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Received, July 5, 2005.

Accepted, January 26, 2006.



THE COMBINED TRANSMASTOID RETRO- AND INFRALABYRINTHINE TRANSJUGULAR TRANSCONDYLAR TRANSTUBERCULAR HIGH CERVICAL APPROACH FOR RESECTION OF GLOMUS JUGULARE TUMORS

COMPLEX TUMORS OF the glomus jugulare present a surgical challenge because of their difficult location, extreme vascularity, and involvement with multiple cranial nerves. Modern microneurosurgical and cranial base techniques have enabled safe total removal of these complicated tumors. We describe a one-stage transjugular posterior infratemporal fossa approach for radical resection of glomus jugulare tumors located around the jugular foramen, the lower clivus, and the high cervical region from an anterolateral direction. This approach is a combination of transmastoid, suprajugular, transjugular, extreme lateral infrajugular transcondylar transtuberular, and high cervical approaches. Total exposure of the jugular foramen can be achieved, and multidirectional approaches can be performed, including infralabyrinthine/suprajugular, retrosigmoid/transcondylar/infrajugular, and transjugular exposures. Exposure of the vertical C7 segment of the infratemporal internal carotid artery and the lower clivus can be performed without permanent rerouting of the facial nerve. The details of this approach are described and illustrated in a stepwise fashion, and the microsurgical anatomy is reviewed.

KEY WORDS: Cranial base approach, Glomus jugulare tumor, Jugular foramen exposure, Microsurgical anatomy

Neurosurgery 59(ONS Suppl 1):ONS-115-ONS-125, 2006

DOI: 10.1227/01.NEU.0000220025.81500.8D

Glomus jugulare tumors are formidable lesions of the cranial base. Guild (14) was the first to coin the term, “glomus jugularis,” or jugular body, to describe paraganglionic tissue composed largely of capillary or precapillary vessels interspersed with numerous epithelioid cells found along the jugular bulb in human temporal bone specimens. He also noted that approximately half of these “glomus tumors” were situated in the adventitia of the jugular bulb dome, and half were situated along the course of the tympanic branch of the glossopharyngeal nerve (Jacobson’s nerve) or the auricular branch of the vagus nerve (Arnold’s nerve). This division eventually led to the distinction of glomus tympanicum tumors (glomus tumors arising from the middle ear) and glomus jugulare tumors (glomus tumors arising from the region of the jugular bulb) (3, 28). Larger tumors involving both regions have been termed “glomus jugulotympanicum” tumors

(23, 33, 35). The majority of glomus jugulare tumors are benign; in rare occasions, they exhibit malignant pathology (2).

The surgical removal of these tumors remains a challenge. They may involve adjacent structures, such as the jugular bulb, carotid artery, middle ear, petrous apex, clivus, infratemporal fossa, and posterior fossa. Two grading systems have been developed to classify glomus tumors on the basis of their location, size, and extent of disease: the Fisch classification (8, 21) and the Glasscock-Jackson classification (17, 18). These classification systems can facilitate operative planning and provide a system for reporting and analysis of surgical results.

Advances in neuroimaging, microneurosurgery, and modern cranial base surgery have allowed safe resection of these tumors with lower rates of morbidity and mortality (1, 2, 4, 6, 9, 11–13, 15–18, 20, 27, 35). Total removal of these tumors increases the likelihood of

achieving surgical cure. Fisch (7, 8) has described several lateral infratemporal fossa approaches for resection of large glomus jugulare tumors (Fisch Type C and D) that emphasize transection and blind sac closure of the external ear canal, permanent rerouting of the facial nerve, and anterior displacement of the mandible for exposure of the vertical infratemporal C7 segment of the internal carotid artery. These maneuvers may result in conductive hearing loss, facial nerve palsy, and problems with jaw opening or mastication, respectively. A combined two-stage resection has also been advocated for Fisch Type D2 tumors (tumors with intracranial extension greater than 2 cm in diameter) (8, 10).

We describe a one-stage transjugular posterior infratemporal fossa approach that allows radical resection of tumors that are located around the jugular foramen, the lower clivus, and the high cervical region from an anterolateral direction. This approach is a combination of the transmastoid, retro- and infralabyrinthine, transjugular, extreme lateral infrajugular transcondylar transtuberular, and high cervical approaches. Total exposure of the jugular foramen can be achieved, and multidirectional approaches can be performed, including suprajugular (infralabyrinthine), transjugular, and infrajugular (retrosigmoid/transcondylar) exposures. Both intracranial and extracranial tumor can be removed in a one-stage procedure. Glomus tumors, schwannomas of the lower cranial nerves, meningiomas, chordomas, and chondrosarcomas at the foramen magnum and high cervical region are accessible through this approach. Transection of the external ear canal and permanent rerouting of the facial nerve is not necessary; instead, slight anterior transposition of the facial nerve, in select cases, can provide adequate exposure of the infratemporal vertical C7 segment of the internal carotid artery, without anterior displacement of the mandible. Furthermore, access to the lower clivus is facilitated by anterior translocation of the vertical portion of the internal carotid artery and inferior translocation of the lower cranial nerves.

This complex approach for total jugular foramen exposure can be simplified in a stepwise fashion: 1) postauricular infratemporal incision; 2) retrolabyrinthine mastoidectomy; 3) high cervical exposure; 4) skeletonization and anterior translocation of the facial nerve; 5) lateral suboccipital craniotomy and transcondylar–transtuberular exposure; 6) removal of the internal jugular vein, jugular bulb, and sigmoid sinus; and 7) intradural exposure.

PREOPERATIVE CONSIDERATIONS

Preoperative high-field, thin-section magnetic resonance imaging with and without gadolinium enhancement is performed to delineate the size, location, and extent of the tumor. The relationship of the tumor to the jugular foramen, brainstem, cranial nerves, temporal bone, and neighboring vasculature is examined carefully. The degree of intracranial extension should be assessed. Evidence of tumor encasing the internal carotid artery can be determined on these images. A

computed tomographic scan of the cranial base is useful to evaluate the bony anatomy of the temporal bone.

Magnetic resonance angiography and venography are particularly useful for assessing cerebrovascular anatomy and the blood supply of the tumor and for confirming patency and dominance of the venous sinuses. Conventional angiography is useful for visualizing the feeding arteries and the venous drainage of the tumor. In patients who have tumor encasing the internal carotid artery, a balloon occlusion test is performed to assess the risk involved with performing a carotid artery sacrifice and subsequent reconstruction of the carotid artery with a high-flow bypass. Tumor involvement may be limited to the periosteal sheath, and a subperiosteal plane of dissection can be achieved to free the tumor from the carotid artery. If tumor has invaded the adventitial wall, however, saphenous vein reconstruction and high-flow bypass of the carotid artery may be necessary (24, 31). Preoperative embolization of feeding arteries is an excellent adjunctive modality for reducing intraoperative blood loss, thereby facilitating the complete removal of glomus jugulare tumors (25, 36). Arterial feeders most commonly arise from the ascending pharyngeal artery and feeders from the external carotid artery.

