Electromagnetic Navigation-Guided Radiofrequency Thermocoagulation in Trigeminal Neuralgia: Technical Note with Three Case Reports

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Abstract

Objective To introduce our device and procedure of electromagnetic navigation (EMN)-guided radiofrequency thermocoagulation (RFT) in patients with trigeminal neuralgia (TN).

Methods The EMN system mainly consists of an electromagnetic localizer, a thermoplastic facial mask with fiducial markers, and navigation software. A new surgical interface in which the foramen ovale (FO) and the trigeminal ganglion (TG) were integrated was used. It was applied in three patients with TN.

Results FO was successfully and accurately cannulated on the first attempt by using EMN guidance. During the follow-up period, pain did not reoccur, and appropriate trigeminal sensory paresthesia was elicited. There were no surgery-related complications.

Conclusion The EMN system is effective and highly accurate for RFT in patients with primary TN. Our modification of the registration system and surgical interface could make the RFT process more simple and accurate.

Keywords

- ► electromagnetic navigation
- ► radiofrequency thermocoagulation
- ► thermoplastic facial mask
- ► image fusion

Introduction

Trigeminal neuralgia (TN) is the most common and severe neurological facial pain, characterized by sudden, usually unilateral, severe, short-term, stabbing, recurrent episodes of pain in the distribution of one or more branches of the trigeminal nerve.[1] Although the pathogenesis of the neurovascular compression of trigeminal nerve in the cerebellopontine angle and the microvascular decompression has been widely accepted,[2–4] percutaneous radiofrequency thermocoagulation (RFT) is still regarded as a safe and effective surgical treatment for TN.[5]

The traditional percutaneous approach to the foramen ovale (FO) and the trigeminal ganglion (TG) is the procedure first described by Hartel.[6] Compared to the guidance of intermittent submental X-ray or computed tomography (CT) fluoroscopy,[7,8] stereotactic techniques improve the accuracy of the puncture and minimize complications.[9–13] All reports were based on an optoelectronic tracking system, which needed an uninterrupted line of sight between the navigation tools.

Electromagnetic navigation (EMN) systems allow for normal, uninhibited handling within their working volume and without compromising the field of view. They have been used

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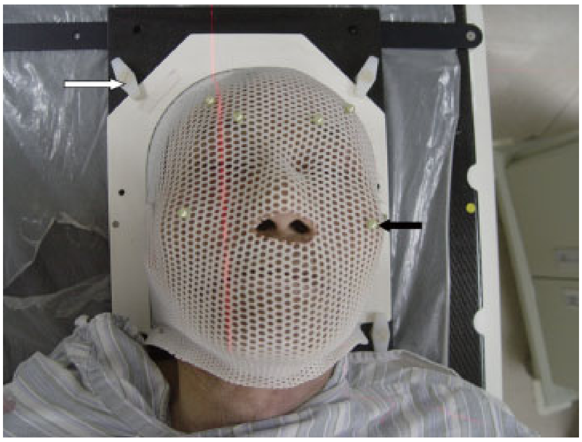

Fig. 1 The thermoplastic facial mask with six fiducial markers (black arrow) and a headset (white arrow) on the computerized tomography scanning table.

in various clinical applications, such as endoscopic sinus surgery,[14] needle biopsy of liver lesions,[15] bronchoscopy[16] and neurosurgery.[17] The development of EMS has allowed a new breakthrough of intraoperative navigation in RFT.

EMN-guided RFT was first introduced by our group and had been successfully performed on three patients with TN from September 2007 to February 2008. This procedure is still consistently used at our institution. Here, we report our techniques and the results while using this new tracking system.

