Cadaveric Study

A Cadaver Study Confirming the Location of Dye after Trigeminal Ganglion Rhizotomy

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Background: Radiofrequency thermal rhizotomy demonstrates an excellent treatment outcome with a high success rate among patients of intractable trigeminal neuralgia. The triangular plexus which is an immediate retrogasserian portion of the trigeminal root is suggested as the best place of lesioning during radiofrequency thermal rhizotomy. However, the anatomy of the triangular plexus has been relatively unrecognized, while the anatomical study related to therapeutic procedure is scarce.

Objective: The purpose of this study is to confirm with gross and microscopic finding of the trigeminal system whether, if an electrode tip is placed on the petroclival junction in lateral cranial view, it actually arrives at the triangular plexus or not. In relation to therapeutic procedure, we examined the triangular plexus with morphological and histological methods.

Study Design: Human cadaveric study.

Setting: An anatomical laboratory in South Korea.

Methods: Percutaneous procedure of radiofrequency thermal rhizotomy under C-arm guidance was performed in 8 cadavers. Final target of the electrode tip was the petroclival junction under true lateral cranial view. The location of the electrode tip was determined under observation of the presence of an injected dye. Triangular plexus size was measured grossly and microscopically. Gross and microscopic evaluation of the triangular plexus was performed.

Results: Among 15 trigeminal systems, 8 showed dye appearance in the triangular plexus, while 6 showed it in the trigeminal ganglion. Overall, 53% of radiofrequency thermal rhizotomy could reach the triangular plexus when an electrode tip was placed on the petroclival junction. The grossly measured average triangular plexus vertical and transverse diameters were 0.8 cm and 1.3 cm, respectively.

Limitation: Only radiologic landmark was used to confirm the location of the electrode tip. However, further study confirming the location of the electrode tip under the guidance of electrical stimulation is needed.

Conclusion: When an electrode tip was placed on the petroclival junction, 53% of radiofrequency thermal rhizotomy could reach the triangular plexus.

Key words: Petroclival junction, trigeminal neuralgia, triangular plexus, radiofrequency thermal rhizotomy

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Among cranial neuralgia, idiopathic trigeminal neuralgia (TN) is the most common form of neuralgia. The main clinical feature of TN is paroxysmal lancinating and electrical shock-like pain of the face, confined within the distribution of the trigeminal nerve (1,2). Although the reported incidence of TN is low, ranging 0.03% – 0.3% (3), severe pain of TN significantly impairs the quality of life with resultant psychologic distress, and may even lead to suicide (4).

As an initial treatment modality, carbamazepine medication shows excellent pain relief for TN. However, 10% of TN patients show minimal response to oral medication, while severe side effects of carbamazepine hamper the popular use of such medication (5). Various effective treatments including microvascular decompression, radiofrequency thermal rhizotomy (RF-TR), glycerol rhizolysis, and percutaneous balloon microcompression are useful options for such intractable cases. Among such procedures, RF-TR demonstrates excellent treatment outcome with a success rate of 80% to 97%, although it shows reoccurrence in some TN patients (6-9). The main advantages of RF-TR are that it can be a good option for poor surgical candidates, and that it allows the possibility of repeated procedure in the same patients. In addition, RF-TR can provide more selective destruction of the trigeminal branch, which is essential for TN in a single nerve distribution (6-8,10,11).

Reported complications in the cases of wrong trajectories with the electrode are intracranial hemorrhage, carotid artery injury, other cranial nerve or brain stem injury, and even blindness (6,12-14).

Considering the serious complications above, accurate and correct positioning of the electrode is the essential key for safe and effective RF-TR. Previous work has suggested the triangular plexus (TP) as the best place to create more selective lesion (15). The sensory trigeminal system located in the Meckel's cave is segmented into 2 parts: the trigeminal ganglion (TG), and the TP. The TP has been defined as the portion of the trigeminal nerve from the posterior margin of the TG to the path over the upper ridge of the petrous bone. The TP is the immediate retrogasserian portion of the trigeminal root, and corresponds to the dorsal sensory rootlet. It makes a triangular shape with a plexual distribution (16). The anatomy of the TP has been relatively unrecognized in contrast to the TG with its 3 divisions. In spite of its importance, the anatomical study related to therapeutic procedure is scarce. It is valuable to pay special attention to the anatomy of this particular segment, as this may contribute to the accuracy and safety of the therapeutic procedures of TN.

