Stereotactic Approach Combined with 3D CT Reconstruction for Difficult-to-Access Foramen Ovale on Radiofrequency Thermocoagulation of the Gasserian Ganglion for Trigeminal Neuralgia

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Zhigang Guo and Baishan Wu contributed equally to the work.

Abstract

Objectives. The authors describe a technique that includes a stereotactic approach in the preoperative plan in cases where the foramen ovale is difficult to access for radiofrequency thermocoagulation of the Gasserian ganglion.

Methods. The study included 395 patients for whom three-dimensional computed tomographic reconstruction of the skull base, maxilla, and mandible was conducted before surgery. Accessibility of the foramen ovale was defined using numerical data from the three-dimensional computed tomographic reconstruction images. In those patients for whom accessibility of the foramen ovale was considered difficult, the authors used a stereotactic frame to design an individual operative plan. Adjustments of a single point of data—that is, a change in X axis, Y axis, or an arc angle—were guided by radiographic fluoroscopy images. After verifying successful cannulation and electroneurophysiology, thermocoagulation targets—especially multiple targets recorded as data on the Z axis of the stereotactic approach—were identified and treated.

Results. There were 24 patients who met the predetermined criteria for having a difficult-to-access foramen ovale—that is, they had at least two contributing factors and/or involvement of division V1. Twenty-one of the 24 patients required a single satisfactory puncture; three patients required two to three punctures to successfully access the foramen ovale. There were no permanent complications from the procedure.

Conclusions. The authors conclude that this stereotactic approach combined with three-dimensional computed tomographic reconstruction model can improve the accuracy, safety, and efficiency of percutaneous radiofrequency thermocoagulation in patients with trigeminal neuralgia for whom the foramen ovale is difficult to access.

Key Words. Computed Tomographic Reconstruction; Foramen Ovale; Radiofrequency Thermocoagulation; Stereotaxis; Trigeminal Neuralgia

Introduction

Trigeminal neuralgia, also known as “tic douloureux,” has an estimated annual incidence of 12.6 per 100,000 persons/years [1]. Patients generally choose anticonvulsant
drugs (alone, or in combination) for management of their disease [2]; however, invasive therapy is an attraction option since it offers the potential for permanent elimination of recurrent pain and lacks the toxic adverse effects that sometimes accompanies medical therapies. Cranietomy and minimally invasive surgery are restricted to those patients refractory to medical therapy. Percutaneous approaches to the treatment of trigeminal neuralgia (TN) were first conceived by neurosurgeons in the early 20th century. The percutaneous procedure of injecting the Gasserian ganglion via the foramen ovale (FO), first described by Hartel in 1914 [3], is still widely used today [4]. More recently, surgeons have probed the Gasserian ganglion using various methods including intraoperative computed tomographic (CT) guidance [5–7], neuronavigator guidance [8,9], and in one report, using a frame-based stereotactic approach with real-time CT scanning [10]. In certain circumstances, the FO is difficult to access, thereby requiring multiple attempts at cannulation with increased possibility of postoperative pain, vascular complications, or hematoma formation [8–10]. Prior studies using CT-guided percutaneous trigeminal radiofrequency thermocoagulation for TN without the use of a stereotactic frame have shown that in patients with the presence of only a single contributing difficulty factor, surgery generally proceeded smoothly and without complication, whereas in patients with two or more difficulty factors, multiple attempts at FO puncture were often necessary [11,12]. According to several reports, 2% to 4% of patients have an anatomically variant FO [13–15], which increases the difficulty of cannulation.

In this study, we present a simple and concise technique that combines a frame-based stereotactic approach with a preoperative, three-dimensional (3D) CT reconstruction of the skull base and mandible. This technique could be beneficial in patients for whom more lengthy surgical interventions might be contraindicated, such as the elderly, patients with cardiopulmonary insufficiency, and patients with cervical spine rigidity. With this combined technique, we can analyze the anatomical characteristics and relative position of the FO. Operative plans are then tailored to each patient so that we can determine the design of the trajectory, identify the best operative position, and predict the main intraoperative difficulties likely to be encountered. Clinical outcomes show that this technique allows for a more efficient operation through accurate probe placement and less need for repeat punctures.

