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Original Research Article

CT-Guided Percutaneous Infrazygomatic Radiofrequency Neurolysis Through Foramen Rotundum to Treat V2 Trigeminal Neuralgia

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Abstract

Objective. Percutaneous radiofrequency thermocoagulation or neurolysis of Gasserian ganglion through foramen ovale (FO) is the classical approach to treat trigeminal neuralgia (TN). However, it has been technically challenging when individual trigeminal sub-branch nerve block is desired through this approach. We have thus developed a novel computed tomograph-guided technique to block the V2 trigeminal nerve through foramen rotundum (FR). With this technique, we have conducted a study of 27 patients with isolated V2 TN. We hypothesize that this new technique will have comparable clinical outcome with the conventional FO approach.

Design. Prospective study.

Setting. Academic hospitals.

Subjects. Twenty-seven patients with isolated classical V2 TN were enrolled and divided into FO group (N = 12) and FR group (N = 15).

Methods. Numeric Rating Scale (NRS) scores for facial pain, at pretreatment, immediate postoperative, postoperative 1 day, and 1, 6, and 12 months were recorded. The primary clinical outcome (successful pain relief with 50% or more reduction in NRS) and secondary adverse clinical outcome (hematoma, facial numbness, masticatory weakness, and corneal involvement) were compared and analyzed.

Results. Both groups have good immediate and sustained pain relief. However, when compared with the FO group, the FR group is associated with shorter procedural time (29.2 ± 9.3 vs 45.4 ± 22.13 minutes, $P < 0.05$), has less nonspecific block in V1 and V3 dermatomes, and has fewer adverse outcomes including masticatory weakness (0/15 vs 5/12) and corneal perforation (0/12 vs 1/15).

Conclusions. We have developed a novel technique to selectively block the V2 trigeminal nerve at FR. This novel FR approach may be a good alternative to the classical FO approach when an isolated V2 branch block is desired.

Key Words. Neuralgia; Radiofrequency; Block; Chronic Pain; Headache

Introduction

The trigeminal nerve is the fifth and largest cranial nerve, responsible for sensation in the face and certain motor functions such as biting and chewing. It consists of three major branches: the ophthalmic nerve (V_1), the maxillary nerve (V_2), and the mandibular nerve (V_3). The three nerve branches exit the cranium via three distinct foramina: the superior orbital fissure, the foramen rotundum (FR), and the foramen ovale (FO), respectively. V1, V2, and V3 converge on the Gasserian ganglion, located within Meckel's cave, which is an arachnoid pouch containing cerebrospinal fluid and contains the cell bodies of incoming trigeminal sensory nerve fibers [1]. In particular, the V2 branch begins at the Gasserian ganglion and passes through the FR to exit the cranium. It subsequently crosses the pterygopalatine fossa and enters the orbit through the inferior orbital fissure [1].

Classical trigeminal neuralgia (TN) is a recurrent, sudden, transient, and stereotyped attack of usually intense sharp or stabbing pain in the distribution of one or more branches of the trigeminal nerve [2]. The reported prevalence of TN is in the range of 4–5 per 100,000, although a recent population-based study of 3,336 subjects in Germany found a lifetime prevalence of TN up to two orders of magnitudes higher, around 0.3% [3,4]. In the United States alone, there are about 15,000 new cases diagnosed each year [5]. TN is more likely to occur in women and the elderly, with peak age between 50 and 80 years. While the cause of TN remains poorly defined, some of the most prevalent descriptions include mechanical compression by arteries or tumor, infections, or central nerve system diseases such as multiple sclerosis. TN typically affects one or more branches of the trigeminal nerve, with V2-only at 17%, V3-only 15%, V1-only 4%, and V2 + V3 around 32% [6].

Initial treatment of TN includes medications such as carbamazepine or oxcarbazepine, which are considered first-line therapy in conjunction with psychological treatment when indicated. If patients fail conservative care, they may be referred for interventions. Examples include percutaneous trans-FO approach to block the Gasserian ganglion with either ethanol as initially proposed by Hartel in 1912 [7] or radiofrequency thermocoagulation as initially proposed by Sweet in 1974 [8], with success rate >80% [9,10]. However, the FO approach can be a difficult and time-consuming procedure for both the pain medicine physician and the patient, requiring precision to place that needle near the Gasserian ganglion. Suboptimal needle positioning could lead not only to treatment failure, but also recurrence and potential complications, including nonspecific block, intracranial hemorrhage, subarachnoid injection, infections, and others [9–11].

Numerous technological advances have been described to improve correct positioning of the needle for safer therapy, including transition from fluoroscopy to computed tomography (CT) guidance, three-dimensional (3D) navigation techniques, and electrophysiological recordings including evoked potential confirmations [12–15]. Here we report a novel CT-guided technique to block the V2 branch via a trans-FR approach. With this technique, we have conducted a study of 27 patients with isolated V2 TN to compare clinical outcomes and complications between the novel FR approach and the conventional FO approach.