Most commonly, placement of electrode tip is controlled by fluoroscopic guidance, especially lateral cranial x-rays, combined with stimulation-induced paresthesia provocation in an awake patient. To locate the electrode tip into the desired TP, the lateral cranial view should confirm that the tip of the needle arrives at the petroclival (PC) junction (6,9). Conversely, other studies suggest that an electrode tip should be placed just behind the clival line to reach the TP (14,15). Although the TP is suggested as the best place of lesioning during RF-TR, there is no anatomical study showing that if an electrode is placed around the PC junction, the TP is targeted.

The primary endpoint of this study is to confirm with gross and microscopic finding of the trigeminal system whether, if an electrode tip is placed into the PC junction in lateral cranial view, not beyond the clival line, it actually arrives at the TP or not. The secondary endpoint is to examine the TP with morphological and histological methods.

Methods

Cadavers

A total of 8 adult Asian cadavers (age range, 65 – 89 years; mean age, 77.7 years, 2 men, 6 women) were used in this study. Those cadavers were supplied from the department of anatomy of our institution for research and educational purposes. Our institutional ethics committees approved this study. Eight cadavers were fixed with a 10% formalin solution via the right femoral artery perfusion within 24 hours after death.

Percutaneous Procedure

The same procedures of RF-TR that are performed for the TG rhizotomy of TN were used in this study. All procedures were performed under C-arm guidance. Cadavers lay in the supine position with neck slightly extended and chin up. A 10-cm pillow was placed under the upper back to facilitate the position of neck extension. The C-arm was tilted caudally 30 to 35 degrees, and rotated to the right or left side 10 to 15 degrees obliquely, to visualize the foramen ovale (FO) (Fig. 1A). The skin entry was done at 2 – 3 cm lateral to the angle of the mouth. To make an equal situation of RF-TR performed during clinical practice, a RF cannula of 22-gauge, 10-cm, 2 mm active tip was used. After confirming the clear visualization of FO, the cannula was inserted in a coaxial manner into the fluoroscopic beam toward the FO. During the needle insertion until the entrance of the FO, intermittent fluoroscopy of anteroposterior (AP) and lateral views was checked. When the cannula arrived just in front of the FO in the lateral view, this cannula was advanced 2 – 5 mm further through the puncture of the FO. After this procedure, the cannula tip was confirmed to reach the junction of the petrous ridge of the temporal bone and the clivus on lateral (Fig. 1B) and AP view (Fig. 1C). After fluoroscopic confirmation of the appropriate location of the cannula tip, 0.2 mL of green tissue dye (Davidson® marking system, Bradley Product, Inc., Bloomington, MN) was injected, and the RF-TR cannula was removed. Both sides of the TG were punctured using the same technique.

