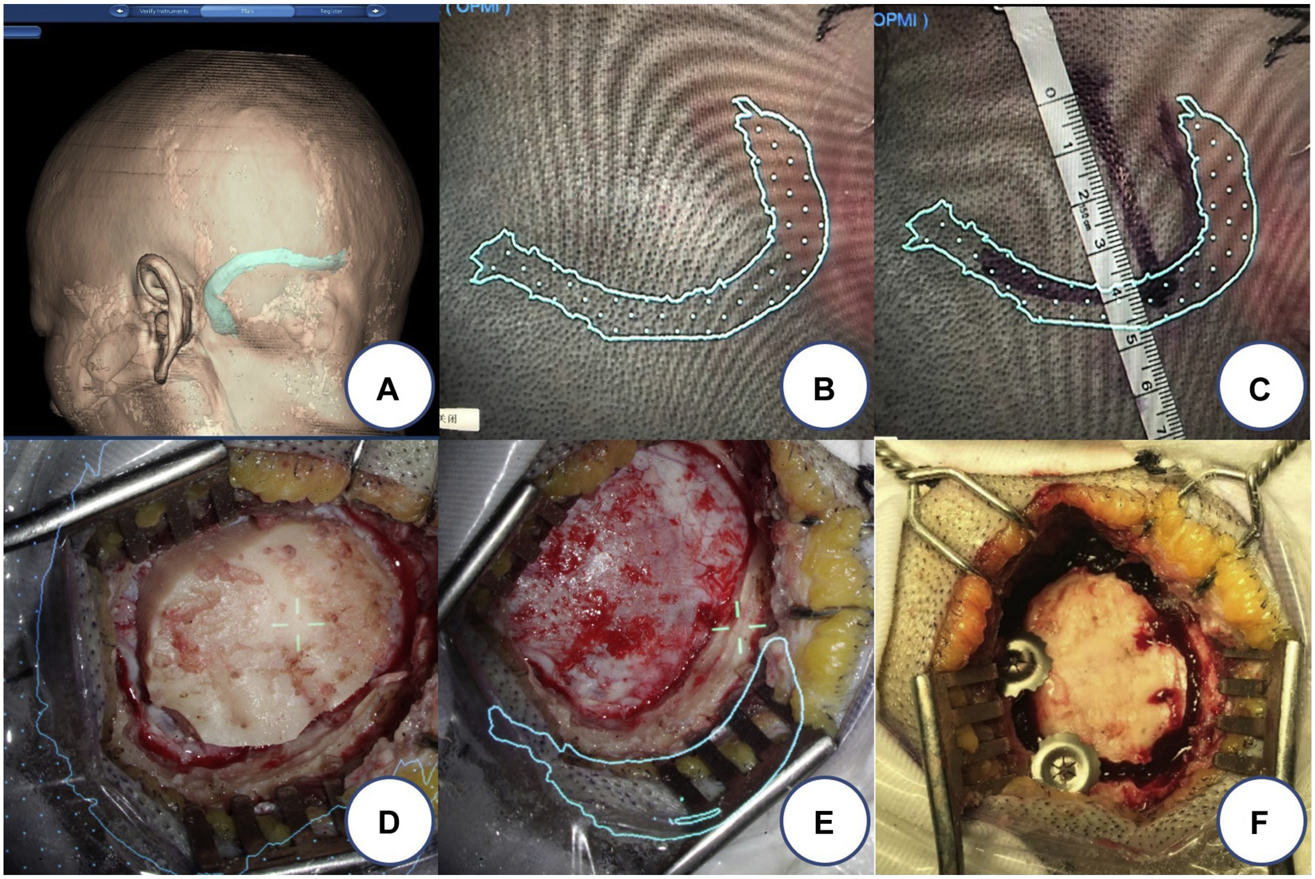

Figure 2. Steps of surgery. (**A**) Three-dimensional visualization of the scalp shows the projection of the transverse and sigmoid sinus. (**B**) Under microscopic navigation, the transverse sigmoid sinus projection is displayed. (**C**) Scalp incision. (**D**) Bone flap opened under microscopic navigation. (**E**) Exposure of the dura mater. (**F**) Bone flap repositioned.

PTN was 31–60 years. The average duration of PTN was 11.4 years (range, 1–20 years). In 6 cases of PTN, the left side of the head was affected; in 4 cases, the right side was affected. The age range of the 11 men and 9 women with HFS was 22–62 years. The average duration of HFS was 7.5 years (range, 2–15 years). In 12 cases of HFS, the left side of the head was affected; in 8 cases, the right side was affected (Table 1).