Methods

*1. Infrazygomatic Needle Access to **FR** in Human Skull Specimen*

Adult human skulls with parietal bones removed were used to help determine optimal needle angle and path to access the FR. A 22G radiofrequency needle was found to easily access the external opening of FR via an infrazygomatic approach, assisted by direct intracranial visualization through the parietal bone opening. A gentle pressure was then applied to further advance the needle into the FR canal (Figure 1A) until it stops. At this point, the needle shaft would be wedged by nearby bony structure including external wall of the maxillary sinus and the inferior border of the zygomatic process. This creates a "tightening and gripping" feel (Figure 1B and 1C).

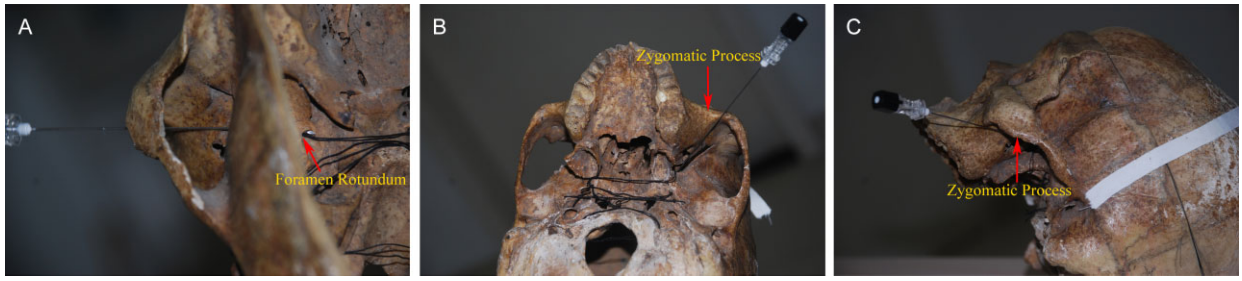

Figure 1 Needle access to foramen rotundum in human skull specimen. (A) Infrazygomatic needle access to foramen rotundum is possible in human skull specimen (cephalic to caudal view). (B) Caudal to cephalic view of radiofrequency needle access to foramen rotundum of human skull specimen. Note that the needle shaft is appressed by the inferior border of zygomatic process and the external wall of maxillary sinus, thus creating a " tight gripping" feel. (C) Lateral view of infrazygomatic needle access to foramen rotundum.

*2. Computed Tomography (CT) Scanning of **FR** with In Situ Needle Preplacement via Infrazygomatic Approach in Human Skull*

The parietal bone was placed back onto the human skull specimen (Figure 1C). A 22G radiofrequency needle was then inserted into the FR via infrazygomatic approach. The skull was then placed on the headrest of a CT machine, with orientation mimicking natural head position of patients (Figure 2A). Subsequent 2 mm scanning images were taken, with orientation parallel to the needle shaft to obtain a CT image frame capturing FR with in situ preplaced needle in the same plane (Figure 2B). Parameters of this particular image frame were recorded, including semi-coronal position, orientation parallel to the plane connecting external acoustic pore and ipsilateral maxillary third molar bone, and various other landmarks including external and internal openings of the FR, supra-orbital fissure, pterygopalatine fossa, and sphenoid sinus. Similar images were obtained from additional human skull specimens and were used to build up a reference image database to guide the actual procedure on patients.

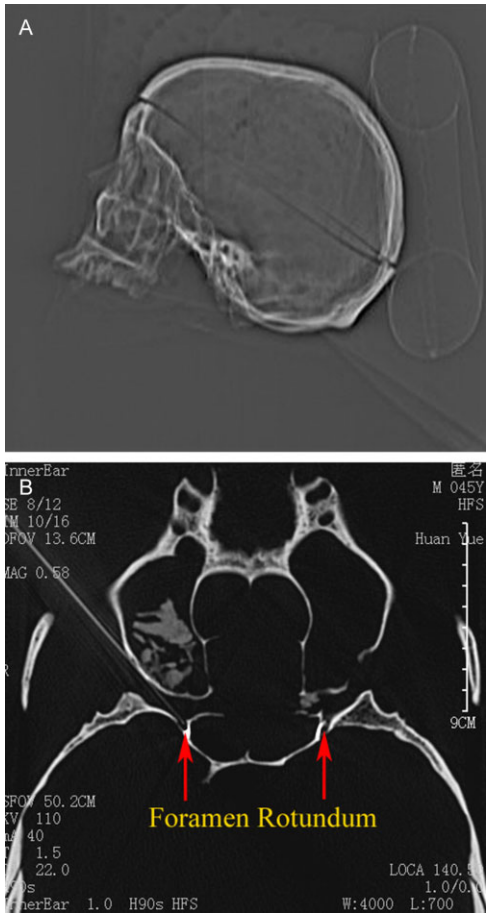

Figure 2 Reference CT image of infrazygomatic needle access to foramen rotundum in human skull specimen. (A) A sample CT image of human skull specimen. Sagittal view was used to locate the foramen rotundum. (B) A sample CT image scan of human skull demonstrates a simultaneous capturing of foramen rotundum with a preplaced radiofrequency needle via infrazygomatic approach. Red arrowheads indicate the bilateral foramen rotundum.

