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The Endoscopic Trans-Sinusoidal Trans-Pterygopalatine Route to the Foramen Rotundum Approach in Trigeminal Neuralgia Treatment

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ABSTRACT

AIM: To describe a new, minimally invasive, and safe access to foramen rotundum via the endoscopic endonasal trans-sinusoidal route for trigeminal nerve blockage.

MATERIAL and METHODS: We studied 5 fresh cadavers bilaterally, and 10 pterygopalatine fossae and maxillary nerves using the endoscopic endonasal trans-sinusoidal trans-pterygopalatine approach.

RESULTS: The proposed approach enabled the maxillary nerve to be visualized after revealing the foramen rotundum with the help of some craniometric measurements. Distance between sphenoid sinus lateral wall and maxillary sinus posterior wall was measured. This measurement was found to be an important triangulation point to determine the location of the entrance to the pterygopalatine fossa. The distance between the foramen rotundum and the sphenopalatine artery was found to be significant. The foramen rotundum diameter was calculated, and the maxillary nerve was found to be situated inferolateral to the foramen rotundum. Therefore, the safe entry zone was determined superomedially. No significant difference was found between male and female and the right and left nostrils.

CONCLUSION: Various surgical procedures have been applied to treat drug-resistant trigeminal neuralgia. Nevertheless, their cure rates remain less than anticipated. Recurrences up to 30% have been reported in the literature. In this study, the endoscopic endonasal transmaxillary trans-pterygopalatine route offers a new perspective on the foramen rotundum approach and provides a panoramic and safe view in previously high-risk percutaneous interventions.

KEYWORDS: Trigeminal neuralgia, Trans-pterygopalatine, Endoscopic, Craniometric

ABBREVIATIONS: V1: Ophthalmic, **V2:** Maxillary, **V3:** Mandibular, **TN:** Trigeminal neuralgia, **RF:** Radiofrequency, **CE:** Common Era/ Christian Era, **MVD:** Microvascular decompression, **GKR:** Gamma knife radiosurgery

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INTRODUCTION

The trigeminal nerve is the largest cranial nerve, which contains both sensory and motor fibers with the primary function of providing sensory and motor innervation to the face (26). The trigeminal nerve arises as two roots, thick and thin, from the ventral side of the pons. The thick one is sensory branch, and the thin one is the motor branch. These two roots course through the pontocerebellar cistern and extend to the petrous apex and after the trigeminal ganglion, the trigeminal nerve divides into branches of V1 (ophthalmic), V2 (maxillary), and V3 (mandibular). These branches transmit pain-heat, pressure-touch, two-point sensitivity, muscle proprioceptive, and vibration sensation to the central nervous system (17,18,32,37).

Trigeminal neuralgia (TN) is classified as symptomatic and idiopathic and impacts both mand and women, however the incidence rate is twice as higher in women in comparison to men. It usually occurs after the age of 50 and occurrence rate increases with age (3,8,24,35).

Although the etiopathogenesis of TN remains unclear, the most widely accepted theory for TN pathophysiology is the firing hypothesis defined by Devor et al. According to Devor et al. the compression or demyelination of the trigeminal afferent neurons at the site of the trigeminal ganglion or nerve are considered to cause an injury that results in more excitable neurons (11). This damage makes the neurons hyperexcitable, hence making them produce autonomous pulses in abnormal places. Janetta suggests, the main reason for nerve compression is the pulsation of the superior cerebellar artery, which uses the same foramen as the trigeminal nerve to enter the skull base (10,15,16,27).

The pressure or pulse created by the superior cerebellar artery is considered to cause damage to the protective myelin sheath of the nerve and may cause electrical instability. As a result, the slightest stimulation becomes sufficient for the onset of pain attacks, and the nerve cannot interrupt the pain signals after the stimulation has ceased (22).

There are many surgical and medical treatment modalities being used for TN. Microvascular decompression, radiofrequency (RF) application, gamma knife, and percutaneous methods of nerve blockage are the main surgical treatment modalities (2,9). The use of carbamazepine is the most effective drug treatment for TN, nevertheless, TN can be drug-resistant (25).