Preoperative assessment for catecholamine secretion by the tumor should be performed in all patients (26, 29). Although the incidence of catecholamine secretion is approximately 4% (5, 19), complications of wide fluctuations in blood pressure and pulse can occur during surgical manipulation of the tumor. The release of norepinephrine can result in a hypertensive crisis, whereas the release of histamine and bradykinin can result in severe hypotension (22). In patients with hypersecreting tumors, pretreatment with alpha or beta blockers is warranted. An abdominal computed tomographic scan should also be obtained to rule out an adrenal source of catecholamine secretion (2).

SURGICAL APPROACH

(see video at web site)

Patient Positioning and Skin Incision

The patient is placed in the supine position with the head turned laterally away from the side of the lesion. A shoulder roll is used to elevate the shoulder ipsilateral to the lesion. All pressure points are carefully padded with foam or gel pads. The patient is secured to the operating table with adhesive tape to allow safe rotation of the table during the operation to improve the surgeon's line of sight. In obese patients with short necks, a lateral position may be used. Intraoperative monitoring, including brainstem auditory evoked responses, somatosensory evoked potentials, motor evoked potentials, and facial nerve monitoring, is used. An electromyographic endotracheal tube can be used for Xth nerve monitoring, and electrodes placed directly into the sternocleidomastoid muscle and the tongue can be used for XIth and XIIth nerve monitoring, respectively. Intravenous corticosteroids and antibiotics are administered at the time of the skin incision.

A retroauricular curvilinear C-shaped skin incision is started approximately 2 to 3 cm posterior to the upper border of the ear (Fig. 1). It continues posteroinferiorly into the neck over the anterior border of the sternocleidomastoid muscle and under the mandibular angle. The skin flap is elevated in two layers. The galeal layer (temporoparietal fascia) is undermined from the skin flap and subsequently elevated with periosteum. The scalp is reflected anteriorly, and the posterior auricular muscle is seen behind the external ear canal. The greater auricular nerve, which runs obliquely across the anterior border of the sternocleidomastoid muscle approximately 2 to 3 cm below the mastoid tip, is carefully identified (Fig. 2). This nerve may be harvested for an interpositional graft for facial nerve anastomosis, if needed. The greater auricular nerve is divided, although a long stump is maintained for those cases in which nerve grafting is needed.

The posterolateral neck muscles are reflected posteriorly to expose the body of the mastoid. These muscles can be anatomically categorized as three layers. The superficial layer is composed of the sternocleidomastoid and the splenius capitis muscles. The middle layer consists of the longissimus capitis and the semispinalis capitis muscles. The deep layer consists of the rectus capitis posterior major, the obliquus capitis superior, and the obliquus capitis inferior muscles (these three muscles form the suboccipital triangle). The superficial and middle layers of muscles are reflected posteriorly to expose the suboccipital triangle and the styloid diaphragm, a thick membranous structure that covers the posterior belly of the digastric muscle. The occipital artery is also covered by the styloid diaphragm and runs under the posterior belly of the digastric muscle.

Retrolabyrinthine Mastoidectomy

The entire body and tip of the mastoid, the spine of Henle, the posterior point of the root of the zygoma, the supramastoid crest, and the asterion must be exposed before the mastoidectomy is performed. The outer mastoid triangle, which is formed by the posterior point of the root of the zygoma, the

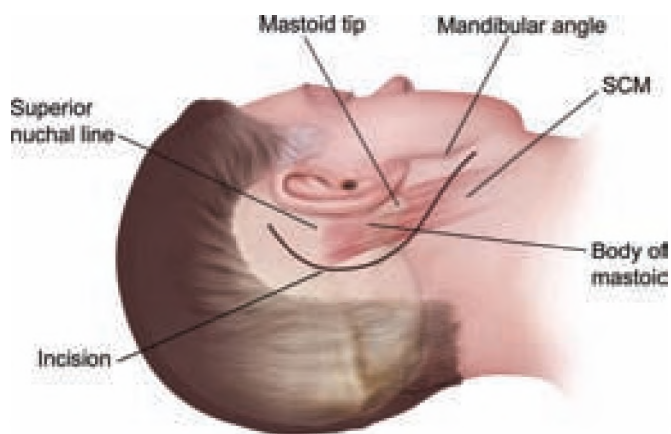


FIGURE 1. Combined retroauricular high cervical skin incision. SCM, sternocleidomastoid.

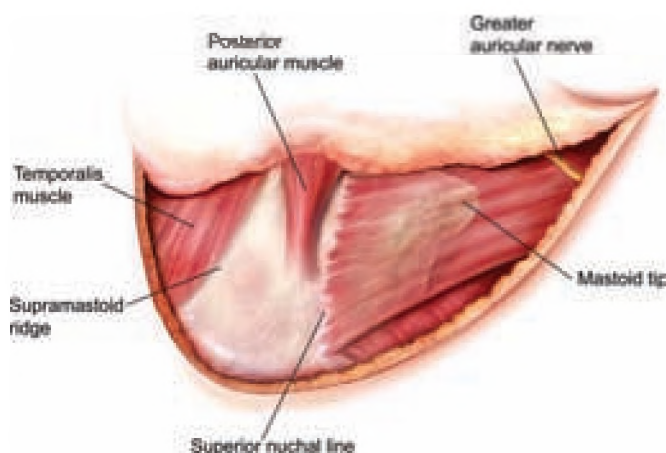


FIGURE 2. Skin is reflected anteriorly to reveal the underlying musculature. The greater auricular nerve is identified.

mastoid tip, and the asterion, marks the area of initial drilling for the mastoidectomy. The cortex over the outer mastoid triangle is removed by using a high-speed drill with a large cutting burr and continuous suction irrigation. The mastoid air cells are then systematically removed by saucerization. The mastoid antrum, located in the anterior and superior portion of the mastoid triangle, is opened, exposing the lateral semicircular canal. The sigmoid sinus and jugular bulb are completely skeletonized, and the mastoid air cells are totally removed to expose the presigmoid dura, the superior petrosal sinus, sigmoid angle, the middle fossa dura, and the retrosigmoid dura (Fig. 3).