*3. CT-Guided Radiofrequency Neurolysis of V2 Branch via **FR** Approach*

Patients with isolated V2 TN were selected. Patients were positioned supine, with head resting naturally on the headrest of the CT machine. A wide tape was gently applied to secure the head to the headrest and prevent accidental head movement. A positioning grid was placed over the cheek of the painful side. Semi-coronal scanning was conducted based on the parameters obtained from the human skull image database, with the scanning frame parallel to the plane connecting external acoustic pore to ipsilateral maxillary third molar bone as shown in Figure 3A. The specific CT image frame (Figure 3B) that simultaneously captured the FR and its external and internal openings was used to help design needle puncture route. The intrinsic ruler of the CT machine was used to measure the distance from the needle entry point to the external opening of FR, as well to help determine the needle entry angle (Figure 3C). The needle skin entry point was marked at the cross point of the vertical line 1 cm lateral to the outer canthus and the horizontal line of the base of the nose (Figure 4A). The skin and subcutaneous tissues were anesthetized with 2 mL of 1% lidocaine using a 27G needle. A 10 cm 22 gauge radiofrequency needle was then inserted and advanced (Figure 4B), based on predetermined parameters including angle, path, and depth, with intermittent CT guidance until reaching the external opening of FR (Figure 4C). A gentle pressure was then applied to further advance the needle tip into the FR canal until it stopped (Figure 4C). Three-dimensional CT images were then reconstructed to make sure that the needle tip was inside the FR (Figure 4D). After confirming that there was no evidence of blood, cerebral spinal fluid, or paresthesia, a sensory test was performed by stimulating the probe at 100 Hz with pulse width at 500 μS and amplitude at 0.2–0.5 mA to generate paresthesia concordant to the patient's usual pain. A motor test was then performed by stimulating the probes at 2 Hz to make certain that the probe was not in proximity to other adjacent nerves. A 0.5 mL of 1% lidocaine was then injected 2 minutes prior to ablation. Subsequently, continuous radiofrequency thermocoagulation was performed using fixed dose mode of 85°C limiting temperature, over 90 seconds for two cycles. The patient was then transferred back to the postprocedure recovery room where the degree of the sensory block was evaluated and recorded (Figure 5). The patient's vital signs were monitored for at

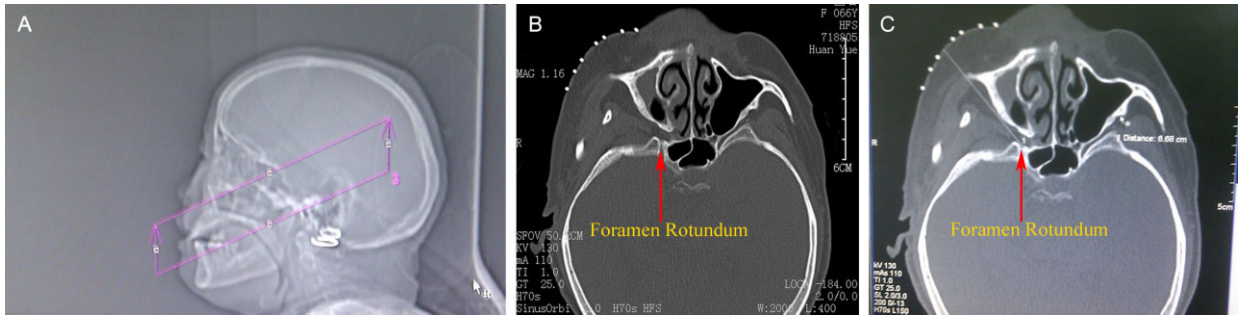

Figure 3 Percutaneous infrazygomatic needle access of foramen rotundum in patients with V2 trigeminal neuralgia. (A) CT scout view is utilized to help localize foramen rotundum in patients. Characteristics of the scanogram include semi-coronal position, orientation parallel to the plane connecting external acoustic pore and ipsilateral maxillary third molar bone. (B) The CT scan that captured simultaneously the foramen rotundum and its external and internal openings was used to design needle puncture route. Note that the white dots on the left top maxillary surface are transactional view of the positioning grid. (C) Computer-simulated needle puncture route was generated, which includes needle entry angle, path, and distance from the needle entry point to the external opening of foramen rotundum.