**Ethical Considerations**

This study was approved by the Ethics Committee of the China-Japan Union Hospital of Jilin University, Changchun, Jilin, China. The protocol was explained in detail and informed consent was obtained prior to the initiation of the CT scan of the entire head for 3D reconstruction. After discussing the risks/benefits and alternatives to participation, patients signed the informed consent form. Patients were given a copy of the consent form, were reminded that their participation was voluntary, and were told that they could withdraw their consent at any time.

**Patients**

A total of 395 patients were enrolled in the study and treated for idiopathic trigeminal neuralgia at our units between May 2012 and May 2014. Before surgery, all patients underwent 3D CT reconstruction of the skull base, maxilla, and mandible to determine ease of access to the FO based on anatomic variability. Specific assessments included relative position between the FO and lateral pterygoid plate, relative position between the FO and mandible, distance between mandible and tooth ridge, and largest transverse diameter and largest anterior–posterior diameter of FO in the direction of the insertion path.

Twenty-four patients had FOs that were considered difficult to access. Characteristics of these patients are shown in Table 1. Two of the 24 patients with difficult-to-access FOs requested our treatment method for the recurrence of pain following a previous microvascular decompression.

**Methods**

**Stereotactic Apparatus Preparation**

With the patient in a sitting position, a line was drawn across the inner canthus first followed by a parallel line 0.5 cm above the superciliary arch. This parallel line was deemed the ‘horizontal line’ of the head. Another line, termed the ‘intermediate line,’ was then drawn between the tip of the nose and the center of the brow and extended to

<table>
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<tr>
<th>Table 1</th>
<th>Characteristics of patients with difficult-to-access foramen ovales (n = 24).</th>
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<tr>
<td><strong>Characteristic</strong></td>
<td><strong>Number of Patients</strong></td>
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<td>Male</td>
<td>6</td>
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<td>Female</td>
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<td><strong>Mean age (range)</strong></td>
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<td><strong>Affected Division(s)</strong></td>
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<td>2–9 years</td>
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<td><strong>Prior Surgery for TN</strong></td>
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<td>Decompressive surgery</td>
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<td>Surgically naive</td>
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the inion. The horizontal and intermediate lines were perpendicular, intersecting at the forehead and at the occiput.

The CT-Stereotactic frame used in this study was manufactured by MIZUHO Medical Innovation (Japan) (http://mizuho.co.jp/english/products/neurosurgery.html). The frame, with marked horizontal and intermediate lines, was aligned with the corresponding lines drawn on the patient’s head. After the scalp was disinfected and injected with 1% lidocaine for local anesthesia, the frame was secured to the head with two long skull pins in the front and two short skull pins in the back.

Surgical Planning and Stereotactic Data Acquisition

Thin-Slice CT Scan and 3D Reconstruction

For each patient, thin-slice scans (0.625 mm) were used to create a 3D reconstruction image of the skull base and mandible for use in preoperative surgical planning. Coronal and sagittal images were also reconstructed to locate and verify the FO as the target (Figure 1).

Targeting the FO

Since each division of the trigeminal nerve branches from a different point of the Gasserian ganglion, the targets depended on the affected division(s). In patients with an affected V1 division, the inner third of the transverse diameter of the FO was the target, whereas for the V2 and V3 divisions, half of the transverse diameter was the target. Each division of the FO was marked on the reconstructed 3D image of the skull base in the direction of the trajectory of the probe. The target was then located on the axial image, and the X and Y coordinates of the stereotactic frame were noted.

Analysis of the Relative Position of the FO

In our experience of failed cases using a stereotactic frame, the main cause of failure was a bent probe. We have found that the relative positions of the FO, lateral pterygoid plate, and mandible in the direction of the insertion path are critical, and that the mandible or the lateral pterygoid plate sometimes obstructs the trajectory.

Figure 1 Target FO on 3D CT reconstruction image.

(A) Anterolateral border of foramen ovale (FO) marked on 3-D CT reconstruction image (yellow arrow); (B) anterolateral border of FO marked on axial CT image (yellow arrow); (C) anterolateral border of FO marked on coronal CT image (yellow arrow); (D) anterolateral border of FO marked on sagittal CT image (yellow arrow).
bending the probe and preventing it from reaching the intended target. Therefore, the trajectory is mapped out preoperatively to avoid these obstacles. Occasionally, it is necessary for the patient to keep the mouth open during the procedure (Figure 2).