Description of Equipments

Noninvasive registration and fixation system

The thermoplastic facial mask (Chengdu Hongyun medical device company, Chengdu, China) was remolded by hot water based on an individual's face contour. After 4 to 5 minutes, the hardened mask was removed. The correct repositioning and precise fit on the patient was verified by successful blocking on the CT headset. Six spherical hollow radiodense markers (diameter, 4 mm) served as recognition points and were identified on the CT scan by the system's software. These markers were placed bilaterally on the forehead, midpoint of the supraorbital ridge, and the vertex of the zygoma of the surface of the mask (►**Fig. 1**).

EMN system

Briefly, a commercially available electromagnetic localizer (AURORA; Northern Digital, Waterloo, ON, Canada), including a field generator, a control unit, and a sensor needle (►**Fig. 2**), was connected to the Surgical View-RFT software (designed by Med-X Research Institute, Shanghai Jiao Tong University, Shanghai, China). Other devices included a movable PC workstation and a high resolution display. This system was able to track the position and orientation of the active needle, which contained a miniature sensor coil at the tip.

RFT system

The radiofrequency generator (Leksell™, Elekta Cop., Sweden) has a built-in impedance monitor, a stimulator, temperature monitor, and a display of voltage and milliamperes. It has a complex timing device that automatically turns off radiofrequency heating at a desired time interval.

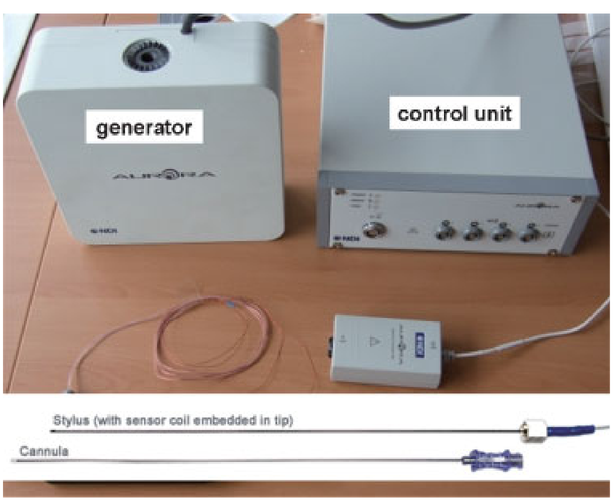

Fig. 2 AURORA electromagnetic localizer.

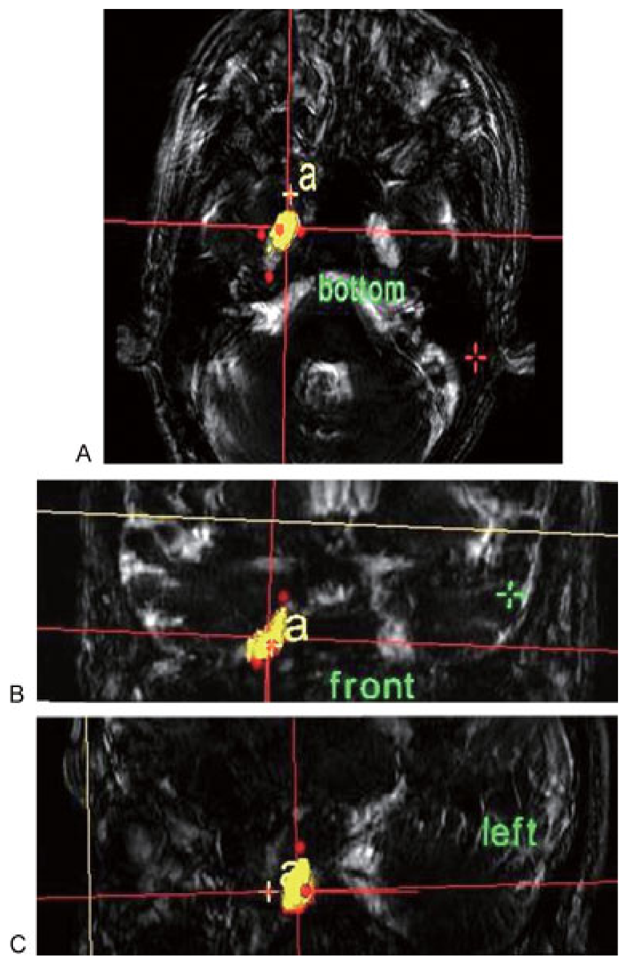

Fig. 3 Segmentation of right trigeminal ganglion (yellow) by the SurgView-RFT navigation software. (A) Axial plane; (B) coronal plane; (C) sagittal plane.

