The Journal of Laryngology & Otology (2015), ***129*** (Suppl. S2), *S12–S20*.
© JLO (1984) Limited, 2015
doi:10.1017/S0022215114002321

Comparison of lateral microsurgical preauricular and anterior endoscopic approaches to the jugular foramen

N KOMUNE[1,2], S KOMUNE[2], K MATSUSHIMA[1], A L RHOTON, JR.[1]

[1]*Department of Neurosurgery, University of Florida, College of Medicine, Gainesville, Florida, USA, and*
[2]*Department of Otorhinolaryngology, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan*

Abstract

Introduction: This project compares access to the anterolateral part of the jugular foramen provided by the lateral microsurgical preauricular and the anterior endoscopic approaches, and defines the important landmarks involved in each approach.

Study Design: Cadaveric study.

Results: The endoscopic transnasal/transmaxillary transpterygoid corridor provides a less invasive route for selected lesions in the jugular foramen than the traditional open route through the preauricular subtemporal infratemporal fossa approach. However, the anterior endoscopic approach provides a smaller channel to the jugular foramen than the preauricular approach.

Conclusions: The anterior endoscopic approach to the anterolateral part of the jugular foramen is a useful alternative to the lateral microsurgical preauricular approach in carefully selected cases. The vaginal process of the tympanic part of the temporal bone provides a valuable landmark to aid in accessing the jugular foramen in both procedures and can be drilled to open the foramen in the preauricular approach.

Key words: Jugular Foramen; Endoscopes; Infratemporal Fossa; Vaginal Process; Skull Base; Microsurgical Anatomy

Introduction

Several anterior surgical approaches to the jugular foramen, each with its own advantages and limitations, have been described.[1–7] The traditional lateral microsurgical approaches to the jugular foramen and infratemporal fossa include Fisch's type C infratemporal fossa approach and the preauricular subtemporal infratemporal fossa approach.[3,5] The preauricular approach, as compared with Fisch's approach, has the advantage of minimising risk to facial nerve function and avoiding sacrifice of the middle and inner ear.[5,6] One disadvantage of the preauricular approach to the jugular foramen is the possible need for a condylar osteotomy or mandibular condylectomy with sacrifice of the temporomandibular joint. Vilela and Rostomily[7] have demonstrated that a modified approach that preserves the temporomandibular joint also provides access to the area of the jugular foramen.

As compared with the lateral microsurgical preauricular approaches, the recently reported anterior endoscopic approach, while providing satisfactory access to the anterolateral part of the jugular foramen, is less invasive and can be performed without injury to the facial nerve, retraction of the temporal lobe or sacrifice of hearing function.[1,2,4] However, its clinical use has remained controversial.

The aim of this cadaveric study was to compare the lateral microsurgical preauricular and anterior endoscopic approaches to the jugular foramen and to define useful landmarks in completing these procedures.

Materials and methods

Eight formalin-fixed cadaveric heads in which the arteries were perfused with red and the veins with blue silicone rubber (Dow Corning Corp., Midland, Michigan, USA), Thinner 200 (Dow Corning Corp.) and RTV catalyst (Dow Corning Corp.) were dissected under 3–40 times magnification. The endoscopic dissection was performed with 0° and 45° angle, 18-cm Hopkins endoscopes (Karl Storz GmbH & Co. KG, Tuttlingen, Germany), connected to a xenon light

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press

source and a high-definition camera. The cadaveric surgical procedures were done as described previously.[2,5]

Results and analysis

Cadaveric dissection: preauricular subtemporal infratemporal fossa approach (Figure 1)

The preauricular subtemporal infratemporal fossa approach includes three distinct exposures: cervical, middle cranial base and infratemporal fossa. The preauricular incision from the frontal scalp to the neck, along with a neck dissection, provides access for control of the major vessels and lower cranial nerves, IX–XII (Figure 1a). A zygomatic osteotomy, elevation of the temporal muscle and frontotemporal craniotomy were completed (Figure 1b insert). The middle fossa floor was drilled to expose V3 and the petrous carotid up to the foramen lacerum after sacrificing the tensor tympani muscle and greater petrosal nerve (Figure 1b and 1c). Drilling the bone between the horizontal portion of the petrous carotid and V3 and sacrificing the bony and cartilaginous portions of the eustachian tube extended the exposure to the entrance of the carotid canal, which is surrounded by a fibrocartilaginous ring (Figure 1c). Care was taken to avoid damage to the genu of the facial nerve or the cochlea, located in the cochlear angle just superior to the lateral genu of the petrous carotid. After cutting the fibrocartilaginous ring around the artery at the entry in the carotid canal, the artery can be translocated anteriorly to provide access for drilling the bone medial to the artery and exposing and following the posterior fossa dura, in which the inferior petrosal sinus courses, inferiorly to the jugular bulb. Skeletonising the junction of the inferior petrosal sinus and jugular bulb exposes the jugular tubercle and lateral edge of the clivus (Figure 1d).

The infratemporal fossa is positioned between the lateral pterygoid plate medially, the mandible laterally, the posterior wall of the maxillary sinus anteriorly, the tympanic part of the temporal bone and the styloid process posteriorly, the infratemporal surface of the greater wing of the sphenoid superiorly, and the medial pterygoid muscle joining the mandible and the pterygoid fascia inferiorly, and is occupied by the lateral and medial pterygoid muscles, branches of V3, the maxillary artery and its branches, and the venous plexus around the pterygoid muscles. The deep fascia of the temporalis muscle and the fascia on the lateral surface of the lateral pterygoid muscle are elevated from the inferior surface of the middle fossa floor and removed to expose these muscles (Figure 1e).

If there is a need to open the jugular foramen wider, a condylectomy is performed after separating the lateral pterygoid muscle from the neck of the mandibular condyle and temporomandibular joint, and the anteromedial half of the vaginal process of the tympanic part of the temporal bone is drilled away (Figure 1f). The root of the styloid process, enclosed by the vaginal process of the tympanic part of the temporal bone, is located just anteromedial to the stylomastoid foramen. Care should be taken to avoid injury of the facial nerve if it is necessary to remove the posterolateral half of the vaginal process including the styloid process.

