Research Study

Anatomy of the Trigeminal Nerve and Its Clinical Significance Via Fusion of Computed Tomography and Magnetic Resonance Imagery

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Background: The Gasserian ganglion (GG) is the primary neuronal aggregation area of the trigeminal nervous system and the epidural structure outside the central nervous system, thus, it has become the most commonly used target for minimally invasive treatment of trigeminal neuralgia (TN). Whether it is the classic trigeminal radiofrequency treatment or GG balloon compression therapy, the intervention target is the GG. The anatomy and imaging anatomy of the GG of the trigeminal nerve is of great importance in the minimally invasive treatment of TN.

Objective: To study the anatomy of the trigeminal nerve and multimodal image fusion, and to provide a basis for a clinical minimally invasive interventional treatment forTN.

Study Design: Review, clinical research study.

Setting: Department of Anesthesiology and Pain Medical Center, Jiaxing, China.

Methods: Dissect the general structure of the trigeminal nerve and its positional relationship with adjacent structures, and use computed tomography (CT) and magnetic resonance imaging (MRI) to observe the trigeminal nerve, and then, perform a fusion of the CT/MR images.

Results: The GG of the trigeminal nerve is located in Meckel's cave of the middle cranial fossa, and the 3 branches of the nerve fibers are intertwined. CT could only clearly show the bony structures adjacent to the GG, rather than the GG in the body, which was inconsistent with MR images. The bony structure was blurred, while the Meckel's cave and nerve roots, where the trigeminal nerve is located, could be clearly distinguished. Fusing the CT/MR images could provide 2 complementary advantages.

Limitations: It does not prove the the balloon position thought to be a "dumbbell" shape is adequate for the successful treatment.

Conclusion: Based on the anatomical structure and position of the trigeminal nerve, it is difficult to achieve highly selective branch treatment of TN with radiofrequency in the GG. For the treatment of TN with percutaneous microballoon compression on the GG, the balloon catheter should be placed in Meckel's cave. While it is not easy to insert into Meckel's cave, the depth of the balloon catheter should be that the distal end is flush with the top of the temporal bone petrous cone.

Key words: Computed tomography, magnetic resonance imaging, image fusion, trigeminal neuralgia

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The Gasserian ganglion (GG) of the trigeminal nerve is a common target for minimally invasive treatment of trigeminal neuralgia (TN) (1-3). Computed tomography (CT), combined with 3-dimensional imaging functions, can clearly show the trigeminal nerve branching out of the cranial orifices (supraorbital fissure, foramen rotundum, and ovale foramen) and the bony structure where the trigeminal ganglion is located; however Meckel's cave cannot be clearly distinguished. Magnetic resonance imaging (MRI) can clearly show Meckel's cave where the trigeminal nerve (TNR) and GG are located, while the bone markers around the ganglion cannot be reconstructed in 3 dimensions. If CT and MR images of the GG of the TN are fused, the deficiency of the 2 imaging methods can be eliminated, and the GG of the TNR can be presented more clearly, leading to improved minimally invasive treatment of TN.

Methods

Ethical Statement

The anatomical object of the GG of the TNR was an isolated skull specimen; the parietal bone and brain tissue were removed beforehand. The fused CT/MR images of the trigeminal GG were from patients with primary TN who were admitted to our hospital. This study conforms to the requirements and restrictions of the Declaration of Helsinki concerning the ethical principles of medical research on humans as interpreted (4), and was submitted to the Medical Ethics Committee of our hospital for discussion and approval (Ethical approval No.: LS2019-134). An informed consent form was signed by the patients or their families.

Methods

Anatomy of the Gasserian Ganglion of the Trigeminal Nerve

We took the head specimens, whose parietal bone and brain tissue were removed but the dura retained, and then removed the lateral wall of one side of the middle cranial fossa, fully displaying the positions of the TNR and GG. The movement of the GG and 3 branches of the trigeminal nerve in the middle cranial fossa were observed (Fig. 1A). The TNR, GG and the 3 branches are marked with a tiny wire (Fig. 1B), then were scanned by CT. We observed the relationship between the GG of the TNR and the skull by 3-dimensional reconstruction (Fig. 1C).

