Chapter 2
Surgical Anatomy of Jugular Paraganglioma

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Introduction

Paragangliomas are classified based on location. The carotid body tumor is the most common paraganglioma, arising at the bifurcation of the common carotid artery in the neck. Paragangliomas arising from the vagus nerve, tympanic plexus, and the wall of the jugular bulb are termed vagal, tympanic, and jugular paragangliomas, respectively. Of these, surgical treatment of the jugular paraganglioma is the most challenging. The difficulty is caused by its deep location and surrounding structures including the carotid artery anteriorly, facial nerve laterally, and vertebral artery and jugular process posteroinferiorly. Furthermore, cranial nerves (CNs) IX to XII pass through the jugular foramen and the hypoglossal canal located inferior to the foramen. Surgical resection of jugular paragangliomas, while minimizing neurological complications, requires both a profound understanding of the microsurgical anatomy of the

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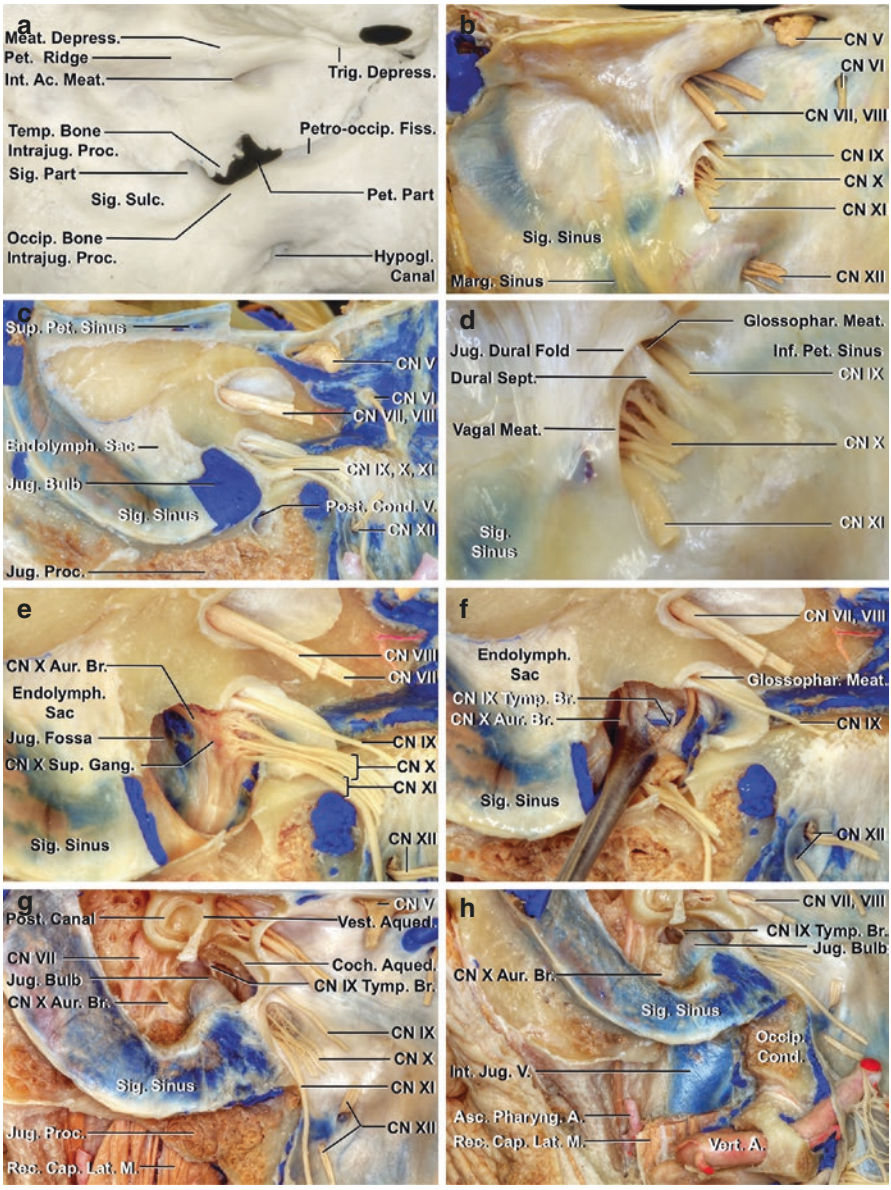
jugular foramen and its surrounding area and selection of an appropriate approach tailored to the extent of disease. In this chapter, cadavers injected with red and blue silicone were dissected to show the basic microsurgical anatomy of the jugular foramen and that specific to the postauricular transtemporal and far-lateral approaches, which are frequently employed in jugular paraganglioma surgery. Specifically, cadavers were dissected in a stepwise manner to understand the intracranial (Fig. 2.1), foraminal (Figs. 2.1, 2.2, and 2.3), and extracranial (Fig. 2.3) anatomy related to the jugular foramen and to show the most relevant surgical views (Figs. 2.4 and 2.5).



Osseous Relationships

The jugular foramen is a hiatus between the temporal bone anterolaterally and occipital bone posteromedially. The petroclival fissure, which separates the petrous portion of the temporal bone and lateral part of the occipital bone, ends at the anteromedial edge of the foramen (Figs. 2.1a and 2.2a). The inferior petrosal sinus courses along the intracranial surface of the fissure, and the inferior petroclival vein courses along its extracranial surface. The occipitomastoid suture, which separates the mastoid part of the temporal bone and squamosal portion of the occipital bone, ends at the posterolateral edge of the foramen. The jugular process, located between the lateral part of the condyle and terminal part of the occipitomastoid suture, forms the posteroinferior border of the jugular foramen (Figs. 2.1b, c, g, h and 2.2). The