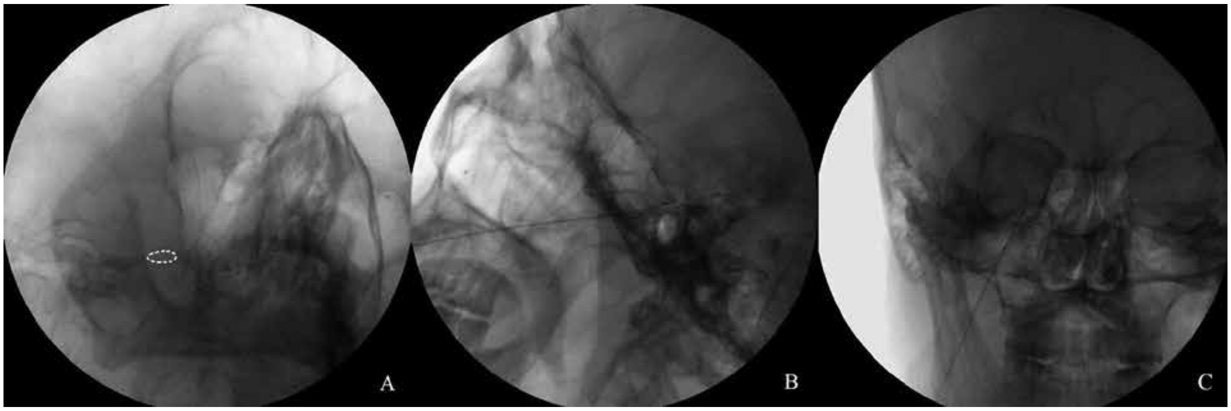

Fig. 1. *Anteroposterior oblique (A), lateral (B), and anteroposterior (C) view under fluoroscopy. The foramen ovale is indicated with white oval shaped dotted circle (A). The needle tip is located in the petroclival line (B). The needle tip reached the junction of the petrous ridge of the temporal bone and the clivus (C).*

Gross Examination of Trigeminal System

As the next step of the percutaneous procedure, dissection of the TG of both sides was performed. Calvaria was removed using a power saw. During removal of calvaria, special attention was paid not to damage the inner structure. The brain, except the pontine and TG area, was carefully removed. Dissection around the TG was performed to include the TP and root, which originates from the pons. During the dissection, the course of the ophthalmic (V1), maxillary (V2), and mandibular (V3) branch of the TG was identified. In addition, we tried to identify the morphologic difference and anatomical location of the TP and TG. Before the harvest of the trigeminal system injected with green tissue dye, we measured the transverse and vertical diameter of the TP. In each cadaver, left and right sides of the TP were measured. An imaginary triangular line was drawn in the TP to measure the transverse and vertical diameter more precisely. The transverse diameter means the base of this triangle where facing the TG. The vertical diameter was defined as the distance from the base to the apex of triangle. The apex of the triangle was placed on the upper petrous ridge.

After finishing measuring the diameter of the TP, the trigeminal system which includes the TP, TG, and root was harvested carefully.

Confirmation of the Location of Electrode Tip

Confirmation of the location of the electrode tip was determined according to the presence of the injected dye within the trigeminal system. Grossly, if the injected green tissue dye was seen more widely in the TP than in the TG, it was considered that the electrode tip reached the TP. In cases of obscurity as to whether the injected dye was seen in the TP or TG under the gross finding, such cases were determined in the microscopic field.

Microscopic Examination of the Trigeminal System

All specimens were fixed in 10% neutral-buffered formalin and processed routinely for paraffin-embedded blocks. Conventional 4 μm sections were obtained from the paraffin blocks, and incubated in an oven at 60°C for an hour. Sections were then dewaxed in xylene for 10 minutes and rehydrated through graded alcohol to distilled water. These slides were stained with hematoxylin and eosin (H&E) dyes according to conventional method.

In the microscopic field, the presence of an injected dye was identified. This identification was performed by a specialist in anatomical pathology with more than 10-years experience and a pain physician who was not involved in the percutaneous procedure. If the injected green tissue dye was observed in the area of the TP more widely than the TG, it was considered that the electrode tip reached the TP. Conversely, if observation of the injected dye showed greater width in the TG than in the TP, it was considered that the electrode tip reached the TG. After finishing the confirmation of the location of dye, the diameter of every nerve bundle in the TP was measured using an imaging analysis system (Image scope, Leica Biosystems Imaging, Inc., CA, USA). Measurement of the nerve bundle and identification of the characteristic histologic finding of TP and TG were performed by a specialist in anatomical pathology.

Statistical Analysis

All statistical analyses were processed using SPSS statistical software (version 25). Descriptive values for measurements were expressed as mean, or mean ± SD.

