Microsurgical anatomy of the jugular foramen

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The authors conducted an autopsy study of 50 jugular foramina and surrounding tissue, using the dissecting microscope. Anatomical findings from this study are presented.

KEY WORDS • jugular foramen • microsurgical anatomy • glossopharyngeal nerve • vagus nerve

The increasing use of magnification in surgery for glossopharyngeal neuralgia, glomus tumors, and jugular neuromas has created a need for more detailed anatomical studies of the jugular foramen. To obtain a better definition of this anatomy, we used the dissecting microscope to examine 50 jugular foramina at autopsy.

Methods
The cerebral hemispheres, rostral brain stem, and tentorium were removed. The brain stem and cerebellum were divided sagittally into right and left halves, and the spinal cord was sectioned at C1–2. A block of bone containing the jugular foramen and adjacent temporal and occipital bone was separated from the adjacent cranial base. These steps yielded a single specimen consisting of one half of the brain stem, the ninth, tenth, and eleventh cranial nerves, the jugular foramen, and surrounding bone. The specimens were then examined in detail with 3 to 20× magnification.

Results
The anterolateral bony wall of the jugular foramen is formed by the temporal bone and the posteromedial wall by the occipital bone. Hovelacque sub divided the bony foramen into a larger, posterolateral compartment (pars venosa) containing the jugular bulb and tenth and eleventh cranial nerves and a smaller anteromedial compartment (pars nervosa) containing the ninth cranial nerve (Fig. 1). These two parts are usually separated by a fibrous bridge connecting the jugular spine of the petrous temporal bone to the jugular process of the occipital bone. We found this bridge to be bone and not fibrous in 13 specimens (26%); it was composed of bone bilaterally in only two. In three specimens the glossopharyngeal nerve left the skull through a separate bony canal anterior to, rather than through, the pars nervosa (Fig. 1 lower). The right foramen was larger than the left in 17 of the 25 cases (68%), equal in three (12%), and smaller than the left in five (20%).
A. L. Rhoton, Jr., and R. Buza

FIG. 1. **Upper:** Posterior view of the skull and jugular foramen. A: Left. B: Right. Bony strut separates pars nervosa and venosa on right but not on left. **Lower:** Artist’s representation of the posterior view of the skull, brain stem, and jugular foramina, same orientation as above. The glossopharyngeal nerve (IX) on the left leaves the skull through a bony canal separate from the jugular foramen. On the right this nerve leaves through a pars nervosa separated by a bony bridge from the pars venosa. The vagus nerve (X) leaves the skull through the medial part of the pars venosa.

We found that the dura over the jugular foramen had two characteristic perforations forming a glossopharyngeal meatus through which the ninth nerve passed to enter the pars nervosa, and a vagal meatus through which vagus and spinal accessory nerves entered the anteromedial part of the pars venosa and jugular bulb (Figs. 2 and 3). The glossopharyngeal and vagal meati were consistently separated by a dural septum whose width ranged from 0.5 to 4.9 mm. The glossopharyngeal meatus was funnel-shaped, becoming narrower as the nerve passed distally. The vagal meatus was a shallow sieve-like dural depression, approximately twice the width of the glossopharyngeal meatus; it lay over the anteromedial part of the pars venosa and varied in shape from elliptical to round, or even rectangular.

The anterior and lateral margins of the glossopharyngeal and vagal meati frequently formed a roof or lip that projected posteromedially over the respective dural exits of the nerves (Figs. 2, 3, 4). This lip projected over the glossopharyngeal meatus in 49 of 50 specimens and was comparable to, but smaller than, the posterior lip of the acoustic meatus. It was either predominantly bony or...
Microsurgical anatomy of the jugular foramen

Fig. 2. Drawing (left) shows direction of view of specimen in photograph (right). Glossopharyngeal and vagal meati are separated by a ductal septum. The vagus and spinal accessory nerves have a separate entrance into the vagal meatus. The glossopharyngeal meatus is covered by a lip or roof arising laterally.

fibrous and projected a maximum of 2.5 mm over the margin of the meatus. The vagal lip was present in only four specimens and projected a maximum of 1 mm over the margin of the meatus.