We then punctured the balloon trocar into the oval foramen, feeding the balloon catheter and filling it with contrast agent to simulate balloon compression to treat TN, and observed the positional relationship between the balloon and the meniscus (Fig. 1D). We then used a contrast agent containing methylene blue to stain the GG and the 3 branches of the trigeminal nerve (Fig. 2A), then ran a CT scan again to observe the positional relationship among the GG, the 3 branches and the skull (Fig. 2B).

CT/MRI Image Fusion of Trigeminal Gasserian-Ganglion

Patients who were diagnosed with TN, had a head CT (Siemens Definition AS 64 row, Siemens, Munich, Germany) and MRI performed after signing informed consent. Siemens Definition AS 64 rows scanning was performed as follows: The patients were supine; a spiral scan of the skull with a thickness of 6 mm, which was reduced to 2.4 mm after treatment, was performed. The baseline was the auditory canthus, and the scanning range was from the skull base to the cranial top. The GE Discovery 750 (GE Healthcare, Chicago, IL) was used for MRI.

The patients were in supine, with T2fs (fat suppression) sequence, with a thickness of 2 mm and an interval of 0.2 mm. The scanning range included the middle and posterior fossa. Image fusion: The CT image of the patients was imported into the Pinnacle 16.2 planning system (Phillips, Best, Netherlands) and set as the Primary image (Primary), and the MR image was set as the fused image (Secondary). After the import, the 2 groups of images were checked to keep the same direction in X, Y, and Z coordinates, and the window width, window level, and image size were adjusted to present the best clarity. According to the contours of the head and face reconstructed from the CT and MR images, and using the positioning mark points during image acquisition as reference marks, manual preliminary registration was performed through image rotation and translation. Then we use normalized mutual information to automatically match 2 sets of images and draw the contours of the body surface, eyeball, brainstem, fourth ventricle and other anatomical structures on MR or CT images, then observed, layer by layer, to judge whether the outline area matched on the 2 sets of images; also observing by reconstructing the coronal and sagittal images. If there was an error, we manually fine-tuned it, and professional physicians and physicists judged the registration effect together until a satisfactory fusion image was obtained.

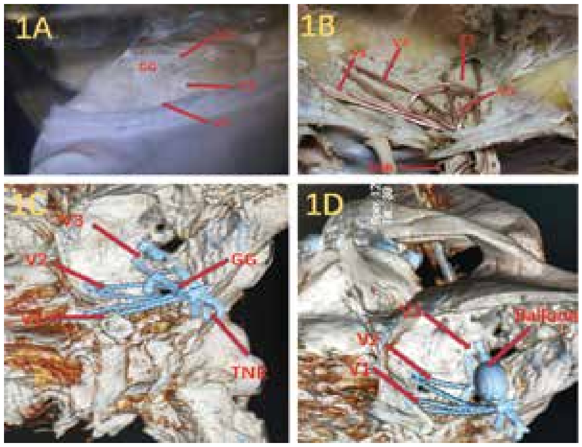

Fig. 1. *A) The gasserian-ganglion(GG) and 3 branches(V1 ,V2 ,V3) of trigeminal nerve in middle cranial fossa. B) The trigeminal nerve root, gasserian-ganglion(GG) and the 3 branches are marked with tiny wire. C) The trigeminal nerve root, gasserian-ganglion(GG) and the 3 branches by CT scanning and 3-dimensional reconstruction. D) Position relationship between the balloon and the gasserian-ganglion during balloon compression treatment of trigeminal nerve on head specimens .*