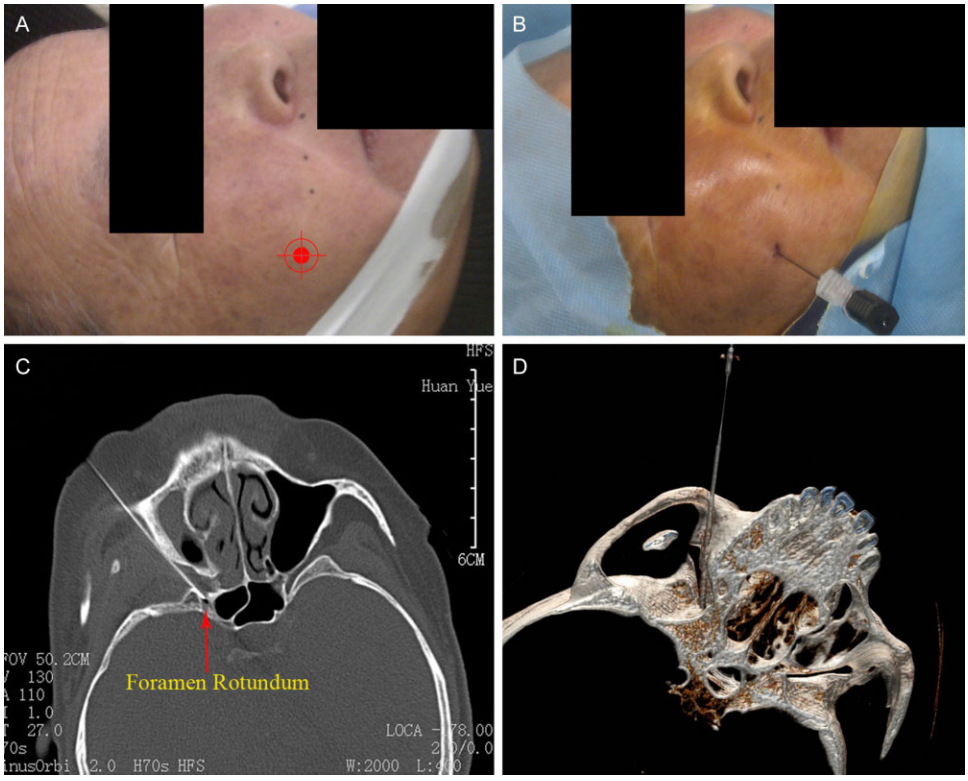

Figure 4 A representative V2 trigeminal neuralgia patient treated via the CT-guided foramen rotundum approach. (A) Skin entry point (red target) was marked at the cross point of the vertical line 1 cm lateral to outer canthus and the horizontal line of the base of the nose. (B) A 10 cm 22-gauge radiofrequency needle was inserted and advanced, based on predetermined parameters. (C) The radiofrequency needle reached foramen rotundum, under intermittent CT guidance. (D) A 3D reconstruction CT image showed that the needle reached foramen rotundum with needle shaft being appressed by inferior border of zygomatic process and the external wall of maxillary sinus.

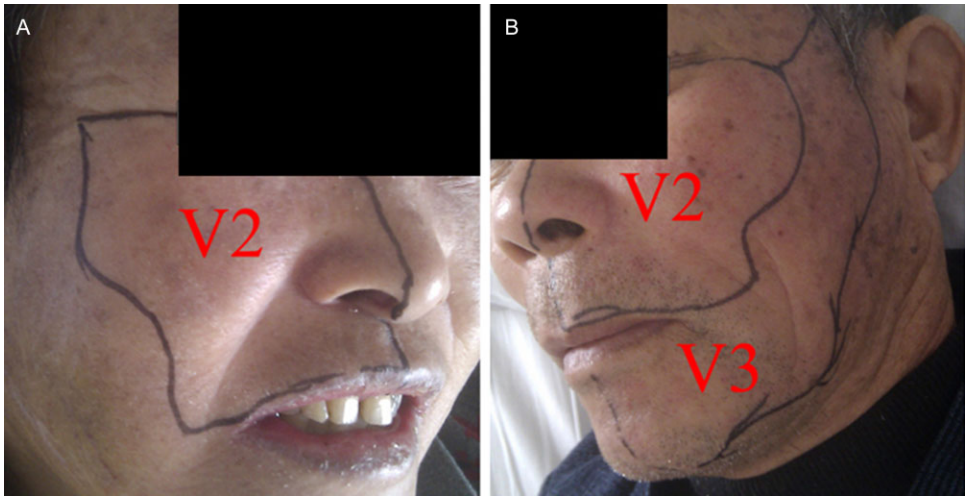

Figure 5 Outcome differences between FR and FO group. (A) A patient at immediate postoperative from FR group showed reduced sensation to cold and tactile stimulation along the right V2 dermatome distribution. (B) A patient at immediate postoperative from FO group showed not only reduced sensation to cold and tactile stimulation along the left V2 dermatome distribution but also along the left V3 dermatome distribution, suggesting a nonspecific block.

least four additional hours before being discharged to home.