This study aimed to present a minimally invasive and feasible endoscopic approach to the surgical treatment of drug-resistant TN. Through the endoscopic endonasal trans-sinusoidal trans-pterygopalatine approach, craniometric measurements were performed to reach the foramen rotundum without damaging the surrounding vascular and neural tissues. The relationship between these triangulation points and the foramen rotundum was revealed, and a safe, targeted, and minimally invasive surgical field was determined.

As mentioned previously, in the endoscopic endonasal trans-sinusoidal trans-pterygopalatine route, the lateral wall of the sphenoid sinus, the sphenopalatine artery, and the pterygopalatine channel are important anatomical points in reaching the foramen rotundum. As indicated in this study, after the foramen rotundum was revealed, the maxillary nerve could be panoramically visualized, and its trace could be clearly understood. This cadaveric study intends to present a new endoscopic surgical treatment method.

MATERIAL and METHODS

In this study, we used five fresh-frozen cadaveric heads of which three were male and two were female between the ages of 67 and 82. The average age was 70.2. The cadavers were all adults, and the pediatric group was excluded. The cadaver heads were pre-separated at a distance of C7-T1. Only fresh-frozen and non-fixed cadavers with bone integrity intact were included in the study. The cadavers were taken from a deep freezer one day before the study for the purposes of defrosting. The heads are positioned with a three-pin Doro skull clamp in the neutral position. The procedure was recorded by video and photos.

In this study, 4 mm, 0-degree Hopkins II Karl Storz neuro endoscope (Karl Storz SE & Co., Tuttlingen, Germany) and a high-resolution camera (Karl Storz) were used. A cold light source (Karl Storz) was used. A high-speed surgical drill (Midas Rex Legend, Medtronic, Minneapolis, MN) was readily available on site. A transnasal skull base bur with a 13 cm × 3 mm diamond tip was used for the drilling procedure.

We identified some landmarks to reach the foramen rotundum through the endoscopic endonasal trans-sinusoidal trans-pterygopalatine approach and attempted to achieve a safe surgical site to minimize complications during the procedure. The same measurements were made in all cadavers. Measurements were done with a 5 mm sized surgical marker device and all the calculations were done proportionally according to this marker. The following parameters were determined:

Parameters:

1. Distance between the sphenoid sinus lateral wall and the drilled maxillary sinus posterior wall (entry point for the pterygopalatine fossa)
2. Distance between the sphenopalatine artery and the foramen rotundum
3. Diameter of the foramen rotundum
4. Distance between the pterygopalatine fissure canal and the foramen rotundum
5. Exit position of the maxillary nerve from the foramen

Statistical Analysis

Statistical analysis was performed using the SPSS 21.0 statistical package program (IBM, SPSS Inc., IL). The relevance of the variables to the normal distribution was tested using the one-sample Kolmogorov–Smirnov test. Non-parametric tests were performed because of the non-normal distribution, with the number of samples being $n=5$ and $n<30$. The Mann–Whitney test, one-way ANOVA, and correlation analysis (Spearman's rho) were used in the statistical analysis. Homogeneity of variance was tested with Levene's test. A p-value of less than 0.05 was considered statistically significant.

RESULTS

The endoscopic endonasal trans-sinusoidal trans-pterygopalatine approach was used to examine 10 pterygopalatine fossae and maxillary nerves. Before the endoscopic procedure, a bilateral subtemporal craniotomy was performed only in the first cadaver head to determine the entry point to the pterygopalatine fossa and foramen rotundum.

After the cadaver head was fixed in a head holder (Doro QR3 USA), it was turned on the right side, and the neck was extended. Starting from the front of the tragus, a horseshoe incision was made.

A 5 cm × 7 cm craniotomy flap was removed using a high-speed drill (Figure 1). Frontal and temporal fossae were accessed through extradural dissection (Figure 2). The foramen ovale and rotundum were revealed, and the trace of the maxillary and mandibular nerves were identified through endoscopy-assisted dissection (Figure 3). A semi-elastic metal stylet was inserted through the foramen rotundum to determine the intranasal target point. The head was turned to the neutral position, and an endoscopic section was performed.

The left nasal passage was accessed with a 0-degree endoscope, and the nasal ostium was enlarged with a modified Ozgen speculum. The middle and superior conchae and the inferior nasopharynx were seen. The middle concha was medialized using a surgical elevator. The anterior wall of the maxillary sinus was reached approximately 1.5 cm inferior and lateral from the nasal ostium. The mucosa was dissected, and the anterior wall was opened. The maxillary sinus was widened with a Kerrison rongeur and a high-speed drill (Figure 4). All the walls of the pyramid-shaped sinus were seen.