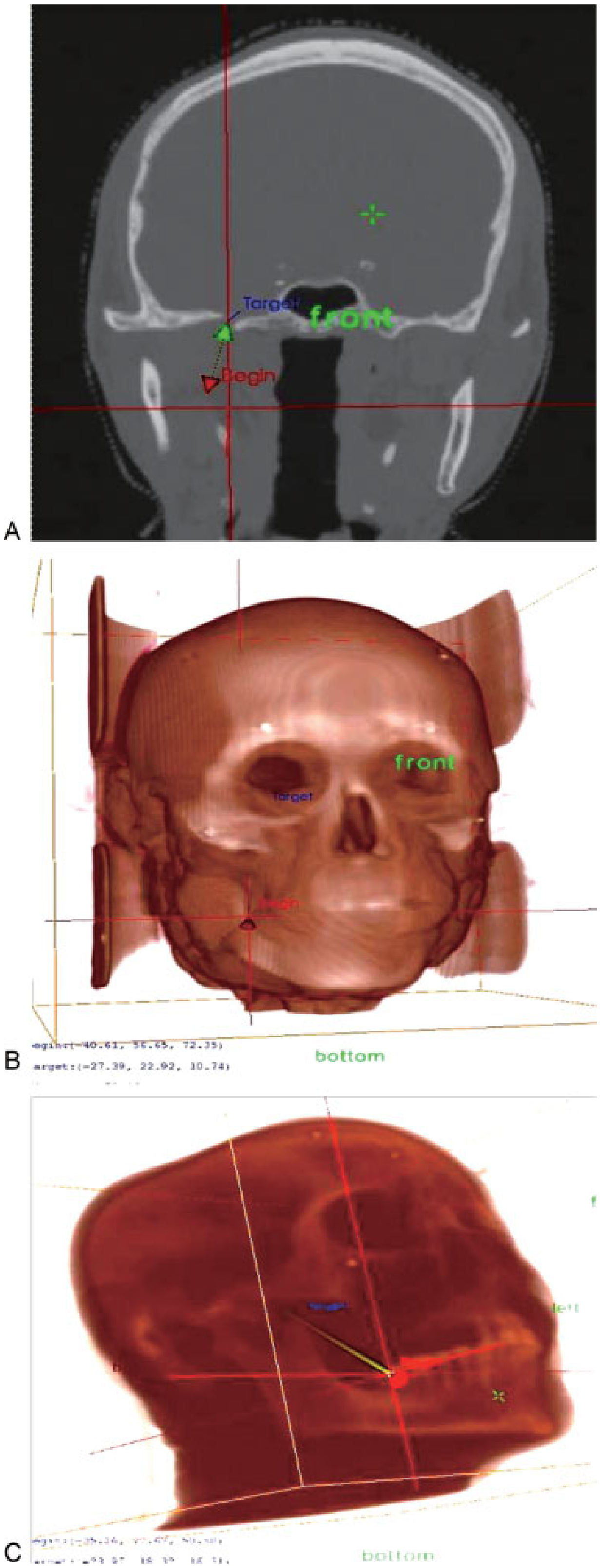

Fig. 4 Planning of the surgical path in the laboratory. (A) The definition of the target in the center of the foramen ovale (green arrow); (B) the definition of the entry point at 2.5 to 3.0 cm lateral and 0.5 cm below the corner of the mouth (red arrow); (C) the reconstruction of the path with a diameter of 3 mm.