Fig. 2.1 Anatomy of the intracranial end of the left jugular bulb and its adjacent area. (**a**) Osseous structures related to the jugular foramen. The jugular foramen sits between the internal auditory canal and hypoglossal canal. The foramen is separated into two parts by the intrajugular processes of the temporal and occipital bones. The petrosal part is the smaller medial part where the pyramidal fossa opens into its superior margin. The sigmoid part is the lateral part where the sigmoid sulcus ends. The petroclival fissure terminates at the anteromedial edge of the foramen. (**b**) The neurovascular relationships of the intracranial end of the jugular foramen and its adjacent area. The foramina for the cranial nerves lie in the anterior wall of the posterior fossa dura. The glossopharyngeal, vagus, and accessory nerves enter into the jugular foramen. The trigeminal nerve enters Meckel's cave. The abducens nerve pierces the dura covering the clivus. The facial and vestibulocochlear nerves enter the internal auditory canal. The hypoglossal nerve enters the hypoglossal canal. (**c**) The dura covering the petrous surface of the temporal bone has been removed. The endolymphatic sac sits on the posterior surface of the petrous bone anterior to the sigmoid sinus. The neural part of the jugular foramen is located between the petrosal and sigmoid parts of the jugular foramen. (**d**) Neurovascular relationships of the intracranial end of the jugular foramen and its adjacent area were shown after removal of the jugular bulb. The glossopharyngeal nerve enters the glossopharyngeal meatus. The vagus and accessory nerves enter the vagal meatus. They are separated by the dural septum. (**e**) The terminal part of the sigmoid sinus and jugular bulb have been removed and the superior margin of the sigmoid part of the jugular foramen and jugular process of the temporal bone have been drilled to expose the course of glossopharyngeal, vagus, and accessory nerves in the foramen. The vagal rootlets form the vagal superior ganglion in the foramen where Arnold's nerve arises. (**f**) Translocating the vagus nerve laterally shows the course of the glossopharyngeal nerve. The superior ganglion of the vagus nerve has been retracted to expose the tympanic branch of the glossopharyngeal nerve. The branch originates from the glossopharyngeal nerve at the external orifice of the jugular foramen. (**g**) Anatomical structures buried in the temporal bone were shown from the posterior cranial fossa. The jugular process and rectus capitis lateralis muscle are obstacles to accessing the jugular bulb. (**h**) Removal of the jugular process and rectus capitis lateralis muscle exposes the posteroinferior surface of the jugular bulb and posterior surface of the internal jugular vein. *A.* artery, *Ac.* acoustic, *Aqued.* aqueduct, *Asc.* ascending, *Aur.* auricular, *Br.* branch, *CN* cranial nerve, *Cap.* capitis, *Coch.* cochlear, *Cond.* condylar, *Cond.* Condyle, *Depress.* depression, *Endolymph.* endolymphatic, *Fiss.* fissure, *Glossophar.* glosopharyngeal, *Hypogloss.* hypoglossal, *Inf.* inferior, *Int.* internal, *Intrajug.* intrajugular, *Jug.* jugular, *Lat.* lateralis, *M.* muscle, *Marg.* marginal, *Meat.* meatal, meatus, *Occip.* occipital, *Petro-occip.* petro-occipital, *Pet.* petrosal, *Post.* posterior, *Proc.* process, *Rec.* rectus, *Sept.* septum, *Sig.* sigmoid, *Sup.* superior, *Trig.* trigeminal, *Temp.* temporal, *Tymp.* tympanic, *V.* vein, *Vert.* vertebral, *Vest.* vestibular