From January to December 2017, 53 patients with PTN and 86 patients with HFS were used as the control group and were treated for MVD using RA in the Department of Neurosurgery, Guangdong Second Provincial General Hospital. The age range of the 28 men and 25 women with PTN was 31–68 years. The average duration of the condition was 13.2 years (range, 1–25 years). In 35 cases of PTN, the left side of the head was affected; in 18 cases, the right side was affected. The age range of the 44 men and 42 women with HFS was 21–60 years. The average duration of the condition was 8.1 years (range, 2–18 years). In 46 cases of HFS, the left side of the head was affected; in 40 cases, the right side was affected (Table 1).

Preoperative head MRA (thin layer: 1 mm; enhanced T1 high resolution isotropic volume excitation [e-Thrive] sequence) and temporal bone CT (layer: 0.5 mm) were performed to exclude intracranial pathology. None of the patients had an associated brain tumor or vascular malformation and secondary MVD.

Image Processing

In the test group, Dcm2niigui (http://people.cas.sc.edu/rorden/mricron/stats.html) was used to convert the original raw Digital Imaging and Communications in Medicine data of head MRA (e-Thrive) and temporal bone CT into NifTI (Neuroimaging Informatics Technology Initiative) format. Images were registered using Coregister (Estimate & Reslice) of SPM12 (http://www.fil.ion.ucl.ac.uk/spm/software/spm12/),[4-6] after which MRIcron (http://people.cas.sc.edu/rorden/mricron/stats.html) was used to fuse the registered images and analyze the development of MACs and their relationship with the ipsilateral sigmoid sinus (Figure 1).

The original Digital Imaging and Communications in Medicine data of head MRA (e-Thrive) and temporal bone CT were imported into the StealthStation S7 navigation system (Medtronic, Minneapolis, Minnesota, USA). After CT and MRA data were fused and the successful fusion was confirmed, the projection of the surgical

Table 2. Relationship Between Mastoid Air Cells and Ipsilateral Sigmoid Sinus

	Affected Side	Unaffected Side
PTN		
Type I	2 (10)	1 (5)
Type II	7 (35)	7 (35)
Type III	1 (5)	2 (10)
HFS		
Type I	4 (10)	3 (7.5)
Type II	13 (32.5)	14 (35)
Type III	3 (7.5)	3 (7.5)
Total		
Type I	6 (10)	4 (6.7)
Type II	20 (33.3)	21 (35)
Type III	4 (6.7)	5 (8.3)

Values are presented as number (%).
PTN, primary trigeminal neuralgia; HFS, hemifacial spasm.

transverse side and sigmoid sinus were marked. Image processing was not conducted in the control group.

Surgery

Under general anesthesia, the patient was placed in the supine position on the contralateral side with the mastoid at the highest point. A Mayfield headholder was used to stabilize the head, and a Medtronic navigation reference frame was created. The O-arm (Medtronic) was used to scan the entire head for automatic convergence registration. The transverse sigmoid sinus was projected through the microscope (Pentero; Carl Zeiss Meditec AG, Jena, Germany) to the scalp, and the surgical incision was designed accordingly (**Figure 2**). The incision was approximately 5 cm long, the subcutaneous and other layers of muscle were dissected, and a spreader was used to expose the skull.

According to the projection of the navigation sinus on the skull, a bone hole was first drilled at the junction of the transverse and sigmoid sinuses using a pneumatic drill. The lateral boundary of the bone flap was the medial edge of the sigmoid sinus, the upper border was the lower edge of the transverse sinus, and the lower edge was close to the orbital space. After opening the bone flap, any open MACs were checked and sealed with bone wax.

The surgical area was thoroughly flushed with saline before opening the dura mater to remove the bone powder. The dura was then opened to release CSF. The root entry zone of the trigeminal or facial nerve was examined, and a polytetrafluoroethylene spacer was inserted between the blood vessel responsible for compression and the nerve. The dura mater was tightly sutured with nonabsorbable 4—0 suture (Ethicon Inc., Somerville, New Jersey, USA), the bone flap was replaced, and the scalp was sutured. The control group had the same surgical procedure as the test group but without the Medtronic navigation reference frame.

Statistical Analysis

Two-sample t tests were performed to assess differences in age; χ^2 test was used to assess differences in sex, diagnosis, side of surgery, and incidence of opening MACs; and Fisher exact test was used to assess CSF leakage between the test group and control group using IBM SPSS Version 20.0 (IBM Corp., Armonk, New York, USA). A value of $P < 0.05$ was considered statistically significant.