Cadaveric dissection: transnasal/transmaxillary transpterygoid approach (Figure 2)

Endoscopic access involves maxillectomy and sphenoethmoidectomy, and exposure of the pterygopalatine and infratemporal fossae, and the paratubal and poststyloid compartments. The mucosa anterior to and along the medial side of the sphenopalatine foramen was elevated carefully to identify the sphenopalatine and posterior nasal arteries, and sphenoethmoidectomy, medial maxillectomy and removal of the posterior wall of the maxillary sinus were completed (Figure 2a).[8] Transmaxillary and septal windows may aid this exposure. Dissecting the periosteum and fat pad exposes the maxillary artery and its terminal branches. The pterygopalatine ganglion is identified posterior to the sphenopalatine artery (Figure 2a). The vidian nerve is identified medial to the sphenopalatine ganglion at its exit from the pterygoid canal. The infraorbital nerve, a branch of V2, is identified lateral to the sphenopalatine ganglion. The lateral pterygoid muscle is detached from the lateral pterygoid plate to expose the foramen ovale and V3, two of several landmarks for identifying the poststyloid compartment of the parapharyngeal space, where the internal carotid artery (ICA), jugular foramen and lower cranial nerves are located (Figure 2b). The base of the pterygoid process was drilled adjacent to the vidian canal to reach the distal genu of the ICA (Figure 2c). The pterygoid process and part of the palatine bone just anterior and superior to the opening of the eustachian tube was drilled away to expose the medial pterygoid, and tensor veli palatini muscles, which were displaced laterally or resected to expose the eustachian tube and levator veli palatini (Figure 2c and 2d). The eustachian tube is followed superiorly and laterally to its attachment to the skull base. The chorda tympani courses anterolaterally after it exits the petrotympanic fissure to join the lingual branch of V3, one of the landmarks for accessing the jugular foramen (Figure 2e). The vaginal process, another important landmark, is identified posterolateral to the attachment of the eustachian tube or the area where the chorda tympani nerve emerges from the skull base (Figure 2f). The stylopharyngeal fascia, which is attached to the vaginal process, covers the anteromedial border of the opening of the carotid canal, and is closely related to and protects the ICA, internal jugular vein (IJV) and cranial nerve IX (Figure 2f). The ICA is translocated laterally to expose the lower cranial nerves. Other landmarks, including the insertion of the levator veli palatini muscle and styloid process, aid in identifying the ICA. The limited surgical space around the jugular

