



# Surgical Approaches to the Internal Carotid Artery at the Extracranial Middle Skull Base

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## Abstract

The aims of this review are to critically review the surgical approaches to the internal carotid artery (ICA) at the skull base as reported in the literature. We discuss the relevant anatomy and the common indications and approaches to the internal carotid artery at the skull base are outlined. We conclude that open surgical approaches to the ICA at the skull base are feasible with careful anatomic dissection and can be performed with minimal morbidity in most cases. The optimum approach continues to be debated.

**Keywords:** Surgical approaches; Carotid artery; Skull base

## Introduction

Operative exposure of the high parapharyngeal and intrapetrous segments of the internal carotid artery (ICA) presents a challenge to the skull base surgeon. Historically, lesions in the portion of the artery above the level of a line drawn between the angle of the mandible and the tip of the mastoid process (Blaisdell line) had been considered inaccessible by standard surgical techniques [1]. Adequate exposure through a standard carotid incision is often not possible. The pathway must be carefully designed to protect the multiple critical neurovascular structures immediately adjacent to the ICA in this area [2]. Over the past decades, with advances in technologies, endovascular therapy has enhanced accessibility of the distal ICA and offers a minimally invasive alternative to open surgery. However, some lesions may not be amenable and long-term results are lacking. So open surgical approaches remain an important part of treatment strategies for lesions in this area. The aims of this review are to discuss the anatomy of the ICA and the skull base and critically review the surgical approaches to the ICA at the skull base reported in the literature.

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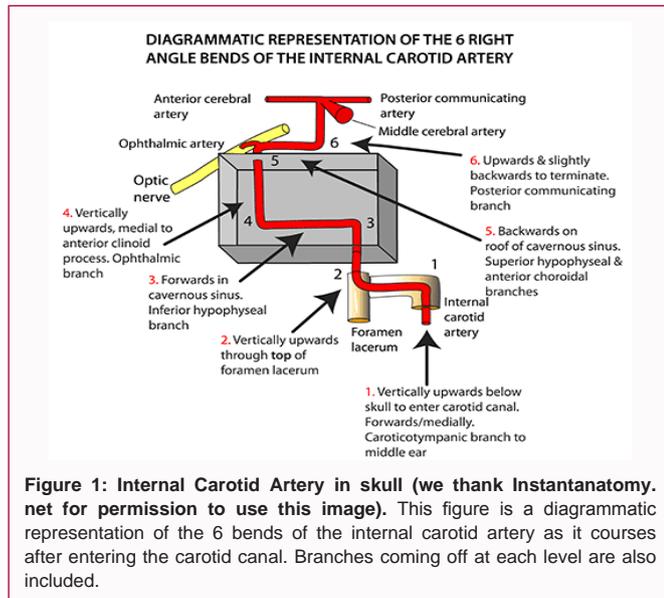
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## Course and Relations

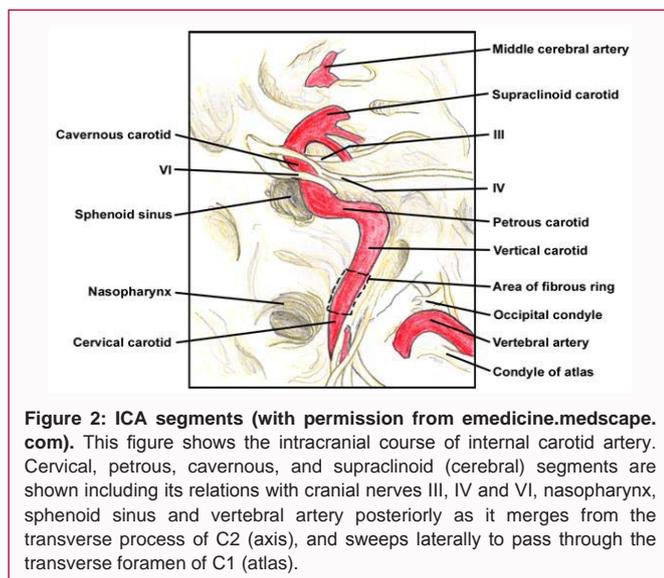
In considering the course and relations of the ICA, it may be divided into four portions: cervical, petrous, cavernous, and cerebral (Figures 1,2 and 3). Through its course, it forms several bands and gives off branches as shown in Figure 1.