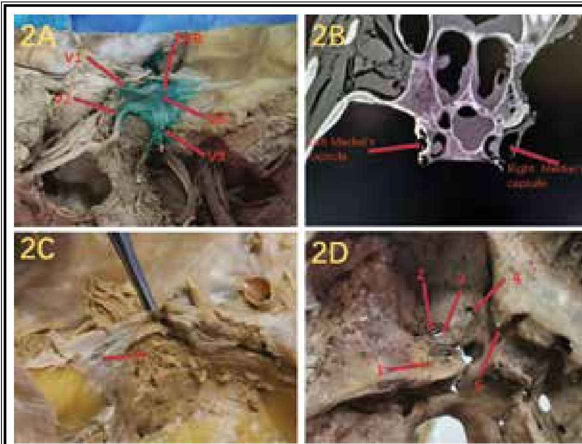

Fig. 2. *A) Use a contrast agent containing methylene blue and Iohexol to stain the gasserian-ganglion and three branches of trigeminal nerve. B) Use a contrast agent containing methylene blue and Iohexol to stain the gasserian-ganglion and three branches of trigeminal nerve, as scanned in the CT semi-coronal position. C) The trigeminal gasserian-ganglion is interlaced with various nerves. D) Overlooking the skull: 1-trigeminal nerve notch; 2-spinous foramen; 3-foramen ovale; 4-foramen rotundum; 5-supraorbital fissure.*

Results

Anatomy of the Trigeminal Nerve, Gasserian Ganglion, and 3 Branches

The structure of the TNR includes 3 branches: the trigeminal nucleus, trigeminal ganglion, and trigeminal nerve (eye branch, maxillary branch and mandibular branch). The trigeminal nucleus is located in the brain stem, which is the aggregation area of secondary neurons of the TNR while the trigeminal ganglion is the gathering area of the first-level trigeminal neuron. Although located in the middle cranial fossa, it is an external structure of the central nervous system and is separate from brain tissue. The 3 branches exit the skull through the superior orbital fissure, and foramen ovale, in turn, and dominate the corresponding facial tissues (Fig. 2C). The GG of the TNR is located in the middle cranial fossa, close to the TNR pressure on the petrosal surface of the temporal bone (lateral to the cavernous sinus) (Fig. 2D).

The extended arachnoid coating is called the trigeminal cistern, or Meckel's cave, in which cerebrospinal fluid surrounds the GG and provides nutrients for it. Outside the capsule there is a cavity formed by the dura mater, which is Meckel's cave. The cavity is the dural structure of the petrous tip of the temporal bone. It is a diverticulum formed by 2 layers of dural fissures at the bottom of the middle cranial fossa. It is the dura mater and arachnoid sheath surrounding the TNR and GG. The cavity has upper, lower, anterior, posterior, and inner and outer side walls, all of which are composed of dura mater. The posterior wall is incomplete, with a trigeminal foramen connected to the prepontine cistern.

The cavity is shaped like a 3-fingered glove. It contains the TNR, Meckel's cave, the TNR and the GG in the capsule and its 3 branches. The anterior and upper walls are adjacent to the venous space behind the cavernous sinus, the outer wall is the dura mater on the inner wall of the middle cranial fossa, the anterior part of the inner wall is adjacent to the posterior ascending part of the cavernous sinus segment of the internal carotid artery, and the posterior part of the wall is attached to the periosteum adjacent to the petrous bone tip. The V1 pair of cranial nerves is sandwiched between the upper part of Meckel's cave and the internal carotid artery, and the lower part is composed of the dura mater or thin bone slices.

The GG contains sensory and motor neurons. It receives sensory afferents from the 3 sensory branches of the trigeminal nerve and sends sensory information to the brain stem via the GG. This sensory information is transmitted from the brainstem to the thalamus and the sensory areas of the opposite brain. The motor branch of the TNR receives information from the motor area of the cerebral cortex. This information crosses the brainstem, passes through the GG, and finally descends to control the movement of the chewing muscles.