As air cells are removed from the mastoid tip region, the digastric ridge will be encountered. The digastric ridge is an important landmark for defining the exit of the VIIth nerve from the fallopian canal through the stylomastoid foramen. For a retrolabyrinthine exposure, the bony labyrinth must be clearly defined with a diamond burr. The fallopian canal containing the facial nerve is usually located 12 to 15 mm deep from the outer cortical surface of the mastoid and 1 to 2 mm anterior to and parallel to the posterior semicircular canal. The facial nerve is carefully skeletonized by using a diamond burr under constant, copious irrigation to prevent thermal injury from the drill. The retrofacial air cells are removed to skeletonize the jugular bulb further. Care should be taken when removing the portion of bone that is situated between the sigmoid sinus and the jugular bulb. This bone can be extremely adherent to the sinus wall, and venous bleeding can occur if the sinus wall is torn during bone removal. One should also keep in mind that the glossopharyngeal canal containing the IXth cranial nerve lies just medial to the jugular bulb. Usually, a membranous septum separates it from the vagus and accessory nerves, but in 20% of cases, there is a separate bony canal.

High Cervical Exposure

The goal of the high cervical exposure is to identify the extracranial portions of the lower cranial nerves, the internal

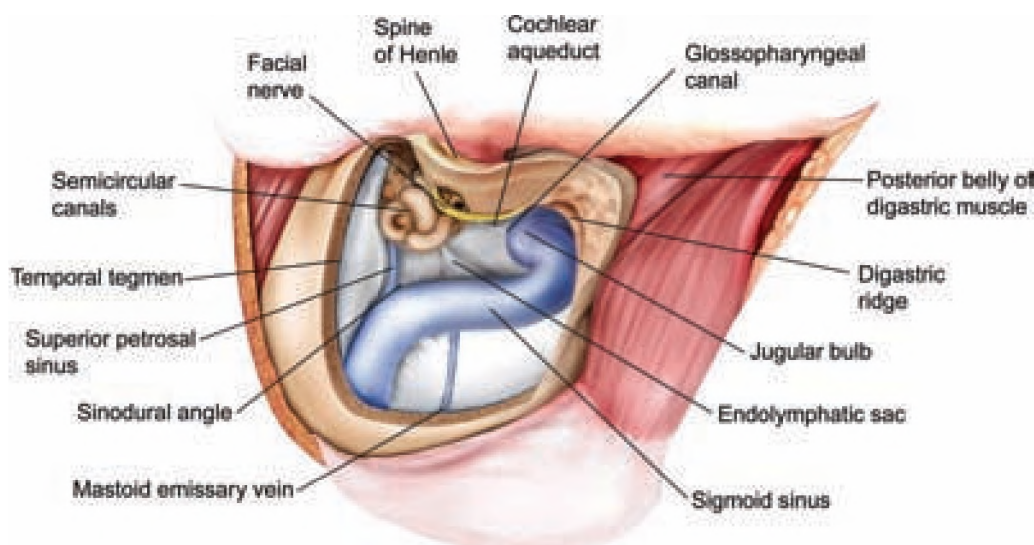


FIGURE 3. A retro- and infralabyrinthine mastoidectomy is performed, carefully skeletonizing semicircular canals, fallopian canal, sigmoid sinus, and jugular bulb. The glossopharyngeal canal containing the IXth cranial nerve lies just medial to the jugular bulb.

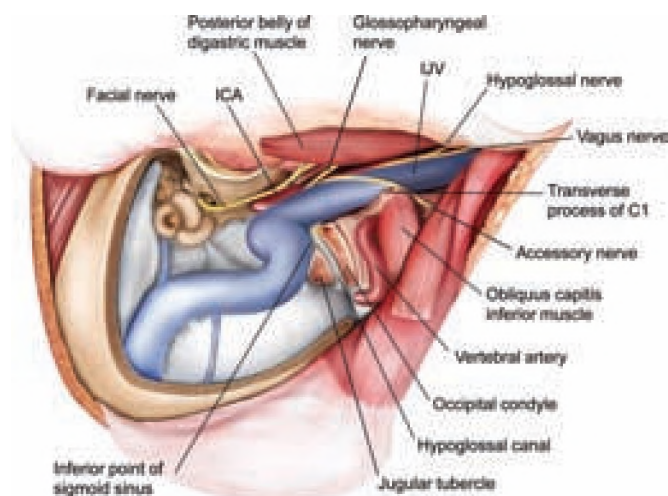


FIGURE 4. A high cervical exposure is performed, and the mastoid tip is removed to expose the lower cranial nerves, internal carotid artery (ICA), and internal jugular vein (IJV).

carotid artery, and the internal jugular vein (Fig. 4). After the subcutaneous tissue and platysma muscle are divided, blunt dissection is used to identify the posterior angle of the mandible, as well as the anterior border of the sternocleidomastoid muscle. The posterior border of the angle of the mandible and the superficial posterior border of the mastoid tip define the anterior and posterior limits of this approach, respectively. These defined borders, with just partial detachment of the muscular insertions, are of primary importance for postoperative functions of neck movement and mastication.

The anterior portion of the sternocleidomastoid muscle is retracted posteriorly to achieve adequate exposure of the pos-

terior belly of the digastric muscle. The stylomastoid diaphragm is removed, and the occipital artery is coagulated. The posterior belly of the digastric muscle is then reflected superoanteriorly to cover and protect the facial nerve. At this point, the digastric branch of the facial nerve can be exposed. The transverse process of C1 should be easily palpable. The lateral point, which is located approximately 3 to 15 mm inferolaterally to the anterior edge of the C1 transverse process, is an important landmark for identifying the accessory nerve, which courses in a posteroinferior direction between the posterior digastric muscle and the

internal jugular vein. In most cases, the accessory nerve courses lateral to the internal jugular vein; in approximately 25% of cases, however, the nerve courses medially.

The hypoglossal nerve, which runs over the internal jugular vein on the lateral surface of the carotid sheath, is identified. The ansa cervicalis can be seen leaving the hypoglossal nerve near the posterior aspect of the internal carotid artery. The carotid sheath is opened, and the vagus nerve is identified in the dorsal aspect of the internal carotid artery. Anterior to the internal carotid artery is the stylohyoid muscle, which is attached posteriorly to the styloid process at the base of the cranium. The stylopharyngeus and the styloglossus muscles are also attached to the styloid process. To increase exposure of the internal carotid artery where it enters the carotid canal at the base of the cranium, the styloid process is then removed from the point of insertion to the base of the cranium without any detachment of the styloid muscles inserted thereon. Approximately 1 to 2 cm inferior to this entry point, the glossopharyngeal nerve can be identified crossing the internal carotid artery inferomedially. The pharyngeal branch of the vagus nerve can be located inferior to the glossopharyngeal nerve. Posterior retraction of the internal jugular vein helps expose the carotid branch of the glossopharyngeal nerve (the carotid sinus nerve).