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press

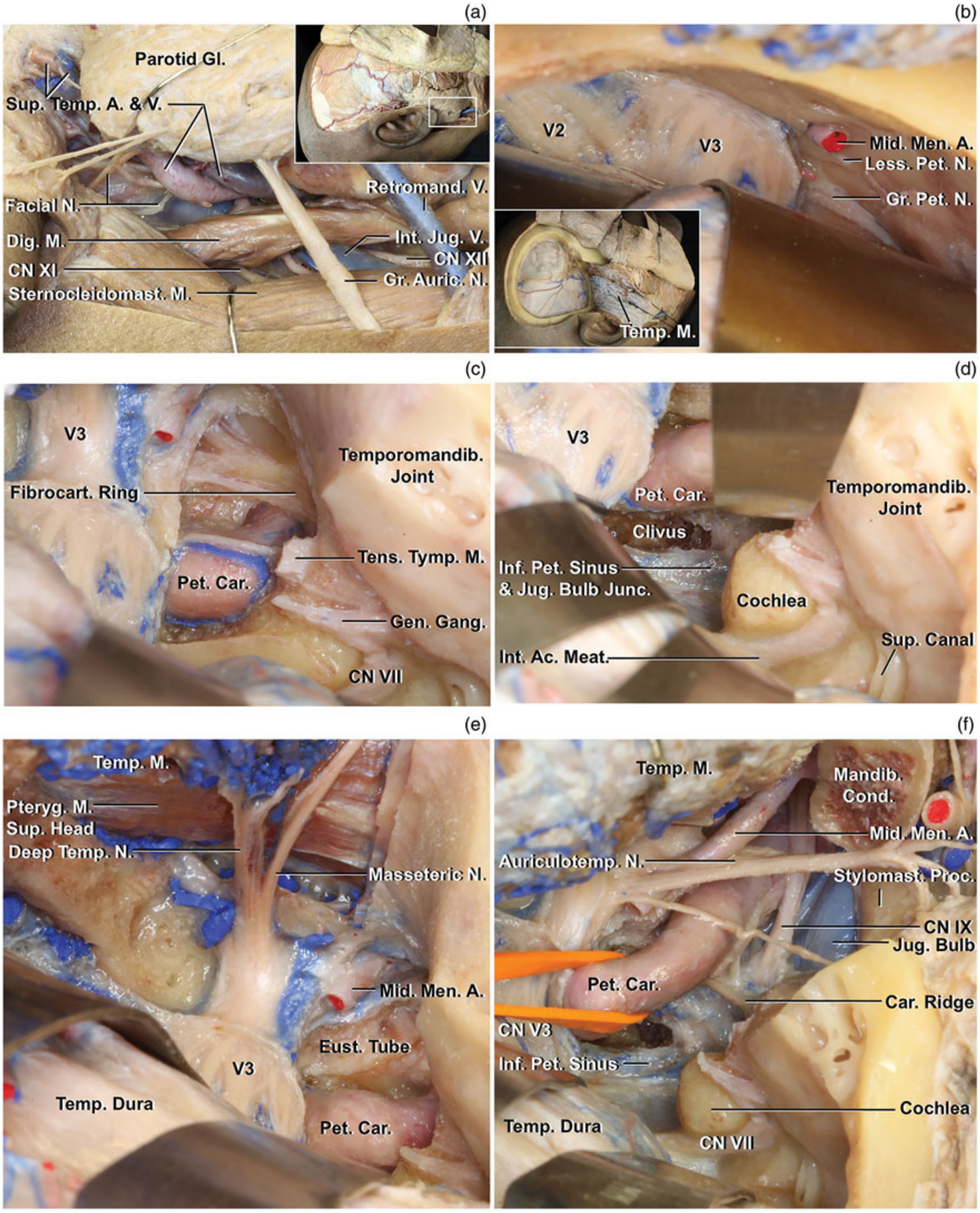

FIG. 1

Preauricular subtemporal infratemporal approach. (a) Right preauricular skin incision (insert). The white square in the insert has been enlarged. A neck dissection has been completed to control the important neurovascular structures in the high cervical region. The retromandibular space has been exposed and the parotid gland is elevated anteriorly while preserving the facial nerve. (b) A large frontotemporal craniotomy and zygomatic osteotomy have been performed (insert). Elevating the temporal dura and dividing the middle meningeal artery exposes V2 and V3. (c) Drilling the middle cranial base to expose the petrous carotid involves sacrificing the greater petrosal nerve, eustachian tube and tensor tympani muscle. The temporomandibular joint is preserved. (d) After translocating the carotid artery anteriorly and drilling the bone medial to the artery, the posterior fossa dura can be followed along the inferior petrosal sinus to the jugular bulb. (e) Removing the middle cranial base exposes the lateral pterygoid muscle and the branches of V3. (f) The lateral pterygoid muscle and mandibular condyle have been removed. Drilling the bone along the posterior part of the glenoid fossa and the anteromedial part of the vaginal process exposes cranial nerve IX and the anterolateral aspect of the jugular foramen. A. = artery; Ac. = acoustic; Auric. = auricular; Auriculotemp. = auriculotemporal; Car. = carotid; Cond. = condyle; Dig. = digastric; Eust. = eustachian; Fibrocart. = fibrocartilaginous; Gen. = geniculate; Gang. = ganglion; Gl. = gland; Gr. = greater; Inf. = inferior; Int. = internal; Jug. = jugular; Junc. = junction; Less. = lesser; M. = muscle; Mandib. = mandibular; Meat. = meatus; Men. = meningeal; Mid. = middle; N. = nerve; Pet. = petrosal/petrous; Proc. = process; Pteryg. = pterygoid; Retromand. = retromandibular; Sternocleidomast. = sternocleidomastoid; Stylomast. = stylomastoid; Sup. = superior/superficial; Temp. = temporal; Temporomandib. = temporomandibular; Tens. Tymp. = tensor tympani; V. = vein