The lateral wall of the sphenoid is an important anatomical landmark (Figure 5). For this purpose, sphenoidotomy was performed to reach the anterior sphenoid ostium. The ostium was pierced with a high-speed diamond drill. The sphenovomeral suture was seen, and posterior sphenoidotomy was completed. The sphenopalatine artery, which extends from the maxillary sinus to the base of the sphenoid sinus, was seen at the base of the sphenovomeral suture. Toward the

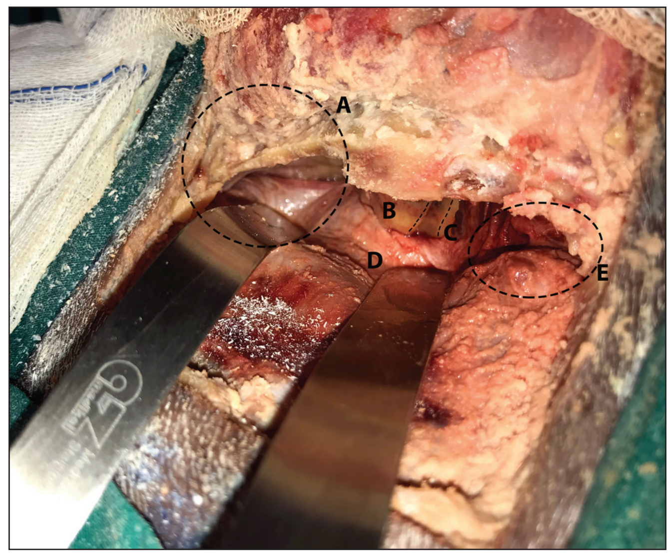

Figure 2: Subtemporal skull base with extradural approach (Right Side). **A.** Middle fossa **B**. Petrosal bone **C.** Groove of Sup. pertosal vein **D**. Dura mater **E.** Posterior fossa.

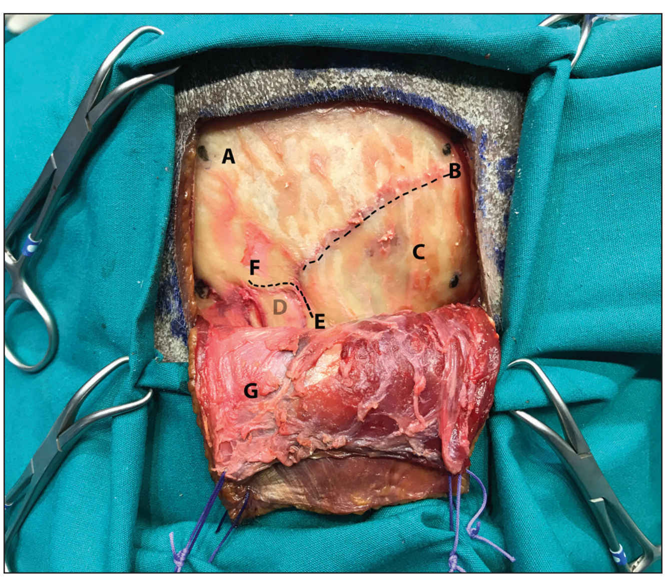

Figure 1: Subtemporal craniotomy; skin and muscle after opening (Right Side). **A.** Parietal Bone **B.** Squamous Fissure **C.** Temporal Bone **D.** Sphenoid Bone **E.** Sphenosquamous fissure **F.** Sphenoparietal fissure **G**. Temporal muscle and skin.