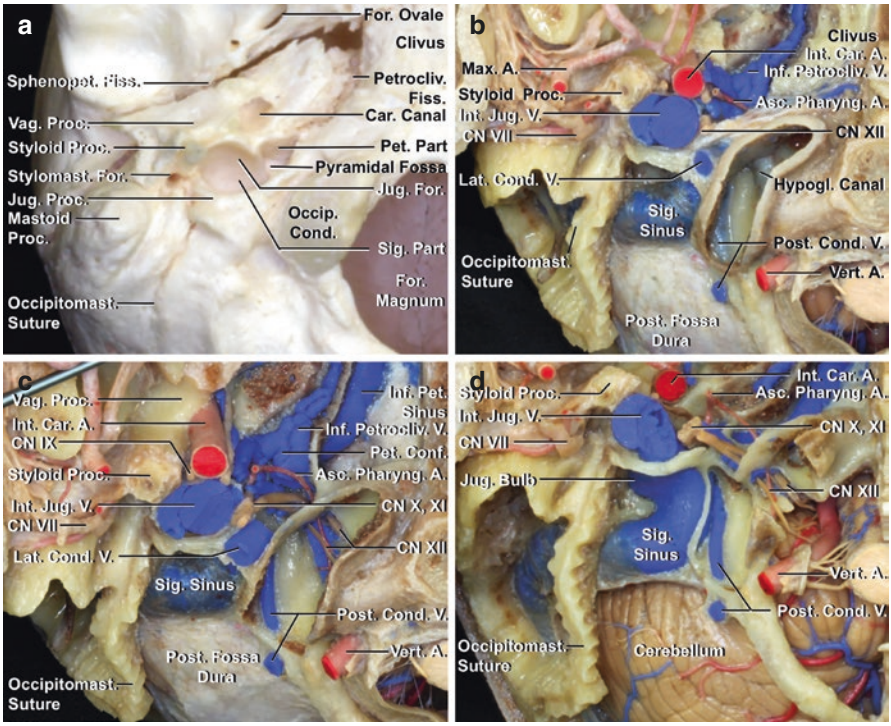


Fig. 2.2 Anatomy of the extracranial end of the jugular bulb and its adjacent area. (**a**) Osseous structures related to the jugular foramen from inferior. The foramen sits behind the carotid canal and styloid process, lateral to the anterior part of the occipital condyle and medial to the styloid foramen. The jugular process forms the posterior surface of the bulb. (**b**) The anatomy of the jugular foramen from inferior. The muscular structures have been removed, and the mastoid process, jugular process, and occipital condyle have been drilled to show the course of the sigmoid sinus. The hypoglossal canal and posterior condylar canal have been skeletonized to show their courses in the occipital condyle and jugular tubercle, respectively. The internal carotid artery courses just anterior to the internal jugular vein. (**c**) The clivus has been drilled to expose the inferior petrosal sinus. The sinus, which courses along the intracranial surface of the petroclival fissure, and the inferior petroclival vein, which courses along the extracranial surface of the fissure, empty into the petrosal confluence before emptying into the internal jugular vein. The lateral condylar vein has been partially removed to expose the course of CN XII and the venous plexus of the hypoglossal canal. The posterior condylar vein empties into the medial surface of the sigmoid sinus. (**d**) The occipital condyle and hypoglossal canal have been drilled to expose the course of the hypoglossal nerve. The alar ligament and dura covering the posterior cranial fossa have been removed. The ascending pharyngeal artery sends the jugular and hypoglossal branches. *A.* artery, *Asc.* ascending, *CN* cranial nerve, *Car.* carotid, *Cond.* condyle, condylar, *Conf.* confluence, *Fiss.* fissure, *For.* foramen, *Hypogl.* hypoglossal, *Inf.* inferior, *Int.* internal, *Jug.* jugular, *Lat.* lateral, *Max.* maxillary, *Occip.* occipital, *Occipitomast.* occipitomastoid, *Pet.* petrosal, petrous, *Petrocliv.* petroclival, *Pharyng.* pharyngeal, *Post.* posterior, *Proc.* process, *Sig.* sigmoid, *Sphenopet.* sphenopetrosal, *Stylomast.* stylomastoid, *Vag.* vaginal, *V.* vein, *Vert.* vertebral

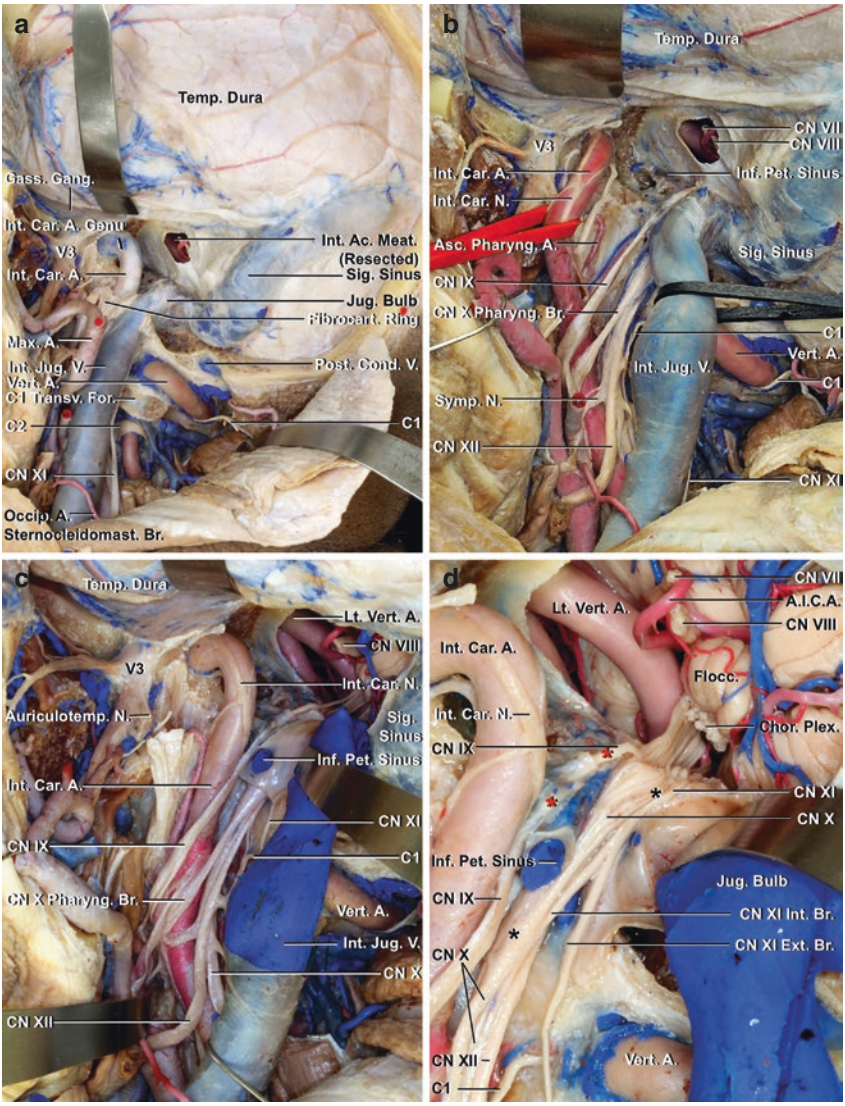


Fig. 2.3 (**a**) The removal of the temporal bone, parotid gland, temporomandibular joint, and pterygoid muscles clearly exposes the neurovascular relationships around the jugular foramen. (**b**). The translocation of the internal carotid artery anteriorly and internal jugular vein posteriorly exposes the course of the lower cranial nerves after they exit the jugular foramen and hypoglossal canal. (**c**) Translocation of the jugular bulb leaving the medial wall of the bulb shows the relationship between the sinuses and cranial nerves. (**d**) Removal of the posterior fossa dura and medial wall of the jugular bulb clearly shows the intracranial, foraminal, and extracranial courses of the lower cranial nerves. *Red* and *black asterisks* indicate the ganglion of the glossopharyngeal and vagal nerves, respectively. *A.* artery, *Ac.* acoustic, *AICA.* anterior inferior cerebellar artery, *Asc.* ascending, *Auriculotemp.* auriculotemporal, *Br.* branch, *Car.* carotid, *CN* cranial nerve, *Cond.* condylar, *Chor.* choroid, *Ext.* external, *Fibrocart.* fibrocartilage, *For.* foramen, *Flocc.* Flocculus, *Gass.* gasserian, *Gang.* ganglion, *Inf.* inferior, *Int.* internal, *Jug.* jugular, *Lt.* left, *Max.* maxillary, *Meat.* meatus, *N.* nerve, *Occip.* occipital, *Pet.* petrosal, *Plex.* plexus, *Post.* posterior, *Pharyng.* pharyngeal, *Sig.* sigmoid, *Sternocleidomast* sternocleidomastoid, *Symp.* Sympathetic, *Temp.* temporal, *Transver.* transverse, *V.* vein, *Vert.* vertebral