### Cervical

This portion of the internal carotid begins at the bifurcation of the common carotid, opposite the upper border of the thyroid cartilage, and runs perpendicularly upward below the skull, where it has an area of fibrous ring making mobilisation difficult (Figure 2). The relationship with nasopharynx, vertebral artery, condyle of atlas and occipital condyle is shown in Figure 2. It passes in front of the transverse processes of the upper three cervical vertebrae, to enter the carotid canal in the petrous portion of the temporal bone. It is comparatively superficial at its commencement, where it is contained in the carotid triangle, and lies behind and lateral to the external carotid, overlapped by the Sternocleidomastoideus, and covered by the deep fascia, Platysma, and integument: it then passes beneath the parotid gland, being crossed by the hypoglossal nerve, the Digastricus and Stylohyoideus, and the occipital and posterior auricular arteries. Higher up, it is separated from the external carotid by the Styloglossus and Stylopharyngeus, the tip of the styloid process and the stylohyoid ligament, the glossopharyngeal nerve and the pharyngeal branch of the vagus. It is in relation, behind, with the Longus capitis, the superior cervical ganglion of the sympathetic trunk, and the superior laryngeal nerve; laterally, with the internal jugular vein and vagus nerve, the nerve lying on a plane posterior to the artery; medially, with the pharynx, superior laryngeal nerve, and ascending pharyngeal artery. At the base of the skull the glossopharyngeal, vagus, accessory, and hypoglossal nerves lie between the artery and the internal jugular vein.



**Figure 1: Internal Carotid Artery in skull (we thank Instantanatomy.net for permission to use this image).** This figure is a diagrammatic representation of the 6 bends of the internal carotid artery as it courses after entering the carotid canal. Branches coming off at each level are also included.



**Figure 2: ICA segments (with permission from emedicine.medscape.com).** This figure shows the intracranial course of internal carotid artery. Cervical, petrous, cavernous, and supraclinoid (cerebral) segments are shown including its relations with cranial nerves III, IV and VI, nasopharynx, sphenoid sinus and vertebral artery posteriorly as it merges from the transverse process of C2 (axis), and sweeps laterally to pass through the transverse foramen of C1 (atlas).

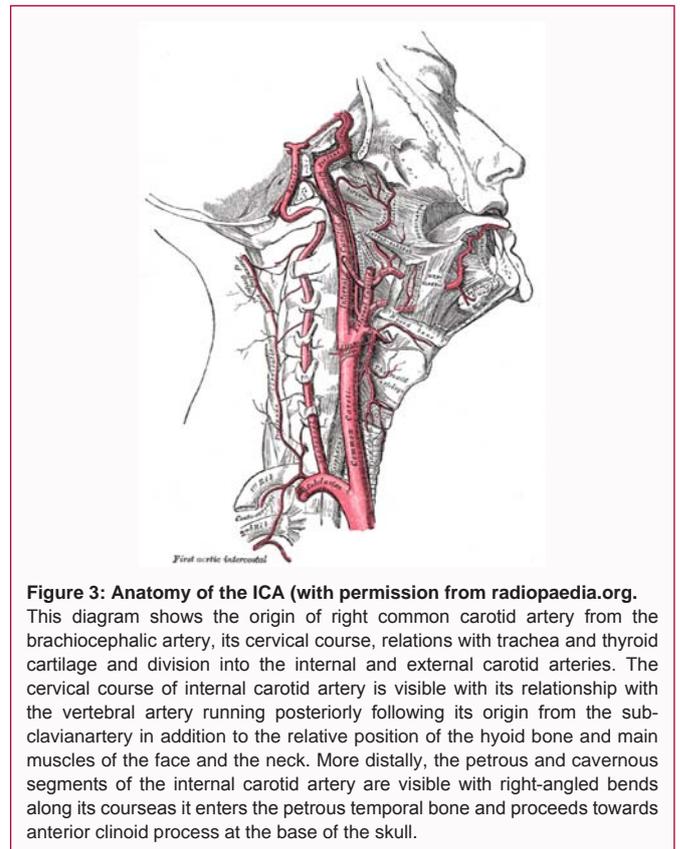
**Petrous**

The cervical ICA becomes the petrous segment of the artery as it enters the petrous temporal bone at the base of the skull anterior to the internal jugular vein and medial to the styloid process.