4. A Comparison Study of Treating Isolated V2 TN via Either FO Or FR Approach

Twenty-seven patients with isolated V2 TN diagnosed between June 2011 and March 2013 at the First Affiliated Hospital, Jiaxing University, were enrolled in the study. There were no apparent hypo- or hyperesthesia in the affected branch of the trigeminal nerve. Brain CT and/or magnetic resonance imaging exams were done preoperative to rule out potential secondary causes for TN including tumor and vascular compression. Postherpetic neuralgia of the trigeminal nerve was also excluded. Demographic data of those 27 patients include: 15 males and 12 females; age ranging from 41 to 82 years with average of 65.0 (±9.8 standard deviation [SD]); duration of pain of 14–53 months with average duration at 31.9 months (±10.2 SD); eight patients with pain in left side and 19 patients in right side. No statistical difference in demographic data was found between FR and FO groups except for the side of the pain ($P < 0.05$), with FR group has higher percentage of patients having pain in the right side than the FO group. Of note, both groups had right side affected more often, consistent to literature. All patients have classical signs and symptoms of classical TN, fulfilling the new The International Classification of Headache Disorders, 3rd edition (ICHD-III) beta diagnostic criteria for classical TN, including episodes of intense, stabbing, electric shock-like pain in the face, but only within the V2 branch dermatomal distribution [2].

The study was approved by the ethics committee of the Department of Pain Medicine, First Affiliated Hospital, Jiaxing University, China. Informed consent was obtained after the indications, and risks of this procedure were explained. Both FO and FR options were provided to patients, who then voluntarily selected either FR (N = 15) or FO (N = 12) approach. Routine preoperative check-up including prothrombin time (PT), partial thromboplastin time (PTT), complete blood count (CBC), basic metabolic panel (BMP), and electrocardiogram (EKG) were conducted. Patients fasted preoperatively for 4–6 hours with discontinuation of baseline pain medication on the day of procedure. All patients received monitored anesthesia care during the procedure.

The 2 mm tip 22G radiofrequency needles were used for the study. The FO group utilized Hartel's approach, which involves reaching the Gasserian ganglion through the FO. The V2 portion of the Gasserian ganglion was subsequently identified in the Meckel's cave and neurolyzed. The FR group used the technique as described above, with which the V2 sub-branch was neurolyzed at the FR. All procedures were performed by a single physician. Time from needle skin entry to successful V2 dermatome paresthesia induced upon electrical stimulation was recorded. Data of needle entry angle, depth, and total number of needle adjustment needed to identify V2 were also recorded. The primary clinical outcome (pain relief based on numeric rating scale [NRS]; >50% reduction of NRS score was considered successful), and secondary adverse clinical outcome (hematoma, facial numbness, masticatory weakness, and corneal involvement) were monitored and recorded blindly by an independent team

Table 1 Technique differences between FR and FO group

Group	Puncture Depth (cm)	Entry Angle (Degree) Angle to Vertical Plane	Entry Angle (Degree) Angle to Coronal Plane	Needle Depth into The Foramen Canal (cm)
FR(N = 15)	6.75 ± 0.25	37.73 ± 4.25	29.13 ± 1.36	0.36 ± 0.10
FO(N = 12)	8.44 ± 0.35	18.08 ± 3.56	29.17 ± 1.47	1.05 ± 0.21

(other than the procedurer) at the immediate postoperative, 1 day, and 1, 6, and 12 months postoperative days.

5. Statistical Analysis

Data was analyzed using SPSS 16.0 software (SPSS, Inc., Chicago, IL, USA). Continuous variables were presented as mean ± standard deviations, and categorical data were shown as numbers and percentages. Comparison of continuous data was performed by Student's *t*-test. The χ^2 test was used to compare groups with categorical variables. *P* values less than 0.05 were considered statistically significant.

Results

1. CT Image Database of FR of Human Skull Was Used to Guide Actual Procedure in Patients

A series of CT images of FR from human skull specimen with preplaced radiofrequency needle were obtained to help build a reference image database to guide actual procedure on patients. As described above, a 22G radiofrequency needle can easily access the FR via the infrazygomatic approach. With this image database, we were able to obtain 100% success in accessing FR via percutaneous infrazygomatic approach for all the 15 patients in FR group of isolated V2 TN. Among them, there were three cases in which the needle was only able to access the external opening of FR (≤2 mm depth into canal), eight cases into the canal (≥2 mm), and four cases deep into the inner opening of FR.