Measuring the FO

We measured the largest transverse diameter (A, mm) and the largest anterior–posterior diameter (B, mm) of the FO in the direction of the trajectory on the 3D reconstructed image of the skull base (Figure 3). We then calculated the anatomical area of the FO (AFO; S1). If the lateral pterygoid plate obstructed the path, we measured the diameters of the covered area (A1 and B1, mm) based on the view from the insertion trajectory direction on 3D CT reconstructed images and calculated this area (S2). The AFO minus the covered area is the ‘available area’ (S3, available puncture area of FO, APFO) and this measurement influenced the difficulty of the operation. We considered an AFO or APFO <15 mm² as a small FO, according to the following formulae: S3 = S1 − S2, S1 = \pi AB/4 (mm²), S2 = \pi A1B1/4 (mm²).

Figure 2 The relative position of FO and mandible on 3D CT reconstruction image.

(A), (B) If the mandible does not obstruct the insertion trajectory, the patient should keep the mouth closed during operation (inset shows amplified FO); (C, D) if the mandible obstructs the probe on the trajectory (yellow arrow on mandible), the patient should keep the mouth open during operation (inset shows amplified FO). See color image online.
Measuring the Angle Range of the Trajectory

On the coronal CT image, we measured the coronal angle range of the trajectory, which is used for the stereotactic procedure as the value of angle of arc arm. The angle is always largest for the V1 division, smaller for the V2 division, and smallest for the V3 division. The arc angle data used in the stereotactic instrument were chosen specifically to avoid the masseter muscle from the angle range of the trajectory. The arc angle data used in the stereotactic instrument were chosen specifically to avoid the masseter muscle from the angle range of the trajectory. The sagittal angle range of the puncture path on the sagittal CT image was also measured and the data used in the stereotactic instrument (Figure 4). For patients with an affected V1 division, the inner third of the transverse diameter of the FO was the target; therefore, to plan the largest angle of trajectory, we also preoperatively measured the distance between mandible and tooth ridge.

Position of the Facial Entry Point

The 3D reconstructed image of the head was used to create a 3D facial image on which we marked a point lateral to the labial commissure. This point was also marked on the corresponding coronal and sagittal
images. If there was no obstruction of the trajectory from the point through to the FO, we used this as the point of skin insertion, and measured the distance from the lateral labial commissure and to the coronal and sagittal angles of the trajectory (Figure 4).

Classification of Access Difficulty

Before developing an effective surgical plan, ease of access to the FO was determined numerically using the data from 3D CT reconstruction image. The accessibility of the FO was deemed suboptimal in the presence of one or more of these factors: 1) whether the insertion trajectory was obstructed by the maxilla, mandible, or if the distance between the mandible and tooth ridge was too small; 2) whether the FO was covered by the lateral pterygoid plate; 3) small size of the FO (i.e., AFO or APFO <15.0 mm²); 4) or whether the V1 division was affected. V1 targeting is more difficult than V2 and V3 not only due to the anatomical position of the nerve from the direction of the basis cranii, but also because the ranges of the values of arm and arc angles available for a stereotactic approach in V1-affected patients are notably less than in V2- or V3-affected patients [16]. In the majority of patients with affected V1 divisions, we recommend using a stereotactic frame to guide the procedure.

Stereotactic Operation

The surgeons used Komai’s stereotactic instrument and a specially designed 177.5 mm-long radiofrequency probe (diameter, 0.9 mm with 5-mm exposed tip) and a probe holder (diameter, 1.0 mm; length, 43.0 mm) capable of holding the radiofrequency lesioning (RFL) needle for the procedures.

Patients were positioned supine with the neck slightly extended. After the scalp was disinfected, draped, and the skin and subcutaneous tissue anesthetized locally along the trajectory of the needle, the stereotactic apparatus was set according to the previously determined 3D coordinates of the target and the angle of trajectory. The tailor-made needle was then inserted through the scalp using C-arm fluoroscopy to verify placement (i.e., the tip of the needle was at the FO and that the needle was not bent). Once placement was verified, the needle was locked in the holder and pushed upward by removing the Z axis of the stereotactic instrument, thereby permitting the needle to access the Gasserian ganglion.
Sensory stimulation studies were conducted using current amplitudes of 0.10–0.15 vol to confirm the division of paresthesia. A response in division V3 was generally produced when the needle tip was approximately 3 to 5 mm above the FO, whereas a response in division V2 was produced when the needle tip was further away—that is, approximately 5 to 10 mm above the FO [9]. Responses were observed in division V1 when the needle tip was positioned at ≥10 mm above the FO. In cases where multiple trigeminal branches were involved, patients were placed under general anesthesia and each division was targeted according to the verified numerical values of the Z axis on electroneurophysiology test results. In patients with a difficult-to-access FO, surgeons adjusted single data points—for example, X axis or the angle of an arc angle, according to the x-ray fluoroscopy images. Thermocoagulation targets, especially multiple targets, were recorded as data on the Z axis. After confirming the absence of any adverse effects, radiofrequency thermocoagulation commenced.