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press

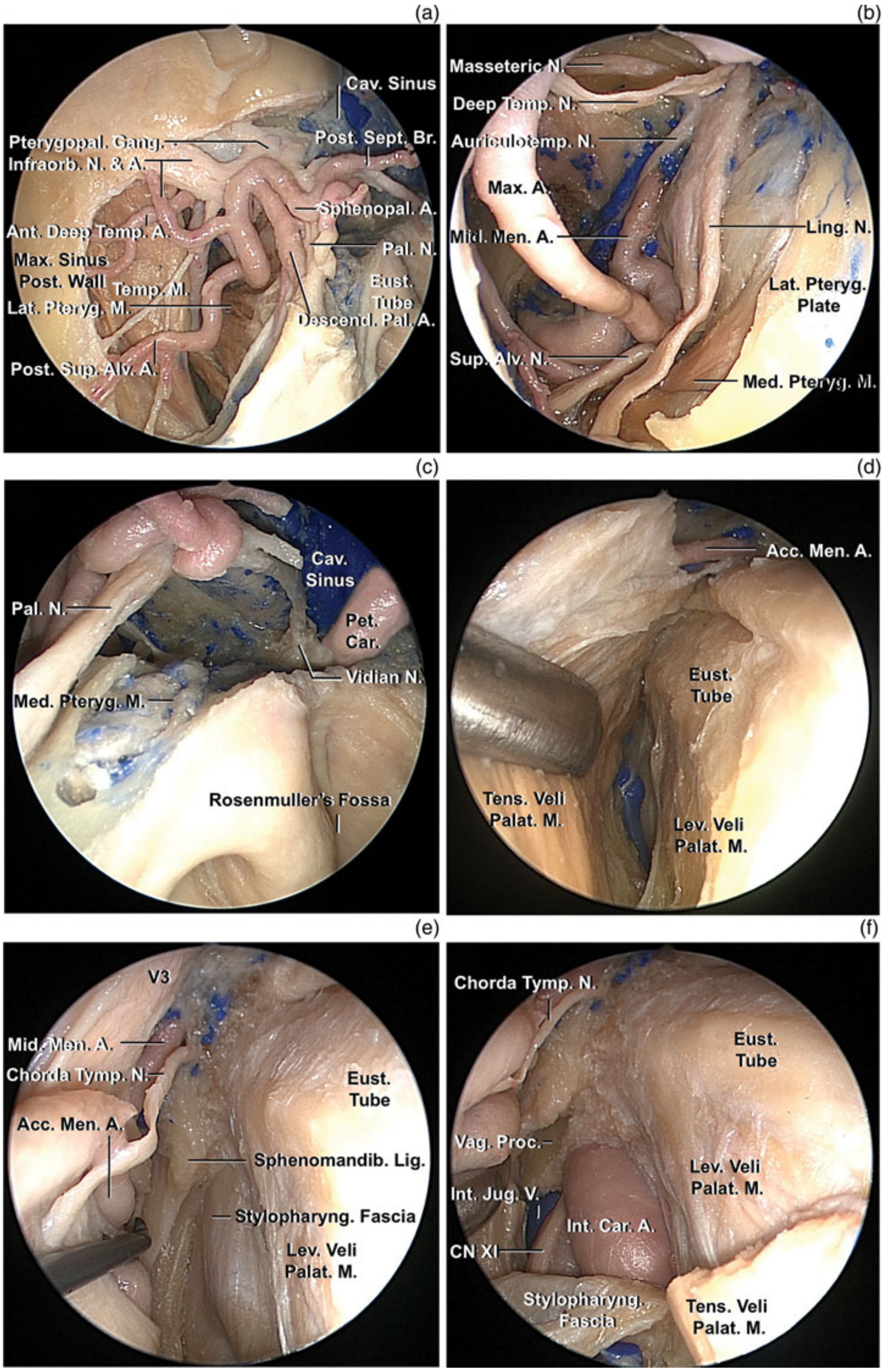

FIG. 2

Endoscopic transnasal/transmaxillary transpterygoid approach to the jugular foramen. (a) A medial maxillectomy, posterior maxillotomy and sphenoethmoidectomy have been completed. Branches of the maxillary artery cross the pterygopalatine fossa. The pterygopalatine ganglion is located just behind the sphenopalatine artery. (b) Removal of the lateral pterygoid muscle exposes the maxillary artery and V3. (c) Drilling the base of the sphenoid sinus and following the vidian canal exposes the second genu of the petrous carotid. The medial aspect of the pterygoid process and the adjacent part of the palatine bone have been removed and the attachment of the medial pterygoid and tensor veli palatini muscles have been exposed. (d) Separating the tensor veli palatini muscle from the eustachian tube opens the corridor to the poststyloid part of the parapharyngeal space and the jugular foramen. (e) Resecting the tensor veli palatini and reflecting the medial pterygoid muscle laterally exposes V3, chorda tympani and middle meningeal artery. The chorda tympani exits the skull base through the petrotympanic fissure and passes just medial to the spine of the sphenoid bone, which has a groove for this nerve. (f) Reflecting the stylopharyngeal fascia, which is attached to the vaginal process and forms the anterolateral part of the carotid sheath, exposes the ICA, IJV and CN IX just below the skull base. A. = artery; Acc. = accessory; Alv. = alveolar; Ant. = anterior; Auriculotemp. = auriculotemporal; Br. = branch; Car. = carotid; Cav. = cavernous; CN = cranial nerve; Desc. = descending; Eust. = eustachian; Gang. = ganglion; ICA = internal carotid artery; IJV = internal jugular vein; Infraorb. = infraorbital; Int. = internal; Jug. = jugular; Lat. = lateral; Lev. = levator; Lig. = ligament; Ling. = lingual; M. = muscle; Max. = maxillary; Med. = medial; Men. = meningeal; Mid. = middle; N. = nerve; Pal. = palatine; Palat. = palatini; Pet. = petrous; Post. = posterior; Proc. = process; Pteryg. = pterygoid; Pterygopal. = pterygopalatine; Sept. = septal; Sphenomandib. = sphenomandibular; Sphenopal. = sphenopalatine; Stylopharyng. = stylopharyngeal; Sup. = superior; Tens. = tensor; Temp. = temporal; Tymp. = tympani; Vag. = vaginal; V. = vein

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press

foramen provided by the endoscopic procedure does not allow drilling of the bone of the vaginal process without resection of the eustachian tube and translocation of the petrous carotid artery.

Relationships of the vaginal process of the temporal bone (Figures 3 and 4)

The osseous landmarks at the border between the infratemporal fossa and the parapharyngeal space are the sphenoid spine and pterygoid process of the sphenoid bone, and the styloid part and vaginal processes of the tympanic part of the temporal bone. The parapharyngeal space is an inverted pyramidal space lateral to the pharynx and deep to the masticator space and the ramus of the mandible. The parapharyngeal space is located between the interpterygoid and buccopharyngeal fasciae and extends from the skull base to the level of the angle of the mandible. The parapharyngeal space is divided into prestyloid and poststyloid parts by the stylopharyngeal fascia. The prestyloid part is filled with fat and connective tissue, the deep portion of the parotid gland, branches of V3, ascending pharyngeal artery, and pharyngeal vein. The poststyloid portion corresponds to the carotid sheath and its enclosed structures, which include the ICA, cranial nerves IX–XII, sympathetic chain, and IJV. The stylopharyngeal fascia is attached to the inferior margin of the vaginal process of the tympanic part of the temporal bone (Figure 3a). The sphenomandibular ligament extends from the petrotympanic and petrosquamous sutures to the ramus of the mandible, and forms a thickened part of the interpterygoid fascia. The vaginal process is an inferior extension of the tympanic part of the temporal bone that encloses the root of the styloid process (Figure 3a and 3b). The anteromedial half of the vaginal process covers the anterior border of the carotid canal and jugular foramen (Figure 3c). The chorda tympani emerges from the petrotympanic suture and passes downward lateral to the tensor veli palatini muscle to join the lingual nerve in the infratemporal fossa. The spine of the sphenoid bone frequently has a groove on its medial surface for the chorda tympani.

Removal of the anteromedial half of the vaginal process is a critical step in exposing the anterolateral aspect of the jugular bulb in both procedures (Figure 4a). Resecting the sphenomandibular ligament and remaining posterior part of the glenoid fossa exposes the carotid ring and sheath, which are made