Results

Puncture of Foramen Ovale

Fifteen sides of the FO of 8 adult cadavers were punctured successfully, and confirmed with submental, lateral and AP cranial view to arrive in the PC junction, not beyond the clival line (Figs. 1A-C). In spite of repeated attempts, one FO was impossible to be punctured. Therefore, 15 trigeminal systems were evaluated.

Gross Finding of the Trigeminal System

The V1, V2, and V3 branches of the TG traversed the superior orbital fissure, the foramen rotundum, and the FO, respectively, to enter the cavernous sinus region. Then they merged together to form the TG. The nerve fibers from the TG formed a plexiform distribution comprising the TP. All specimens showed the triangular shape of the TP with the broadest margin facing the TG, and its apex formed around the upper petrous ridge. Beyond the upper petrous ridge, those fibers of TP turned into the root, and coursed posteriorly to reach the pons (Figs. 2A, B).

Determination of the Electrode Tip Location

Among the 15 trigeminal systems of gross evaluation, the location of injected dye could be identified in 8 trigeminal systems (Fig. 3A). However, in the remaining 7 trigeminal systems, we were uncertain as to whether the injected dye was in the TP or TG. Therefore, final determination of the electrode tip location was performed depending on the location where green tissue dye was observed in the microscopic finding. Among the 15 trigeminal systems, 8 showed dye appearance in the TP, while 6 showed it in the TG. In one trigeminal system, no dye appearance was found on either gross or microscopic evaluation. Overall, when an electrode tip was placed on the PC junction, 53% of RF-TR could reach the TP (Table 1).

Microscopic Finding of the Trigeminal System

Microscopically, the TG was semilunar shaped. The TG consists of aggregates of ganglion cells with a characteristic round-shaped cell body. From the TG, small nerve bundles extend to the TP with a radiating pattern. Each of the nerve bundles in the TP is surrounded by meningothelial cells, and radiates through loose connective tissue. These nerve bundles are transformed into a densely packed structure in the root region. The border where the ganglion cells of the TG converted to the cells of the nerve bundle of the TP was identifiable (Fig. 3B, ×40).

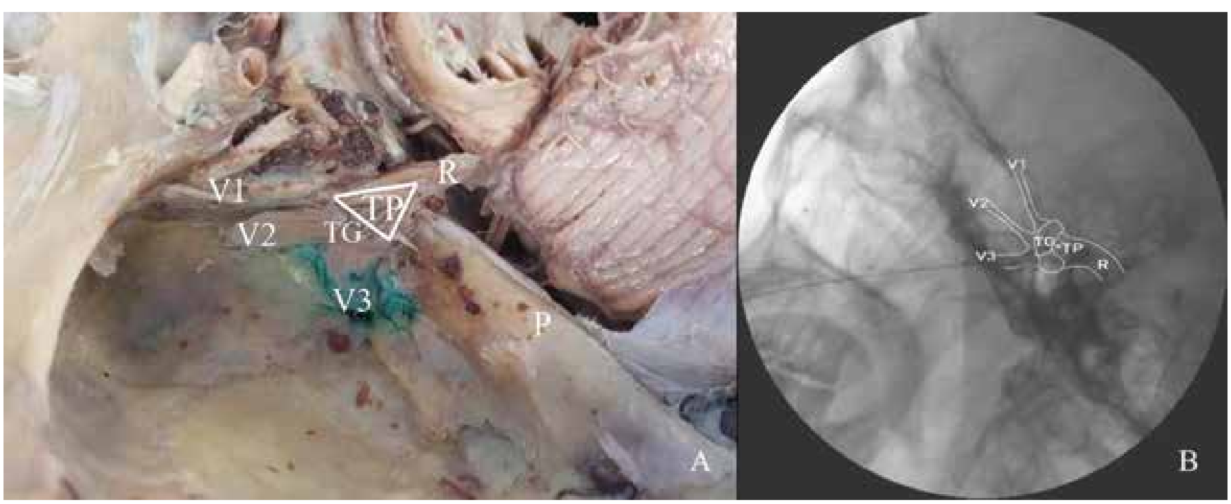

Fig. 2. *Trigeminal system (A) and its schematic illustration on lateral view (B). V1 = ophthalmic nerve. V2 = maxillary nerve. V3 = mandibular nerve. TG = trigeminal ganglion. TP = triangular plexus. R = root. P = petrous ridge. Asterisk (B) indicates the distal part of the electrode.*