Imaging Anatomy of the Trigeminal Nerve, Gasserian Ganglion, and 3 Branches

Because Meckel's cave in the in vitro head specimen had dried up, in addition to the bony structure, the ellipsoidal Meckel's cave outside the ascending part of the internal carotid artery cavernous segment was also clearly discernable on CT scanning (Fig. 2B), but it could not show the 3 branches of the trigeminal nerve. Therefore, we delineated the TNR, GG and 3 branches with a fine metal wire or injected methylene blue containing contrast agent into the above group, and then reconstructed the 3-dimensional relationship between the TNR structure and the skull by CT scanning (Figs. 1B-D,2A-B). In vivo CT images could also accurately and clearly show the cranial holes of each branch of the TNR, whereas it could not show Meckel's cave and the meniscus within. On the other hand, in MR images, the TNR (Fig. 3A), Meckel's cave and the GG were particularly clear, and even the V1 branch of the TNR was clearly identified (Fig. 3B). However, the bone wall on the medial side of the GG was blurred.

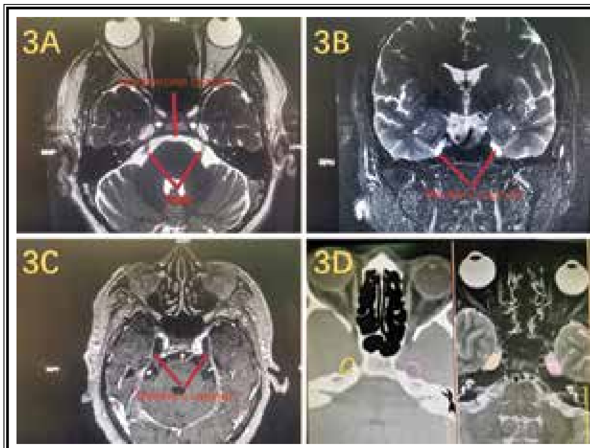

Fig. 3. *A) T2 image of MRI can clearly show the trigeminal nerve roots. B) T2 image of MRI can clearly show the Meckel's capsule where the gasserian ganglion of trigeminal nerve is located. C) T1 image of MRI can clearly show the Meckel's capsule where the gasserian ganglion of trigeminal nerve is located. D) CT/MRI image fusion can show the Meckel's capsule.*

CT/MRI Image Fusion of the Meniscus of the Trigeminal Nerve

After fusion of the head CT/MR images, the position of the GG could be clearly delineated on the CT image, so that the positional relationship between Meckel's cave where the GG and the position of the head could be visually presented (Figs. 3C,3D).

Discussion

TN is one of the most common types of head and face pain seen in a clinic. Due to the severe pain, it affects the patient's daily life such as speaking, eating, washing the face, and brushing the teeth, and often makes the patient miserable. GG is the primary neuronal aggregation area of the trigeminal nervous system and the epidural structure outside the central nervous system, thus, it has become the most commonly used target for minimally invasive treatment of TN. Whether it is the classic trigeminal radiofrequency treatment or GG balloon compression therapy (5), the intervention target is the GG. Therefore, the anatomy and imaging anatomy of the GG of the TNR is of great importance in the minimally invasive treatment of TN. However, the GG is located in Meckel's cave in the middle cranial fossa, whose location is deep. So it is impossible to be shown by C-arm x-ray, ultrasonic imaging, or even more advanced CT scanning in vivo. Therefore, the classic x-ray image-guided radiofrequency or balloon compression operation of GG depends on the relative position of the skull as well as operator experience.

Since the GG and 3 branches in vivo cannot be shown on a CT image, we delineated the dissected TNR, the GG, and 3 branches with fine metal wire when dissecting the TNR of a cranial specimen. After CT scanning and reconstruction, the relationship between the TNR structure and the skull position can be relatively intuitively revealed (Figs. 1C, 1D), thereby providing a reference for clinical operation and teaching.

