Endoscopic approaches to the trigeminal nerve and clinical consideration for trigeminal schwannomas: a cadaveric study

Laboratory investigation

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Object. The course of the trigeminal nerve straddles multiple fossae and is known to be very complex. Comprehensive anatomical knowledge and skull base techniques are required for surgical management of trigeminal schwannomas. The aims of this study were to become familiar with the endoscopic anatomy of the trigeminal nerve and to develop a minimally invasive surgical strategy for the treatment of trigeminal schwannomas.

Methods. Ten fresh cadavers were studied using 5 endoscopic approaches with the aid of 4-mm 0° and 30° endoscopes to identify surgical landmarks associated with the trigeminal nerve. The endoscopic approaches included 3 transcranial keyhole approaches (the extradural supraorbital, extradural subtemporal, and retrosigmoid approaches), and 2 endonasal approaches (the transpterygoid and the transmaxillary transpterygoid approaches).

Results. The trajectories of the extradural supraorbital, transpterygoid, and extradural subtemporal approaches corresponded with the course of the first, second, and third divisions of the trigeminal nerve, respectively. The 3 approaches demonstrated each division in intra- and extracranial spaces, as well as the Meckel cave in the middle cranial fossa. The interdural space at the lateral wall of the cavernous sinus was exposed by the extradural supraorbital and subtemporal approaches. The extradural subtemporal approach with anterior petrosectomy and the retrosigmoid approach visualized the trigeminal sensory root and its neighboring neurovascular structures in the posterior cranial fossa. The transmaxillary transpterygoid approach revealed the course of the third division in the infratemporal fossa.

Conclusions. The 5 endoscopic approaches effectively followed the course of the trigeminal nerve with minimal invasiveness. These approaches could provide alternative options for the management of trigeminal schwannoma.

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Key Words • endoscopy • schwannoma • skull base • trigeminal nerve

TRIGEMINAL schwannoma is rare, but it is the second most common schwannoma after vestibular schwannoma. Schwann cell tumors arise from any section of the trigeminal nerve, and a variety of symptoms and signs may develop as a result. The tumors are usually benign and can be cured by radical resection. To date, several microsurgical strategies have been developed, and excellent results have been reported. However, because trigeminal schwannomas often present with complicated developing patterns, skull base techniques based on comprehensive anatomical knowledge are necessary for radical removal of the tumor. Also, for reaching trigeminal schwannomas in the middle cranial fossa, the importance of using the interdural space between the inner and outer layers of the lateral wall of the cavernous sinus has been emphasized for reducing morbidity.

In addition to continued development of microscopic surgical techniques, the recent advent of the endoscope has facilitated the use of less invasive surgical methods in a neurosurgical setting, and successful resections by endoscopic endonasal approaches have been described for trigeminal schwannomas in the Meckel cave and the infratemporal fossa. We previously studied purely endoscopic extradural, supraorbital, and subtemporal approaches (F. Komatsu et al., unpublished data) in the laboratory to manage skull base neoplasms. The endoscopic extradural approaches offer less invasive transcranial routes to the central skull base and have the potential to manage trigeminal schwannomas. The aims of this study are to better understand the course of the trigeminal nerve and its related anatomical landmarks by 5 different endoscopic approaches, including 3 transcranial routes (the extradural supraorbital, extradural subtemporal, and retrosigmoid approaches) and 2 endonasal routes (the transpterygoid and transmaxillary transpterygoid approaches), and to consider a minimally invasive surgical strategy for trigeminal schwannomas based on the endoscopic anatomy.

Abbreviations used in this paper: GSPN = greater superficial petrosal nerve; ICA= internal carotid artery.
Endoscopic anatomy of the trigeminal nerve

Methods

All anatomical dissections were performed in the Laboratory of Microsurgical and Endoscopic Anatomy at the Medical University of Vienna. The protocol of this study was approved by the local institutional research committee. Ten fresh cadaver heads were used. Two of the 10 specimens were injected with red and blue silicone to the arterial and venous systems, respectively. In the other 8 specimens, only the arterial system was injected with red silicone, and the venous system was not injected to facilitate recognition of the cavernous sinus nerves. A 4-mm-diameter endoscope was used that measured 18 cm in length, with 0° and 30° rod lenses (Karl Storz GmbH and Co.) connected to a light source via a fiber optic cable and to a camera fitted with 3-chip, high-definition sensors. Both video and digital images were recorded during dissection. Single-shaft instruments for endoscopic endonasal surgery were used for all dissection procedures. Three endoscopic transcranial keyhole approaches (the extradural supraorbital, extradural subtemporal, and retrosigmoid approaches) and 2 endoscopic endonasal approaches (transpterygoid and transmaxillary transpterygoid approaches) were performed (Fig. 1). Cadaveric heads were positioned to simulate the surgical position in each approach.