Anterior Translocation of Facial Nerve

The facial nerve in the fallopian canal is fully skeletonized from the genu to the stylomastoid foramen with a diamond burr. The mastoid tip is removed with a high-speed drill to decompress the facial nerve from the stylomastoid foramen. The periosteum surrounding the facial nerve is very adherent and is kept intact to protect the nerve. This maneuver protects

the stylomastoid artery, which is the blood supply to the mastoid segment of the facial nerve. Further bone removal of the mastoid and complete skeletonization of the jugular bulb will better define the anterior and lateral aspect of internal jugular vein at the level of the jugular foramen. The styloid process is detached from the base of the cranium as discussed above and reflected anteriorly to expose the vertical C7 (infratemporal) segment of the internal carotid artery. If necessary, the vertical segment of the facial nerve can be slightly translocated anteriorly to provide added exposure of the vertical C7 segment of the internal carotid artery. This maneuver is used selectively and produces less risk of facial nerve palsy in contrast with permanent facial nerve rerouting. The carotid canal is drilled out to expose the petrous segment of the internal carotid artery. Injury to the glossopharyngeal nerve, which exits dorsal to the internal carotid artery and behind the internal jugular vein, must be avoided. Jacobson's nerve (the tympanic nerve), which diverges from the glossopharyngeal nerve, exits between the C7 segment of the internal carotid artery and the jugular bulb.

Suboccipital and Transcondylar–transtubercular Exposure

The suboccipital triangle, which is bound by the deep layer of muscles (medially by the rectus capitis posterior major; inferiorly by the obliquus capitis inferior, and superolaterally by the obliquus capitis superior muscle), is the key anatomic landmark for this portion of the exposure. The rectus capitis posterior major muscle inserts superiorly on the inferior nuchal line and inferiorly on the spinous process of C2; the obliquus capitis inferior muscle inserts superiorly on the transverse process of C1 and inferiorly on the spinous process of C2; the obliquus capitis superior muscle inserts superiorly at the temporo-occipital suture and inferiorly on the transverse process of C1. The suboccipital triangle, which involves the dorsal ramus of the C1 nerve root and the V3 horizontal segment of the vertebral artery, can be opened by detaching the insertions of the superior and inferior oblique muscles from the transverse process of C1 and reflecting them posteriorly. The rectus capitis posterior major is detached from the inferior nuchal line and reflected posteriorly. The C1 lamina and vertebral artery will become more apparent.

The suboccipital triangle may not always be a safe landmark for identifying the vertebral artery because of variations in the horizontal course of the artery. A safer way to identify the vertebral artery is to follow the lamina of C1 along its superior margin to identify the C1 vertebral sulcus ("J" groove). The vertebral artery is encased by a venous plexus as it exits the foramen transversarium of C1, courses posteriorly behind the lateral mass of C1 in the vertebral sulcus, and turns medially to pierce the atlanto-occipital membrane and dura (Fig. 5). Several small muscular branches and the posterior meningeal artery arise from the horizontal segment of the vertebral artery, which can be safely coagulated. In some cases, the posterior spinal artery and posterior inferior cerebellar artery can

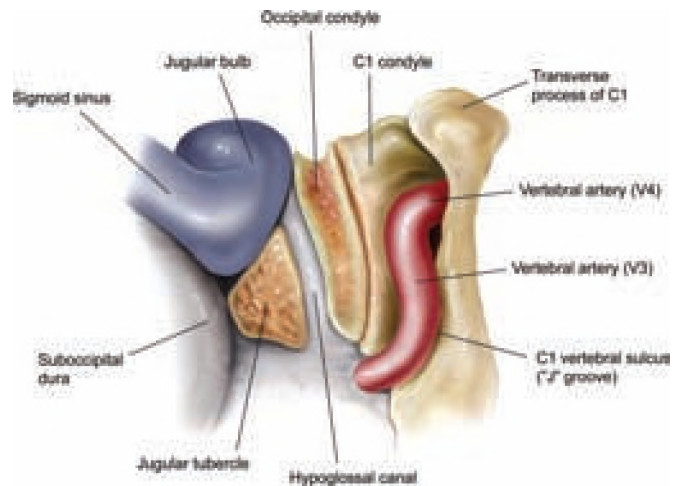


FIGURE 5. The medial third of the occipital condyle and jugular tubercle are removed with a high-speed drill. The extradural hypoglossal canal is found between the jugular tubercle and occipital condyle.

arise extradurally and can potentially be injured. Subperiosteal dissection of the vertebral artery from the vertebral sulcus reduces bleeding from the venous plexus by leaving the periosteal sheath around the artery intact. Next, the atlanto-occipital membrane is sharply divided to expose the underlying craniocervical dura.

A lateral suboccipital craniectomy or craniotomy is then performed with a craniotome and rongeurs. The craniectomy usually extends medially toward the midline, superiorly to the inferior nuchal line, inferiorly to the posterior rim of the foramen magnum, and laterally up to the occipital condyle. The sigmoid sinus and jugular bulb must be totally exposed with rongeurs and a high-speed drill. The posterior condylar emissary vein will be encountered as it travels from the jugular bulb and exits the condylar fossa via the condylar canal to join the extradural venous plexus. Hemostasis can be achieved by packing the vessel with Surgicel.

Extradural reduction of the occipital condyle and jugular tubercle are the key maneuvers in this step (Fig. 5). Removal of the posterior and medial one-third of the occipital condyle is generally adequate to increase the surgical corridor to the ventral foramen magnum. If 50% or more of the condyle has been resected or destroyed by the lesion, instability of the craniovertebral junction increases, and an occipitocervical stabilization should be strongly considered (36). The posteromedial aspect of the occipital condyle is removed with a high-speed diamond drill while the vertebral artery is protected. After removal of the cortical layer of bone, the soft cancellous bone is encountered. Venous bleeding from the condylar emissary vein within the condylar canal is controlled with bone wax and Surgicel. Further drilling will expose another cortical layer of bone that covers the hypoglossal canal, which is situated superior to the occipital condyle and inferior to the jugular tubercle (Fig. 5). The hypoglossal canal contains the hypoglossal nerve, a meningeal branch of the ascending pha-

ryngeal artery, and the venous plexus of the hypoglossal canal, which communicates the basilar venous plexus with the marginal sinus that encircles the foramen magnum. Identification of the medial aspect of the hypoglossal canal usually indicates that approximately one third of the posterior condyle has been removed. Because the hypoglossal canal is directed anteriorly and laterally at a 45 degree angle with the sagittal plane, further skeletonization of the canal to its lateral extent will usually result in approximate removal of the lateral aspect of the posterior two thirds of the condyle.