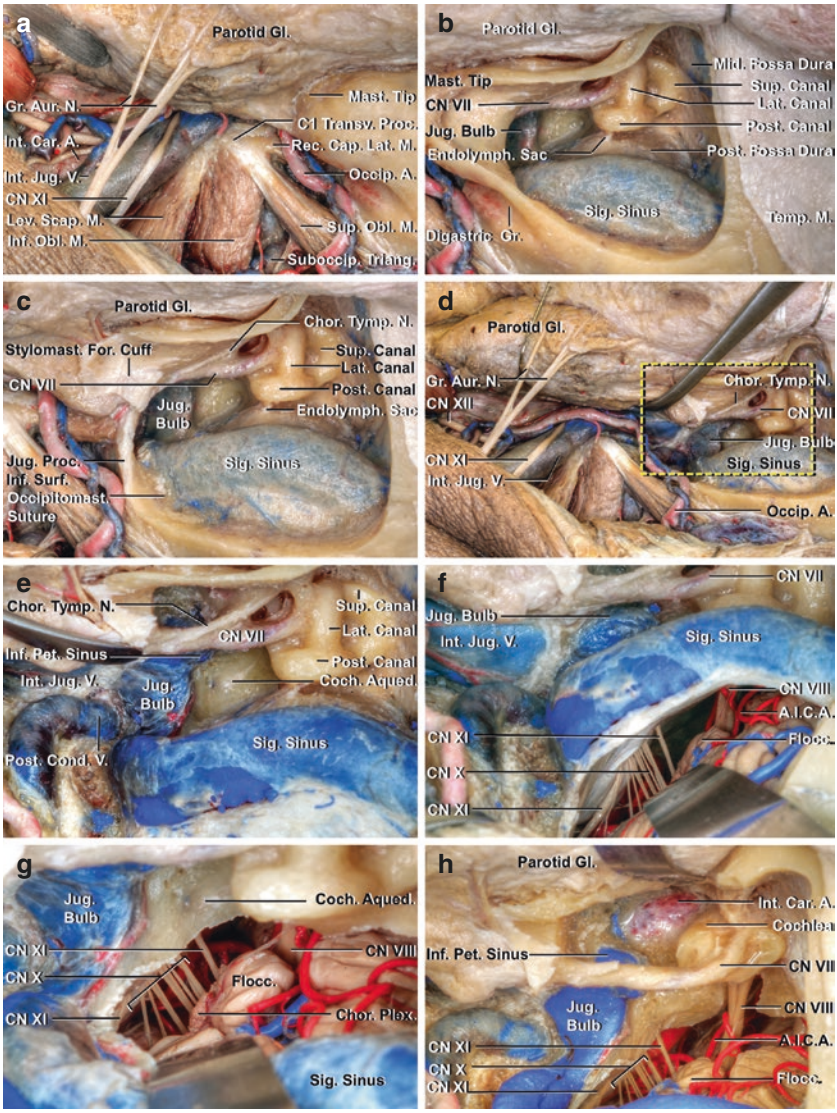


Fig. 2.4 Postauricular transtemporal approach. (**a**) High cervical exposure. (**b**) Infralabyrinthine mastoidectomy. (**c**) The removal of the mastoid tip exposes the insertion of the rectus capitis lateralis muscle into the jugular process. (**d**) Removal of the jugular process and the rectus capitis lateralis exposes the posteroinferior surface of the jugular bulb. (**e**) Enlarged view of the *dotted area* in (**c**) after the Fallopian bridge technique was performed. (**f**) View of the presigmoid approach. (**g**) View of the retrosigmoid approach. (**h**) Removal of the external auditory canal and infracochlear drilling exposes the internal carotid artery medial to the jugular bulb. *A.* artery, *A.I.C.A.* anterior inferior cerebellar artery, *Aur.* auricular, *Aque.* aqueduct, *Cap.* capitis, *Car.* carotid, *Chor.* chorda, choroid, *CN* cranial nerve, *Coch.* cochlear, *Cond.* condylar, *Endolymph.* endolymphatic, *Flocc.* flocculus, *For.* foramen, *Gl.* gland, *Gr.* greater, groove, *Inf.* inferior, *Int.* internal, *Jug.* jugular, *Lat.* lateral, lateralis, *Lev.* levator, *N.* nerve, *M.* muscle, *Mast.* mastoid, *Mid.* middle, *Obl.* oblique, *Occip.* occipital, *Occipitomast.* occipitomastoid, *Pet.* petrosal, *Plex.* plexus, *Post.* posterior, *Proc.* process, *Rec.* rectus, *Scap.* scapula, *Sig.* sigmoid, *Suboccip.* suboccipital, *Sup.* superior, *Surf.* surface, *Stylomast.* stylomastoid, *Temp.* temporalis, *Triang.* triangle, *Tymp.* tympani, *M.* muscle, *Transv.* transverse, *V.* vein