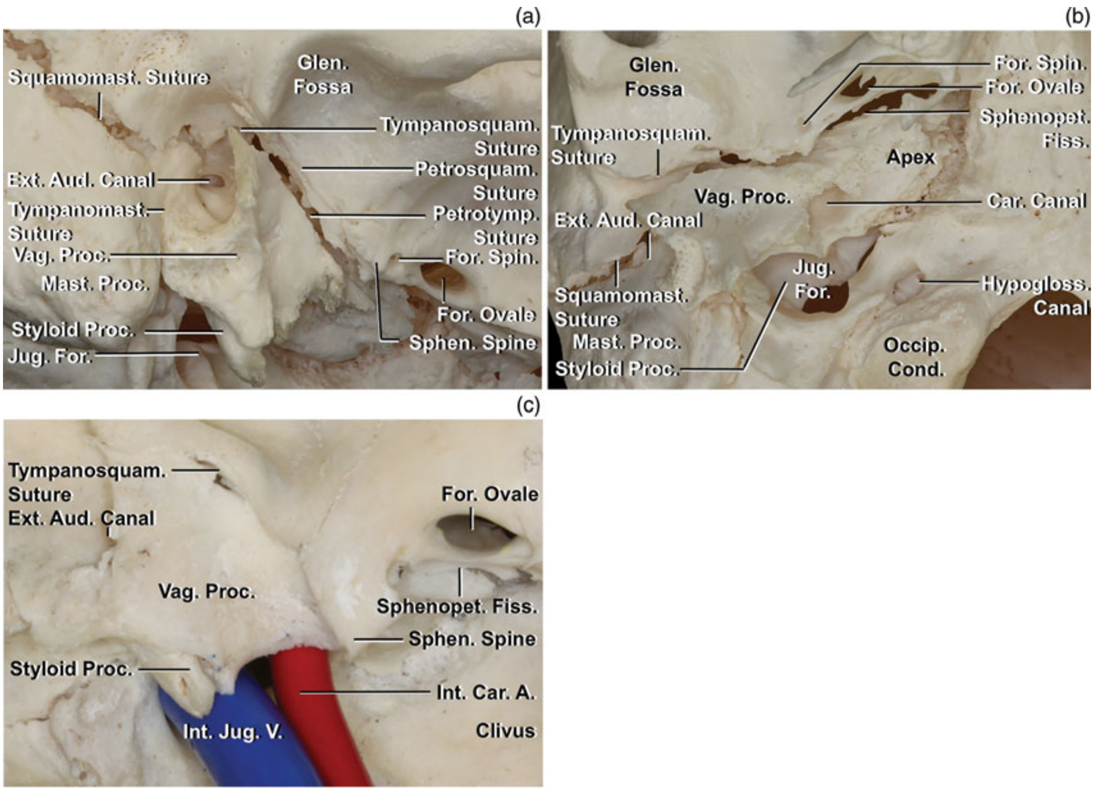

FIG. 3

Osseus anatomy related to the vaginal process of the temporal bone. (a) The vaginal process forms the inferior part of the tympanic part of the temporal bone, and encloses the styloid process. The tympanic part articulates with the squamous, petrosal and mastoid parts of the temporal bone at the tympanosquamous, petrotympanic and tympanomastoid sutures, respectively. (b) The vaginal process projects downward along the anterolateral edge of the carotid canal and jugular foramen. (c) The ICA and IJV pass just posteromedial to the vaginal process. The spine of the sphenoid bone is located anteromedial to the vaginal process. A. = artery; Aud. = auditory; Car. = carotid; Cond. = condyle; Ext. = external; Fiss. = fissure; For. = foramen; Glen. = glenoid; ICA = internal carotid artery; IJV = internal jugular vein; Int. = internal; Jug. = jugular; Hypogloss. = hypoglossal; Mast. = mastoid; Meat. = meatus; Occip. = occipital; Petrosquam. = petrosquamous; Proc. = process; Petrotymp. = petrotympanic; Sphen. = sphenoid; Spin. = spinosum; Sphenopet. = sphenopetrosal; Squamomast. = squamomastoid; Tympanomast. = tympanomastoid; Tympanosquam. = tympanosquamous; Vag. = vaginal; V. = vein