2. Comparison of Demographic Data and Procedure Details Between FR and FO Groups

Demographic data comparison between FR and FO groups was conducted. There are no significant differences found for age, duration of the pain, and average pre-procedure NRS scores (6.80 ± 1.15 for FO group and 6.58 ± 1.08 for FR group). The needle entry angle, distance from entry point to external opening of foramen, and depth into the foramen canal are summarized in Table 1. The needle skin entry point of FR group is marked at the cross point of the vertical line 1 cm lateral to the outer canthus and the horizontal line of the base of the nose, which is approximately 5 cm lateral to the base of the nose, whereas the needle skin entry point of FO group is marked at approximately 2 cm lateral to the ipsilateral corner of the mouth. FR group had an average depth into the FR canal of about 3.6 ± 0.99 mm, whereas FO group had an average depth into the FO canal of about 10.5 ± 2.07 mm.

3. Outcome Difference Between FR Group and FO Group

Table 2 summarizes the difference between FR and FO group in operation time, number of times needed to adjust the needle, complications, and immediate and prolonged pain relief (>50% reduction of NRS scores) over 12 months of follow-up.

Both groups have high success rate for needle access to the targeted foramen. In the FR group, once the needle was placed in the FR, readjustment of needle position was rarely required (on average 0.27 times) before paresthesia in V2 dermatome upon 0.2–0.5 mA high frequency sensory stimulation can be induced. In contrast, multiple needle position readjustments (on average 3.17 times) were required to localize the V2 portion of the Gasserian ganglion in the FO group, after the needle was advanced deep into the FO. In some cases, as many as seven times of needle readjustments were required along with stronger stimulation at 0.5–1 mA before paresthesia could be reproduced in the V2

Table 2 Procedure and outcome differences between FR group (N = 15) and FO group (N = 12)

Group	Procedure Time (min)	#Needle Adjustment	Complication Hematoma	Complication Facial Numbness	Complication Masticatory Weakness	Complication Corneal Perforation	Pain Relief (/Total Patients) 1 day	1 week	1 month	6 months	12 months
FR	29.2 ± 09.03*	0.27 ± 0.45**	2***	15***	0**	0	15/15	15/15	15/15	15/15	15/15
FO	45.4 ± 22.13	3.17 ± 1.95	2	12	5	1	10/12	12/12	12/12	10/10	9/10

Note: *indicates $P < 0.05$, ** indicates $P < 0.01$, and *** indicates $P > 0.05$.

dermatome. Consequently, the FO group was associated with significantly longer procedural time than the FR group (45.4 ± 22.13 minutes vs 29.2 ± 9.3 minutes, $P < 0.05$).

Both groups have good immediate postoperative pain relief (NAS score: 0.33 ± 0.49 for FR group and 0.25 ± 0.45 for FO group; $P > 0.05$) with FR group slightly superior to FO group for sustained pain relief. The FR group (15 patients in total) has 100% sustained pain relief (>50% NRS scores reduction) up to the 12-month follow-up visit (15 out of 15; $P < 0.01$). No pain reoccurrence was observed. In contrast, the FO group (12 patients in total) found only nine out of 10 patients with sustained pain relief at the 12-month follow-up visit (two cases lost to follow-up visit at 6 months; $P < 0.01$). In addition, there were two cases from the FO group who experienced pain recurrence within 24 hours postoperative. A detailed history review suggested that these two cases were associated with prolonged needle exploration and multiple needle readjustments before paresthesia in V2 dermatome could be induced. These two cases were then transitioned to the FR group, and subsequent FR block was able to give these two patients successful and sustained pain relief for 12 months. To be statistically conservative, these two cases continued their follow-up visits as a part of the FO group.

As expected, all FR group patients described various degrees of facial numbness in V2 dermatome post procedure (Figure 5A). However, no patient from the FR group experienced numbness in either V3 or V1 dermatomes, difficulty with mouth opening, or weakness in masticatory muscles (Table 2). In contrast, not only did all the patients in FO group feel facial skin numbness in V2 dermatome, but 6 out of 12 patients in the FO group also felt numbness in either V1 or V3 dermatome (Figure 5B). Among those, five out of six patients experienced difficulty in mouth opening, weakness in masticatory muscles, and reduced sensory function in ipsilateral buccal mucosa and lateral side of the tongue. Furthermore, one out of those six patients experienced immediate postoperative skin numbness in temporal and frontal head areas, with ipsilateral conjunctiva congestion. Corneal ulceration developed 2 weeks later, which unfortunately led to corneal peroration 6 weeks later despite aggressive treatment. The ulcer and peroration subsequently healed but were complicated with permanent vision loss.

As summarized in Table 2, though our FR approach did not cause masticatory muscle weakness, which is a known complication of the conventional FO approach [9,10,15], our method does lead to persistent facial numbness for months in the region of the pain, similar to the FO group. In addition, our FR approach involves percutaneous puncture of facial skin and tissues, which are rich in blood supply. We have observed about a 15% rate of facial hematoma, similar to the FO group.