RESULTS

The relationship between MACs and the ipsilateral sinus was classified into three types as follows: type I, MACs did not exceed the lateral edge of ipsilateral sigmoid sinus (10 of 60); type II,

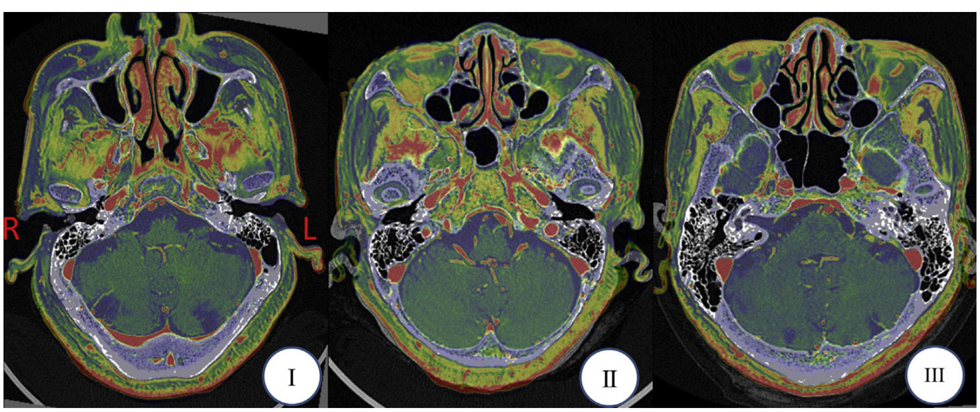

Figure 3. Relationship between mastoid air cells (MACs) and ipsilateral sigmoid sinus. I, MACs did not exceed the lateral edge of the ipsilateral sigmoid sinus. II, MACs exceeded the ipsilateral lateral edge of the sigmoid sinus but did not exceed the medial edge. III, MACs exceeded the medial edge of the ipsilateral sigmoid sinus.

Table 3. Occurrence Rate of Thick Emissary Veins

	Affected Side (*n* = 15)	Unaffected Side (*n* = 15)	All Sides (*n* = 30)
PTN	2 (10)	2 (10)	4 (13.3)
HFS	7 (17.5)	3 (7.5)	10 (33.3)
Total	9 (15)	5 (8.3)	14 (46.7)

PTN, primary trigeminal neuralgia; HFS, hemifacial spasm.

MACs exceeded the ipsilateral lateral edge of the sigmoid sinus but did not exceed the medial edge of the sigmoid sinus (42 of 60); and type III, MACs exceeded the medial edge of the ipsilateral sigmoid sinus (8 of 60) (Table 2 and Figure 3). Treatments in 26 patients with types I and II avoided unnecessarily opening MACs. The condition in 4 patients with type III was repaired after having to open MACs. No sinuses were injured during the surgeries, and the bone flaps were completely repositioned. It was found that the thick emissary veins in 14 cases migrated into the sigmoid sinus through the bone hole in the skull (Table 3 and Figure 4). The test and control groups showed no significant differences in diagnosis, age, sex, side of surgery,