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press

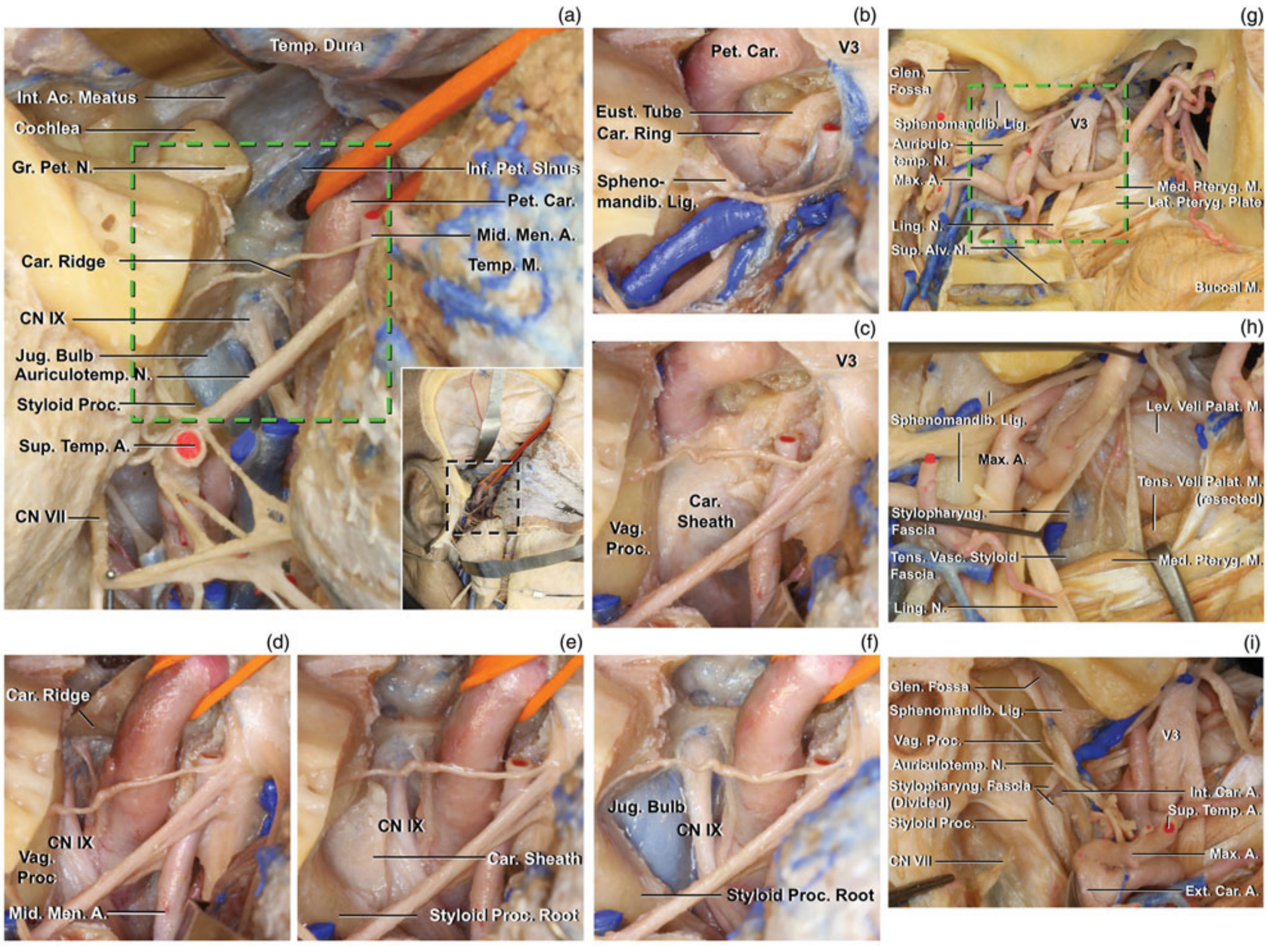

FIG. 4

The vaginal process in open and endoscopic approaches to the jugular foramen. (a) The insert (lower right) shows the incision and exposure for the preauricular subtemporal infratemporal fossa approach. The parotid gland has been removed to show the surgical area clearly. The black interrupted square shows the enlarged area. The green interrupted square shows the area in (b)–(f). (b)–(f) Step-by-step dissection of the vaginal process. (b) Removal of the mandibular condyle exposed the sphenomandibular ligament, which is attached along the tympanosquamous, petrotympanic and petrosquamous sutures. (c) Removal of the sphenomandibular ligament and drilling of the posterolateral part of the glenoid fossa and part of the vaginal process exposed the cartoid sheath. (d) Removal of the carotid sheath exposed CN IX. Translocation of the ICA exposes the carotid ridge. (e) Removing the lateral part of the anteromedial half of the vaginal process exposes the remaining carotid sheath, which covers the anterolateral edge of the jugular bulb. (f) Additional removal of the carotid sheath exposed the IJV. (g)–(i) The anatomical relationships of the vaginal process in the lateral view. (g) After completing the endoscopic transnasal/transmaxillary transpterygoid approach to the jugular foramen, the infratemporal fossa is exposed laterally. The posterior wall of the maxillary sinus has already been removed. The green interrupted line shows the area enlarged in (h). (h) The tensor veli palatini and the tensor–vascular–styloid fascia have been dissected. The stylopharyngeal fascia, which covers the levator veli palatini muscle, is located medial to the tensor–vascular–styloid fascia. The sphenomandibular ligament is attached to the tympanosquamous and petrotympanic sutures. (i) The fascia has been removed to expose the vaginal process. Dividing the stylopharyngeal fascia, which attaches to the vaginal process of the tympanic part of the temporal bone, exposes the ICA. A. = artery; Ac.= acoustic; Alv.= alveolar; Auriculotemp.= auriculotemporal; Car.= carotid; CN = cranial nerve; Ext.= external; Eust.= eustachian; Glen.= glenoid; Gr.= greater; ICA = internal carotid artery; IJV = internal jugular vein; Inf.= inferior; Int.= internal; Jug.= jugular; Lat.= lateral; Lev.= levator; Lig.= ligament; Ling.= lingual; Max.= maxillary; M.= muscle; Mid.= middle; Med.= medial; Men.= meningeal; N.= nerve; Palat.= palatini; Pet.= petrosal/petrous; Pteryg.= pterygoid; Proc.= process; Sphenomandib.= sphenomandibular; Stylopharyng.= stylopharyngeal; Sup.= superior; Temp.= temporal; Tens.= tensor; Vag.= vaginal; Vasc.= vascular

of fibrocartilaginous and fibrous tissue, respectively, surrounding the ICA at the skull base (Figure 4b and 4c). Removing the anteromedial part of the vaginal process allows division of the carotid ring for translocating the carotid artery anteriorly. Opening the carotid sheath exposes cranial nerve IX (Figure 4d). However, access to the anterolateral aspect of the jugular foramen is blocked by the remaining anteromedial part of the vaginal process. Removing the remaining anteromedial part of the vaginal process and resecting the remaining carotid sheath covering the IJV exposes the anterolateral aspect of the foramen (Figure 4e and 4f).

The vaginal process is a reliable landmark to identify the stylopharyngeal fascia and the neurovascular structures in the poststyloid space. Just below the skull base, the anterolateral part of the carotid sheath is formed not by the tensor–vascular–styloid fascia, which fills the gap between the tensor veli palatini muscle and styloid process, but by the stylopharyngeal fascia (Figure 4g–i). In the anterior endoscopic approach, the surgical route just lateral to the eustachian tube

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press

and levator veli palatini muscle can access the vaginal process and stylopharyngeal fascia, but it is difficult to drill the vaginal process because of the limited space in the endoscopic approach (Figures 2e and 4i).

Discussion

The infratemporal fossa and anterolateral aspect of the jugular foramen have traditionally been accessed by lateral microsurgical and not endoscopic approaches. Recently, anterior endoscopic access to the jugular foramen has also been reported, although it remains controversial.[1,2,4,5,7] The infratemporal fossa is a complicated area. Surgical approaches to this deep region may be associated with bleeding and injury of nerves. The best approach should provide enough space to resect the tumour completely without injuring adjacent neural and vascular structures. This study examined the anatomic basis of the advantages and disadvantages of each approach to the infratemporal fossa and jugular foramen.