Discussions

TN is one of the most common causes of facial pain [2,16]. Initial treatment usually involves pharmacological therapy. Interventions are usually reserved for patients who failed medical therapy, including microvascular decompression [17] and various ablative procedures such as rhizotomy with radiofrequency [9,10,18,19], mechanical balloon compression [20], chemical (alcohol and glycerol) injection [21,22], radio-surgery with gamma-knife [23], and peripheral neurectomy. A systematic review published in 2008 from the American Academy of Neurology and the European Federation of Neurological Societies concluded that those interventions are possibly effective in the treatment of TN [24]. Among them, the percutaneous procedure has been considered relatively low cost, minimally invasive, high in safety, and an excellent alternative for patients who could not tolerate or are not willing to have open craniotomy for microvascular decompression surgery [24].

Among the percutaneous techniques, radiofrequency rhizotomy offers the highest rates of sustained pain relief. Percutaneous trigeminal rhizotomy for the treatment of TN was first attempted by Hartel as early as in 1914, and radiofrequency ablation was introduced by Sweet in 1970s. The Hartel technique describes a method of reaching the Gasserian ganglion by passing a needle from the external side of the mouth, inserting it at the level of the upper mid-molar tooth, and passing it cephalad and inward until the needle tip reaches the temporal bone in front and to the outer side of the FO. This allows the needle to further advance into the inner side of the FO to finally reach the Gasserian ganglion [24–27]. Although the procedure has been an established treatment for TN for many decades with successful pain relief in about 80%–98% of patients [7,9,10,26–28], the importance of accurate placement of the radiofrequency needle and correct positioning of the electrode cannot be overemphasized. Outside of the FO, many vascular or neural structures can accidently be pierced, including carotid artery, jugular foramen, and inferior orbital fissure. Inside the FO, the dural fold in Meckel's cave could be accidentally pierced as well. In both situations, adverse or catastrophic neural and/or vascular complications could occur, including intracranial bleeding, seizure, or total spinal [9–11]. Extensive efforts have thus been made to improve the visualization and needle placement, including evolution from the conventional fluoroscopic guidance to the use of CT guidance, various neuro-navigation systems using 3D reconstruction techniques, and more recently, antidromically elicited evoked potentials of the trigeminal nerve that were used to guide needle placement in patients under general anesthesia [13–16,18]. Those techniques have been useful in improving clinical outcome and have reduced perioperative iatrogenic injury of vital structures around the FO.

In spite of these improvements, the conventional FO approach has been associated with significant complications, especially for treating trigeminal sub-branch

neuralgia. Anatomically speaking, the V3 nerve that exits through the FO could be easily injured when the radiofrequency needle goes through the FO, leading to masticatory weakness and facial numbness along V3 dermatome. Once the needle is inside the Meckel cave, it is often difficult to differentiate the sub-branches from each other [9,10,29]. As a result, prolonged needle repositioning and adjustments are often required before individual sub-branch can be identified, thus significantly increasing the risk of dural puncture, infection, and intracranial bleeding. As shown in our study, while the final target is the V2 branch, the FO group patients had nonspecific block to other sub-branches (V1 and V3) as high as 50% (six out of 12), including one case affecting the V1 sub-branch that resulted in vision loss. Due to these concerns, a selective V2 block sometimes is done under C-arm fluoroscopy guidance at the pterygopalatine fossa [30–33], which is safer but less effective for more proximal disease and could be complicated by simultaneous block of adjacent sphenopalatine ganglion and parasympathetic fibers. Consequently, it is imperative to develop new approaches that can specifically target V2 sub-branch with minimal morbidity and mortality from direct trauma of vital structures around the FO.

We have therefore proposed to block the V2 trigeminal nerve via a trans-FR approach. The V2 branch begins at the Gasserian ganglion and passes through the FR to exit the cranium. It subsequently crosses the pterygopalatine fossa and enters the orbit through the inferior orbital fissure. When comparing with the conventional FO approach during which the Gasserian ganglion portion (inside the Meckel's cave) that gives rise to V2 branch was ablated, our FR approach ablates the V2 branch at more peripheral location (either the proximal branch of V2 at external opening or inside the FR canal, 11/15 cases, were ablated, or the Gasserian ganglion portion that gives rise to V2 branch at internal opening or inside the Meckel's cave, 4/15 cases, were ablated, depending on the needle depth into the FR). When comparing with the pterygopalatine fossa approach or the peripheral neurectomy approach at the infraorbital canal, our approach ablates the nerve at much more proximal location.

We started the project by first creating a CT image database of infrazygomatic needle insertion to FR in human skull specimen. The average diameter of the FR in adults is 3.0 ± 0.4 mm, smaller than the FO (4.6 ± 0.9 mm) [34]. Currently, there are few available fluoroscopy and/or CT images of infrazygomatic needle access of FR in human. We found that, in human skull specimen, the radiofrequency needle was able to directly access the FR via an infrazygomatic approach. In addition, the radiofrequency needle can be further advanced into the FR canal with a gentle pressure. This finding has made it possible to target the FR, where V2 exits and is completely separated from V1 and V3. The needle puncture route is also away from oral, nasal, and pharyngeal spaces, thus minimizing risk of infection. Last but not least, the needle path and FR canal orientation are not fully parallel/coaxial to each other, making it less likely for the needle tip to completely go through FR to reach Meckel's cave, which further minimizes risks of incidental dural puncture, intracranial infection, and bleeding. Taken together, the FR approach is feasible from an anatomical perspective and may be safer than the conventional FO approach when V2 trigeminal sub-branch nerve block is desired.