However, this kind of TNR anatomical structure delineation was relatively inaccurate. We injected methylene blue containing a contrast agent into the TNR structure of the skull specimen for stain tracing (Figs. 2B, 2C), however, the imaging results were not satisfactory because the TNR structure was not uniformly stained. Since the imaging mechanism of MRI is different from that of CT, it relies on the rearrangement of positively charged H+ protons under a strong magnetic field, so it has a strong display ability for soft tissues with high water content; thus it can display the TNR, the GG, and 3 branches (Figs. 3A-C). However, due to the low water content of the bone structure, MRI is relatively fuzzy. MRI is relatively time consuming, and if MRI is used to guide clinical puncture operation, special needles and instruments that can enter a strong magnetic field must be used, so it is not suitable for large-scale clinical application at present. For this reason, we assumed that CT and MR images can be combined to integrate their advantages in developing bone structure and soft tissue, so that the image structure of the TNR can be presented more intuitively in the same fusion image.

CT/MRI image fusion technology is a kind of image postprocessing method which originated in the 1990s. Using computer multimode image technology to integrate them together results in synchronous visualization of multiple information. Medical imaging plays an intuitive complementary role, can improve the accuracy of clinical diagnosis and treatment, not only avoids the tedious need for multiple films during viewing but also effectively reduces subjective errors caused by subjective judgment. Therefore, this technology is recognized and used in clinical tumor radiotherapy (6). Weltens C et al (7) analyzed the application of CT/MR image fusion in brain tumors. Nishioka T et al (8) reported the diagnostic effect and value of CT/MR image fusion technology in CT patients with nasopharyngeal carcinoma. So et al (9) and Wong et al (10) reported the application and value of CT/MR images fusion in radiotherapy of bone metastases. The above literature all believe that CT/MR image fusion can obtain respectively the advantages of high density bone tissue or calcification and low density soft tissue with high water content, which is conducive to the precise location and radiotherapy of tumor foci and radiotherapy.

After being performed on the head of the same patient by CT scan and MRI, we found that the TNR structure in vivo could not be displayed on the CT images, but the bony structures such as the TNR impression can be clearly distinguishable. The TNR, the GG, and the branches of the TNR can be clearly displayed on MR images, while the surrounding bony markers are blurred. After CT/MR image fusion, the position relationship between the GG and its surrounding bone structure can be clearly delineated (Figs. 3D, 4A), which can provide a clearer view for minimally invasive interventional treatment of TN than CT or MRI for reference.

By studying the anatomy of the TNR and the fusion of CT/MRI multimode images, the following 2 clinical ideas can be provided for the minimally invasive interventional treatment of trigeminal neuralgia:

1) The classic GG radiofrequency is difficult to realize the highly selective treatment of TNR branches.

Because the nerve fibers of the branches of the TNR are intertwined and arranged (Fig. 2C), it is inappropriate to select the treatment target in the GG for highly selective radiofrequency treatment of a certain branch, and it may be futile to try to achieve high selective radiofrequency treatment by adjusting for the position of the radiofrequency needle in the GG. It is therefore more appropriate to transfer the target of radiofrequency therapy from the classic intracranial GG to cranial orifices of each branch that exits the extracranial TNR (e.g., supraorbital fissure, foramen rotundum, and foramen ovale), in order to achieve highly selective branch therapy.

This method not only eliminates the problem of high selectivity of radiofrequency therapy, but also avoids the needle entering the cranium, so that it can avoid serious complications, such as intracranial hemorrhage and infection associated with a puncture. This theory has been confirmed by the multicentric clinical study of Huang et al(11,12), and the technical specifications for the treatment of TN with CT-guided extracranial non-GG radiofrequency have been formulated, making the radiofrequency treatment of TN more accurate, efficient, and safe.