Radiofrequency Thermocoagulation

The target response of thermocoagulation was mild-to-moderate (not intense) hypalgesia, primarily in the affected division. The temperatures and time required to create each radiofrequency heat lesion depended on the division(s) affected. Division V1 sites required a single radiofrequency heat lesion at 60–65°C for 90 seconds. When V2 was affected close to the V1 division, a single lesion was created at 72°C for 90 seconds. If other parts of division V2 or division V3 were affected, one or two lesions were created at 75°C for 120 seconds.

Results

Dimensions of the FO

Data of FO in Totality

In all 395 patients, the dimensions of the FO on the coronal 3D CT reconstructed image differed from those on the image in the insertion trajectory direction. The largest anterior–posterior diameter measured on the image in the insertion trajectory direction was always smaller than the anatomical diameter. In this study, all diameters were measured from the perspective of the insertion trajectory on the 3D CT reconstructed image. Among the 395 patients, the largest anterior–posterior diameter ranged from 8.3 mm to 2.5 mm with an average of 4.3 mm, while the largest transverse diameter ranged from 11.2 mm to 3.7 mm with an average of 7.3 mm.

Small FO in Anatomy

In all 395 patients, the dimensions of the FO were obtained from the perspective of the insertion trajectory on the 3D CT reconstructed image. Among the 395 patients, the largest anterior–posterior diameter was 4.30(±1.10 mm); range: 2.5 mm to 8.3 mm) while the largest transverse diameter was 7.30 mm (±1.30 mm); range: 3.7 mm to 11.2 mm). For this study, any FO with a transverse diameter <6.0 mm and/or an anterior–posterior diameter <3.2 mm was classified as anatomically small. The calculation for measurement of an ellipse is \( \pi AB/4 \), where A and B are the radii of the ellipse; however, the A and B values in this study were taken from the 3D CT reconstruction images and represented the diameters of the ellipse. Therefore, the formula was divided by four to calculate the area of anatomical FO (AFO) (ie, \( \pi AB/4 \), or \( \pi 6.0\text{mm}^2/4 = 15.0\text{mm}^2 \)). In this study, we classified the FO as small anatomically if the AFO was <15.0 mm².

There were 18 patients (4.6%) with a largest transverse diameter <6.0 mm and 20 patients (5.1%) with a largest anterior–posterior diameter <3.2 mm. There were some instances where patients had small largest transverse diameters coupled with small anterior–posterior diameters. In these patients, we calculated the area of AFO. The largest AFO was 46.7 mm², the smallest was 11.4 mm², and the average was 21.8 mm². Of the entire study population (N = 395), 15 patients (3.8%) had AFO <15.0 mm², and were, thereby, classified as having a small anatomical FOs.

Small FO Caused by The Lateral Pterygoid Plate

Anatomic Variability

It is possible to categorize a normal-sized FO as a small FO if the lateral pterygoid plate is found to obstruct the trajectory. Therefore, we calculated the area of APFO. Twelve patients (3.0%) had FOs obstructed by the lateral pterygoid plate, seven of whom had one-third the AFO covered and five of whom had half the AFO covered. In these 12 patients, the largest APFO was 27.7 mm², the smallest was 11.0 mm², and the average was 17.3 mm². Eight of these 12 patients had an AFO >15.0 mm², but APFOs <15.0 mm². These eight patients were classified as having a small FO due to lateral pterygoid plate anatomic variability.

Patients with Small FO

In total, 23 patients were identified as having small FO: 15 cases due to small anatomical variation and eight cases due to lateral pterygoid plate anatomic variability.