When the internal carotid artery enters the canal in the petrous portion of the temporal bone, it first ascends a short distance, then curves forward and medial ward, and again ascends as it leaves the canal to enter the cavity of the skull between the lingula and petrosal process of the sphenoid. It emerges through foramen lacerum and passes vertically upwards. The artery is separated from the bony wall of the carotid canal by a prolongation of dura mater, and is surrounded by a number of small veins and by filaments of the carotid plexus, derived from the ascending branch of the superior cervical ganglion of the sympathetic trunk.

**Cavernous**

In this part of its course, the artery is situated between the layers of the dura mater forming the cavernous sinus, but covered by the lining membrane of the sinus. It at first ascends toward the posterior



**Figure 3: Anatomy of the ICA (with permission from radiopaedia.org).**

This diagram shows the origin of right common carotid artery from the brachiocephalic artery, its cervical course, relations with trachea and thyroid cartilage and division into the internal and external carotid arteries. The cervical course of internal carotid artery is visible with its relationship with the vertebral artery running posteriorly following its origin from the subclavian artery in addition to the relative position of the hyoid bone and main muscles of the face and the neck. More distally, the petrous and cavernous segments of the internal carotid artery are visible with right-angled bends along its course as it enters the petrous temporal bone and proceeds towards anterior clinoid process at the base of the skull.

clinoid process, then passes forward by the side of the body of the sphenoid bone, and again curves upward on the medial side of the anterior clinoid process, and perforates the dura mater forming the roof of the cavernous sinus. This portion of the artery is surrounded by filaments of the sympathetic nerve, and on its lateral side is the abducent nerve.

**Cerebral**

Having perforated the dura mater on the medial side of the anterior clinoid process, the ICA passes between the optic and oculomotor nerves to the anterior perforated substance at the medial extremity of the lateral cerebral fissure, where it gives off its terminal or cerebral branches.

**Branches**

The cervical portion of the internal carotid gives off no branches. Those from the other portions are as shown in Figures 1-3. The figures also show relationship of the branches with important nerves and other anatomical landmarks.

1. From the Petrous Portion
  - a. Caroticotympanic branch to middle ear
  - b. Artery of the Pterygoid Canal
2. From the Cavernous Portion
  - a. Cavernous
  - b. Inferior hypophyseal
  - c. Semilunar
  - d. Anterior Meningeal
  - e. Ophthalmic

3. From the Cerebral Portion
  - a. Anterior Cerebral
  - b. Middle Cerebral
  - c. Posterior Communicating
  - d. Superior hypophyseal
  - e. Anterior Choroidal

## Skull Base Anatomy

The skull base forms the floor of the cranial cavity and separates the brain from other facial structures. The 5 bones that make up the skull base are the ethmoid, sphenoid, occipital, paired frontal, and paired parietal bones. The skull base can be subdivided into 3 regions: the anterior, middle, and posterior cranial fossae.

### Anterior skull base

The anterior limit of the anterior skull base is the posterior wall of the frontal sinus. The anterior clinoid processes and the planum sphenoidale, which forms the roof of the sphenoid sinus, mark the posterior limit. The frontal bone forms the lateral boundaries. The major structures in this area are the olfactory bulb and tract.

### Middle skull base

The greater wing of the sphenoid helps form the anterior limit of the middle skull base. The posterior limit is the clivus, which is formed from the sphenoid and occipital bones. The greater wing of the sphenoid forms the lateral limit as it extends laterally and upward from the sphenoid body to meet the squamous portion of the temporal bone and the anteroinferior portion of the parietal bone. The greater wing of the sphenoid forms the anterior floor of the fossa. The anterior aspect of the petrous temporal bone forms the posterior floor of the middle cranial fossa.

### Posterior skull base

The posterior skull base consists of primarily the occipital bone, with contributions from the sphenoid and temporal bones. The midbrain, the pons, the medulla, and the cerebral and cerebellar hemispheres lie in the posterior fossa.