The glossopharyngeal nerve arose from the upper medulla, just caudal to the origin of the facial nerve, 2.0 to 4.0 mm dorsal to the olive, and coursed ventral to the choroid plexus protruding from the foramen of Luschka on its way to the jugular foramen (Figs. 5, 6, 7). Its length from brain stem to dura ranged from 15.0 to 21.0 mm, the average being 17.6 mm. The glossopharyngeal nerve frequently had both a dorsal and ventral component. The larger dorsal component arose from the medulla as one root except in two cases in which it originated as two rootlets, and the two rootlets remained separate throughout their course to the meatus in only one case (Fig. 6 lower). Glossopharyngeal diameter after all the rootlets had joined to form a single root varied from 0.4 to 1.1 mm. In 27 specimens one or two smaller rootlets arose ventral to the main dorsal bundle; the ventral fibers are considered a motor component and the main dorsal rootlet a sensory component.

The vagus nerve consisted of a series of rootlets arising caudal to the glossopharyngeal nerve along a line 2.0 to 5.5 mm in length (Figs. 5 and 6). The most rostral vagal fibers usually arose immediately adjacent to the glossopharyngeal origin, from which they were sometimes separated by as much as 2.0 mm. Vagal rootlet diameter varied from 0.1 to 1.5 mm. The vagus was composed of multiple combinations of large and small rootlets that passed ventral to the foramen of Luschka, choroid plexus of the cerebellopontine angle, and flocculus of the cerebellum to the anteromedial part of the pars venosa (Figs. 5, 6, 7). Occasionally, several small rootlets were found originating ventral to the majority of the vagal rootlets. Vagal rosette length from brain stem to dural vagal meatus ranged from 15.0 to 22.9 mm, with the mean 17.1 mm.

The superior glossopharyngeal ganglion was easily visible intracranially in 16 specimens. The superior vagal ganglion was partially visible above the dura in seven specimens, and in these only the superior part was visible.

The cranial rootlets of the accessory nerve arose as a line of rootlets ranging in diameter from 0.1 to 1.0 mm just caudal to the vagal fibers (Fig. 5). The brain stem origin of the rostral fibers of the glossopharyngeal nerve
was separated from the caudal vagal fibers by a maximum of 1.5 mm. Separation of the lower vagal fibers from the upper accessory rootlets was sometimes difficult because they often entered the vagal meatus as a single bundle.

The upper rootlets of the spinal portion of the accessory nerve originated several millimeters caudal to the lowest cranial accessory fibers and either coursed to join the cranial accessory bundle or entered the lower border of the vagal meatus separate from the cranial accessory rootlets (Fig. 2). The spinal accessory fibers passed superolaterally; the length of these fibers from the level of C-1 to the vagal meatus ranged from 17.0 to 26.0 mm. The diameter of the main trunk of the spinal portion of the accessory nerve ranged from 0.8 to 1.5 mm, the average being 1.2 mm. Although the cranial and spinal portions of the accessory nerve most frequently entered the vagal meatus together, a dural septum separated them in six specimens. In 36 specimens some of the ascending rootlets entered the dura caudal to the vagal meatus and ascended a maximum of 1.2 mm within the dura to join the remaining rootlets at the pars venosa.
Microsurgical anatomy of the jugular foramen

**Fig. 4.** View of left jugular foramen from above. *Left:* Dural roof over glossopharyngeal meatus, dural septum separating glossopharyngeal and vagal meati, and view down acoustic meatus to show transverse crest. *Right:* Same specimen with dural roof removed to show relation of nerves to sigmoid sinus and jugular bulb.

**Fig. 5.** Broken line on drawing of lateral views of the brain stem outlines area shown in each diagram schematically demonstrating brain stem origin and variations of rootlet size of the ninth, tenth, and eleventh cranial nerves (IX, X, and XI). Large ovoid structure is the inferior olive and broken line circles outline of cranial VII and VIII. The most cephalad shaded circles indicate glossopharyngeal origin, intermediate open circles vagal origin, and caudal black circles accessory origin. Cranial IX usually originates as one large rootlet, X as a series of large and small rootlets, and XI as a series of small rootlets. *Left:* Left side. Note small ventral rootlets of IX in A, B, C, and small ventral rootlet between IX and X in A. Glossopharyngeal rootlet is larger than rostral rootlet of X in all except D in which rostral vagal rootlet is larger than IX. *Right:* Right side. Note wide separation of origin of IX and X in C, small ventral rootlet of IX in C, and small ventral rootlets IX and X in A. Cranial IX is smaller than upper vagal rootlet in A and D.
A. L. Rhoton, Jr., and R. Buza

Fig. 6. Upper: Lateral view of left side of brain stem as outlined by broken line in drawing (left). Glossopharyngeal nerve (IX) and vagus (X) arise just ventral to foramen of Luschka. Vagus originates immediately adjacent to IX. Lower: Ventral view. Cranial IX consists of two rootlets with a separate brain stem origin. Nerves run ventral to choroid plexus protruding from the foramen of Luschka to exit at glossopharyngeal and vagal meati.

