Suprajugular extension of the retrosigmoid approach: microsurgical anatomy

Laboratory investigation

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Object. Jugular foramen tumors often extend intra- and extracranially. The gross-total removal of tumors located both intracranially and intraforaminally is technically challenging and often requires a combined skull base approach. This study presents a suprajugular extension of the retrosigmoid approach directed through the osseous roof of the jugular foramen that allows the removal of tumors located in the cerebellopontine angle with extension into the upper part of the foramen, with demonstration of an illustrative case.

Methods. The cerebellopontine angles and jugular foramina were examined in dry skulls and cadaveric heads to clarify the microsurgical anatomy around the jugular foramen and to define the steps of the suprajugular exposure.

Results. The area drilled in the suprajugular approach is inferior to the acoustic meatus, medial to the endolymphatic depression and surrounding the superior half of the glosopharyngeal dural fold. Opening this area exposed the upper part of the jugular foramen and extended the exposure along the glosopharyngeal nerve below the roof of the jugular foramen. In the illustrative case, a schwannoma originating from the glosopharyngeal nerve in the cerebellopontine angle and extending below the roof of the jugular foramen and above the jugular bulb was totally removed without any postoperative complications.

Conclusions. The suprajugular extension of the retrosigmoid approach will permit removal of tumors located predominantly in the cerebellopontine angle but also extending into the upper part of the jugular foramen without any additional skull base approaches.

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KEY WORDS • cerebellopontine angle • cranial nerve • jugular foramen • microsurgical anatomy • retrosigmoid approach • temporal bone

Jugular foramen tumors that extend both intra- and extracranially through the foramen are challenging lesions that may require a combination of skull base approaches for removal. The retrosigmoid approach is commonly selected when the main mass of the tumor is primarily intracranial. However, a tumor that extends into the upper part of the jugular foramen may be difficult to remove by the retrosigmoid approach and often requires additional extensions or approaches for removal. This article presents a new extension of the retrosigmoid approach designed to remove cerebellopontine tumors that extend into the upper part of the jugular foramen above the jugular bulb. In the approach, the bone superior to the jugular foramen and below the internal acoustic meatus, including the intrajugular process, is drilled. This study was designed to clarify the microsurgical anatomy around the jugular foramen and to define the suprajugular extension of the retrosigmoid approach (Fig. 1).

Methods

The region around the jugular foramen was studied in step-by-step dissections of 20 suprajugular areas in 10 dry skulls and 12 cerebellopontine angles from 6 cadaveric heads using an operating microscope (Carl Zeiss Corp.) (Table 1). The arteries were perfused with red and the veins with blue-colored silicone. Bone dissections were performed with a Midas Rex drill (Midas Rex Institute). The length of cranial nerve (CN) IX inside the jugular foramen exposed by this approach was also measured after drilling the suprajugular region.

Abbreviation used in this paper: CN = cranial nerve.
**Results**

**Osseous Structures**

The jugular foramen can be regarded as a hiatus between the temporal and occipital bones, with its anterolateral margin formed by the petrous part of the temporal bone and its posteromedial margin formed by the condylar part of the occipital bone. The jugular foramen differs from some other cranial foramina in that it does not descend vertically through the bone but is directed forward under the petrous part of the temporal bone which forms a roof to the foramen. When viewed from directly su-

<table>
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<tr>
<th>Description</th>
<th>Mean (mm)</th>
<th>Range (mm)</th>
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<tbody>
<tr>
<td>A. lateral edge of the porus of the internal acoustic meatus to the endolymphatic depression</td>
<td>9.6</td>
<td>7.4–12.6</td>
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<td>B. lateral edge of the porus of the internal acoustic meatus to the posterior jugular ridge</td>
<td>11.5</td>
<td>8.4–16.1</td>
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<td>C. lateral edge of the porus of the internal acoustic meatus to the posterior tip of the intrajugular process</td>
<td>9.9</td>
<td>6.9–11.6</td>
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<tr>
<td>D. lateral edge of the porus of the internal acoustic meatus to upper edge of the pyramidal fossa</td>
<td>6.0</td>
<td>4.9–8.4</td>
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<tr>
<td>E. lateral edge of the porus of the internal acoustic meatus to medial edge of the pyramidal fossa</td>
<td>8.8</td>
<td>5.0–12.6</td>
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<tr>
<td>F. upper edge of the pyramidal fossa to the medial edge of the pyramidal fossa</td>
<td>4.5</td>
<td>2.0–6.7</td>
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<tr>
<td>G. upper edge of the pyramidal fossa to posterior tip of the intrajugular process</td>
<td>3.6</td>
<td>1.4–5.1</td>
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* See Fig. 3B.
ior the foramen has a roof formed by the intrajugular process that hides the roof of the jugular bulb, which occupies the jugular fossa and fills the foramen. It is through this roof of the foramen that the suprajugular approach is directed (Fig. 2).