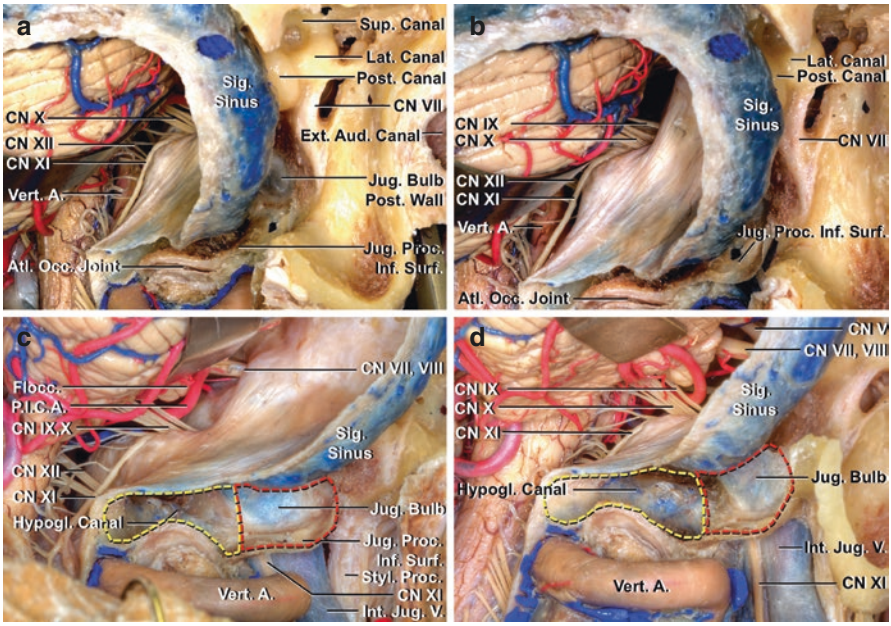


Fig. 2.5 Far-lateral approach. (**a**, **b**) Posterolateral view of the far-lateral approach. (**c**, **d**). Posteroinferior view of the far-lateral approach. *Yellow* and *red dotted lines* indicate the area for the occipital condyle and jugular process, respectively. *A.* artery, *Atl. Occ.* atlanto-occipital, *Aud.* auditory, *CN* cranial nerve, *Ext.* external, *Flocc.* flocculus, *Hypogl.* hypoglossal, *Int.* internal, *Inf.* inferior, *Jug.* jugular, *Lat.* lateral, *P.I.C.A.* posterior inferior cerebellar artery, *Post.* posterior, *Proc.* process, *Sig.* sigmoid, *Styl.* styloid, *Sup.* superior, *Surf.* surface, *V.* vein, *Vert.* vertebral

jugular foramen has three parts: two venous portions including the sigmoid and petrosal and a neural compartment, the intrajugular part. The two venous components, a large lateral part and small medial part, are separated by bony processes, the intrajugular processes of the temporal and occipital bones and intrajugular ridge, which extends forward from the intrajugular process of the temporal bone (Figs. 2.1a, e and 2.2a). The processes are joined by a fibrous or less commonly an osseous bridge, the intrajugular septum, separating the sigmoid and petrosal parts of the foramen [1]. The larger sigmoid part receives drainage from the sigmoid sinus, and the smaller petrous part receives drainage from the inferior petrosal sinus (Figs. 2.1a, b and 2.2a). The pyramidal fossa, a small triangular recess located on the medial side of the intrajugular process of the temporal bone, extends along the anterior surface of the petrous part of the jugular foramen (Figs. 2.1a and 2.2a). Around or in the jugular foramen, the dura of the posterior fossa is attached to the small foramina, mastoid canaliculus, tympanic canaliculus, and cochlear aqueduct. The small foramen on the lateral wall of the jugular fossa is called the mastoid canaliculus, and the auricular branch of the vagus nerve (Arnold's nerve) passes through it (Fig. 2.1e, g). The cochlear canaliculus transmits the perilymphatic duct and cochlear aqueduct; its orifice is located just superior and lateral to where the glossopharyngeal nerve enters the intrajugular part of the jugular foramen. The tympanic canaliculus for Jacobson's nerve, a branch of the glossopharyngeal nerve, is located on or close

to the medial part of the carotid ridge. The carotid ridge separates the carotid canal from the jugular foramen and extends to the intrajugular process of the temporal bone (Figs. 2.1a, e, f and 2.2a) [2].

Arterial Relationships

The major arteries related to the jugular foramen are the internal carotid artery and the ascending pharyngeal artery, which usually arises from the external carotid artery. After bifurcating from the common carotid, the internal carotid artery courses straight upward, posteromedial to the external carotid artery and anteromedial to the internal jugular vein, to reach the skull base (Fig. 2.3a–c). At the level of the entrance of the carotid canal, the internal jugular vein courses just behind the artery. The artery enters into the carotid canal with the carotid sympathetic nerves, ascends, then turns anteromedially to form the posterior genu of the petrous carotid artery (Fig. 2.3a, c, d). The genu is located anteroinferior to the cochlea.

The ascending pharyngeal artery, a branch of the external carotid artery, divides into two major branches: the pharyngeal trunk anteriorly and neuromeningeal trunk posteriorly. Branches from the neuromeningeal trunk include two branches to the dura around the jugular foramen and adjacent area [3, 4]. The hypoglossal branch enters into the hypoglossal canal and the jugular branch into the jugular foramen (Fig. 2.2c, d). After arising from the external carotid artery, the ascending pharyngeal artery ascends straight upward between the internal and external carotid arteries while giving rise to branches to the neighboring muscles, nerves, and lymph nodes [3, 4]. The ascending pharyngeal artery also branches off the inferior tympanic artery, which passes through the tympanic canaliculus along with Jacobson's nerve to reach the tympanic cavity [1].