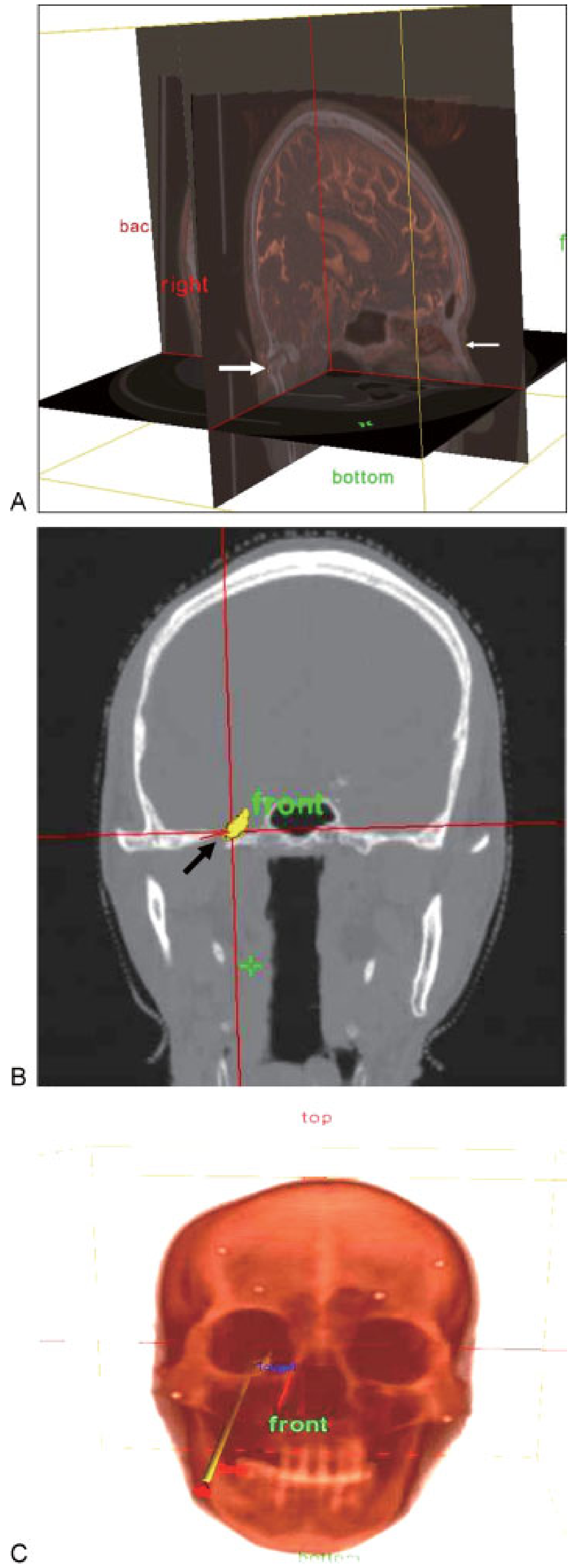

Fig. 5 The procedures of integration of computerized tomography (CT)/magnetic resonance imaging (MRI) and construction of the surgical interface. (A) The integration of CT/MRI basing on nasal point (thin white arrow) and bilateral outside crests of condyle (thick white arrow); (B) loading of the segmented trigeminal ganglion which was just above the foramen ovale (black arrow); (C) the surgical interface with the integrated image and the path.