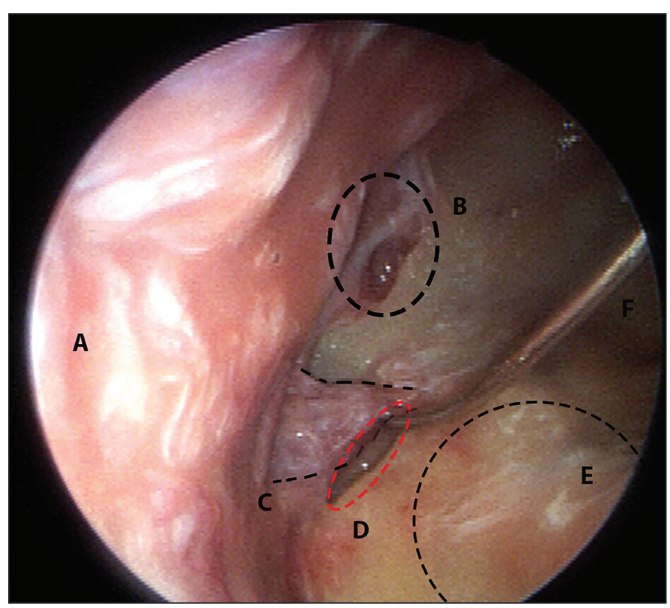

Figure 3: Subtemporal extradural foramen rotundum approach with an endoscope**. A.** Dura mater **B.** Fissura Orbitalis Superior **C.** N.maksillaris **D.** Foramen rotundum **E.** Temporal fossa.

deep end, the anterior sella and inferior clivus were seen. The optic protuberance was seen on the superior side of the lateral wall of the sphenoid sinus, and the carotid protuberance was seen on the inferolateral side of the optic protuberance. The connection between the posterior wall of the maxillary sinus and the sphenoid sinus was examined through the guidance of a stylet (Figure 6).

The position of the foramen rotundum was determined at an average distance of 4.3 mm from the perpendicular line on the lateral wall of the sphenoid sinus using a stylet. The foramen rotundum was opened using a high-speed diamond drill, and the maxillary nerve was reached (Figure 7).

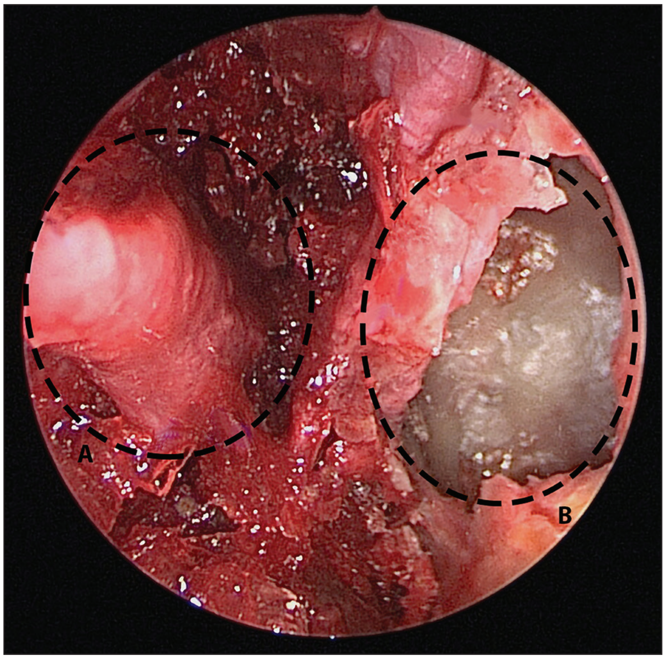

Figure 4: Middle concha and maxillary sinus relationship (Left Ostium). **A.** Medialization of the middle turbinate **B.** Anterior wall of the maxillary sinus.

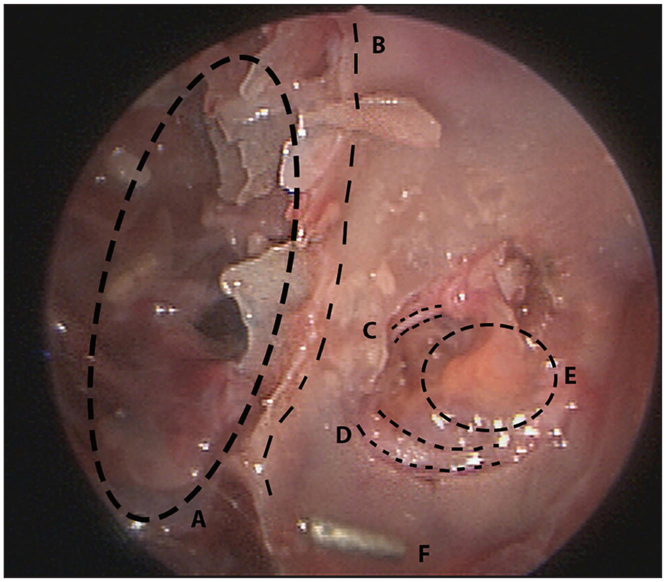

Figure 5: The relation between the sphenoid sinus and the maxillary sinus (Left Ostium). **A.** Sphenoid sinus **B**. Sphenoid sinus lateral wall **C.** Palatin artery aberrant branch **D.** Sphenopalatine artery **E.** N.maksillaris **F**. Measuring marker.