Results

Endoscopic Extradural Supraorbital Approach

After a 4-cm skin incision and supraorbital keyhole craniotomy (2.5 cm in width, 1.5 cm in height), a 4-mm 30° endoscope was inserted into the extradural space by peeling off the dura mater. The endoscope was directed posteriorly until the sphenoid ridge appeared and then medially to identify the orbital roof and the base of the anterior clinoid process (Fig. 2A). The lateral part of the anterior cranial fossa, including the frontal bone and the lesser and greater wings of the sphenoid bone, were removed using a drill until the dorsal aspect of the middle cranial fossa dura was exposed. The orbital roof was also removed by drilling. Hence, the superior and lateral margins of the superior orbital fissure were opened (Fig. 2B). In addition, an extradural endoscopic anterior clinoidectomy and optic canal unroofing were performed using a 4-mm 0° endoscope, visualizing the clinoidal (Dolenc) triangle, carotidoculomotor membrane, and the clinoid segment of the ICA (Fig. 2C). Then, the periosteal dura mater of the dural fold stretching between the periorbita and middle cranial fossa dura was sharply divided, and the dural layers of the lateral wall of the cavernous sinus were bluntly separated into inner and outer layers, and the interdural space between the 2 layers was expanded (Fig. 2D). The sphenoparietal sinus draining into the cavernous sinus was exposed and cut during separation of the 2 layers (Fig. 2E). After exposure of the lateral wall of the cavernous sinus, the oculomotor nerve and the trochlear nerve were identified. The temporal lobe, still covered with dura, was retracted laterally, and the first division of the trigeminal nerve (V1), second division of the trigeminal nerve (V2) with the foramen rotundum, and the third division of the trigeminal nerve (V3) with the foramen ovale, gasserian ganglion, and Meckel cave were visualized through a semitransparent inner dural layer without intruding into the cavernous sinus and subdural space (Fig. 2F). The trajectory of this approach corresponded with the course of V1. The trigeminal sensory root in the posterior cranial fossa was not recognizable with this approach.

Endoscopic Extradural Subtemporal Approach

A 4-cm vertical linear skin incision was made just anterior to the tragus from the inferior rim of the zygomatic arch, and a keyhole craniotomy (2.0 cm in width, 2.5 cm in height) was performed just above the posterior zygomatic root. A 4-mm 0° endoscope was introduced into the extradural space, and the middle cranial fossa dura was peeled away from the middle cranial fossa floor. The middle meningeal artery was exposed and cut at its cranial entrance, and the V3 with the foramen ovale appeared anteromedially (Fig. 3A). The GSPN was exposed from the dural adhesion, and the dura elevation reached the petrous ridge. Four anatomical landmarks—the trigeminal impression, GSPN, petrous ridge, and arcuate eminence—were identified (Fig. 3B). The lateral wall of the cavernous sinus was then separated into 2 layers, inner and outer, at the upper border of the V3. The outer layer was elevated, and the interdural space was exposed. After this, each division of the trigeminal nerve, gasserian ganglion, and Meckel cave were visualized.
rian ganglion, and the Meckel cave were visible. The oculomotor and trochlear nerves were visualized at the upper limit of the exposure (Fig. 3C).

After successful exposure of the lateral wall of the cavernous sinus, the middle cranial fossa floor around the foramen ovale was drilled off to follow the course of the V3. The superior part of the infratemporal fossa was exposed, and the V3 gave rise to the buccal nerve and the deep temporal nerve on the upper head of the lateral pterygoid muscle. The upper and lower heads of the lateral pterygoid muscles were removed, and the superior part of the infratemporal fossa was displayed, exposing the maxillary artery and the lateral pterygoid plate (Fig. 3D).