Fisch and Pillsbury[3] described the postauricular infratemporal approach with several variations for the management of tumours of the jugular foramen and infratemporal fossa.[5] Fisch's approach is divided into three types: A, B and C. Type A and B approaches access the area around the jugular foramen and the petrous apex. They involve a postauricular incision with transection of the external ear canal, removal of the middle ear structures and translocation of the facial nerve, which leads to conductive hearing loss and temporary or permanent facial palsy. Type C does not involve translocation of the facial nerve and can be utilised to access the infratemporal fossa and the nasopharyngeal, parasellar, retromaxillary and paratubal areas. The preauricular subtemporal infratemporal fossa approach reduced some of the disadvantages of the postauricular approach while also accessing lesions of the anterior part of the jugular foramen and infratemporal area.[5] This approach minimises manipulation of the extracranial portion of the facial nerve and may avoid conductive hearing loss. This procedure was modified by Vilela and Rostomily[7] to preserve the temporomandibular joint in accessing the infratemporal fossa. To access the jugular foramen from anteriorly by this approach requires translocation of the petrous carotid artery after anterior petrosectomy. The addition of the zygomatic osteotomy to the preauricular subtemporal infratemporal fossa approach provides better access to the anterolateral cranial base and infratemporal fossa. Important structures surrounding the petrous carotid include the geniculate ganglion, cochlea, eustachian tube, tensor tympani muscle, cranial nerves VII and VIII, and greater petrosal and mandibular nerves. The preauricular subtemporal infratemporal fossa approach provides access to the entire petrous carotid.[5,9,10] In their dissections, Vilela and Rostomily[7] showed that only a limited part of the jugular foramen can be exposed if the glenoid fossa and mandibular condyle are not resected. Removing the glenoid fossa and mandibular condyle makes it easier to mobilise the petrous carotid and provides space for drilling the vaginal process that blocks anterolateral access to the jugular foramen. Drilling the anteromedial half of the vaginal process opens the anterolateral part of the jugular foramen (Figure 4a–f). If wider exposure is needed, the root of the styloid process can be resected and the posterolateral part of the vaginal process drilled.

- **The anterior surgical approaches to the jugular foramen include the traditional microsurgical preauricular subtemporal infratemporal fossa and recently reported transnasal/transmaxillary transpterygoid endoscopic approaches**
- **As compared with the preauricular approach, the endoscopic approach is less invasive and can be performed without retraction of the temporal lobe and resection of the temporomandibular joint**
- **The anterior endoscopic approach may be considered if the tumour extends from the jugular foramen into the infratemporal fossa and pushes the structures in the carotid sheath posteriorly and the dissection of the pterygoid muscles and branches of the maxillary artery is to be minimised**
- **The microsurgical preauricular approach is preferred if the tumour extends anteriorly and pushes the internal carotid artery and internal jugular vein anteriorly**
- **The vaginal process of the tympanic part of the temporal bone is a valuable landmark for accessing the jugular foramen in both approaches**
- **Drilling the anteromedial half of the vaginal process exposes the anterolateral aspect of the jugular foramen**

Surgical access by the anterior endoscopic approach is limited to the anterolateral aspect of the jugular foramen, because of the need to manage the neurovascular structures in the infratemporal fossa. Structures along the endoscopic route to the jugular foramen include the maxillary artery and its branches, lateral and medial pterygoid, and tensor and levator veli palatini muscles, eustachian tube, vaginal process of the temporal bone, ICA and lower cranial nerves. Advantages of the anterior endoscopic approach include: (1) lack of brain exposure; (2) access to tumours pushing structures in the carotid sheath posteriorly while minimising dissection of the pterygoid muscles and branches of the maxillary artery; (3) resection of the mandibular condyle or the middle-ear canal

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press

is not necessary; and (4) the facial nerve is not transposed. The disadvantages include difficulty in managing bleeding in the infratemporal fossa from the branches of the maxillary artery and the pterygoid venous plexus. Injury of small arteries is managed by pressure, packing, and coagulation. However, injury of the ICA is life threatening and can be extremely difficult to control under endoscopic view without a second incision, because the surgical corridor made by the endoscopic procedure is deep and narrow. Proximal control or lowering arterial pressure may slow blood loss. Once the site of injury to the artery is identified, it can be repaired endoscopically.[11] In microsurgical exposure, the ruptured artery is sutured or repaired with a muscle patch, U-CLIP (Medtronic, Inc., Minneapolis, MN) anastomotic devices and/or Teflon®.[12–14] Endovascular treatments include placement of a stent or embolisation. However, these options are limited by the time delay of preparation or a tortuous carotid that cannot be stented. Navigation systems may make surgery more accurate and safe.

The most important step in the endoscopic approach is to identify and control the parapharyngeal segment of the ICA. Landmarks helpful in identifying the parapharyngeal carotid artery are the tensor and levator veil palatini muscles, eustachian tube, V3, chorda tympani, vaginal process of the temporal bone and stylopharyngeal fascia (Figures 2e, 2f and 4g–i). Endoscopic access may not be suitable if the great vessels are displaced anteriorly by the tumour. Dallan *et al.*[1] reported that there are two main corridors for accessing the jugular foramen endoscopically, superior and inferior. The inferior one through the medial pterygoid muscle is the more direct route and avoids dissecting through the lateral pterygoid muscle in the superior route. Falcon *et al.*[2] emphasised that the eustachian tube, medial pterygoid plate and styloid process are the most useful landmarks. In our dissections, the eustachian tube, vaginal process of the temporal bone and stylopharyngeal fascia provided useful landmarks for reaching the jugular foramen (Figures 2e, 2f and 4g–i).