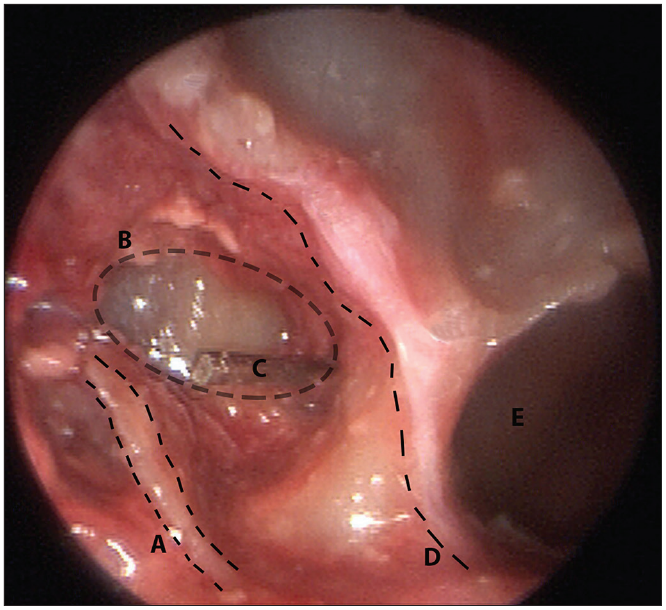

Figure 6. Confirmation of the foramen rotundum with stylet (Right Ostium). **A.** Sphenopalatine artery **B.** Foramen rotundum and n.maksillaris passing through **C.** Stylet **D.** Sphenoid sinus lateral wall **E.** Sphenoid sinus.

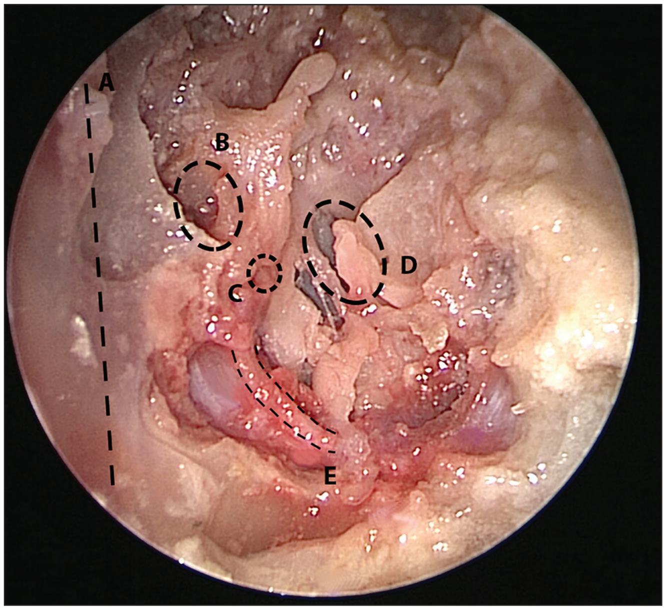

Figure 7: Relationship with foramen rotundum vascular structures (left ostium). **A.** Sphenoid sinus lateral wall **B.** Pterygopalatine canal –fissure **C.** Palatin artery **D.** N.maksillaris **E.** Sphenopalatine artery.

Anatomical Measurements

The distance between the sphenoid sinus lateral wall and the maxillary sinus posterior wall was 4.32 mm (SD: 1.29 mm) (Table I). ANOVA was performed (p=0.929 (Table II). This measurement was found to be an important triangulation point to determine the location of the entrance to the pterygopalatine fossa.

The distance between the sphenopalatine artery and the foramen rotundum was 3.7 mm (SD: 0.81 mm) (Table I). ANOVA was performed (p=0.085). No significant variation was found between the sphenopalatine artery and the foramen rotundum.