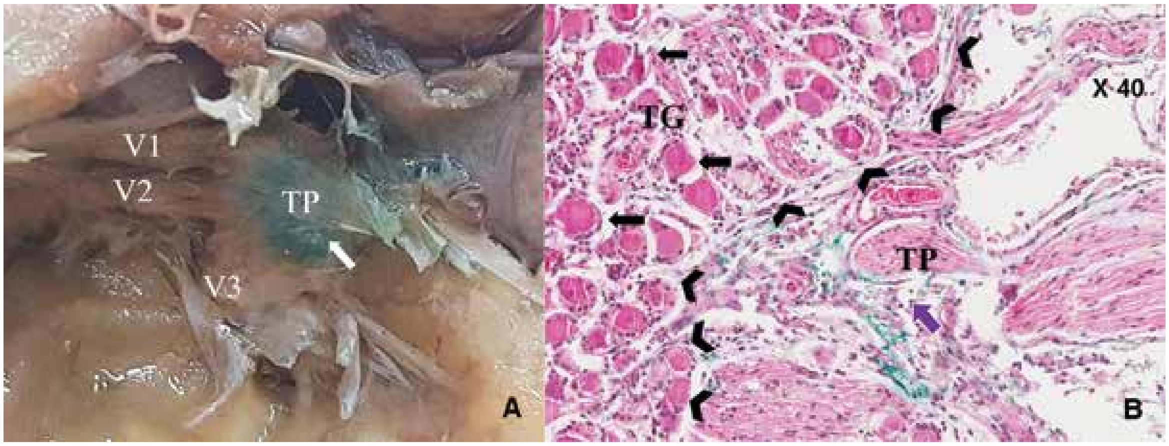

Fig. 3. *Trigeminal system showing injected green tissue dye (white arrow) in the triangular plexus (A). Injected green tissue dye (purple arrow) was microscopically observed dominantly in the area of the triangular plexus. Arrow heads indicate the border between the trigeminal ganglion and triangular plexus. Area of the triangular plexus showed the nerve bundles with loose connective tissues. Within the trigeminal ganglion, round-shaped sensory cell bodies (black arrow) are seen (× 40) (B). V1 = ophthalmic nerve. V2 = maxillary nerve. V3 = mandibular nerve. TG = trigeminal ganglion. TP = triangular plexus.*

Gross and Microscopic Measurement of the Triangular Plexus

Gross and microscopic measurements of the TP were performed in 15 trigeminal systems. The grossly measured average TP vertical and transverse diameters were 0.8 cm and 1.3 cm, respectively (Table 2, Fig. 4A).

An average 33 nerve bundles per one TP were measured. This region was made in order to include every bundle that was seen microscopically. The microscopically measured average TP bundle size was 188.04 μm (134 – 242 μm) (Table 3, Fig. 4B, ×10).

Discussion

In this study, one FO was impossible to puncture. The anatomy and nearby structure of the FO is critical for successful performance of RF-TR. The FO is located in the greater wing of the sphenoid bone which varies greatly in shape and size (17). A previous study found 6 distinctive shapes of FO and 5 anomalous variants from the anatomical view (18). Significant variability in the FO's shape and size might affect successful cannulation. Also, poor visualization of FO due to old age of cadaver 1 (88 years) during RF-TR might be one reason.

The TP demonstrated a plexual distribution (97.4%) with anastomoses (96.7%) and somatotopic distribution. At the TP level, somatotopy of sensory fibers is almost clear-cut as in the TG. The shape of the TP was characterized by its triangular form. The characteristic triangular blade of the TP, like a hand in a glove, was formed due to abundant anastomosis (19).