An endoscopic anterior petrosectomy was performed to demonstrate the sensory root of the trigeminal nerve in the anterolateral space in the posterior cranial fossa. The anterior petrous bone, which was surrounded by the trigeminal ganglion anteriorly, the cochlea, and the arcuate eminence posteriorly, was drilled off, and the posterior cranial fossa dura was exposed. The dural incisions were made above and beneath the superior petrosal sinus, and the superior petrosal sinus was divided. The tentorium and posterior cranial fossa dura were incised, and the trigeminal sensory root and its neighboring structures in the posterior cranial fossa are demonstrated. AE = arcuate eminence; AF = acoustic-facial bundle; AICA = anterior inferior cerebellar artery; AT = auriculotemporal nerve; BN = buccal nerve; DN = deep temporal nerve; FO = foramen ovale; FR = foramen rotundum; FS = foramen spinosum; MA = maxillary artery; MC = Meckel cave; MD = middle cranial fossa dura; MMA = middle meningeal artery; PC = petrosal segment of the ICA; PO = anterolateral aspect of the pons; PP = lateral pterygoid plate; PR = petrosus ridge; SCA = superior cerebellar artery; TI = trigeminal impression; TL = temporal lobe; TS = trigeminal sensory root; IV = trochlear nerve; VI = abducent nerve.
Endoscopic anatomy of the trigeminal nerve

Endoscopic Retrosigmoid Approach

After a 4-cm straight skin incision, a 2.5-cm craniotomy was made at the edges of the transverse and sigmoid sinuses. The dura mater was opened, and an endoscope was introduced between the tentorial surface of the cerebellum and the tentorium cerebelli. Bridging veins were visible on the tentorial surface of the cerebellum, and the bridging veins were sectioned when they obscured the course of the trigeminal nerve (Fig. 4A). The endoscope advanced along the anterolateral margin of the cerebellum, and the trigeminal sensory root and Meckel cave came into view anterior to the petrosal vein. The superior cerebellar artery ran superior to the trigeminal nerve. The trochlear nerve coursed anteriorly along the lower margin of the tentorium, and it pierced the free edge of the tentorium in the posterior part of the oculomotor trigone. The oculomotor nerve followed its course anterior to the midbrain (Fig. 4B). The endoscope was then inserted between the petrosal surface of the cerebellum and petrous bone, and relationships between the trigeminal sensory root, acoustic-facial bundle, and glossopharyngeal and vagus nerves were demonstrated (Fig. 4C). The endoscope proceeded toward the trigeminal nerve, and the abducent nerve and the basilar artery were identified anterior to the trigeminal nerve (Fig. 4D).

Endoscopic Endonasal Transpterygoid Approach

To approach the infratemporal fossa, the sphenoidectomy and ethmoidectomy were performed as mentioned previously. The inferior turbinate and the medial maxillary wall were removed, and the posterior wall of the maxillary sinus was widely exposed (Fig. 6A). The posterior wall of the maxillary sinus was completely removed to open the pterygopalatine fossa, and the branches of the maxillary sinus are partially covered with ICA and the abducent nerve. Asterisks indicate the middle cranial fossa dura. Right: Contents of the pterygopalatine fossa and the pterygoid process were partially removed to show the anatomical relationship between the vidian nerve and V3. The V3 is located lateral to the vidian nerve, and the vidian nerve prevents further exposure of V3. The course of V2 corresponds with the trajectory of the transpterygoid approach. CL = clivus; FR = foramen rotundum; MC = Meckel cave; PG = pituitary gland; PV = posterior vertical segment of the ICA; VN = vidian nerve; II = optic nerve; VI = abducent nerve.
artery in the pterygopalatine fossa were demonstrated from fat tissue. The arterial system in the pterygopalatine fossa was isolated from fat tissue (Fig. 6B). The arterial system in the pterygopalatine fossa was isolated from fat tissue. We list the superficial and deep bellies (lateral and medial portions) of the temporal muscle were easily recognizable and occupied most of the infratemporal fossa. The lower head of the lateral pterygoid muscle originated from the lateral pterygoid plate medial to the deep belly of the temporal muscle. The upper and lower heads of the lateral pterygoid muscle were removed to identify the foramen ovale, while the endoscope proceeded posteriorly along the base of the lateral pterygoid plate. The maxillary artery was usually visible ventrally between the lower head of the lateral pterygoid muscle and the deep belly of the temporal muscle. Once the foramen ovale was recognized behind the lateral pterygoid plate, the lateral pterygoid plate was partially removed to improve the exposure of the V3. Hence, the buccal nerve, deep temporal nerve, lingual nerve, and inferior alveolar nerve were demonstrated.