Venous Relationships

Both intracranial and extracranial drainage empty into the jugular bulb and adjacent part of the jugular vein. The sigmoid part of the jugular foramen receives the drainage from the sigmoid sinus. The sigmoid sinus descends and crosses the occipitomastoid suture, then empties into the sigmoid part, and courses anterior, superior, and slightly lateral to reach the jugular bulb (Figs. 2.1h and 2.2d). The superior surface of the jugular bulb is usually located below the internal auditory canal. It occasionally extends upward to the level of the upper margin of the canal [1]. The bulb is usually larger on the right side, reflecting the larger diameter of the sigmoid sinus on that side [1]. The internal jugular vein starts from the bulb and courses downward posterior to the internal carotid artery and styloid process (Figs. 2.1h, 2.2b, c, and 2.3a). The inferior petrosal sinus courses along the intracranial surface of the petroclival fissure and empties into the petrosal confluence before emptying into the jugular bulb (Figs. 2.2c and 2.3d).

There are several veins connecting the jugular foramen or internal jugular vein with the extracranial venous plexus. The posterior condylar emissary vein passing through the posterior condylar canal, which starts at the center of the condylar fossa, usually empties into the medial part of the sigmoid sinus (Fig. 2.2). The vein connects to the venous plexus around the vertebral artery and sigmoid sinus. The inferior petroclival vein, which courses along the extracranial surface of the petroclival fissure, usually empties into the petrosal confluence (Fig. 2.2b, c). The lateral condylar vein originates from the petrous confluence; courses lateral to the occipital condyle, medial to the internal jugular vein, carotid artery, and CNs IX–XII; and joins the venous plexus around the third segment of the vertebral artery. The venous plexus of the hypoglossal canal, which is also known as the anterior condylar vein, passes through the hypoglossal canal and communicates with the marginal sinus and petrosal confluence (Fig. 2.2b, c). The petrosal confluence has multiple connections with the sigmoid part of the jugular foramen, which usually consists of a large main channel and several small channels. The main channel drains into the medial wall of the jugular bulb between the glossopharyngeal and vagus nerves or directly into the internal jugular vein below the extracranial orifice (Figs. 2.2c and 2.3c) [1].

Neural Relationships

The glossopharyngeal, vagus, and accessory nerves pass through the intrajugular part of the jugular foramen and course along the medial margin of the intrajugular process of the temporal bone to reach the medial wall of the internal jugular vein (Fig. 2.1c, d). The hypoglossal nerve passes through the hypoglossal canal and descends along the medial wall of the internal jugular vein with the vagus and accessory nerves (Figs. 2.1a and 2.2b).

The glossopharyngeal nerve passes through the glossopharyngeal meatus, which is a dural recess located between the jugular dural fold and dural septum, then turns downward and courses along the medial side of the intrajugular ridge to exit the jugular foramen (Figs. 2.1f, 2.2c, and 2.3c). As the nerve courses downward in the high cervical region after it exits the foramen, it courses between the internal carotid artery and internal jugular vein to reach the lateral surface of the internal carotid artery deep to the styloid process (Figs. 2.2c and 2.3c). While the nerve passes through the jugular foramen, it expands at the site of its superior and inferior ganglia (Fig. 2.3d) [1]. Jacobson's nerve arises from the glossopharyngeal nerve at the external orifice of the jugular foramen and passes through the tympanic canaliculus to enter the tympanic cavity where it branches to form the tympanic plexus (Figs. 2.1f–h and 2.3d) [1].

The vagal nerve enters into the vagal meatus inferior to the glossopharyngeal meatus (Fig. 2.1d, e). As it passes through the foramen, its roots gather and form the superior ganglion; this is where the accessory nerve communicates with the vagal nerve (Figs. 2.1e and 2.3d). Arnold's nerve branches off at the level of the superior vagal ganglion and courses lateral in a groove on the anterior wall of the jugular

bulb to reach the lateral wall of the jugular fossa (Figs. 2.1e and 2.3d) [1]. The branch then enters into the mastoid canaliculus, ascends to the mastoid segment of the facial canal, and sends an ascending branch to the facial nerve before turning downward to exit the temporal bone through the tympanomastoid fissure.

The accessory nerve enters the vagal meatus and meets the vagal nerve at the level of the superior vagal ganglion. The accessory nerve then divides into internal and external branches after it exits the jugular foramen. The internal branch joins the vagus nerve, and the external branch descends obliquely between the internal carotid artery and internal jugular vein and then backward across the lateral surface of the vein to reach the sternocleidomastoid and trapezius muscles (Fig. 2.3b–d) [1]. The external branch usually courses along the lateral, but occasionally the medial, surface of the internal jugular vein to reach the muscles. In our dissection, the accessory nerve coursed downward between the internal jugular vein and transverse process of C1 (Fig. 2.3a, b).

Though the hypoglossal nerve passes through its own canal and not the jugular foramen, it joins the glossopharyngeal, vagus, and accessory nerves, which exit the jugular foramen just below the skull, and these nerves descend together along the internal carotid artery and internal jugular vein (Figs. 2.2d and 2.3b–d). After the hypoglossal nerve exits the hypoglossal canal, it descends and turns anteriorly toward the tongue at the level of the transverse process of the atlas (Figs. 2.2d and 2.3c).

Surgical Anatomy for Jugular Paraganglioma: Postauricular Transtemporal Approach and Far-Lateral Approach

To access jugular paragangliomas, Fisch's infratemporal fossa type A approach and its extension are commonly used [5, 6]. The postauricular transtemporal approach is a modification of Fisch's infratemporal fossa type A approach [7]. To clarify the microsurgical anatomy of the jugular foramen and its surrounding structures in the surgical view, cadaveric dissection of the postauricular transtemporal approach has been performed step-by-step for this chapter. If the tumor extends into the posterior cranial fossa, the far-lateral approach and its extension or the transjugular procedures are required. Since many approaches have been reported, surgeons should precisely understand the surgical anatomy of the area and select or combine, if necessary, these approaches based on the tumor location and extension [8–25].