We subsequently conducted a study of 27 patients with isolated V2 TN to compare clinical outcomes and complications between FR and FO approaches. Among the differences observed between the two groups, the difference in procedural time stood out the most. The FR group required much less procedure time than the FO group (29.2 ± 9.3 minutes vs 45.4 ± 22.13 minutes, $P < 0.05$), with the need for needle readjustment (once needle is inside the foramen) almost none for FR group (average 0.27), in contrast to 3–4 times needed for the FO group (average 3.17), before paresthesia in V2 dermatome distribution could be induced. In addition, the stimulation intensity needed to induce paresthesia is much lower in FR group than the FO group. Possible underlying reasons for those differences include: 1) FR (3.0 ± 0.4 mm) in adults is smaller than FO (4.6 ± 0.9 mm) such that the needle is in closer proximity to the nerve; and 2) for FR group patients, no significant advancement of the needle is needed once it is in the FR to block V2 nerve, whereas for FO group patients, the needle needs to be further adjusted and advanced for about 10 mm before it reaches Meckel's cave to block the V2.

The need to advance the needle deep into FO and the requirement for multiple needle adjustments before V2 portion of the Gasserian ganglion could be identified have led to a longer procedural time in FO group, which can be associated with more patient discomfort and increased risks for injuries to adjacent V3 and V1 nerves. In our study, the FO group had six out of 12 patients experiencing facial numbness not only in V2 dermatome but also in V1 or V3 dermatome. In contrast, all FR group patients experienced facial numbness only in the V2 dermatome.

Clinical outcome of the FR group has been satisfying, with significant pain relief (>50% NRS score reduction) at both immediate postoperative and 1- to 12-month follow-up visits. No pain reoccurrence was observed at the 12th month follow-up visit. The FO group has in general significant pain relief as well, though not as robust as the FR group. Ten out of 12 cases were followed up to 12 months, among them one case had pain recurrence at the 12th month follow-up visit. In addition, there were two patients in the FO group who had pain reoccurred on postoperative day 2. These two cases were subsequently transitioned to the FR group on the next day and were successfully treated with sustained pain relief for 12 months.

CT-guided Gasserian ganglion blocks are not commonly utilized in clinical practice. Many pain medicine physicians and neurosurgeons use standard fluoroscopic guidance due to concerns that CT guidance requires additional trouble scheduling and prolongs the duration of the

procedure. Candido et al. published a case report on using CT guidance for a Gasserian ganglion block for a patient with V1 TN secondary to herpes simplex type I [35]. The patient had remarkable pain relief that was sustained beyond a 6-month period with no adverse effects. Our study demonstrates that a novel CT-guided approach via the FR can be a good alternative to the classical FO approach when an isolated V2 branch block is desired in some selected patients, including those who have failed the conventional FO approach treatment, those with FO abnormality or calcification such that radiofrequency needle may not be possible to go through, those who may be at risk for general anesthesia [15], and those who have experienced masseter weakness from prior FO approach treatment (our approach ablates V2 at FR, where V2 is completely separated from V3). While there are no published studies randomizing patients to CT guidance vs fluoroscopic guidance to treat TN, other CT guidance techniques for other technically challenging pain blocks, such as celiac plexus block, have shown improved efficacy and lower side effects [36].

Our study has its own limitations. Patients were not truly randomized as patients were given the options to choose either FO or FR approach. However, following steps were taken to maximally minimize potential bias: 1) Patients were given a full description of both procedures before the operation, with no preference given by the consent team; 2) there were no significant statistical differences of demographic data between FR and FO group patients; 3) all procedures were performed by a single physician; 4) postoperative evaluation and follow-up visits were conducted blindly by an independent team (other than the procedurer); and 5) primary outcome (pain score) and secondary outcome (paresthesia, motor dysfunction, and hematoma) have been followed up for both short term and long term up to 1 year, which may reduce the probability of placebo effect as placebo effect in general decreases over time [37]. In spite of those steps, potential bias cannot be fully excluded from our study.

In summary, we have developed a novel technique to selectively block the V2 trigeminal nerve through the FR. With this novel technique, when compared with the classic approach through the FO, we demonstrate similar pain relief up to at 1 year follow-up visit, and fewer adverse effects, except for facial hematoma and facial numbness, which are no worse than the classic approach. CT guidance also lowers procedure duration time and is better tolerated by the patients. Future studies utilizing this novel approach at the FR are indicated.

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