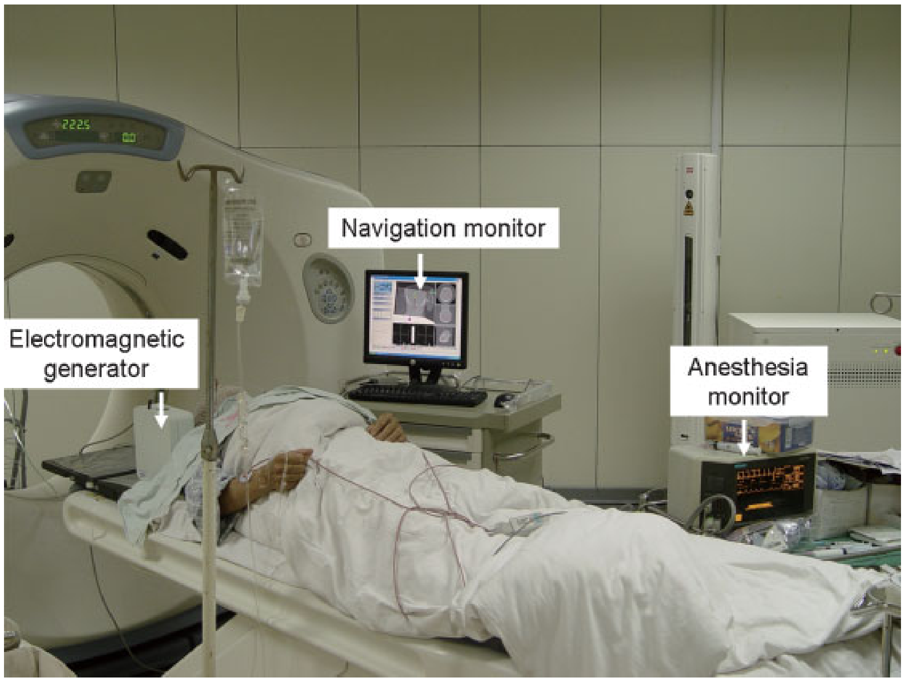

Fig. 6 Clinical setup in the computerized tomography suite: the patient's head was fixed in the mask; the electromagnetic generator was mounted 10 cm away from the head; the electromagnetic navigation system with the workstation and the monitor and the anesthesia monitor were placed next to the patient.

Procedures and Techniques

Image acquisition before operation

The preoperative images were acquired on a spiral CT scanner (Light Speed 4 scanner, GE Corp., USA) and a 1.5 T magnetic resonance (MR) scanner (Sgi; GE Medical System, USA). The parameters for spiral CT scans were: 512 × 512 cm matrix, 0° gantry tilt, 1.25 mm slice thickness, 1.25 mm spacing, 27.5 mm/rot, 120 kV power and 100 mA. MR imaging was performed using a 3D FIESTA sequences (FIESTA, fast imaging by employing steady-state acquisition) with the following parameters: TR 7.9 milliseconds, TE 2.0 milliseconds, FA 70°, FOV 220 × 198 mm, matrix 512 × 320, 60 partitions, slice thickness 1 mm, acquisition time 7 minutes 19 seconds.

All scans were obtained with the patient wearing the thermoplastic facial mask with fiducial markers. After scanning, the dataset was transferred using a DICOM 3.0 protocol.

Planning in the laboratory

The DICOM data of the CT and the MRI scans were transferred to the Surgical View-RFT EMN system in the laboratory. Following an image check, the computer reformatted the planar images to generate a three-dimensional data volume. Interactive workflow allowed us to create a freely rotating three-dimensional surface model of the patient's head. On the MR image, the operator identified at least two landmarks bordering the TG in the axial, coronal, and sagittal planes. The segmented TG was automatically reconstructed by the software (►**Fig. 3**). The digital image was stored as a visualization tool kit file. On the CT scan, the surgical path was defined. The target was located at the center of the FO and the entry point was 2.5 to 3.0 cm lateral to, and just below (0.5 cm), the corner of the mouth (►**Fig. 4**). The entry point could be adjusted until no bones were blocking the preview of the path. The surgical path was reconstructed with a diameter of 3 mm and was stored as a path layer network file.

The integration of both CT and MRI scans were based on three anatomic landmarks: the nasal point and the two outside crests of the bilateral condyle, which were identified manually. Original CT slices were overlaid with the MRI data by linear transformation (►**Fig. 5A**). The segmented TG was inserted into the integrated image (►**Fig. 5B**) and then the surgical path was inserted (►**Fig. 5C**). The surgical interface was subsequently created and stored.