Bone removal is next directed superiorly toward the jugular tubercle, a rounded prominence found at the junction of the basilar and condylar parts of the occipital bone. It is situated slightly medial and inferior to the jugular bulb, superior to the hypoglossal canal, and medial to the jugular foramen. Failure to reduce a prominent jugular tubercle adequately may result in an obstructed view of the basal cisterns and clivus anterior to the lower cranial nerves. The jugular tubercle should be drilled away as much as possible. The glossopharyngeal, vagus, and accessory nerves, which cross over the posterior aspect of the jugular tubercle into the jugular foramen, are in very close proximity and may be at risk of damage by direct trauma, stretching of the dura, and heat generated by the drill. To minimize these risks, the center of the tubercle is cored out with a high-speed diamond drill and copious irrigation, leaving an eggshell-thin layer of bone covering the dura that can be elevated with a microdissector. The lower cranial nerves take a hairpin bend and exit under the jugular vein and bulb. The inferior petrosal sinus enters the anterior medial aspect of the jugular bulb by multiple channels coursing between the glossopharyngeal and the vagus nerves.

Removal of Internal Jugular Vein, Jugular Bulb, and Sigmoid Sinus

After complete exposure of the sigmoid sinus, jugular bulb, and internal jugular vein, the tumor mass can be palpated within these venous structures. Prominent vasa vasorum of the jugular vein wall can be appreciated because of the hyper-vascularity of the tumor. After all arterial feeders to the tumor are coagulated, the internal jugular vein is then ligated just inferior to the tumor mass (Fig. 6). The sigmoid sinus is occluded just above the tumor mass with a suture ligature. The lateral wall of the internal jugular vein is incised and removed with the tumor up to the jugular bulb and sigmoid sinus (Figs. 7–13). Bleeding is controlled with Surgicel packing and soft micro-paddies. The plane of dissection between the tumor and the medial wall of the jugular bulb is preserved. The tumor is carefully removed from the pars nervosa with care taken not to damage the lower cranial nerves. Bleeding from the inferior petrosal sinus may be controlled by packing with Surgicel. Bipolar coagulation is avoided here to minimize damage to the lower cranial nerves. The dural sheath of the lower cranial nerves should be kept intact to decrease the risk of damage. The glossopharyngeal nerve is separated from the vagus and accessory nerves by a fibrous crest and passes

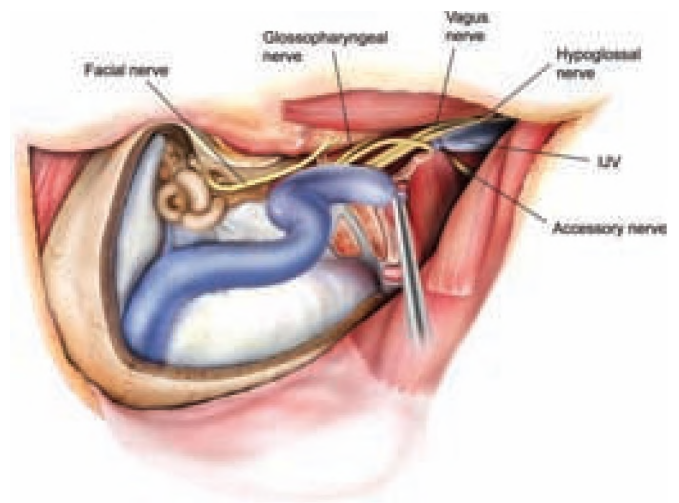


FIGURE 6. The internal jugular vein (IJV) is ligated and divided just inferior to the tumor mass.

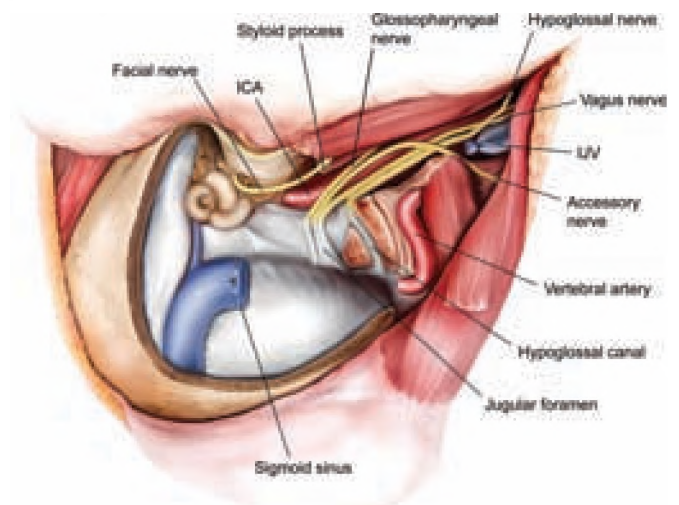


FIGURE 7. The sigmoid sinus is ligated and divided just superior to the tumor mass. The medial wall of the jugular foramen is left intact. ICA, internal carotid artery; IJV, internal jugular vein.

through the pars nervosa of the jugular foramen called the glossopharyngeal or IXth nerve canal (as stated above, the IXth nerve canal is formed as a separate bony canal in 20% of cases). The cochlear aqueduct opens into the entrance porus of the IXth nerve.

Retrosigmoid Intradural Exposure

This portion of the operation is necessary for accessing the intradural portion of glomus jugulare tumors. A curvilinear incision of the dura is made several millimeters posterior to the sigmoid sinus, extending inferiorly toward the entry point where the vertebral artery pierces the dura (Fig. 8). The incision can be extended up to the junction of the transverse-sigmoid sinus if more exposure of the cerebellopontine angle

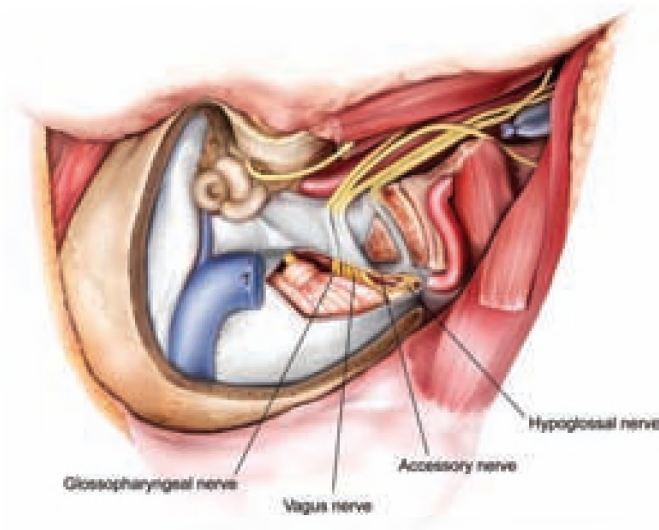


FIGURE 8. Intradural exposure is performed to inspect for intracranial extension of tumor through the jugular foramen.