Discussion

The 5 different endoscopic approaches described in this study effectively demonstrated the course of the trigeminal nerve, related anatomical structures, and the multiple fossae with superb illumination. We list the surgical plans for efficient removal of the different classes of trigeminal schwannomas in Table 1.

The characteristics of trigeminal schwannomas have been well described in previous reports. The majority of the tumors of the trigeminal nerve have a soft consistency and are almost avascular in nature. Trigeminal schwannomas are well defined from neighboring neurovascular structures, and cranial nerves and the ICA are usually displaced rather than engulfed. When the tumors lie in the middle cranial fossa, they are situated in the interdural space, which is between the inner and outer layers of the lateral wall of the cavernous sinus. They do not intrude into the cavernous sinus and subdural space. Therefore, tumor removal itself is relatively easy, and the lesion can be removed most safely by using the interdural space. The complicated development patterns that characterize trigeminal schwannomas have prompted several authors to classify them into distinct categories. According to the classification by Yoshida et al., tumors involving only 1 compartment are classified into the following 3 types: Type M, middle cranial fossa tumor in the interdural space; Type P, posterior cranial fossa tumor in the intradural space; and Type E, extracranial tumor in the extradural space. Tumors in multiple compartments are classified as Type MP, which are dumbbell-shaped tumors in the middle and posterior cranial fossae, and Type ME, which are dumbbell-shaped tumors in the middle cranial fossa and the extracranial space. We subdivided Type E tumors into categories by location, with E1 in the orbit, E2 in the pterygopalatine fossa, and E3 in the infratemporal fossa. Effective exposure and visualization of the components, which are affected by the tumors, and using the interdural space at the lateral wall of the cavernous sinus seem to be of paramount importance for successful surgical outcome of trigeminal schwannoma.

We devised an endoscopic surgical strategy for trigeminal schwannomas based on the results of this study as follows. Type M tumors could be managed by 3 endoscopic approaches. The extradural supraorbital or subtemporal approach could be used to treat the tumors from an anterolateral or lateral trajectory, respectively. The extradural transcranial approaches adequately exposed the interdural space at the lateral wall of the cavernous sinus under endoscopic manipulation and distinctly visualized the trigeminal nerve and surrounding structures. The endonasal transpterygoid approach is the only route for removing Type M tumors without brain retraction from an anteromedial trajectory; however, the amount of exposure of the middle cranial fossa is limited compared with the extradural supraorbital or subtemporal approaches. In cases of Type ME tumors, the optimal approach should be decided by which divisions of the trigeminal nerve are affected by the tumors. The course of the V1 corresponds with the trajectory of the extradural supraorbital approach, and the approach clearly demonstrated the orbit, superior orbital fissure, and the lateral wall of the cavernous sinus, indicating suitability for Type ME1 or E1 tumors originating from the V1. By the same token, the transpterygoid approach effectively exposed the pterygopalatine fossa, foramen rotundum, and Meckel cave along the course of the V2, and the transpterygoid approach could properly manage Type ME2 or E2 tumors. The V3 in the middle cranial fossa and the foramen ovale are easily identifiable by the extradural subtemporal approach, and the V3 can
be followed up to the superior part of the infratemporal fossa by drilling off the middle cranial fossa floor. A Type ME3 tumor with small infratemporal fossa extension could be resected by the extradural subtemporal approach. However, the transmaxillary transpterygoid approach would be more suitable for Type ME3 tumors that are mainly located in the infratemporal fossa or for Type E3 tumors, rather than the extradural subtemporal route.2,9,22 With respect to dumbbell-shaped Type MP tumors, the extradural subtemporal approach can optimally display the structures around the Meckel cave, and endoscopic anterior petrosectomy or anterior petrous bone erosion by a trigeminal schwannoma would create a corridor to the posterior cranial fossa. Because endoscopy clearly visualizes neurovascular structures in the posterior cranial fossa via a subtemporal route, this approach may increase the likelihood for successful removal of the dumbbell-shaped Type MP tumors during a single-stage operation.19 The retrosigmoid approach would be required in cases of Type MP tumors whose main components are in the posterior cranial fossa or Type P tumors.