At the intracranial orifice, the foramen is located inferior to the internal acoustic meatus, medial to the endolymphatic depression in which the endolymphatic sac sits, and superolateral to the jugular tubercle. The foramen has 2 main venous parts: sigmoid and petrosal, which receive the flow of the sigmoid and inferior petrosal sinuses respectively. These 2 parts are separated by the intrajugular process and intrajugular ridge of the temporal bone. The intrajugular ridge extends downward from the intrajugular process along the medial side of the jugular bulb (Fig. 2E). CNs IX–XI pass through the intrajugular part of the foramen adjacent the intrajugular process. A small recess, the pyramidal fossa, extends upward along the inferior surface of the temporal bone on the medial sides of the intrajugular process and ridge to create a deep groove in which CN IX courses. When viewed in a posterior to anterior direction, the petrous part of the temporal bone, including the intrajugular process, projects posteriorly to form a roof to the jugular foramen under which the jugular fossa and bulb reside. Removing this roof of the jugular foramen exposes the upper part of the foramen (Fig. 3A), removing the lateral half of the intrajugular process exposes the medial edge of the sigmoid part of the foramen (Fig. 3A and C), and removing the medial half of the intrajugular process exposes the pyramidal fossa (Fig. 3A and D). Additional drilling of the superior wall of the pyramidal fossa exposes the entire fossa and the cisternal aperture of the cochlear aqueduct, which opens at the superior apex of the fossa (Fig. 3A and E).

**Neural and Dural Structures**

At the intracranial orifice of the foramen, the intrajugular process is not seen because it is hidden under its dural covering (Fig. 4A). The dura mater over the jugular foramen has 2 characteristic dural perforations: the glossoopharyngeal meatus, through which CN IX passes, and the vagal meatus, through which CNs X and XI exit the dura (Fig. 4C). The dural vagal meatus is located inferior to and is separated by a dural septum from the glossoopharyngeal meatus (Fig. 4B). The inferior petrosal and sigmoid sinuses and the endolymphatic sac, which resides in the endolymphatic depression, can be seen between the layers of the dura (Fig. 4A). After removal of the dura of the suprajugular region that extends downward from the lower edge of the internal acoustic meatus and along the medial edge of the endolymphatic depression, the intrajugular process is exposed lateral to the glossoopharyngeal and vagal meati (Fig. 4B). The dura of the suprajugular region turns down inside the jugular foramen to enclose the jugular bulb. Drilling the roof of the jugular foramen exposes the superior wall of the jugular bulb and the cisternal aperture of the cochlear aqueduct and provides additional exposure of the glossoopharyngeal and vagal dural folds (Fig. 4C). CNs IX–XI with their dural folds course laterally along the medial side of the intrajugular ridge, and turn inferiorly inside the jugular foramen on the medial side of the jugular bulb. The cochlear aqueduct opens into the pyramidal fossa just above where CN IX turns downward at the dural roof of the foramen. In the suprajugular approach, the dura covering the posterior surface of the temporal bone is removed up to the medial edge of the endolymphatic sac, which is situated between the layers of the dura at the medial edge of the endolymphatic depression (Fig. 4D). The dura is strongly adhered along the endolymphatic depression. In the laboratory, the medial edge of the intrajugular ridge and the jugular bulb can be removed to expose the entire descending course of CNs IX–XI inside the jugular foramen, but this is not a part of the suprajugular approach. CN IX gives origin to the tympanic branch, which enters the tympanic canalculus, and CN X gives origin to the auricular branch, which merges with a branch from CN IX to course along the inner surface of the sigmoid part to enter the mastoid canalculus (Fig. 4G).

**Vascular Structures**

There are 2 main venous parts in the jugular foramen: the petrosal part, which receives the flow of the inferior petrosal sinus and associated venous channels, referred to as the petrosal confluens; and the sigmoid part, into which the sigmoid sinus drains and in which the jugular bulb sits (Fig. 4E). The jugular bulb receives drainage from both intra- and extracranial sources directly from the sigmoid sinus and through the petrosal confluens, which includes the inferior petrosal sinus, the venous plexus of the hypoglossal canal, and the posterior and lateral condylar emissary veins. The venous plexus of the hypoglossal canal connects the petrosal part to the marginal sinus and the posterior condylar emissary vein connects the jugular bulb or sigmoid sinus to the vertebral venous plexus. A lateral condylar emissary vein may also connect the jugular bulb to the vertebral venous plexus on the extracranial side.17, 29

After reaching the posterior edge of the jugular foramen, the sigmoid sinus bulges laterally and upward to form the jugular bulb, which occupies the jugular fossa. The bulb may infrequently extend upward into the posterior wall of the internal auditory meatus to the level of the upper margin of the meatus. Several small channels positioned below the horizontal courses of CNs IX–XI connect the jugular bulb with the petrosal confluens. Drilling further anterior below the internal acoustic meatus exposes the petrous portion of the internal carotid artery (Fig. 4H).  