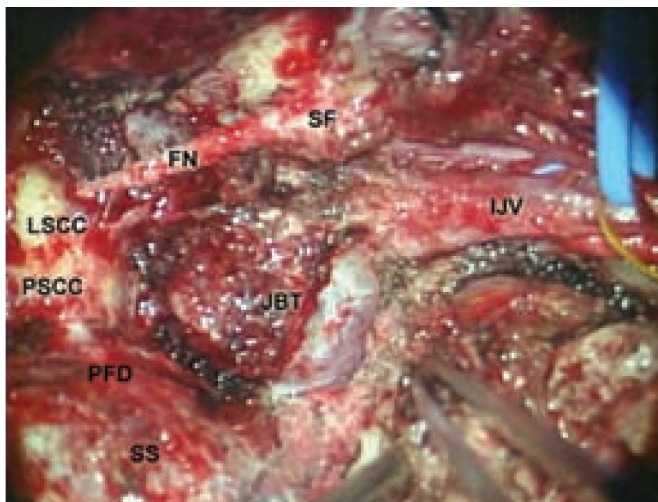


FIGURE 9. Intraoperative photograph (right-sided approach) demonstrating a glomus the jugulare tumor in the jugular bulb. JBT, jugular bulb tumor; IJV, internal jugular vein; FN, facial nerve; SF, styloid mastoid foramen; LSCC, lateral semicircular canal; PSCC, posterior semicircular canal; PFD, posterior fossa dura; SS, sigmoid sinus.

is needed. The anterior leaflet of dura is reflected laterally and held with tacking sutures for maximal exposure. Adequate reduction of the occipital condyle and jugular tubercle should provide a straight surgical trajectory to the ventral craniovertebral junction, parallel to the intracranial course of the vertebral artery. Structures of the inferior aspect of the cerebellopontine angle and the cerebellomedullary angle are visualized. Sharp arachnoid dissection is performed, and the following structures can be visualized: Vth through XIIth cranial nerves, basilar artery, vertebral artery, vertebrobasilar junction, posterior inferior cerebellar artery, and anterior-

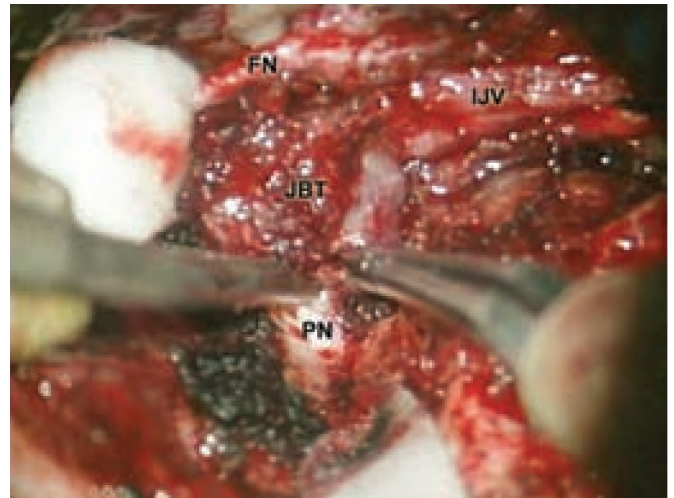


FIGURE 10. Trans-sigmoid technique. The sigmoid sinus is ligated, and the tumor within the jugular bulb is elevated sharply from the pars nervosa (PN) leaving the medial wall intact to help preserve the lower cranial nerves. FN, facial nerve; IJV, internal jugular vein; JBT, jugular bulb tumor.

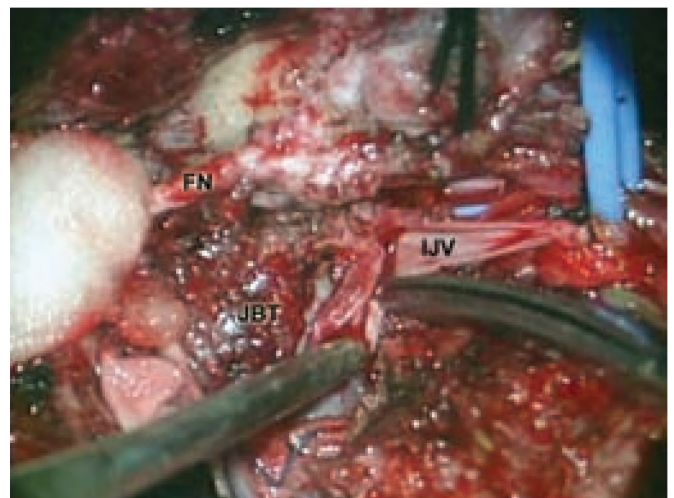


FIGURE 11. The internal jugular vein (IJV) is ligated inferiorly, and the lateral wall of the IJV is opened with sharp dissection and reflected superiorly with a sucker tip. JBT, jugular bulb tumor; FN, facial nerve.

inferior cerebellar artery. The intradural aspect of the jugular foramen is inspected for any tumor invasion. The tumor is carefully dissected from the lower cranial nerves and removed. Often, the blood supply to intradural extensions is from branches of posterior inferior cerebellar artery, which can be simply cauterized (30).

Transjugular Transsigmoid Pars Nervosa Translocation Technique

Inferior translocation of the lower cranial nerves and an anterior translocation of the vertical C7 segment of the internal carotid artery are used for gaining access to the lower clivus.