The mean diameter of the foramen rotundum was 2.57 mm (SD: 0.74 mm) (Table I). ANOVA was performed (p=0.063) (Table II). This parameter provided an estimate of the width of the area to be drilled, thus preventing us from going beyond the foramen rotundum.

The mean distance between the pterygopalatine fissure canal and the foramen rotundum was 1.36 mm (SD: 0.47 mm) (Table I). ANOVA was performed (p=0.716) (Table II). This measurement is important because the pterygopalatine artery turns toward the palatine artery.

The foramen rotundum was divided into four quadrants to determine the exit position of the maxillary nerve from the foramen (Figure 8). The mean number of data obtained by assigning numbers to each quadrant was 2.1 (SD: 0.73) (Table I). ANOVA was performed (p=0.694–0.05) (Table II). The maxillary nerve was found to settle at the inferolateral part of the foramen rotundum, and the safe entrance zone was determined as the superomedial portion (Figure 8).

The ANOVA results showed no significant difference between the right and left nasal ostium parameters [parameter 1 (p=0.929–0.05), parameter 2 (p=0.085–0.85), parameter 3 (p=0.063–0.05), parameter 4 (p=0.716–0.05), and parameter 5 (p=0.694–0.05)] (Table II).

Homogeneity of variance was tested with Levene's test. As shown in Table III, all data are homogeneous.

Group variables were detected for right and left nostrils. For the 5 parameters, the measurements taken from the right and left nostrils were similar (Table IV).

DISCUSSION

Although the first information about TN was obtained in the CE II century, its physiopathology has not been established clearly yet. Many studies have been conducted to understand the mechanism of this type of pain and to establish a treatment. In 1962, carbamazepine, which was used in the treatment of epilepsy, was found to be very effective against TN (25). Today, it remains the first choice and the most effective drug in medical treatment. Surgical interventions in TN were initiated by targeting Gasser's ganglion. In 1959, Gardner and Miklos practiced vascular decompression by working on vascular pressure theory and used a piece of gelatin to separate the vascular structure from the trigeminal nerve. Nowadays, this method has become a Teflon insertion between the trigeminal nerve and the vascular structure through retromastoid suboccipital intervention. According to the literature, the rate of pain-free patients following microvascular decompression (MVD) surgery in the first year varies between 80% and 87% (28,30,34). Approximately 8% of the patients had additional invasive procedures after MVD surgery (21,36).

Table I: Measurement Values of all Parameters

Parameter		Distance between the sphenoid sinus lateral wall and drilled maxillary sinus posterior wall	Distance between sphenopalatine artery and foramen rotundum	Foramen rotundum diameter	Distance between pterygopalatine canal-fissur and foramen rotundum	Exit position of maxillary nerve from foramen rotundum
1.cadaver	left	2.9 mm	4.1 mm	2.2 mm	2.2 mm	3
	right	2.7 mm	4.4 mm	2.9 mm	1.9 mm	1
2.cadaver	left	5.7 mm	3.4 mm	2.5 mm	0.9 mm	2
	right	6.8 mm	2.9 mm	1.9 mm	1.2 mm	3
3.cadaver	left	5.2 mm	2.9 mm	1.9 mm	1.2 mm	3
	right	3.4 mm	5 mm	2.8 mm	1.2 mm	2
4.cadaver	left	4.1 mm	2.7 mm	2.5 mm	0.7 mm	2
	right	4.2 mm	4.7 mm	4.1 mm	1 mm	2
5.cadaver	left	3.5 mm	3.2 mm	1.6 mm	1.5 mm	1
	right	4.7 mm	3.7 mm	3.3 mm	1.8 mm	2