Both the microsurgical preauricular and anterior endoscopic approaches can access the anterolateral aspect of the jugular foramen, but they follow completely different routes. Understanding the anatomy around the vaginal process of the temporal bone is important for both approaches. Von Ludinghausen *et al.*[15,16] reported that osseous landmarks, including the spine of the sphenoid bone, styloid process and vaginal process of the tympanic part of the temporal bone are encountered in the lateral microsurgical approaches to the infratemporal fossa. The vaginal process has received little attention as a landmark in the endoscopic approach to the jugular foramen.[1,2,4] However, it proved to be a useful landmark in this study. The fascia attached to the vaginal process protects the major neuromuscular structures, and opening it exposes the ICA, IJV and cranial nerve IX. In the lateral microsurgical approaches, drilling the anteromedial half of the vaginal process exposes the anterolateral aspect of the jugular foramen. However, in the anterior endoscopic access, it is rarely possible to drill this process because the exposure is too limited unless the eustachian tube is resected and the petrous carotid is translocated.

The microsurgical preauricular approach is preferred if the tumour extends from the jugular foramen into the infratemporal fossa and pushes the ICA and IJV anteriorly and it is necessary to open the jugular foramen. The anterior endoscopic approach provides a less invasive route, and may be considered if the tumour extends anteriorly and pushes the structures in the carotid sheath posteriorly and the dissection of the pterygoid muscles and branches of the maxillary artery is to be minimised.

Conclusion

The vaginal process is a well-known landmark in the lateral open access approaches to the infratemporal fossa. This study shows that it is also a valuable landmark in the anterior endoscopic approaches to the jugular foramen. Advances in endoscopic technique have increased the use of the anterior endoscopic approaches to the lateral skull base. However, both the microsurgical preauricular and anterior endoscopic approaches have advantages and disadvantages. Thus, the approach should be selected based on the type, location and extension of the primary tumour, and tailored to the anatomy of the patient. The surgical space provided by the endoscopic approach is limited and drilling the bone around the jugular foramen risks injury to critical vessels. However, the use of the endoscopic transnasal/transmaxillary transpterygoid approach may reduce surgical morbidity in well-selected patients.

Acknowledgements

The authors deeply appreciate Ms Robin Barry's assistance with the preparation of the illustrations and Ms Jessica Striley's editorial assistance.

Funding

This work was supported by a University of Florida Foundation and a research grant from The Uehara Memorial Foundation.

Ethical standards

Ethical approval for this study was obtained from the Ethics Committee of the University of Florida. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guidelines and with the Helsinki Declaration of 1975, as revised in 2008.

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press

References

1 Dallan I, Bignami M, Battaglia P, Castelnuovo P, Tschabitscher M. Fully endoscopic transnasal approach to the jugular foramen: anatomic study and clinical considerations. *Neurosurgery* 2010;**67**:1–7
2 Falcon RT, Rivera-Serrano CM, Miranda JF, Prevedello DM, Snyderman CH, Kassam AB *et al*. Endoscopic endonasal dissection of the infratemporal fossa: anatomic relationships and importance of eustachian tube in the endoscopic skull base surgery. *Laryngoscope* 2011;**121**:31–41
3 Fisch U, Pillsbury HC. Infratemporal fossa approach to lesions in the temporal bone and base of the skull. *Arch Otolaryngol* 1979;**105**:99–107
4 Lee DL, McCoul ED, Anand VK, Schwartz TH. Endoscopic endonasal access to the jugular foramen: defining the surgical approach. *J Neurol Surg B, Skull Base* 2012;**73**:342–51
5 Sekhar LN, Schramm VL Jr., Jones NF. Subtemporal-preauricular infratemporal fossa approach to large lateral and posterior cranial base neoplasms. *J Neurosurg* 1987;**67**:488–99
6 Sen CN, Sekhar LN. The subtemporal and preauricular infratemporal approach to intradural structures ventral to the brain stem. *J Neurosurg* 1990;**73**:345–54
7 Vilela MD, Rostomily RC. Temporomandibular joint-preserving preauricular subtemporal–infratemporal fossa approach: surgical technique and clinical application. *Neurosurgery* 2004;**55**:143–53
8 Simmen DB, Raghavan U, Briner HR, Manestar M, Groscurth P, Jones NS. The anatomy of the sphenopalatine artery for the endoscopic sinus surgeon. *Am J Rhinol* 2006;**20**:502–5
9 Osawa S, Rhoton AL Jr., Tanriover N, Shimizu S, Fujii K. Microsurgical anatomy and surgical exposure of the petrous segment of the internal carotid artery. *Neurosurgery* 2008;**63**:210–38
10 Witiak DG, Pensak ML. Limitations to mobilizing the intrapetrous carotid artery. *Ann Otol Rhinol Laryngol* 2002;**111**:343–8
11 Van Rompaey J, Bowers G, Radhakrishnan J, Panizza B, Solares CA. Endoscopic repair of an injured internal carotid artery utilizing femoral endovascular closure devices. *Laryngoscope* 2014;**124**:1318–24
12 Cavallo LM, Briganti F, Cappabianca P, Maiuri F, Valente V, Tortora F *et al*. Hemorrhagic vascular complications of endoscopic transsphenoidal surgery. *Minim Invasive Neurosurg* 2004;**47**:145–50
13 Fukushima T, Maroon JC. Repair of carotid artery perforations during transsphenoidal surgery. *Surg Neurol* 1998;**50**:174–7
14 Laws ER Jr. Vascular complications of transsphenoidal surgery. *Pituitary* 1999;**2**:163–70
15 von Ludinghausen M, Kageyama I, Miura M, Alkhatib M. Morphological peculiarities of the deep infratemporal fossa in advanced age. *Surg Radiol Anat* 2006;**28**:284–92
16 Krmpotic Nemanic J, Vinter I, Ehrenfreund T, Marusic A. Postnatal changes in the styloid process, vagina processus styloidei, and stylomastoid foramen in relation to the function of muscles originating from the styloid process. *Surg Radiol Anat* 2009;**31**:343–8

Address for correspondence:
Albert L Rhoton, Jr.,
Department of Neurosurgery,
P.O. Box 100265,
Gainesville, FL,
32610-0265, USA

Fax: 352-392-8413
E-mail: rhoton@neurosurgery.ufl.edu

Competing interests: None declared

https://doi.org/10.1017/S0022215114002321 Published online by Cambridge University Press