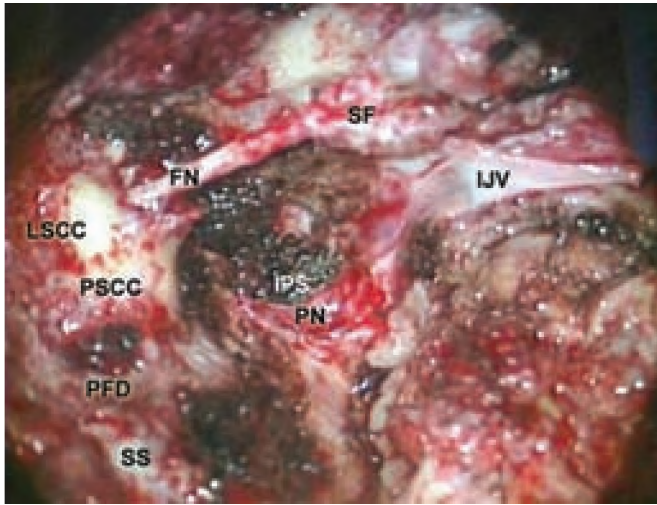


FIGURE 12. Intraoperative photograph of final view after the tumor has been removed. The medial wall of the internal jugular vein and pars nervosa are intact. Surgical is gently packed in the inferior petrosal sinus (IPS) to achieve hemostasis. PN, pars nervosa; IJV, internal jugular vein; FN, facial nerve; SF, styloid mastoid foramen; LSCC, lateral semicircular canal; PSCC, posterior semicircular canal; PFD, posterior fossa dura; SS, sigmoid sinus.

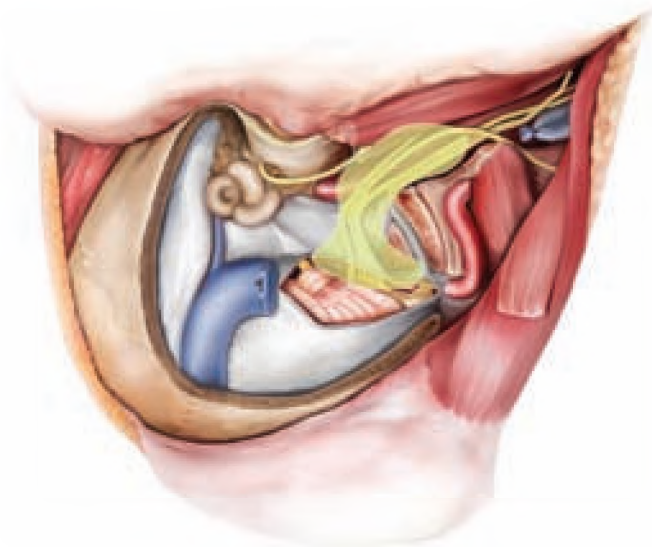


FIGURE 13. Illustration demonstrating the final view after the tumor has been removed. The yellow shadow indicates the tumor's previous location.

The key maneuver is to preserve the dural sleeve covering these nerves to protect them from mechanical injuries. With this technique, the dura of the internal auditory canal is exposed from an inferior direction. The inferior petrosal sinus can be seen completely as the partial clivectomy continues to the petrous apex. Dorello's canal is also exposed extradurally.

Closure

After adequate hemostasis, the wound is irrigated with bacitracin saline solution. Cranial base reconstruction and prevention of a cerebrospinal fluid leak is paramount to the success of surgery. A watertight dural closure should be the goal. If there is a large defect, as in the cases of larger tumors, an autologous fascial graft or pericranial flap followed by fibrin glue may be used. Autologous fat is used to pack the mastoid defect and remaining anatomic dead space. In some cases, a vascularized free tissue transfer (free flap) may be necessary to achieve an adequate reconstruction. The muscle and skin are closed in several layers. Temporary lumbar drainage can be used (approximately 3–4 d) to facilitate healing of the dural closure.

SURGICAL RESULTS

The described approach has been performed by the senior author (TF) on 129 jugular foramen tumors, 30 of which were glomus jugulare tumors. Gross total resection was achieved in 22 (73.3%) patients, near-total resection in six (20%) patients, and subtotal resection in two (6.7%) patients. The mean follow-up period was 28.5 months.

Eight (26.7%) patients had a worsened VIIIth nerve palsy, four of which were permanent. Four (13.3%) patients developed a worsened VIIIth nerve palsy, all of which were permanent. Nine (30%) patients developed worsened IXth and Xth nerve palsies, six of which were permanent. Three patients required a laryngoplasty. Five (16.7%) patients developed a worsened XIth nerve palsy, two of which were permanent. Three (10%) patients developed a worsened XIIth nerve palsy, two of which were permanent. One patient had temporary paresis, and another patient had temporary ataxia postoperatively. None required stabilization for occipitocervical instability. There was no operative mortality.

Complication Avoidance

Complications from surgical resection of glomus jugulare tumors include cranial nerve deficits, vascular injury, cerebrospinal fluid leakage, and meningitis. Despite a significant reduction in the mortality rate from surgical removal of glomus jugulare tumors, postoperative morbidity in these patients is still considerable, largely from associated permanent cranial nerve palsies (12, 32). Although patients with larger tumors can present with pre-existing lower cranial nerve palsies, it is important not to incur new and permanent cranial nerve palsies. Anatomic preservation of cranial nerves and intraoperative cranial nerve monitoring are useful in minimizing these risks. Because anterior translocation of the facial nerve usually results in transient facial nerve palsy, this technique should be used judiciously. The periosteum surrounding the facial nerve, which contains the blood supply to the nerve, must be kept intact to optimize facial nerve preservation. It may be prudent to leave tumors that seem to have invaded cranial nerves. Al-Mefty and Teixeira (2) have advo-

cated intrabulbar dissection (preserving the anterior and medial walls of the jugular bulb against the lower cranial nerves) to help minimize manipulation and preserve the function of the lower cranial nerves. This technique can be performed as long as the tumor has not invaded the medial wall of the jugular bulb or infiltrated the lower cranial nerves.

Although preoperative embolization of arterial feeders can minimize intraoperative blood loss, it is important to devascularize all arterial feeders to the tumor intraoperatively before ligation of the internal jugular vein and sigmoid sinus. Al-Mefty and Teixeira (2) have advocated managing the venous outflow in a similar fashion to arteriovenous malformations because of the considerable blood that may be shunted through collateral venous drainage. In one patient, a shunt tube was inserted to re-establish venous outflow because of premature ligation and sectioning of the internal jugular vein that resulted in profuse hemorrhage.

DISCUSSION

The transjugular infratemporal fossa approach described above allows for single-staged radical resection of large complex glomus jugulare and glomus jugulotympanicum tumors. Although this article primarily addresses the techniques and nuances of removing glomus jugulare tumors using this approach, other complex jugular foramen tumors, such as schwannomas and meningiomas, can be accessed with this exposure as well. This approach has the advantage of providing total exposure of the jugular foramen with multidirectional angles of attack. The infratemporal carotid artery can be exposed without transection of the external ear canal, permanent rerouting of the facial nerve, or mandibular translocation.