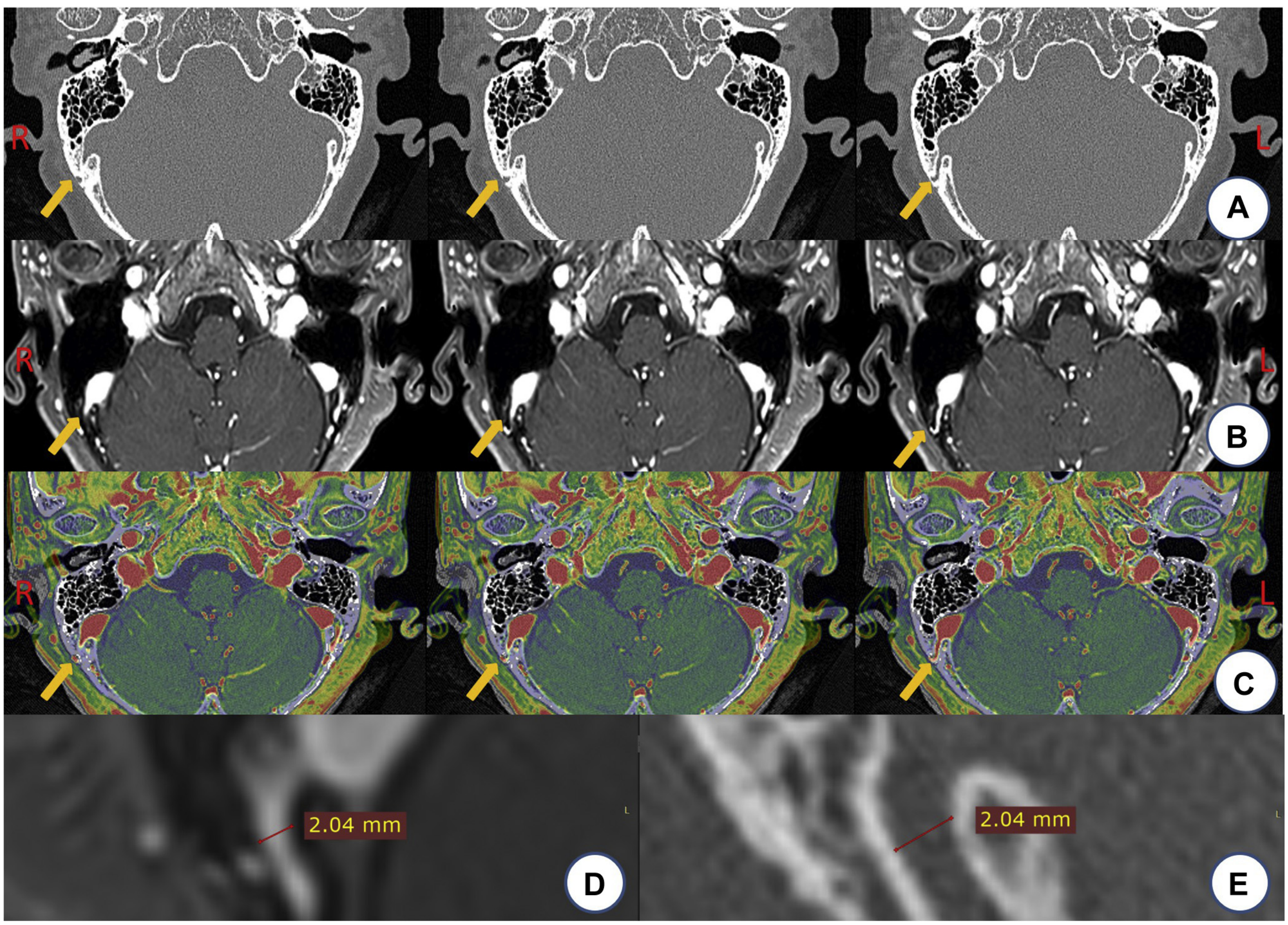

Figure 4. (**A**) Temporal bone computed tomography shows the hole of the skull through which the emissary vein passes (*yellow arrows*). (**B**) Head magnetic resonance angiography (enhanced T1 high resolution isotropic volume excitation) shows the emissary vein (*yellow arrows*). (**C**) Emissary veins (*yellow arrows*) displayed after image registration and fusion. (**D** and **E**) Head magnetic resonance angiography (enhanced T1 high resolution isotropic volume excitation) and computed tomography measured the width of the emissary vein and bone tube.

Table 4. Demographic Characteristics of Test and Control Groups

Characteristics	Test Group (n = 30)	Control Group (n = 139)	P Value
Diagnosis, PTN/HFS	10/20	53/86	0.622
Age, years, mean ± SD	42.10 ± 9.6	42.64 ± 11.6	0.812
Sex, female/male	15/15	67/72	0.858
Side of surgery, left/right	18/12	81/58	0.826
Incidence of MACs open, number (%)	4 (13.3)	59 (42.4)	0.003
Incidence of CSF leakage, number (%)	0 (0)	1 (0.7)	1.000
Incidence of scalp infection, number (%)	0 (0)	3 (2.2)	1.000

PTN, primary trigeminal neuralgia; HFS, hemifacial spasm; MACs, mastoid air cells; CSF, cerebrospinal fluid.

scalp infection, or CSF leakage ($P > 0.05$), but the groups showed significant differences in the incidence of opening MACs ($P = 0.003$) (Table 4). No CSF leakage or scalp and intracranial infection occurred in any of the patients during 1–6 months of follow-up.