The course of the posterior inferior cerebellar artery (PICA) in relation to the ninth, tenth, and eleventh cranial nerves was determined. After arising from the vertebral artery, the PICA looped upward for a variable distance ventral to all or some of the nerve rootlets before passing dorsally at a variable point between the rostral border of the ninth and the caudal part of the eleventh cranial nerve (Fig. 8). Usually the artery turned dorsally between the vagal rootlets. A meningeal artery passed through the subarachnoid space to enter the jugular foramen in four specimens; in each, the vessel was a branch of the anterior inferior cerebellar artery (Fig. 9).

The dura surrounding the jugular foramen contained the sigmoid and inferior petrosal sinuses. The sigmoid sinus provided lateral drainage into the pars venosa and became the jugular bulb. The inferior petrosal sinus drained the clival area and consisted of one or more channels that coursed rostral to, caudal to, or between the three nerves. The inferior
Microsurgical anatomy of the jugular foramen

Fig. 7. Lateral view of left jugular foramen, and ninth, tenth, and eleventh cranial nerves (IX, X, and XI). Vagus nerve enters anteromedial wall of jugular bulb just anterior to the inferior petrosal sinus.

Fig. 8. Drawings show different courses taken by posterior inferior cerebellar artery in relation to the ninth, tenth, and eleventh cranial nerves. The most common course was for artery to turn dorsally through rootlets of the tenth nerve (D).

Fig. 9. Left jugular foramen, same view as Fig. 2. Dural septum separates glossopharyngeal and vagal meatus. Roof projects medially, partially covering the meati. Meningeal branch of posterior inferior cerebellar artery passes into jugular foramen. Vagus nerve (X) is reflected laterally.

Discussion

The subdivision of the foramen into a “pars nervosa” containing the inferior petrosal sinus and the glossopharyngeal nerve and a “pars venosa” containing the jugular bulb, vagus and accessory nerves, and the posterior meningeal artery was proposed by Hovelacque. 7 DiChiro, et al., 5 found these compartments separated by either a fibrous or bony septum that joins the jugular spine of the petrous bone to the jugular process of the occipital bone. They found a unilateral bony separation in 13.2% and a bilateral separation in 4.7%, and discovered the glossopharyngeal nerve encased in its own bony canal separate from the pars nervosa in just three instances (6%), an incidence significantly different from the 25% reported by Partridge. 8 We found a bony bridge separating the two parts unilaterally in 36%, and bilaterally in 8%. The pars venosa was larger on the right in 68% of

The petrosal sinus left the skull through the pars nervosa or venosa before entering the medial wall of the jugular bulb (Fig. 10); it terminated anterior to the point where the cranial nerves descend in the anteromedial wall of the jugular bulb in 48 specimens, and posterior to the nerves in two (Fig. 7).
FIG. 10. Artist’s representation of most frequent patterns of entry of the inferior petrosal sinus into the jugular bulb. A and C are from left side, B and D from right. The inferior petrosal sinus is shown as a single or multipronged dark arrow. A. Sinus passes below IX, X, and XI before entering the pars venosa. B. Sinus passes between IX and X. C. Different branches of sinus pass around nerves as shown. D. The sinus passes rostral to IX, enters the pars nervosa, and passes extracranially to join anteromedial part of jugular bulb.

the skulls we examined, a figure agreeing well with that of DiChiro, et al. and with the well-known predominance of the right lateral sinus.

Tarlov demonstrated the smaller rootlets emerging ventromedially to the main bundle of the glossopharyngeal nerve to be motor and the larger main bundle to be sensory. The vagus and the cranial and spinal accessory nerves also contain small ventral rootlets considered to be motor originating from the motor nuclei of ninth, tenth, and eleventh cranial nerves.

Dandy described endocranial sectioning of the glossopharyngeal nerve for neuralgia; because this alone did not adequately control the neuralgia, he later advocated the additional sectioning of “perhaps 1/6 to 1/6 of the vagus.” Tarlov sectioned the cephalic third part of the vagal-accessory group and produced analgesia of the epiglottis, but only hypalgesia over the mucosa of the lower pharynx and larynx. In this second case he sectioned the cephalic half of the vagal-accessory complex; this caused both analgesia and transient paralysis of the ipsilateral soft palate, pharynx, and larynx. In our study the structure of the vagus nerve was variable, being composed of all large or all small rootlets or any combination of the two. We suggest that fewer of the rostral rootlets be cut if the diameter of the upper rootlets are large rather than small; the diameter of the largest rootlets was 1.5 mm and the smallest 0.1 mm.