## Indications

The common indications for surgical approach to the ICA at the skull base are outlined below:

### Difficult carotid endarterectomy

Management of carotid bifurcation atherosclerotic stenosis is a cornerstone of stroke prevention. The standard approach for carotid endarterectomy (CEA) provides excellent access to the cervical carotid artery, but lesions that extend outside this zone can be difficult to treat surgically. The high location of the carotid bifurcation at or above the level of the C2 cervical vertebra and a very distal extension of internal carotid atherosclerotic disease may challenge vascular surgeons performing CEA by increasing technical difficulty and possibly the incidence of cranial nerve injury. Division of the digastric muscle, mandibular manipulations such as anterior translational movement when the mandible moves forward with teeth, condyles and rami all moving in the same direction and to the same degree or subluxation can help in accessing lesions of the distal cervical ICA. In addition, by division of tethering artery and vein to sternocleidomastoid, the descending hypoglossal branch of ansa cervicalis or the occipital

artery can help in mobilisation of the hypoglossal nerve and exposure of more distal internal carotid artery. Although rarely required, these high carotid exposures may be associated with increased difficulty in directly visualising the end point of the endarterectomy and with increased incidence of cranial nerve injury, particularly cranial nerve IX [3,4]. Nasotracheal intubation has also been suggested in some early reports, but the recent evidence from a cadaveric study suggests nasotracheal intubation does not improve access to a high carotid artery bifurcation as compared with orotracheal intubation [5]. Carotid artery stenting (CAS) is an alternative in these patients, however anatomic factors that may complicate this process include difficult access with aortoiliac tortuosity, a sharply angulated aortic arch (type III), or a carotid lesion with more than two 90° bends within a short distance of the target lesion [6]. Significant distal ICA tortuosity may also complicate the placement and stabilisation of a distal embolic protection device [7]. Pending more evidence from ongoing clinical trials, CEA will remain the mainstay of treatment and vascular surgeons will need to develop strategies to effectively manage anatomically challenging lesions.

### Carotid body paragangliomas

Carotid body tumours (CBTs) belong to the classification of paragangliomas because they originate from paraganglia in chromaffin-negative glomus cells derived from the embryonic neural crest, functioning as part of the sympathetic nervous system. These cells normally act as special chemoreceptors located along blood vessels, particularly in the carotid bodies (at the bifurcation of common carotid artery in the neck) and in the aortic bodies (near the aortic arch) [8]. Most of these lesions are benign; however some can show malignant behavior with few reports of histological confirmation of malignant CBTs [9]. There are no clear histological features for diagnosis of malignant carotid body paragangliomas to differentiate them from benign tumours. Paragangliomas tend to occur in sites where basement membrane penetration, the hallmark of malignancy in many epithelial tumours, cannot be assessed. Histologic features such as nuclear pleomorphism, necrosis, mitotic rate, and local invasion may be seen in benign paragangliomas and are not diagnostic of malignancy. According to 2004 World Health Organisation criteria, the diagnosis is reserved for tumours with local, regional and distant metastasis [10]. The treatment modalities for CBTs are surgical excision and/or radiotherapy. Surgical removal is the treatment of choice as it provides immediate and complete tumour removal. CBT surgery remains a challenge for surgeons because of tumour's location in the vicinity of critical blood vessels and cranial nerves. In addition to its location, additional difficulty is its high vascularity, as its blood supply is the richest per gram of tissue of any tumour [11]. CBTs are usually classified by the criteria described by Shamblin et al. [12] (Table 1) which is used to assess invasiveness. Complete resection of Shamblin class III CBTs is very challenging and often requires temporary interruption of cerebral circulation for vascular reconstruction with significant risk of permanent vascular and neural defects [13].