DISCUSSION

RA is a commonly used surgical approach for cranial nerve (e.g., trigeminal, facial, glossopharyngeal) MVD and cerebellopontine angle or jugular foramen tumors[7-10]; however, RA frequently infringes on and opens MACs so that CSF gains access into MACs, which leads to CSF leakage (nasal leakage, incision leakage, or rhinorrhea and incision leakage) and further develops into scalp infection or meningitis, a common complication with this approach.[2,3,8-10] The literature reports that the incidence of CSF leakage after RA is 5.6%–10.3%.[1,11-14]

According to the literature, the causes of CSF leakage are associated with the following 4 factors[1,2,11,12,15,16]: 1) infringement on and opening MACs during craniotomy, 2) tightness of dura suture, 3) nonreplacement of the skull bone flap resulting in lack of adequate pressure support between the dura mater and the muscle and allowing CSF to easily flow from it, and 4) postoperative high intracranial pressure. Some studies have proposed methods for reducing CSF leakage after RA,[2,17,18] including using the original bone flap to reset the skull; using bone wax or bone material to seal MACs; closely affixing the dura mater; and using artificial dura mater, muscle, and adipose tissue to improve the repair effect of the dura mater. The study by Stoker et al.[13] concluded that complete reconstruction of the suboccipital cranial defect decreases the risk of CSF leakage by 5.6%–23.4%.

We believe that to achieve the best surgical results using RA, the edge of the bone flap should be as close to the medial edge of the sigmoid sinus as possible so that the sigmoid sinus can be opened to the maximum extent, the lateral cerebellar cistern can be exposed to the maximum extent, and cerebellar injury can be avoided by reduced traction on the cerebellum; however, the closer the bone flap is to the sigmoid sinus, the more likely it is that MACs will be opened. Thus, it is particularly important to evaluate the development of MACs before surgery and their relationship with the sigmoid sinus as well as their precise positioning during surgery. The study by Tamura et al.[3] found that preoperative assessment of petrous pneumatization is necessary to prevent CSF leakage.

According to the results of temporal bone CT and head MRA, we classified the relationship between MACs and the sigmoid sinus into 3 types. In type I, MACs did not exceed the lateral edge of ipsilateral sigmoid sinus and were not easily opened because the medial edge of the sigmoid sinus must be exposed before opening the bone flap. In type II, MACs developed past the ipsilateral lateral edge of the sigmoid sinus but did not exceed the medial edge. This type is likely to cause the unnecessary opening of MACs during surgery, even if MACs are already open because tiny leaks are easily overlooked and it is difficult to detect them without careful observation. This poses a potential risk of CSF leakage. In type III, MACs exceeded the medial edge of the ipsilateral sigmoid sinus. These MACs were generally easily observed by the surgeon and had to be opened.

During a routine craniotomy using RA, the surgeon must first search for the asterion of the skull and then drill a hole to find the transverse and sigmoid sinuses junction (TSSJ) below it; however, Li et al.[12] reported that the incidence of CSF leakage was 5.6% (29 of 516) after opening the bone flap when using the asterion as a landmark, which might be related to opening MACs. In addition, da Silva et al.[19] found that locating TSSJ based on the asterion is not accurate. They suggested that using navigation anatomic landmarks for registration is a more reliable method for locating TSSJ during RA craniotomies to avoid unnecessary sinus exposure. This alternative method proved to be fast and accurate. We also believe that finding the asterion based on the intersection of the skull suture for RA craniotomy presents specific challenges. The asterion differs in individuals, and it is usually necessary to create larger exploration holes in the asterion to find TSSJ, which increases the risk of opening MACs and might increase the risk of CSF leakage.

Two methods are suggested for accurately finding TSSJ for RA craniotomy. First, one preoperatively marks the sinus morphology and rational design incision and then combines this with intraoperative microscopic navigation to find the position of TSSJ below the skull for more accurate drilling. With the sigmoid sinus medial border displayed as a boundary using the microscope, the bone flap can be opened with a skull drill. Second, the thick emissary veins (>1.5 mm diameter) penetrated the sigmoid sinus through the bone hole of the skull in 14 cases, which was clearly identified during surgery and on preoperative temporal bone CT and head MRA scans as well as on the images after registration and fusion. By measuring the distance between the emissary vein and sinuses, the edges of the sigmoid and transverse sinuses can be accurately located during surgery.

The aforementioned methods not only protect the sinuses but also avoid unnecessarily opening MACs from excessive grinding of the bone flap under type II conditions and shorten surgery time. This resulted in significant differences in the incidence of opening MACs ($P = 0.003$). The reason we consider that the results showed no significant differences in CSF leakage and scalp infection is that the number of patients in the test group was small and we attached great importance to the treatment of MACs and dura mater so that our incidence of CSF leakage (0.7%) is much lower than that reported in the literature (5.6%–10.3%).[1,11-14]

CONCLUSIONS

Image processing and intraoperative microscopic navigation can avoid unnecessarily opening MACs and may reduce postoperative CSF leakage and scalp infection after RA craniotomy.

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