Real-time navigation-guided puncture

Intraoperatively, patients were positioned supine with the head slightly fixed by the mask (►**Fig. 6**). The electromagnetic generator was located 10 cm away from the patients' heads. All patients were given atropine (0.5 mg intramuscularly) and sedated with intravenous propofol. Blood pressure, heart rate, and oxygen saturation were continuously monitored during the procedure. A 1% Lidocaine solution was used for local anesthesia. The patient-image registration was performed by using 6 markers on the surface of the mask. The root mean square error between the recognition points was less than 0.5 mm. The surgical interface was then loaded. The surgeon viewed the needle on the monitor as it moved along the planned path (►**Fig. 7A**). The needle was advanced precisely into the FO and reached the TG by adjusting the direction of needle tip (►**Fig. 7B**).

RFT procedure

The sensor needle was replaced by a radiofrequency electrode. The sensory response to square-wave electrostimulation at 50

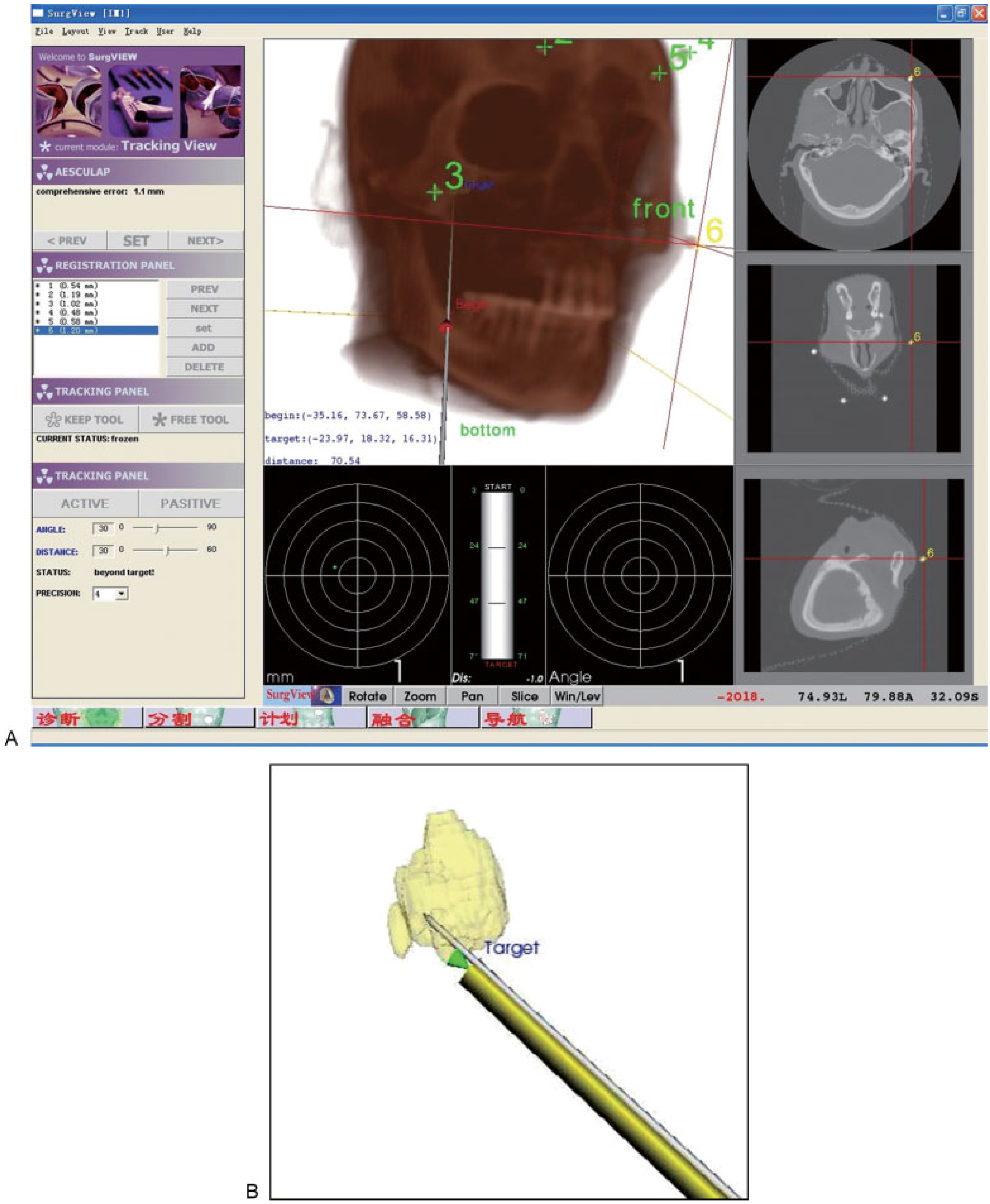

Fig. 7 Screen shots showing the location of the needle tip. (A) The needle was inserted along the planned path; (B) the needle was advanced into the foramen ovale, reaching the trigeminal ganglion.

to 100 Hz confirmed the optimal location of the electrode tip within the TG. This response correctly showed the targeted branches of the trigeminal nerve. Under intravenous general anesthesia, the radiofrequency current was then applied for 300 seconds at temperatures ranging from 65° to 80°C. Thereafter, the patients were woken up and the sensitivity of the face and cornea was tested.

Patients

From September 2007 to February 2008, three patients diagnosed with primary TN voluntarily chose the EMN-guided RFT. Diagnosis of TN was made according to the IASP criteria.[1] Among the three patients, two feared more invasive surgical intervention and one had failed to respond to microvascular decompression. All patients had failed drug

Table 1 Clinical information of the patients