The strategies utilised to aid in surgical resection include preoperative embolisation and use of intraoperative shunting. The routine use of preoperative embolisation is controversial because of the potential neurologic complication associated with the accidental reflux of particulate matter into the ophthalmic or cerebral circulation. Some authors advocate its use for larger tumours as it may decrease the tumour vascularity and subsequent intraoperative blood loss. The

**Table 1:** The Shamblyn classification of carotid body tumours [12].

Class	Tumour characteristics
I	Splaying of the carotid bifurcation with little attachment to the carotid vessels; complete resection with very little morbidity
II	Partial surrounding of internal and external carotid artery; complete resection more challenging
III	Complete surrounding of the carotid vessels; complete resection often requires major vessel reconstruction

**Table 2:** Historical techniques for ICA exposure at the base of skull (before 2000).

Author	Year	No. of pts	Technique	Results
Fisch et al [38]	1980	5	Subtotal petrosectomy with permanent anterior displacement of the facial nerve, and middle ear obliteration	Good recovery with preservation of carotid flow before and after procedure, reducing the risk of neurological complications and mortality
Welsh et al [39]	1981	7	Mandible osteotomy with resection of ICA lesion and vein bypass	One patient has postoperative hemiplegia
Purdue et al [40]	1981	1	Anterior mobilisation of the parotid gland with removal of mastoid along with a portion of the inferior wall of auditory canal	Glossopharyngeal nerve has to be sacrificed and potential for damage to XII cranial nerve is present
Glasscock et al [41]	1983	1	Modified infratemporal fossa approach with superficial parotidectomy, condylar mandibulectomy and resection of mastoid tip, tegmen and zygomatic process of temporal bone	Surgically induced facial paralysis and persistent incomplete Horner's syndrome
Pellegrini et al [42]	1984	2	Rerouting of facial nerve	Unclear long-term results
Sandmann et al [43]	1984	29	Dissection of the digastric muscle, and detachment of the styloid process	One recurrent stroke, two transient ischaemic attacks, cranial nerve damage in 21 cases
Fisher et al [44]	1984	24	Mandibular subluxation	No objective or subjective TMJ dysfunction but risk of injury to marginal mandibular nerve and lingual vein, contamination with oral flora and potential compression of contralateral carotid sheath
Larsen et al [45]	1992	2	Vertical ramus osteotomy	Potential oral flora contamination, possibility of malocclusion, inappropriate bone healing and delay in oral intake
Alimi et al [46]	1996	6	Unilateral venous graft restoration, reaching the vertical portion of the intrapetrous ICA in two patients and the horizontal portion in four	One graft thrombosis, no neurological events, no stroke, five facial paresis, one total deafness

apparent benefit of embolisation should be weighed against the risk of stroke.

An intraoperative shunt can also be used in the following circumstances to aid in CBT resection and shorten surgical time [14]:

**To avoid the injury of cranial nerves:** when the large size of the tumour and the narrow operative space make it difficult to excise the tumour and easy to injure the cranial nerves, under the guidance of the shunt, the direction of the ICA is more distinct, and cranial nerves are more clear, which helps tumour dissection.

**To decrease the size of the tumour:** with the use of the shunt, the blood supply to the tumour decreases, thereby decreasing the size of the tumour.

Even with the use of these adjuncts, complete surgical resection may not be possible through a transcervical approach alone and more radical exposure is warranted.

### Internal carotid artery aneurysms

Internal carotid artery aneurysms (ICAA) are rare. Surgical ICAA repair accounts for less than 1% of all aneurysm repairs [15]. Aneurysms of the ICA developed at the base of the skull in the infratemporal fossa are even rarer [16]. The aetiology of ICAA is multiple including atherosclerosis, fibromuscular dysplasia, post-traumatic and infectious lesions [17]. Prevention of thrombo-embolic complications is the main indication for treatment; however surgical approach to these lesions faces anatomical difficulties due to the complexity of the region and the close relation between the ICA and the cranial nerves, mainly the facial nerve [18]. Endovascular stent-grafting is particularly attractive in this situation and has been used but its role is still in its infancy with arterial dissection, embolism during deployment, stent fracture, intimal hyperplasia, and long-

term occlusion as potential risks associated with it and uncertain long-term results. The alternatives to surgical repair are ligation of the ICA and ligation of the ICA combined with external carotid/internal carotid bypass [19]. However, these options are less preferred due to the high incidence of ischaemic complications and stroke [17,18]. As a consequence, the direct surgical repair seems to be the best solution, leaving the challenging problem of the approach to the ICA at the base of the skull.