Table II: Anova Results for All Parameters

				Square of the total	Sd	Mean Square	F	p
Distance between the sphenoid sinus lateral wall and drilled maxillary sinus posterior wall	Between groups	(Combined)		0.016	1	0.016	0.008	0.929
		Linear Term	Contrast	0.016	1	0.016	0.008	0.929
	Groups inside			15.18	8	1.898		
	Total			15.196	9			
Distance between sphenopalatine artery and foramen rotundum	Between groups	(Combined)		1.936	1	1.936	3.849	0.085
		Linear Term	Contrast	1.936	1	1.936	3.849	0.085
	Groups inside			4.024	8	0.503		
	Total			5.96	9			
Foramen rotundum diameter	Between groups	(Combined)		1.849	1	1.849	4.663	0.063
		Linear Term	Contrast	1.849	1	1.849	4.663	0.063
	Groups inside			3.172	8	0.397		
	Total			5.021	9			
Distance between pterygopalatine canal-fissur and foramen rotundum	Between groups	(Combined)		0.036	1	0.036	0.142	0.716
		Linear Term	Contrast	0.036	1	0.036	0.142	0.716
	Groups inside			2.028	8	0.254		
	Total			2.064	9			
Exit position of maxillary nerve from foramen rotundum	Between groups	(Combined)		0.1	1	0.1	0.167	0.694
		Linear Term	Contrast	0.1	1	0.1	0.167	0.694
	Groups inside			4.8	8	0.6		
	Total			4.9	9			

Table III: Homogeneity Test Results of Variance of Parameter Measurements (According to the Table III, All Data are Homogeneous)

	Levene Statistics	sd1	sd2	p
Distance between the sphenoid sinus lateral wall and drilled maxillary sinus posterior wall	0.134	1	8	0.724
Distance between sphenopala-tine artery and foramen rotundum	1.572	1	8	0.245
Foramen rotundum diameter	1.101	1	8	0.325
Distance between pterygopalatine canal-fissur and foramen rotundum	0.394	1	8	0.548
Exit position of maxillary nerve from foramen rotundum	0.59	1	8	0.464

Table IV: Mann-Whitney Test Results for All Data of Right and Left Nasal Ostium

	All Data
Mann-Whitney U	274
Wilcoxon W	599
Z	-0.748
p(2-sided)	0.454

*Grouping Variable: Nasal ostium left-right side

Gamma knife radiosurgery (GKR), which was used by Leksell, is now an option in the treatment of TN. The rate of pain-free patients after GKR in the first year varied at 72%-77% (28). Approximately 42% of these patients (30% RF, 12% MVD) required additional invasive treatment in the following years (13, 29). RF is the fastest-performing method, but the duration of its efficiency is short (12,14,33). By contrast, MVD surgery is the most effective and has the longest time of efficacy (28,30,34). The GKR method was determined to be a highly effective method in patients who could not undergo surgery,

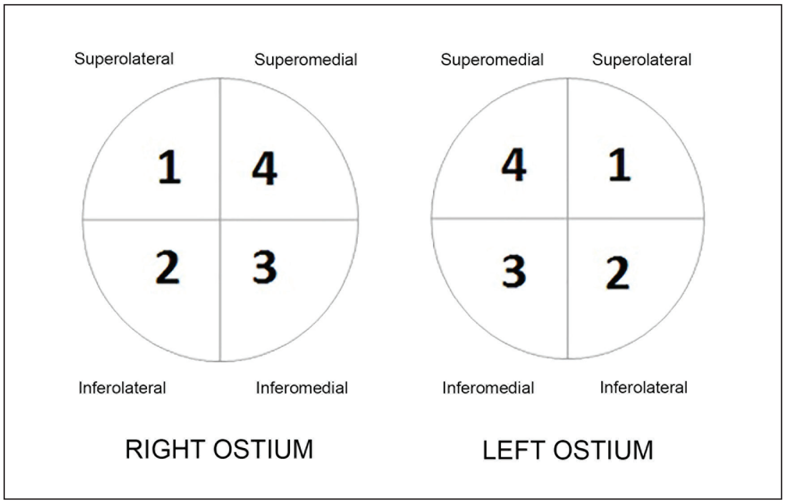

Figure 8: Exit position of the maxillary nerve from the foramen.

who could not benefit from the RF method, or who do not accept surgical methods (29).

When we have analyzed the development of endoscopy to date, we found that there was an obvious interest in the minimal surgical interventions that had been ongoing for years. Then when we looked at the development of endoscopy in neurosurgery, we found that it was used intraventricularly in 2 children with hydrocephalus for the first time. The first use of the endoscope in pituitary surgery was performed by Cushing in 1909. In later years, endoscopic approaches to craniopharyngioma, chordoma, and para sellar lesions were performed. Endoscopic use in neurosurgery practice has become increasingly favored because it is a minimally invasive procedure and enables shorter hospital stays (7).