	Patient 1	Patient 2	Patient 3
Age (years)	58	50	52
Gender	Male	Male	Female
Symptom duration (years)	3	0.5	5
Side	Right	Right	Left
Distributions	V2 and V3	V2 and V3	V2 and V3
VAS (0–10)	10	9	9
Efficacy of carbamazepine	Invalid at the dose of 1000 mg/d	Severe side effect of vertigo	Invalid at the dose of 1200 mg/d

VAS, visual analogue scale.

therapy in the past, either due to lack of effectiveness or drug intolerance. All patients had been evaluated previously by either cranial MRI or CT scans to exclude any lesion or tumor in the cranial or facial region. The relevant clinical information of all patients was summarized in ►**Table 1**. The study protocol was approved by and in accordance with the recommendations of the human research committee at our institution. Prior to scanning and surgical procedures, all patients provided written consent.

Electromagnetic registration was successfully completed in all three patients. FO was successfully cannulated on the first attempt as confirmed by electrostimulation. No unexpected mucosal penetration and cerebrospinal fluid leakage occurred during the puncture. All patients experienced an immediate relief from pain.

Discussion

Since the pioneering work on cannulation of the FO by Taptas[18] and Hartel,[6] RFT of TN has been used in large series.[5,7,8] Conventional punctures of the FO, which measures 6.5×3 mm[9] in diameter, is performed freehand and controlled by intermittent submental X-ray or CT fluoroscopy.[7,8] The failure rate of puncture was as high as 4%.[5] In addition, there were cases of inadvertent puncture of the foramen lacerum and carotid artery, inferior orbital fissure, and jugular foramen.[9] The recent development of navigation-guided RFT allows surgeons to make accurate, safe punctures on the first attempt.[9–13] Different image-guided and computer-assisted techniques have been successfully tested and applied to RFT. A novel approach to this type of image-guided surgery consists of using optical tracing systems, such as infrared ray