In addition to the above relatively common indications, ICA blunt trauma causing pseudo-aneurysm, dissection or stenosis and other tumours may mandate surgery at this level.

## Approaches

### Historical perspective

Several techniques have been proposed as outlined in Table 2. However, they were mostly associated with more or less perturbation of the facial nerve, temporal bone and mandible causing significant functional morbidity. We reviewed the contemporary literature to evaluate and critically review the approaches in current use as discussed below.

### Transcervical approaches

Adequate exposure can be occasionally achieved especially for lesions located in the lower parapharyngeal space with adjuncts including resection of the posterior belly of digastric muscle with identification and preservation of facial nerve. This procedure can also be combined with parotidectomy to gain access to tumours and other lesions in the middle parapharyngeal space. This is based on compartmentalisation of the parapharyngeal space as described by Shahinian et al. [20]. The authors suggest a cervical submandibular approach for tumours in the inferior parapharyngeal

space (hypopharynx) extending inferiorly into the cervical area. For tumours in the midparapharyngeal space (mesopharynx) a parotid-cervical approach can be used with anterior and inferior retraction of the mandible. For smaller tumours of the superior parapharyngeal space (epipharynx) extending to the skull base an infratemporal fossa approach with a preauricular incision and a plane of dissection anterior to the middle ear, petrous horizontal internal carotid artery, and the eustachian tube is recommended sparing the middle ear, temporomandibular joint, and the cranial nerve V3. For massive tumours of the entire parapharyngeal spaces that extend to or through the skull base superiorly or encase the petrous portion of the internal carotid artery an infratemporal fossa type approach is required with blind closure of external auditory canal, a mandatory conductive hearing loss, removal of the temporomandibular articular disc, and sacrifice of cranial nerve V3.

### Lateral infratemporal approaches

The transcervical incision can be extended if more exposure is needed with a preauricular incision laterally into the temporal area. The temporal branch of facial nerve should be preserved. The temporomandibular joint (TMJ) is freed, intact from the temporal fossa and distracted anterior to the articular eminence with resection of the mastoid tip often needed. The Eustachian tube is identified and removed and the middle meningeal artery is usually ligated to allow greater access [2]. Bone is removed over the proximal ascending and horizontal portions of the petrous carotid until sufficient exposure is gained. At the conclusion, TMJ is replaced in the glenoid fossa and posterior joint capsule is sutured back in its place. A similar approach, with some modifications has also been described by Malikov et al. [18].

- Prasad et al. [21] have recently described three lateral skull base infratemporal fossa approaches for upper parapharyngeal space tumours. Type A with permanent anterior transposition of the facial nerve to provide optimum exposure of the jugular foramen and to allow control over the distal parapharyngeal ICA up to the vertical petrous portion.
- Type B for tumours with antero-medial extension with respect to ICA. This approach provides access to the vertical and horizontal portions of the petrous ICA.
- Type D for tumours with antero-lateral extension with respect to ICA. This approach consisted of a preauricular incision with dissection anterior to the horizontal petrous ICA and the Eustachian tube.

### Midline mandibulotomy

The ICA runs in the parapharyngeal space and can therefore be approached from medial direction using combined midline mandibulotomy and an extended cervical incision. Vikatmaa et al. [22] reported their experience in five cases. Lip split and intraoral mucosal incision are performed with medial mobilisation of the tongue and lateral rotation of the mandible. Injury to the marginal mandibular branch of the facial nerve is avoided by identifying it 1 cm anteriorly and inferiorly to the mandibular angle or ligating and elevating the facial vessels to protect it [23]. The tympanic bone and the carotid canal can be reached and distal ICA control can be obtained. The bony structures of the skull base do not need routine resection.

A new exposure technique with application of double mandibular

osteotomy has been described by Ktenidis et al. [24] in the treatment of giant ICAA. An osteotomy was made at the base of the condylar process to increase mandibular mobility and to allow rotation of the body and ramus of the mandible when a second mandibular osteotomy was carried out anterior to the mental foramen. The coronoidectomy improved the exposure of the parapharyngeal space, increased mandibular segment mobility, and prevented postoperative trismus.