This study aimed to achieve a minimally invasive and feasible endoscopic approach for the surgical treatment of drug-resistant TN. Through the endoscopic endonasal trans-sinusoidal trans-pterygopalatine route, craniometric measurements were performed to reach the foramen rotundum without damaging the surrounding vascular and neural tissues, and the triangulation points were determined. The location and diameter of the foramen rotundum are based on this triangulation point, the position and the trace of the sphenopalatine artery, the position of the maxillary artery, and the branches in the pterygopalatine fossa were standardized.

This study is the first to present an alternative approach to and standardized craniometric measurements for drug-resistant TN surgery. A minimally invasive and effective approach to the middle fossa foramens through the endoscopic endonasal route was described. The topographic measurements enabled us to diminish the complication risk during a surgical procedure. Also knowing the topographic locations of the sphenopalatine artery and maxillary nerve will be useful for determining the safe entry site. The craniometric design of the study can be applied safely without a need for neuronavigation.

As TN treatment have a similar success rate, feasibility, and complication rate of the procedure determines the treatment modality. Anesthesia Dolorosa, loss of corneal reflex, facial numbness (60%), and low mortality rate are expected complications with percutaneous procedures (1,4,19). Gamma knife can cause neuronal damage because of the targeted nerve is in the cisternal part and close to the brain stem. This modality has limitations as inadequate pain control in the acute phase, high recurrence rate, and hypoesthesia (5,20). Because of these reasons, a safer modality can be the choice. MVD can control the pain in the acute phase, however it is major surgery and has complications such as hemifacial spasm, hearing loss, and vascular injury (23,31). With the endoscopic approach in trigeminal neuralgia treatment, after foramen rotundum was revealed, the maxillary nerve can be accessed. A panoramic view is gives us the advantage to see neuronal and vascular structures more definitely, thus lowers the neuronal and vascular damage. The endoscopic approach is more minimally invasive and safer in terms of complication risk, and this modality can take place in neurosurgery practice in the future.

With today's endoscopic 3D image systems, a near-perfect sense of depth can be obtained. Implementation of the new surgical approach in operating rooms using these systems will be much easier and safer. Without a doubt, reducing the risk of complications by visualizing and preserving vascular and neural structures is vital to the success of the procedure for clinicians. We consider that endoscopic middle fossa approaches can be safely performed, but they represent an unexplored area that needs to be examined anatomically and described craniometrically. It is important to know the basic endoscopy technique, sinus anatomy and variations, and vascular and neural tissue traces for such an approach. Modification of the approach is possible through further cadaveric studies. The modification and the development of the approach will enable its use not only in TN but also in vascular and tumoral pathologies of the middle cranial fossa. The introduction of this approach into clinical practice will help to develop and complete its principles in shorter surgical times.

To date, various invasive surgical procedures have been used to treat drug-resistant TN, but their cure rates are less than expected. Recurrences up to 30% have been reported in the literature (6). In this study, the endoscopic endonasal trans-sinusoidal trans-pterygopalatine route to the foramen rotundum provides a new perspective in performing safe, feasible, and minimally invasive surgery.

In this study, 5 cadavers were used, and we had limited information as well. More reliable and comparable measurements can be obtained with larger study groups. The other limiting factor is that this study was not conducted in surgical cases. After obtaining enough cadaveric experience, application of this approach to surgical cases can provide us with detailed information about the complications of surgery. As the endoscopic study gives a two-dimensional view, microscopic three-dimensional studies can provide additional data.

CONCLUSION

In the treatment of TN, the endoscopic endonasal trans-sinusoidal trans-pterygopalatine route to the foramen rotundum was taken by providing a minimally invasive and wide-field vision without damaging critical neurovascular structures. The craniometric measurements of the sphenoid sinus lateral wall and the pterygopalatine fissure revealed that the foramen rotundum was detectable. After calculating the average diameter of the foramen rotundum, the fenestration area was determined. After the fenestration area was divided into four quadrants, the maxillary nerve was found to be inferolateral to the foramen rotundum. The entrance region should be superomedial to reduce maxillary nerve injuries.

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AUTHORSHIP CONTRIBUTION

Study conception and design: MAO, ATB

Data collection: MAO, NC

Analysis and interpretation of results: NA, MAO

Draft manuscript preparation: MAO, ATB

Critical revision of the article: BUS, NA

All authors (MAO, ATB, NC, BUS, NA) reviewed the results and approved the final version of the manuscript.

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