In our series of 30 patients, eight patients had a worsened facial nerve palsy, four of which were permanent. This can be accounted for by wide opening of the facial canal and partial transposition of the VIIth nerve. This maneuver was used judiciously when exposure of the C7 infratemporal carotid artery was needed. In two cases, the tumor had engulfed the VIIth nerve, and this portion of the nerve involving the tumor was removed. Reconstruction of the facial nerve was performed using cable nerve graft interposition with the sural nerve in one case and an indirect hypoglossal-facial nerve anastomosis in the other case. Postoperatively, the patients eventually recovered facial nerve function to House-Brackmann Grades II and III, respectively.

Although the semicircular canals were preserved, and transection of the ear canal was not performed in the patients in this series, four patients developed a worsened VIIIth nerve palsy. These four patients harbored extensive tumors with significant intradural component. Factors that may have compromised VIIIth nerve function at surgery include traction on the cochlear nerve during manipulation of the tumor, cerebellar retraction, or violation of the cochlea during drilling of the infralabyrinthine space.

None of the patients in this series developed occipitocervical instability. Because only the posterior and medial third of

the occipital condyle was removed, stability of the craniocervical junction was maintained, and occipitocervical stabilization was not necessary. In a biomechanical study by Vishteh et al. (34), occipitocervical instability was shown to increase when 50% or more of the condyle was resected.

CONCLUSION

The combined transmastoid retro- and infralabyrinthine transjugular transcondylar transtubarcular high cervical approach can be performed in a stepwise fashion for resection of complex glomus jugulare tumors. Total exposure of the jugular foramen can be achieved, and multidirectional approaches can be performed, including suprajugular, infrajugular, and transjugular exposures.

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Acknowledgment

We thank Kristin Kraus for her editorial assistance during the preparation of this article.

COMMENTS

The authors describe a variation of the infratemporal fossa approach. This transjugular posterior infratemporal fossa approach provides access to the lower clivus, high cervical region, jugular bulb, and jugular foramen. This approach combines the transmastoid, suprajugular, and extreme lateral infrajugular transcondylar transtubaric approaches.

As described by Fisch (1-4), the classic infratemporal fossa approach is divided into three types. The Type A approach is directed toward the jugular bulb and enhances access to the intrapetrous carotid artery. It requires anterior rerouting of the facial nerve and provides access to the mandibular fossa and posterior infratemporal fossa.

In the Type B approach, the horizontal portion of the intrapetrous carotid artery is exposed to gain access to the petrous apex and clivus.

The middle meningeal artery, the glenoid fossa, and the third division of the trigeminal nerve must be sectioned. The eustachian tube is obliterated, and an osteotomy of the zygoma is also necessary. If the Type A procedure is contraindicated, the facial nerve is not rerouted; however, its upper division can be stretched slightly.

The Type C approach extends the Type B approach anteriorly and medially to gain access to the pterygopalatine fossa, parasellar regions, and nasopharynx.

These three procedures result in conductive hearing loss, facial nerve palsy, and mandibular problems. Tumors with an intracranial extension of more than 2 cm require a two-stage resection. The authors describe a one-stage posterior infratemporal fossa approach that allows radical resection through a transmastoid, retrolabyrinthine, infralabyrinthine, transjugular, extreme-lateral, infrajugular, transcondylar, transtubaric high cervical approach. The jugular foramen is exposed completely and the intracranial-extracranial tumor is removed in one sitting. This combination of approaches seems to be less invasive and associated with fewer complications than those described previously. However, the extent of tumor resection with respect to the anterior clivus depends on the corridor that the tumor has created.

Overall, this is a fine variation of the multiple approaches to tumors of the jugular foramen and anterior cranial base.

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1. Fisch U: Infratemporal fossa approach to tumours of the temporal bone and base of the skull. *J Laryngol Otol* 92:949-967, 1978.
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The authors describe in precise details a complex surgical approach for glomus jugulare tumors. The technique seems more complicated in theory than in practice. As the elaborate definition states, the approach is the combination of previously noted and widely used techniques to the cranial base, such as the transmastoid retrolabyrinthine approach (clivus meningiomas), the anterolateral approach (high cervical tumors), and the transcondylar, transjugular, and transtubaric approach (extreme lateral approach) for tumors of the occipital foramen, the jugular foramen, and vertebrobasilar aneurysms.

The advantage of the technique is its ability to attack the tumor from many angles, to remove growths in one stage, and to control the principal intra- and extracranial extensions. Furthermore, the technique saves hearing, as it avoids the rerouting of the facial nerve that is often accompanied by partially recoverable paralysis of the nerve and avoids mobilization of the jaw, with the consequent chewing problems that are the typical of the infra-temporal approaches.

In describing results, however, facial palsy, loss of hearing, and partial removals are not uncommon despite the extensive approach, showing that the removal of large tumors is not problem-free.

This approach would seem not to be indicated for purely glomus tympanicum tumors, but would be used mainly for large glomus jugular tympanicum tumors, in which the rerouting of the facial nerve seems to facilitate the controlling of the carotid artery and the anterior

extension of the neoplasm. Craniospinal instability is not reported, which would confirm the fact that removal of the outer third of the condyle does not affect the stability of the craniospinal junction, even if the tuberclectomy described would seem to require a wider condylectomy.

On the whole, the results are good and confirmed the efficacy of the approach and the principle that unnecessary maneuvers must be avoided, thus reducing the invasiveness of the approach as much as possible.

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This report is idealistic on a surgical technique to resect glomus jugulare tumor. It utilizes a route running along the lateral wall of the craniocervical junction (namely the lateral mass of atlas, occipital condyle) and drilling the jugular tubercle. Therefore, instead of extensively drilling the petrous bone, the exposure is enlarged on the inferior side (the cervical side). In fact, as we previously reported (1, 2), this technique typically keeps the facial nerve in the fallopian canal and avoids its transposition. This reduces the rate of postoperative facial nerve palsy. It also helps to preserve the lower cranial nerves that are followed from the cervical area to the posterior fossa at their

origin from the brainstem. In glomus tumors, the tumoral extension is often important and in many directions; therefore, the surgery must follow into the petrous bone. In schwannoma, there only is an enlargement of the jugular foramen. No petrous bone drilling is necessary, and most times a mastoidectomy is sufficient to expose the sigmoid sinus. Between the exposure of the origin of the internal jugular vein and the end of the sigmoid sinus, only the jugular tubercle has to be drilled to open the jugular foramen. This exposure is facilitated by the resection of the transverse process of C1 and therefore needs the exposure of the vertebral artery between C2 and the foramen magnum dura. This technique requires time and practice to master, but it is a wonderful avenue to the jugular foramen.

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