Distance Between Mandible and Tooth Ridge

According to the 3D CT reconstruction images, we analyzed the relative position of the involved FOs of all patients with the insertion trajectory. The distance between the mandible and tooth ridge ranged from 8.4 mm to 18.8 mm with an average of 13.0 mm (±2.2 mm). In 12 patients, the distance between the mandible and tooth ridge was too small (<9.0 mm) with the insertion trajectory obstructed by the osseous mandible.
Quantification of Patients with Difficult-to-Access FO

Of the 395 patients treated, 15 patients had cases of small anatomical FO; eight patients had small FOs due to lateral pterygoid plate anatomic variability; 12 patients had smaller-than-normal distances between the mandible and tooth ridge; and six patients had affected V1 divisions. For a FO to be considered difficult-to-access, a patient had to meet at least two of the aforementioned criteria or had only division V1 involved. As such, 24 of the 395 patients in the study met the criteria for having a difficult-to-access FOs.

Results of Surgery and Difficulty Rates

In most patients, the needle entered the FO smoothly according to the preoperative plan, confirmed with C-arm fluoroscopy (Figure 5). Twenty-one of the 24 patients (87.5%) required a single satisfactory puncture and three patients (12.5%) required two to three punctures to successfully target the FO. In one of these three patients, the V1 division was affected, the AFO was normal (largest transverse diameter, 5.2 mm; largest anterior–posterior diameter, 4.2 mm; AFO, 17.1 mm²), and there was no obstruction of the trajectory by the lateral pterygoid plate or the mandible. We first targeted close to divisions V2 and V3 of the Gasserian ganglion, adjusted the arc angle of the trajectory, and then confirmed that the probe was inserted at the semilunar ganglion close to division V1. In another of these three patients, where the V1 and V2 divisions were affected and the FO was small (largest anterior–posterior diameter, 2.7 mm; largest transverse diameter, 7.3 mm; AFO, 15.0 mm²), the mandible also obstructed the trajectory (Figure 6). In the third patient requiring multiple punctures, division V2 was affected, the FO was covered by the lateral pterygoid plate (AFO, 46.7 mm²; APFO, 16.1 mm²), and the trajectory was obstructed by the mandible (Figure 7).

Figure 5 Probe placement in FO confirmed by C-arm radiography during operation.

Images A, B, and C were taken from the direction of the inferior margin of the mandible.

Images D, E, and F were taken from the lateral border of the face.

(A) Marked FO (yellow arrow) on a 3D CT reconstruction image by C-arm radiography; (B) C-arm radiography in the direction of the inferior margin of mandible during operation; (C) probe placement into the FO confirmed by C-arm radiography; (D) the direction of 3D CT reconstruction image from lateral border of face represents the direction of C-arm radiography during operation and marked FO (yellow arrow); (E) C-arm radiograph during operation; (F) probe placement into the FO confirmed by C-arm radiography.
**Treatment Effects**

The curative effect of surgery was evaluated during follow-up visits 12 to 24 months after the procedure. The patients were asked to describe their postoperative pain using a visual analogue scale (ratings of 1 to 10, where 10 = the most pain and 1 = no pain at all) and were also questioned about their facial numbness, medication use, time to pain relief, and duration of relief. Postoperative pain scores in 22 patients (91.7%) had decreased from 10 to 3 by ≤10 days after the operation. Two patients (8.3%) reported decreased pain scores from 10 to 3 eight weeks after the operation. There were no permanent complications or morbidities from the procedures. Six patients (25.0%) experienced mild numbness after they were treated with our method, and facial numbness usually subsided within six months after surgery. During the 12- to 24-month follow-up period, 20 patients (83.3%) experienced no pain recurrence and four patients (16.7%) experienced pain recurrences 1 to 2 years after surgery.

**Discussion**

Radiographic fluoroscopy-guided percutaneous needle penetration of the FO has been used since 1976 [17]. Computed tomographic fluoroscopy was then introduced for guidance of the rhizotomy needle insertion through the FO [6] and Gasserian ganglion [18–22]. Percutaneous radiofrequency thermocoagulation has proved an invaluable innovation in the treatment of patients with TN with high success rates, acceptable curative effects, excellent safety features, and high levels of patient satisfaction [23–29]. Placement of the cannula through the FO using a free-hand technique and intraoperative images is generally a straightforward procedure; however, even in the hands of experienced neurosurgeons, the rate of puncture failure ranges from 10% to 20% [26,30]. Frame-based stereotactic systems offer several advantages over the free-hand technique, including a very high degree of accuracy, a rigid probe holder, and direct placement of the needle at the FO through the probe holder. A special advantage of the stereotactic system is that when multiple areas must be targeted,

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**Figure 6** 3D CT reconstruction images of a difficult-to-access FO resulting from both a lateral pterygoid plate anatomic variability and mandibular obstruction of the trajectory.