In addition to excellent exposure and visualization of skull base structures, endoscopy offers a less invasive procedure and has the potential advantages of promoting early recovery and reducing a patient's discomfort during the postoperative period. According to previous descriptions, 11.1%–60.3% of patients with trigeminal schwannomas have mastication problems attributed to trigeminal motor root dysfunction.4,7,17,20,23,25 Keyhole surgery eliminates temporal muscle elevation and zygomatic osteotomy, which is performed using a conventional craniotomy. Therefore, mastication function is more likely to be preserved even through transcranial routes. Furthermore, the temporal muscle is often used as a pedicle flap for reconstruction of the middle cranial fossa when conventional extradural approaches with skull base techniques are performed. To avoid harvest of the temporal muscle and associated morbidity, we have developed a reconstruction method using the deep temporal fascia.16 The pedicled deep temporal fascial flap, which is harvested endoscopically, could be applied for middle cranial fossa reconstruction even through a subtemporal keyhole. Endoscopic extradural keyhole surgery would be beneficial for the quality of life of patients with trigeminal schwannoma who already have mastication problems as symptoms.

Although endoscopic keyhole approaches offer minimally invasive surgery, purely endoscopic surgery via transcranial intradural routes is somewhat controversial. The endoscope clearly visualizes focal structures in deep-seated areas. On the other hand, it cannot display an overview of the surgical field. Purely endoscopic manipulation carries risks of neurovascular injury proximal to the endoscopic tip by inserting and withdrawing instruments in the intradural space. In contrast to intradural space, because extradural space is basically surrounded by bones and dura mater and does not contain vital structures, purely endoscopic keyhole surgery in extradural space could be carried out safely. Regarding the retrosigmoid approach, it surely displays neurovascular structures in the posterior cranial fossa but only uses intradural space. Therefore, endoscope-assisted microsurgery would be safer than purely endoscopic surgery.

### TABLE 1: Features of endoscopic approaches to the trigeminal nerve

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<tr>
<th>Approach</th>
<th>Tumor Type &amp; Exposure</th>
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<tr>
<td>extradural supraorbital</td>
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<td>E1 = orbit; E2 = pterygopalatine fossa; E3 = infratemporal fossa</td>
<td>extradural subtemporal</td>
<td>extradural transpterygoid</td>
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<td>E1 = orbit; E2 = pterygopalatine fossa; E3 = infratemporal fossa</td>
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- **E1 = orbit; E2 = pterygopalatine fossa; E3 = infratemporal fossa**
- **M = middle cranial fossa; P = posterior cranial fossa**
- **† Limited exposure.**
Finally, we demonstrated the endoscopic anatomy of the trigeminal nerve with surgical landmarks and proposed an endoscopic surgical strategy for trigeminal schwannoma. However, as this is only a cadaveric study, follow-up reviews after clinical applications are thus required.

Conclusions

Endoscopic approaches including the extradural supraorbital, extradural subtemporal, retrosigmoid, transpterygoid, and transmaxillary transfacial approaches effectively and clearly visualized the course of the trigeminal nerve, related anatomical landmarks, and multiple fossae. It is possible that endoscopic extradural supraorbital and subtemporal approaches could expose the interdural space at the lateral wall of the cavernous sinus under purely endoscopic manipulation with safety. Based on the described strategy, the endoscopic approaches could manage trigeminal schwannomas with minimal invasiveness and may contribute to early recovery of patients and lower morbidity after operation.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: F. Komatsu. Acquisition of data: F. Komatsu, M. Komatsu. Analysis and interpretation of data: all authors. Drafting the article: F. Komatsu. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: F. Komatsu. Administrative/technical/material support: Tschabitscher. Study supervision: Tschabitscher.

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