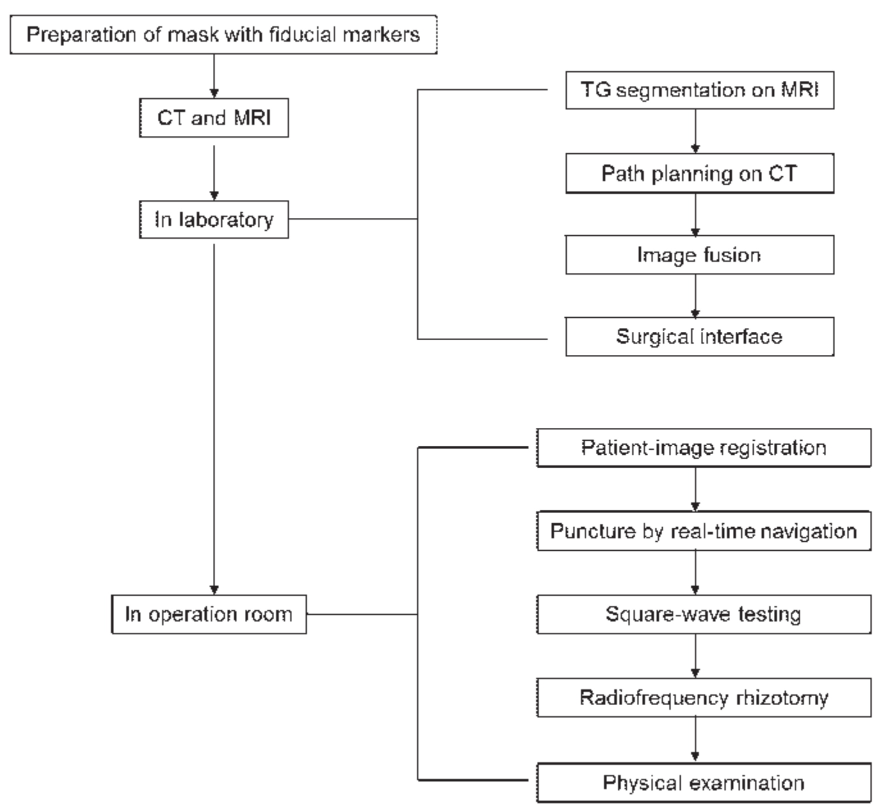

Fig. 8 The diagram of our electromagnetic navigation-guided radiofrequency thermocoagulation process.

and laser. Nevertheless, the trackers that are attached to the patient and to the surgical instruments are needed for continuous registration of their position, known as "uninterrupted line-of-sight." This may lead to difficulties in cannulating near the reflective spheres.

EMN systems are a more recent development. These systems calculate the position of a localizing device from signals induced in sensors by an electromagnetic field transmitter. The advantage of the EMN system is that there is no need for uninterrupted line of sight between the navigation tools. This allows for normal, uninhibited handling within their working volume and an uncompromised field of view. Positions can be captured even inside the body or on the surface of the patient's skin by means of flexible magnetic sensors.[17,19,20]

Although so far no randomized controlled trials are available to directly compare the optoelectronic tracking system and electromagnetic tracking system, our technique showed results that are comparable to those guided by the optoelectronic tracking system. In our practice, we also prefer to use the thermoplastic mask with fiducial markers as part of the fixation and registration system of our procedure. In addition, we modified the surgical interface of navigation-guided RFT, which can display the FO and TG simultaneously. A summary of our EMN-guided RFT process is shown in ►**Fig. 8**.

Conclusion

Our results indicate that the use of the EMN system is an effective and highly accurate method for RFT in patients with primary TN. The device facilitates the surgical procedure by providing a free and undisturbed surgical field, non-invasive fixation, and registration frame. It allows the surgeon to anticipate targeted branches of the trigeminal nerve. Further studies involving a larger series of patients would help to confirm our results.

Conflict of Interest
None

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