For the postauricular transtemporal approach, the first step is high cervical exposure to control and avoid damage to the internal jugular vein, internal carotid artery, and lower cranial nerves. Detaching the muscles from the mastoid process, including the sternocleidomastoid, semispinalis, longissimus, and digastric muscles, exposes the rectus capitis lateralis muscle, transverse process of C1, and suboccipital triangle. To access the jugular foramen, transverse process of C1, mastoid tip, parotid gland covering the facial nerve, and rectus capitis lateralis are still obstacles (Fig. 2.4a).

Next, an infralabyrinthine retrofacial mastoidectomy is necessary to access the jugular bulb, mainly for the exposure of its superior and lateral aspects (Fig. 2.4b). After exposing the sigmoid sinus, drilling downward along the anterior surface of the sigmoid sinus exposes the jugular bulb. Carefully drilling the bone above the jugular bulb exposes the cochlear aqueduct, a landmark for identifying the glossopharyngeal groove of the temporal bone; the cochlear aqueduct opens into the pyramidal fossa located medial to the glossopharyngeal groove of the temporal bone (Fig. 2.4c and e). Drilling the bone inferiorly into the jugular process can expose the posterior surface of the jugular bulb (Fig. 2.4c). Removing the mastoid tip and drilling the bone along the occipitomastoid suture downward while exposing the sigmoid sinus exposes the insertion of the rectus capitis lateralis muscle into the inferior surface of the jugular process (Fig. 2.4d). In this stage, extreme care should be taken to avoid damage of the sinus, and it is necessary to control the bleeding from the veins connecting to the internal jugular vein, jugular bulb, sigmoid sinus, and anterior condylar confluence. The removal of the jugular process and rectus capitis lateralis are a critical step to expose the posteroinferior aspect of the jugular bulb (Fig. 2.4d, e).

Without anterior rerouting of the facial nerve and removal of the jugular process, the surgical field is limited. Some authors have reported that paragangliomas can be removed without rerouting the facial nerve, but this depends on the case. To gain a wide enough surgical view for access to the paraganglioma and control of the petrous carotid artery, the removal of the styloid process and base of the tympanic bone, temporomandibular joint, parotid gland, pterygoid muscles, and external auditory canal in addition to the anterior rerouting of the facial nerve should be considered. The fallopian bridging technique can provide exposure of the area anterolateral to the jugular bulb and the middle ear cavity. In this dissection, the junction of the inferior petrosal sinus and jugular bulb has been identified (Fig. 2.4e). However, it is extremely difficult to control the petrous carotid artery. After removal of the external auditory canal, infracochlear drilling exposes the petrous carotid artery medial to the jugular bulb (Fig. 2.4h). Both distal and proximal control of the internal carotid artery can be achieved after rerouting the facial nerve anteriorly, which is the basic principle for jugular paraganglioma resection [26–31]. In some cases, the approach without rerouting or minimal inferior rerouting of the facial nerve has been performed by several authors to preserve the facial nerve function (Fig. 2.4e) [32–34].

Intracranial extension of a paraganglioma can be accessed by the addition of the presigmoid, retrosigmoid, or trans-sigmoid approach. Opening the dura in the style of the trans-sigmoid approach is commonly used to attain total resection of the tumor. For this step, a precise understanding of the relationships among the intracranial and extracranial structures of the jugular foramen is crucial. In this chapter, views of the presigmoid and retrosigmoid routes are shown. These approaches can provide access to the area superior and medial to the jugular foramen. For the retrosigmoid approach, the addition of a lateral suboccipital craniotomy is needed to access the lower cranial nerves intracranially. The lateral suboccipital approach (retrosigmoid approach) is one of the most popular procedures to reach the CP

angle. The far-lateral approach is an extensive modification of the lateral suboccipital approach. The basic far-lateral procedure without the drilling of the occipital condyle can reach the intrajugular area where the lower cranial nerves (IX, X, and XI) enter the jugular foramen intracranially.

After detaching the muscles from the superior and inferior nuchal line and reflecting these muscle inferiorly, the condylar fossa, vertebral artery, and the surrounding venous plexus, which is continuous with the posterior condylar emissary vein passing through the condylar canal located superior to the occipital condyle, can be exposed. Then, craniotomy is performed according to the extension of tumor. Furthermore, partial condylectomy can be added if necessary. The far-lateral approach provides enough space to access the lower cranial nerves intracranially (Fig. 2.5). Without removing the jugular process and the rectus capitis lateralis, exposing the jugular bulb may be impossible (Fig. 2.5c, d). To expose the hypoglossal canal and its junction with the medial surface of the internal jugular vein, drilling the occipital condyle is necessary (Figs. 2.2a, b and 2.5b, d). Drilling the jugular process after detaching the rectus capitis lateralis muscle from its inferior surface exposes the posteroinferior surface of the jugular foramen (Fig. 2.5c, d).