**Suprajugular Drilling**

The drilling area above the jugular foramen, which we referred to as the suprajugular region, is limited by the internal acoustic meatus above and the endolymphatic depression laterally (Fig. 5). The downward deflection of the dura along the upper edge of the jugular bulb provides a reliable landmark for identifying this edge of the bulb and foramen. Developing a dural flap based along the upper edge of the jugular foramen and folded downward behind CNs IX–XI protects the nerves during drilling (Fig. 5B).
Fig. 2. Photographs of a dry skull showing the osseous relationships of the jugular foramen. The bone drilled in the suprajugular approach is highlighted in red. **A and B:** The jugular foramen viewed from directly superior (A) and posterosuperior (B). In the view from above (A), the jugular foramen, located between the temporal and occipital bones, is hidden below the petrous part of the temporal bone. The jugular foramen has a larger sigmoid part through which the sigmoid sinus drains and a smaller petrosal part through which the inferior petrosal sinus empties. The foramen is best seen in the posterosuperior view (B) directed forward under the petrous part of the temporal bone. The temporal bone forms a roof to the jugular foramen. **C and D:** The jugular foramen in the view from below (C) and anteroinferior (D). In the view from below (C), one cannot see directly through the jugular foramen because it is roofed by the temporal bone. The shape of the jugular foramen is best seen in the anteroinferior view (D). **E:** In a posterosuperior view, the intrajugular process projects posteriorly between the petrosal and sigmoid parts to form the roof of the jugular foramen. It is through this roof of the foramen that the suprajugular approach is directed. The intrajugular ridge extends downward from the intrajugular process along the medial side of the jugular fossa, in which the jugular bulb resides. **F:** CN IX, after turning downward below the pyramidal fossa, passes forward along the medial side of the intrajugular process and ridge. CNs X and XI pass downward on the medial side of the intrajugular process but not the intrajugular ridge. Ac. = acoustic; Car. = carotid; CN = cranial nerve; Coch. = cochlear; Cond. = condyle; Depress. = depression; Endolymph. = endolymphatic; Fiss. = fissure; For. = foramen; Int. = internal; Intrajug. = intrajugular; Jug. = jugular; Mag. = magnum; Meat. = meatus; Occip. = occipital; Pet. = petrosal; Petrocliv. = petroclival; Proc. = process; Sig. = sigmoid; Stylomast. = stylomastoid; Tuberc. = tubercle.
Photographs illustrating the stepwise dissection of a right jugular foramen in a dry skull (posterosuperior view). A: The intrajugular process of the temporal bone forms the roof of the jugular foramen. The lateral (red) and medial (blue) half of the intrajugular process and the superior wall of the pyramidal fossa (green) are removed in the suprajugular approach. B: Measurements related to the suprajugular approach (Table 1). C: The lateral half of the intrajugular process has been removed to expose the jugular fossa in which the jugular bulb sits. D: Removing the medial half of the intrajugular process exposes the lower part of the pyramidal fossa through which CN IX passes. E: Removing the superior wall of the pyramidal fossa exposes the entire pyramidal fossa and the cisternal aperture of the cochlear aqueduct. Ac. = acoustic; Coch. = cochlear; Depress. = depression; Endolymph. = endolymphatic; Fiss. = fissure; For. = foramen; Hypogl. = hypoglossal; Int. = internal; Intrajug. = intrajugular; Jug. = jugular; Meat. = meatus; Med. = medial; Pet. = petrosal; Petrocliv. = petroclival; Post. = posterior; Proc. = process; Sig. = sigmoid; Subarc. = subarcuate; Tuberc. = tubercle.