Table 1. *Location of tissue dye appearance of the trigeminal system under microscopic evaluation.*

Cadaver	Gender	Age	Right side	Left side
1	M	88	None	TP
2	F	85	TG	TP
3	M	71	TG	TP
4	F	89	TG	TG
5	F	65	TP	TP
6	F	72	TP	TP
7	F	85	TG	None
8	F	67	TG	TP

TG = trigeminal ganglion, TP = triangular plexus

Table 2. *Vertical and transverse diameter of the triangular plexus.*

Cadaver	Gender	Age (years)	TP (mean VD, cm)	TP (mean TD, cm)
1	M	88	0.7	1.3
2	F	85	0.8	1.2
3	M	71	0.8	1.5
4	F	89	0.8	1.1
5	F	65	0.7	1.2
6	F	72	0.8	1.7
7	F	85	0.8	1.3
8	F	67	0.9	1.4
Average		77.7	0.8	1.3

The vertical and transverse diameter of the triangular plexus from cadaver 1 to 8 were measured at left and right side of the trigeminal system except cadaver 1 which showed only one foramen ovale puncture. M = male, F = female, TP = triangular plexus, VD = vertical diameter, TD = transverse diameter.

In this study, we could confirm the triangular shape of the TP, with its base facing the TG, and its apex being placed on the upper petrous ridge. The average vertical and transverse diameters of the grossly measured TP were 0.8 cm and 1.3 cm, respectively. This size means that the triangular shape of the TP is a broad-based triangle with relatively short height. When placing an electrode on the TP, it is suggested that the V1 and V3 division should be in the most superior-medial and inferior-lateral parts of the TP, respectively. In the cases of V2, it should be placed between the V1 and V3 (20). Therefore, when placing an electrode on the TP, this shape of triangle should be considered. Essentially, this small area of triangle requires more sophisticated movement of an electrode within the TP under the guidance of electrical stimulation.

Table 3. *Microscopic size of nerve bundle in the triangular plexus.*

Cadaver	Right side (μm)	Left side (μm)
1	none	165 ± 105
2	169 ± 86	175 ± 56
3	214 ± 56	203 ± 112.6
4	176 ± 81	134 ± 59
5	158 ± 95	175 ± 104
6	174 ± 91	139 ± 110
7	225 ± 110	242 ± 95
8	180 ± 91	184 ± 95
Average	191 ± 75	183 ± 75

Values are mean ± SD.

Previous study showed that the TP contained bundles of nerve fibers of diameter up to 100 – 150 μm, especially located in the superficial part of the TP (18,21). The diameter of the nerve bundle measured in this study was larger than previous study.

The TG forms a semilunar shape. In contrast to the TP, the TG did not show any plexual distribution without anastomosis nor arachnoid sheet. However, it also showed clear somatotopic distribution like the TP (19).

Microscopically, we could confirm a definite difference between the TG and TP. The TG showed aggregates of ganglion cells with a characteristic round-shaped cell body, whereas the TP showed the nerve bundles with loose connective tissue. The border between the different types of cells of TP and TG could be identified. This is the reason why we tried to identify the location of an injected dye under microscopic examination. There are few studies showing TP-TG junction precisely.

This study demonstrated that when an electrode tip was placed on the PC junction, 53% of RF-TRs could reach the TP. Although controversies exist about the radiologic landmark to reach the TP (6,9,14,15), most pain physicians target the PC junction especially if a patient is suffering V2 TN. A previous case report showed a brain stem injury after RF-TR. In that report, the view of lateral cranial x-ray demonstrated that the electrode tip was located far behind the clival line