References

1. Rhoton AL Jr. Jugular foramen. Neurosurgery. 2000;47(3 suppl):S267–85.
2. Komune N, Komune S, Morishita T, Rhoton AL Jr. Microsurgical anatomy of subtotal temporal bone resection en bloc with the parotid gland and temporomandibular joint. Neurosurgery. 2014;10(Suppl 2):334–56.
3. Hacein-Bey L, Daniels DL, Ulmer JL, Mark LP, Smith MM, Strottmann JM, Brown D, Meyer GA, Wackym PA. The ascending pharyngeal artery: branches, anastomoses, and clinical significance. AJNR Am J Neuroadiol. 2002;23(7):1246–56. Review
4. Rhoton AL Jr. The foramen magnum. Neurosurgery. 2000;47(3 suppl):S155–S93.
5. Fisch U. Infratemporal fossa approach to tumors of the temporal bone and base of the skull. J Laryngol Otol. 1978;92(11):949–67.
6. Fisch U, Pillsbury HC. Infratemporal fossa approach to lesions in the temporal bone and base of the skull. Arch Otolaryngol. 1979;105(2):99–107.
7. Katsuta T, Rhoton AL Jr, Matsushima T. The jugular foramen: microsurgical anatomy and operative approaches. Neurosurgery. 1997;41(1):149–201.
8. Al-Mefty O, Teixeira A. Complex tumors of the glomus jugulare: criteria, treatment, and outcome. J Neurosurg. 2002;97(6):1356–66.
9. Borba LAB, Ale-Bark S, London C. Surgical treatment of glomus jugulare tumors without rerouting of the facial nerve: an infralabyrinthine approach. Neurosurg Focus. 2004;17(2):E8.
10. Bruneau M. The juxtacondylar approach to the jugular foramen. Neurosurgery. 2008;62(3 Suppl 1):75–8.
11. Gardner G, Cocke EW, Robertson JT, Trumbull ML, Palmer RE. Combined approach surgery for removal of glomus jugulare tumors. Laryngoscope. 1977;87(5 Pt 1):665–88.
12. George B, Lot G, Tran Ba Huy P. The juxtacondylar approach to the jugular foramen (without petrous bone drilling). Surg Neurol. 1995;44(3):279–84.
13. Inserra MM, Pfister M, Jackler RK. Anatomy involved in the jugular foramen approach for jugulotympanic paraganglioma resection. Neurosurg Focus. 2004;17(2):41–4.

14. Liu JK, Sameshima T, Gottfried ON, Couldwell WT, Fukushima T. The combined transmastoid retro- and infralabyrinthine transjugular transcondylar transtubercular high cervical approach for resection of glomus jugulare tumors. Neurosurgery. 2006;59(Suppl 1):ONS115–25.
15. Mazzoni A. The petro-occipital trans-sigmoid approach for lesions of the jugular foramen. Skull Base. 2009;19(1):48–56.
16. Mazzoni A, Sanna M. A posterolateral approach to the skull base: the petro-occipital trans-sigmoid approach. Skull Base Surg. 1995;5(3):157–67.
17. Michael LM, Robertson JH. Glomus jugulare tumors: historical overview of the management of this disease. Neurosurg Focus. 2004;17(2):E1.
18. Nakamizo A, Akagi Y, Watanabe T, Kawahara N, Sasaki T. Posterior transjugular and transcervical approach for glomus tumors within the head and neck. Br J Neurosurg. 2013;27(2):212–7.
19. Oghalai JS, Leung MK, Jackler RK, McDermott MW. Transjugular craniotomy for the management of jugular foramen tumors with intracranial extension. Otol Neurotol. 2004;25(4):570–9.
20. Patel SJ, Sekhar LN, Cass SP, Hirsch BE. Combined approaches for resection of extensive glomus jugulare tumors. A review of 12 cases. J Neurosurg. 1994;80(6):1026–38.
21. Pellet W, Cannoni M, Pech A. The widened transcochlear approach to jugular foramen tumors. J Neurosurg. 1988;69(6):887–94.
22. Rhoton AL, Buza R. Microsurgical anatomy of the jugular foramen. J Neurosurg. 1975;42(5): 541–50.
23. Sekhar LN, Schramm VL, Jones NF. Subtemporal-preauricular infratemporal fossa approach to large lateral and posterior cranial base neoplasms. J Neurosurg. 1987;67(4):488–99.
24. Sen C, Hague K, Kacchara R, Jenkins A, Das S, Catalano P. Jugular foramen: microscopic anatomic features and implications for neural preservation with reference to glomus tumors involving the temporal bone. Neurosurgery. 2001;48(4):838–47.
25. Wen HT, Rhoton AL, Katsuta T, de Oliveira E. Microsurgical anatomy of the transcondylar, supracondylar, and paracondylar extensions of the far-lateral approach. J Neurosurg. 1997;87(4):555–85.
26. Sanna M, Bacciu A, Falcioni M, Taibah A, Piazza P. Surgical management of jugular foramen meningiomas: a series of 13 cases and review of the literature. Laryngoscope. 2007;117(10):1710–9. Review
27. Sanna M, De Donato G, Piazza P, Falcioni M. Revision glomus tumor surgery. Otolaryngol Clin North Am. 2006;39(4):763–82, vii. Review
28. Sanna M, Flanagan S. The combined transmastoid retro- and infralabyrinthine transjugular transcondylar transtubercular high cervical approach for resection of glomus jugulare tumors. Neurosurgery. 2006;61(6):E1340. author reply
29. Sanna M, Jain Y, De Donato G, Rohit LL, Taibah A. Management of jugular paragangliomas: the Gruppo Otologico experience. Otol Neurotol. 2004;25(5):797–804.
30. Sanna M, Khrais T, Menozi R, Piaza P. Surgical removal of jugular paragangliomas after stenting of the intratemporal internal carotid artery: a preliminary report. Laryngoscope. 2006;116(5):742–6.
31. Sanna M, Shin SH, Piazza P, Pasanisi E, Vitullo F, Di Lella F, Bacciu A. Infratemporal fossa approach type a with transcondylar-transtubercular extension for Fisch type C2 to C4 tympanojugular paragangliomas. Head Neck. 2014;36(11):1581–8.
32. Borba LA, Araujo JC, de oliveira JG, Filho MG, Moro MS, Tirapelli LF, Colli BO. Surgical management of glomus jugulare tumors: a proposal for approach selection based on tumor relationships with the facial nerve. J Neurosurg. 2010;112(1):88–98.
33. Nonaka Y, Fukushima T, Watanabe K, Friedman AH, JT ME Jr, Cunningham CD 3rd, Zomorodi AR. Less invasive transjugular approach with fallopian bridge technique for facial nerve protection and hearing preservation in surgery of glomus jugulare tumors. Neurosurg Rev. 2013 Oct;36(4):579–86; discussion 586.
34. Pensak ML, Jackler RK. Removal of jugular foramen tumors: the fallopian bridge technique. Otolaryngol Head Neck Surg. 1997;117(6):586–91.