Fig. 4. Photographs illustrating the stepwise exposure of the right jugular foramen in a cadaveric specimen. A: The posterior surface of the temporal and occipital bones surrounding the jugular foramen. B: The dura has been removed from the area to be drilled in the suprajugular approach. The intrajugular process, located between the petrosal and sigmoid parts of the foramen has been exposed. CN IX passes just below the pyramidal fossa into which the cochlear aqueduct opens. C: The glossopharyngeal and vagal dural folds surround the upper edge of the glossopharyngeal and vagal meati. The jugular bulb, cisternal aperture of the cochlear aqueduct, and intrajugular ridge have been exposed. D: Removing the dura mater along the posterior surface of the temporal bone lateral to the jugular foramen exposes the endolymphatic sac. CN IX, after entering the dura, passes forward along the medial side of the intrajugular ridge. CNs X and XI pass along the medial side of the intrajugular process and turn downward before reaching the intrajugular ridge. Note: Steps D–H, although not a part of the usual suprajugular approach, illustrate additional anatomy important in planning the approach. E: Removing the posterior part of the intrajugular ridge exposes the descending segments of CNs IX–XI. F: The jugular bulb and sigmoid sinus have been removed to show the relationship of the nerves and intrajugular ridge to the sigmoid part of the foramen. G: The tympanic and auricular branches arising in the jugular foramen have been exposed. The tympanic branch arises from CN IX and enters into the tympanic canaliculus. The auricular branch arises from CN X, which is not seen, joins a small branch from CN IX, and enters into the mastoid canaliculus. H: Drilling anterior to the suprajugular region exposes the petrous part of the internal carotid artery. A. = artery; Ac. = acoustic; Aur. = auricular; Br. = branch; Car. = carotid; CN = cranial nerve; Coch. = cochlear; Cond. = condylar; Depress. = depression; Endolymph. = endolymphatic; Glossopharyng. = glossopharyngeal; Inf. = inferior; Int. = internal; Intrajug. = intrajugular; Jug. = jugular; Lat. = lateral; Metat. = meatus; Pet. = petrosal, petrous; Proc. = process; Sept. = septum; Sig. = sigmoid; Stylomast. = stylomastoid; Tympan. = tympanic; V. = vein.
Fig. 5. Photographs illustrating the suprajugular extension of a retrosigmoid approach in a cadaveric specimen. A: Retrosigmoid exposure of the left cerebellopontine angle. B: The dura mater in the suprajugular region has been opened and a dural flap folded downward to protect CNs IX–XI during drilling. C: The lateral half of the intrajugular process has been drilled to expose the jugular bulb. D: Drilling the medial half of the intrajugular process exposes CNs IX–XI below the pyramidal fossa. E: Completing the suprajugular drilling adds 5 mm to the length of exposure of CN IX distal to the dural glossopharyngeal meatus. A. = artery; A.I.C.A. = anterior inferior cerebellar artery; Ant. = anterior; CN = cranial nerve; Flocc. = flocculus; Intrajug. = intrajugular; Jug. = jugular; Labyr. = labyrinthine; Med. = medial; Pet. = petrosal; Proc. = process; Sept. = septum; Sup. = superior; V. = vein.
The area exposed for the approach is limited above by the internal acoustic meatus, CNs VII and VIII, and the labyrinthine artery and below by CNs IX–XI and the jugular bulb. Care is required to protect the anterior inferior cerebellar artery, which may course below CN VIII; the posterior inferior cerebellar artery, which courses dorsally around the medulla at any site between CN IX and lower margin of CN XI; and the bridging veins, such as the glossoopharyngeal and vagal veins, which course from the medulla to the jugular bulb. Removing the suprajugular bone provides access to an average of 5 mm (range 4.2–6.7 mm) of CN IX below the dural roof of the jugular foramen (Fig. 5E).