(A) Left FO on skull base (black arrow); (B) 3D CT reconstruction image in direction of insertion shows mandibular obstruction on the trajectory (black arrow); (C) the biggest transverse diameter of FO is 7.3 mm (inset shows amplified FO); (D) the biggest longitudinal diameter of FO is 2.7 mm (inset shows amplified FO).
every target can be represented and recorded as data on the Z axis and ablated during a single episode of general anesthesia with minor adjustments. Frame-based, frameless, and intraoperative MRI-guided stereotactic systems are now widely used in neurosurgery, particularly in needle brain lesion biopsies, with frame-based needle biopsies associated with the highest diagnostic yield [31]. Frame-based techniques have long been considered the gold standard for sampling intracranial lesions with the rigid frame providing excellent targeting precision [32]; however, while they are accurate navigating systems, multiple adjustments are required to precisely position the probe device along the appropriate trajectory to the target in some patients [8,10]. Gasserian block under fluoroscopy guidance for the treatment of TN may be difficult because of anatomic variability and/or in accurate location of the FO [22]. In addition, probes may be bent during cannulation by the bony structures of the cranial base and the bony prominence around the FO. If the cannula is bent, it may deviate greatly from the actual target resulting in failed cannulation of the FO [20,33].

Three-dimensional (3D) CT reconstruction images of the skull-rotation angle have been used to target the FO in patients with TN [22]. In recent years, neuronavigator guidance has been used in cases where the FO was difficult to access [10,34]. In patients with a difficult-to-access FO, the procedure is challenging and can be fraught with untoward side effects including puncture of the foramen lacerum, inferior orbital fissure, carotid artery, and/or jugular foramen, any of which could result in lasting neural and vascular sequelae, arrhythmia, corneal ulcer, or blindness [20,31,35,36].

To overcome these problems, we have developed a numerically controlled surgical model using 3D CT reconstruction images of the skull base and mandible that permit analysis of key preoperative measurements to determine which patients are likely to have a difficult-to-access FO. This method includes an assessment of the surgical difficulty, the entry point on the face, the design of the insertion trajectory, and whether the mouth should be kept open during the operation. All of these factors can influence the success rate of the procedure.
Having performed successful stereotactic operations in brain tumors, including some brainstem tumors, for at least a decade [37,38], we felt our team had an adequate skill set to utilize the stereotactic techniques. The patients treated in our study had TN with affected divisions V1, V2, and/or V3. We used a stereotactic approach in patients with difficult-to-access FO as determined by 3D CT reconstruction images obtained preoperatively and used the same targets used by Patil and colleagues in patients with affected V2 and/or V3 divisions [10], and used the inner third of the transverse diameter of the FO as the target for patients with affected V1 divisions. For patients with affected V1, V1 plus V2, V1 plus V2 and V3 divisions, it was necessary to choose a suitable angle of arc arm preoperatively so as to direct the RFL needle. We used a 177.5 mm radiofrequency probe to enable targeting of the FO target directly without having to consider the length of the needle trajectory or how deeply the needle should be placed.

Overall, 24 of the 395 patients in the study met the criteria for having a difficult-to-access FO. Using our numerically controlled surgical model, we successfully cannulated 21 patients with difficult-to-access FOs (21/24, 87.5%) with a single puncture. Three patients (3/24, 12.5%) required two to three punctures to successfully target the FO. One of these patients had a small FO with the trajectory obstructed by the mandible and the lateral pterygoid plate. This patient was considered to have the most difficult-to-access FO. After adjusting the trajectory angle a few times, we were able to successfully complete the cannulation.

A comparison of the success rates in terms of a single, satisfactory puncture of the FO showed the outcomes to be nearly equal among patients with more easily accessed FO who did not undergo a framed-based surgical approach and patients with difficult-to-access FOs for whom stereotactic frames were incorporated in the surgical procedure (87.6% versus 87.5%, respectively). The authors conclude that this stereotactic approach combined with three-dimensional computed tomographic reconstruction model can improve the accuracy, safety, and efficiency of percutaneous radiofrequency thermocoagulation in patients with trigeminal neuralgia for whom the foramen ovale is difficult to access.

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