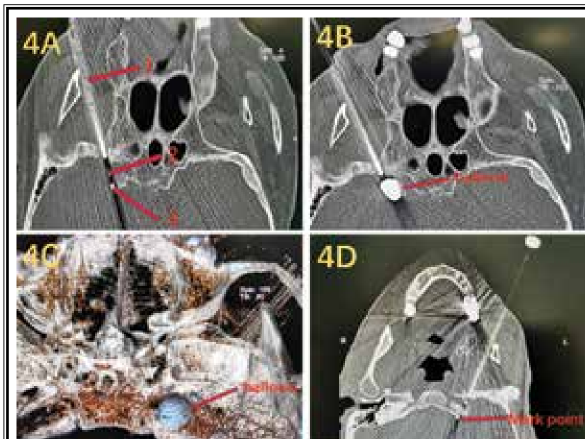

Fig. 4. *A) In clinical practice, balloon compression treatment of trigeminal neuralgia in the balloon catheter distal Mark should be in line with the temporal bone petrous cone. 1-puncture needle; 2-balloon catheter; 3-Mark point at the distal end of the catheter. B) In clinical, the balloon's normal shape and position. C)In clinical, the balloon's normal shape and position after three-dimensional reconstruction. D) The balloon catheter was too deep in the treatment of trigeminal neuralgia, and the distal Mark point was over the tip of temporal bone petrous cone.*

2) During GG compression therapy, the balloon catheter should be located in Meckel's cave, and the distal end should not exceed the apex of the petrous cone of the temporal bone.

Meckel's cave is where the GG is located and is surrounded by the dura mater of the middle cranial fossa and the wall of the petrosal bone. The inner wall is the TNR depression (Fig. 2D), anteromedial adjacent to the posterior ascending part of the cavernous segment of the internal carotid artery. The posterior part is connected to the anterior cistern and the trigeminal foramen, thus, the GG was lateral to the trigeminal hole. Huang et al (13) summarized their clinical experience and pointed out that the distal end of the balloon catheter should be flush with the tip of the petrous cone of the temporal bone during balloon compression (Fig. 4A). At this time, the filling balloon can compress the GG in Meckel's cave on the TNR pressure (Figs. 4B, 4C). If the catheter crosses the tip of the petrous cone and enters the posterior cranial fossa (Fig. 4D), the filled balloon will be compressed by the trigeminal hole into a dumbbell shape (Figs. 5A, 5B), which might not affect the therapeutic effect of TN, but might cause diplopia complications due to compression of the abducens nerve root.

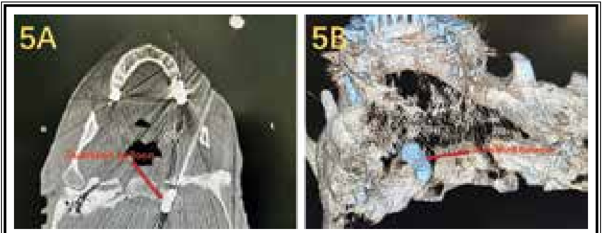

Fig. 5. *A) The balloon catheter was too deep, and the distal Mark point crossed over the tip of temporal bone petrous cone. When the balloon was filled, it showed a dumbbell shape due to the squeeze of the trigeminal foramen. B) In clinical, the balloon's dumbbell shape and position after 3-dimensional reconstruction.*

Limitations

It is not clear that the balloon position thought to be a "dumbbell" shape is in fact that, and may be adequate for successful treatment. In a subsequent study, we propose a series of patients be treated by balloon compression in which the final position of the balloon is documented by CT/MR fusion and results.

Conclusions

Based on the anatomical structure and position of the TNR, it is difficult to achieve highly selective branch treatment of TN with radiofrequency in the GG. For the treatment of TN with percutaneous microballoon compression of the GG, the balloon catheter should be placed in Meckel's cave. However, it is not easy to insert into Meckel's cave, and the depth of the balloon catheter should be such that the distal end is flush with the top of the temporal bone petrous cone.

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