### Other approaches

Transnasal endoscopic approaches to the skull base are an alternative to more traditional open approaches in selected cases. What is crucial in these approaches is the anatomy of the ICA, which takes a complicated, tortuous course through this area [25]. The lateral pterygoid plate and posterior border of mandibular ramus are important anatomic landmarks during the endoscopic approach to the infratemporal fossa. Endoscopic transvestibular approach has also been described by Chan et al. although the risk of this approach is the tunnel-like exposure, surrounded by vital structures [26]. Hybrid approach with combined open and endovascular treatment for saccular ICA aneurysm with redundant ICA loop has also been reported [27]. Preoperative endovascular stenting has been proposed in patients having high risk of ICA injury. The main purpose is to reinforce the arterial wall allowing a safe subadventitial dissection during tumour removal. Anterior exposure of the infratemporal fossa and distal control of the carotid artery at the level of the carotid canal has been recently described through a transcervical approach, performing double mandibular osteotomies with superior reflection of the middle mandibular section [28]. In addition, exposure and mobilisation of the intrapetrous carotid artery using a retrosigmoid approach is feasible and could represent a viable option for the possibility of total resection of selected skull base tumours, even when involvement of the carotid canal is present [29].

## Discussion

Exposure of the ICA near the base of the skull is complex and associated with substantial morbidity. Recent progress in endovascular technology has raised the possibility of treating some of these lesions without radical surgical exposure but there have been only sporadic reports and further development and long-term results are awaited. Surgery continues to be the mainstay especially in the management of carotid body and other parapharyngeal space tumours. The main aims are selecting a technique with adequate intraoperative visibility for radical resection and minimal functional and cosmetic sequelae.

Several different historic techniques have been reported in the literature in the last four decades but most of them are associated with significant and unacceptable morbidity. More recently, acceptable results have been reported with lateral infratemporal approaches and midline mandibulotomy but the optimum technique has not been defined. Proponents of the lateral infratemporal approaches suggest there is low immediate morbidity associated with this procedure with excellent long-term results [18]. Although, the petrous ICA can also be exposed by the posterior approach, this is less preferred to prevent profound conductive hearing loss associated with this technique [30]. With the lateral approach, drilling free both the vertical and horizontal portions of the petrous carotid artery allows the removal of bone around 270° of the artery. This allows excellent mobility of the artery for bypass [31]. The morbidity from this type of resection results primarily from cranial nerve dysfunction, Eustachian tube

dysfunction with possible need for myringotomy and tube placement and loss of chorda tympany nerve, however permanent cranial nerve injuries are uncommon [30]. Patients should also be advised of possible TMJ discomfort and taste disturbances.

Other group of surgeons prefers the midline and paramidline mandibulotomies with lateral luxation of the ipsilateral mandible, which gives an excellent exposure to the oral cavity and oropharynx and has been widely used for resection of tumours. With these techniques, they claim the skull base can be widely exposed and the distal ICA runs lateral to the nasopharyngeal cavity superficially under the mucous membrane [22]. Although the sterility is obviously compromised, the risk of major infection problems is low. They suggest the lateral approach can lead to injury to the glossopharyngeal and vagus nerves lying just medial to the styloid process. In a cadaveric anatomic study by Beretta et al, the last 10 mm of skull base remained unexposed and the operative field remained narrow (range 5°-49°) making a distal anastomosis impossible or hazardous to perform [32]. However, the argument against mandibulotomy is facial scarring from lip splitting mandibulotomies, and malocclusion, loss of mental nerve, paralysis of the mandibular branch of facial nerve, tracheostomy in 6% to 27% of the cases and delayed wound healing with other mandibulotomies [33-35]. Even the more recent single subcutaneous midline mandibulotomy has the drawback of tooth morbidity and in some cases the application of tension band or segmental arch bar that is required to prevent rotation of the alveolus [21,36,37].

## Conclusion

Open surgical approaches to the ICA at the skull base are feasible with careful anatomic dissection and can be performed with minimal morbidity in most cases. The optimum approach continues to be debated and until long-term results are available, skull base surgeons will continue with their preferential technique. There are insufficient data to draw any definite conclusions on which method to choose in the management of high ICA lesions. The role of endovascular therapy will continue to expand but further research is warranted before their widespread adaptation.

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