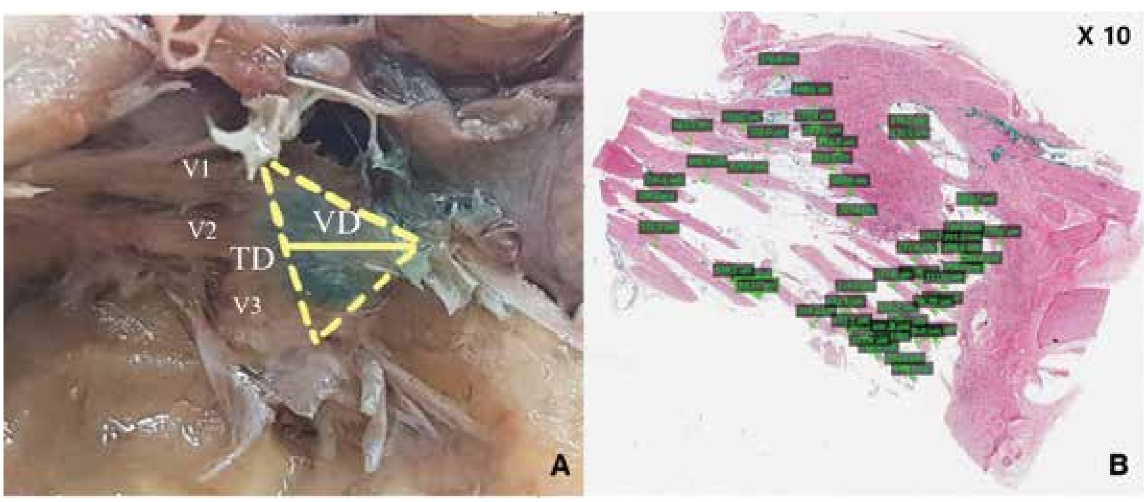

Fig. 4. *Dotted triangle showing measurement of gross size of the triangular plexus (A). Green numerical number within the black rectangle indicates the region where microscopic measurement of the nerve bundle of triangular plexus was performed (× 10) (B). V1 = ophthalmic nerve. V2 = maxillary nerve. V3 = mandibular nerve. TD = transverse diameter. VD = vertical diameter.*

(14). Since a vital structure is located behind the clival line, how far away an electrode should be placed from the clival line is a matter of importance. Sudden blindness can occur as a complication of percutaneous trigeminal procedure if an electrode is not positioned correctly (22). A previous retrospective evaluation of the electrode tip location in RF-TR showed that 69% of RF-TR cases were behind the clival line. Concretely, an electrode tip was located 3.05 – 1.57 mm behind the clival line. Only 7% of RF-TR cases showed that an electrode tip was located precisely on the posterior edge of the clivus (15).

In this study, about half of the RF-TR cases could not reach the TP. During the percutaneous procedure of RF-TR, obtaining a true lateral cranial view is essential to assess the final location of the electrode tip. During the percutaneous procedure, we could encounter some difficulties in obtaining a true lateral cranial view. Two cadavers had distorted necks. Although in such cases, we tried to obtain a true lateral cranial view by rotating to an oblique angle, this phenomenon might affect the decision of the location of the electrode tip.

This study includes several limitations. First, the procedure of RF-TR does not inject any material but the lesioning around the electrode shaft. Therefore, this study for identifying an electrode tip location through an injection of tissue dye might be different from an actual RF-TR in the clinical situation. However, to minimize such difference, we injected a tissue dye as small as 0.2 mL. Usually 0.2 – 0.4 mL of glycerol is injected into the TG to include the trigeminal system (23).

Second, to confirm the location of the electrode tip, only a radiologic landmark was used in this study. However, in the clinical situation of RF-TR, final placement of the electrode should be determined under the guidance of electrical stimulation. Therefore, further study confirming the location of the electrode tip under the guidance of radiologic landmark and electrical stimulation is needed.

Conclusion

In conclusion, when an electrode tip was placed on the PC junction, 53% of RF-TR could reach the TP. The TP showed a triangular shape with an average vertical and transverse diameters of 0.8 cm and 1.3 cm, respectively. Therefore, careful and delicate movement of an electrode within the trigeminal system is required to prevent further damage of vital structures.

Also, further study to improve the safety of percutaneous trigeminal procedure is required.

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