Illustrative Case

This 37-year-old woman presented with a right jugular foramen schwannoma. Magnetic resonance imaging showed a round homogeneously enhancing tumor in the cerebellopontine angle and inside the upper part of the jugular foramen (Figs. 6A–C). The jugular bulb was displaced posteroinferiorly by the tumor. The patency of the sigmoid sinus and the internal jugular vein was confirmed by digital subtraction angiography. The retrosigmoid suprajugular approach was performed by one of the senior authors (M.K.).

After lateral suboccipital craniotomy and removal of tumor from the cerebellopontine angle (Fig. 7A and B), additional tumor was seen at the intradural surface of the jugular foramen (Fig. 7B and C). The dura above the jugular foramen was opened, and the tumor was exposed by drilling the intrajugular ridge and the pyramidal fossa (Figs. 3A and 7E). The tumor extending into the upper part of the jugular foramen was removed completely with preservation of the lower cranial nerves (Fig. 7F). Extubation was performed immediately after surgery, and laryngoscopy the next day did not demonstrate any cranial nerve deficits. Postoperative MRI and CT scans confirmed the complete resection of the lesion (Fig. 6D, E, and G). As of the most recent follow-up examination, 4 months after the operation, the patient had no neurological deficit or sign of recurrence.

Discussion

The jugular foramen is one of the most difficult regions to access surgically because of its deep location, the presence of vital structures, and the frequent intracranial and extracranial involvement. The various surgical approaches for jugular foramen tumors have been developed cooperatively by neurosurgeons and otorhinolaryngologists. The current commonly selected approaches are the retrosigmoid, far lateral with its transcondylar or paracondylar extensions, postauricular transtemporal, and the preauricular subtemporal-infratemporal approaches. The retrosigmoid approach, or the far lateral approach, and its extensions are commonly selected to access and remove tumors located predominantly intracranially.

However, a small residual component inside the upper part of the jugular foramen is often difficult to access via the retrosigmoid approach, even with its transcondylar extension. Some transmastoid or presigmoid approaches, including the infralabyrinthine modification, provide access to tumor in the foramen, but this access may not provide satisfactory exposure of the intracranial part. A 2-staged surgery that combines a retrosigmoid...
The retrosigmoid suprajugular approach has been used successfully for jugular foramen schwannomas.\textsuperscript{15,18,30,38} However, the suprajugular extension with drilling the roof of the jugular foramen through the retrosigmoid approach provides access to intracranial lesions extending into the upper part of the foramen.\textsuperscript{27} The postauricular transtemporal or paracondylar approaches may be appropriate for a tumor that fills the foramen and extends extracranially.\textsuperscript{2,3,6,13,20,22}

Jugular foramen schwannomas have been classified into 4 types by Kaye et al. and Samii et al.: Type A, the tumor is intracranial with minimal enlargement of the jugular foramen; Type B, the tumor is located mainly within the bone and foramen with or without intracranial extension; Type C, the tumor is primarily extracranial with or without extension into the bone or intracranially; and Type D, dumbbell-shaped tumors with both intracranial and extracranial components.\textsuperscript{15,21,26} The retrosig-
The suprajugular approach would be suitable for Type A schwannomas extending into the upper part of the jugular foramen. The frequency of this type has varied from 8.6% to 50% of jugular foramen schwannomas in different series. 8,19,26,31,36

The origin, radiological characteristics, and pathological behavior of jugular foramen schwannoma have been reviewed elsewhere. 5,8,18,26,31,36 In the nonpathological jugular foramen, CNs IX–XI course superomedial to the jugular bulb. If the tumor originates from CNs IX–XI and develops inside the upper part of the jugular foramen with intracranial extension, the lesion would occupy the superior part of the jugular foramen and displace the jugular bulb posteroinferiorly as in our illustrative case. The suprajugular approach provides an efficient and direct exposure to such lesions, while reducing the risk of jugular bulb injury.

The area drilled in the suprajugular approach is defined as the area below the internal acoustic meatus, roof of the jugular foramen, and anteromedial part of the endolymphatic depression. The structures to be avoided are CNs IX–XI and the jugular bulb. CNs IX–XI have dural folds around them that aid in their preservation during drilling. Jugular bulb injury is a risk when drilling, especially if the jugular bulb is high. 35 The tumor will be located under the drilling area if the tumor displaces the jugular bulb inferiorly, thus reducing the risk to the jugular bulb. Preoperative evaluation of the position and height of the jugular bulb may aid in safely drilling the area above it.

Suprajugular drilling may provide access to an additional 6.7 mm (average 5.0 mm) of CN IX inside the jugular foramen. The inferior petrosal sinus and the petrous portion of the internal carotid artery are located anterior to the suprajugular region. Drilling further anteriorly, as proposed in the inframeatal approach for petrous apex tumors involving the inframeatal area, is ineffective in accessing the upper part of the jugular foramen. 28 Drilling the area deep to the endolymphatic depression could give wider access inside the jugular foramen, but adds to the risk of injury to the jugular bulb–sigmoid sinus junction.

Conclusions

The suprajugular extension of the retrosigmoid approach will permit removal of some tumors located mainly in the cerebellopontine angle with extension into the upper part of the jugular foramen. A detailed preoperative evaluation of the tumor’s influence on the surrounding structures, including assessment of the position and height of the jugular bulb, will aid in safely drilling and exposing this area.

Disclosure

Support for this study was provided by the University of Florida Foundation. 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: K. Matsushima, Kohno, Komune, T. Matsushima. Acquisition of data: Rhoton, Matsushima, Komune. Analysis and interpretation of data: Rhoton, K. Matsushima, Kohno. Drafting the article: K. Matsushima, Miki. 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: Rhoton. Administrative/technical/material support: Rhoton. Prepared illustrations: Miki.

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