We had thought that a large glossopharyngeal diameter might be associated with
Microsurgical anatomy of the jugular foramen

A small diameter of the upper vagal rootlets of the tenth nerve, or that a large tenth nerve might be associated with a small ninth nerve, since the two nerves arise from the same nuclei and have a similar function. This idea that more fibers might be distributed to one nerve leaving the other smaller could not be confirmed. When the diameter of the dorsal root of the ninth nerve was compared to the mean of the upper rootlets of the tenth nerve, no significant correlation was found. A smaller diameter of the ninth nerve was not commonly associated with a large mean diameter of the upper rootlets of the tenth, nor was a large ninth nerve diameter associated with a small diameter of these rootlets.

In glossopharyngeal neuralgia, Adson has noted the need to section the glossopharyngeal nerve proximal to the superior ganglion. The superior ganglion was intracranial in 32% of our specimens and within or exocranial to the foramen in 68%. The superior ganglion of the vagus could be seen endocranially in only 14%, much less frequently than the glossopharyngeal ganglion. The only location where the ninth nerve could consistently be identified from the tenth was just proximal to the dural meati where a dural septum consistently separated the glossopharyngeal and vagus nerves. This septum varies in width from 0.5 to 4.9 mm and serves to identify the glossopharyngeal from the vagus nerve. The close origin of the ninth and tenth nerves and frequent arachnoidal adhesions between the two made separation difficult in their course through the subarachnoid space or adjacent to the brain stem, except in the few cases in which there was a 1 to 2 mm separation between their origin at the medulla. The glossopharyngeal nerve consistently arose caudal to the acoustic nerve origin, dorsolateral to the facial nerve origin, and adjacent to the vagus. A fibrous or bony roof or lip over the exit of the glossopharyngeal nerve was found in all except one specimen. Aubaniac referred to the area of the ninth nerve’s exit as the “pyramidal fossa,” a finding similar to our description of “funnel-shaped,” and he found it covered in almost all cases. This roof or lip is comparable to, but smaller than, the posterior lip of the internal acoustic meatus. The vagal entrance into the dura (vagal meatus) does not have a roof as does the glossopharyngeal nerve. Only infrequently did a small bone shelf project over the lateral perimeter of the vagal meatus.

The cranial rootlets of the accessory nerve arise caudal to the main body of the vagal roots and are more properly regarded as inferior vagal rootlets, since they arise from vagal nuclei. In 42 specimens, both rostral vagal and cranial accessory fibers entered the vagal meatus as a single unit.

The PICA was found in various relations to the glossopharyngeal, vagus, and accessory nerves. The most frequent finding was that the artery originated ventral to the nerves and then passed dorsally through the vagal rootlets. Watt and McKillop did not find the artery coursing between the glossopharyngeal and vagus nerves, as was seen in four of our specimens. They also described a possible high origin of the PICA, from the basilar artery, but no such variant was seen in our series.

A posterior meningeal artery passing from the anterior inferior cerebellar artery to the jugular foramen as noted by Hovelacque was seen in only four of our specimens.

**Summary**

Significant findings in this study of 50 jugular foramina and surrounding structures were as follows:

1. The foramen was consistently separated into two parts; a pars nervosa containing the ninth cranial nerve and a pars venosa containing the tenth and eleventh cranial nerves and the jugular bulb.
2. A fibrous bridge separated the two parts in 37 specimens and a bone bridge was present in 13.
3. The ninth cranial nerve left the skull through a bony canal separate from the pars nervosa in 6%.
4. The pars venosa of the right foramen was larger than the left in 68%, smaller in 20%, and equal to the left in 12%.
5. A dural septum separated the ninth from the tenth nerve as they left the subarachnoid space. Just above this septum was the only point at which these two nerves could consistently be separated.
6. The superior ganglion of the ninth nerve could be seen intracranially in 32%; the
superior ganglion of the tenth nerve was intracranial in only 14%.
7. The cranial nerves usually coursed in the anteromedial wall of the jugular bulb.
8. The posterior inferior cerebellar artery could turn dorsally through the cranial nerves at any point between the rostral aspect of the ninth and the caudal end of the cranial portion of the eleventh nerve. The most common pattern was for the artery to travel dorsally through the rootlets of the tenth nerve.
9. The inferior petrosal sinus followed a variable course around the ninth, tenth, and eleventh cranial nerves and left the skull through either the pars nervosa or venosa prior to entering the jugular bulb.

References

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