Chapter 9
Management of Internal Carotid Artery in Skull Base Paraganglioma Surgery

Sampath Chandra Prasad, Paolo Piazza, Alessandra Russo, Abdelkader Taibah, Francesco Galletti, and Mario Sanna

Introduction

The surgical management of skull base paragangliomas is particularly challenging as a result of their complex anatomical location, the local major neurovascular structures, and the proximity of intracranial structures. The internal carotid artery (ICA) is often involved by tympanojugular paragangliomas (TJPs) in its upper cervical and petrous portions [1]. Similarly carotid body paraganglioma and the vagal paragangliomas are also intimately related to the ICA. Early attempts to resect tumors involving the ICA were associated with high rates of morbidity and mortality [2]. However, today, significant reduction in morbidity has been achieved in the surgical management of this subset of tumors due to advances in preoperative interventional neuroradiology and refinements in skull base microsurgery [3]. To avoid intraoperative morbidity and mortality from vascular compromise, various modalities of management of the cervical and intratemporal ICA have been described. These modalities include cervical-to-petrous ICA saphenous vein bypass grafting [4], permanent balloon occlusion (PBO) [5, 6], and intravascular reinforcement with stenting [7–12].

Skull base paragangliomas require an accurate preoperative neurovascular evaluation taking into consideration the degree of ICA involvement, the anatomical

S.C. Prasad (✉) • A. Russo • A. Taibah • M. Sanna
Department of Neurotology and Skull Base Surgery, Gruppo Otologico, Piacenza, RM, Italy
e-mail: sampathcp@gmail.com

P. Piazza
Department of Neuroradiology, University of Parma, Parma, Italy

F. Galletti
Faculty of Medicine and Surgery, Azienda Ospedaliera Universitaria Di Messina, Messina, Italy

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and functional integrity of the Circle of Willis, previous surgery or radiotherapy, and the patient's age and the general condition of the patient [3, 10, 13–15]. Patients can be considered as having a high risk of intraoperative ICA injury if (1) encasement of the ICA reaches more than half (i.e., 180–360°) of the arterial circumference, (2) there is evidence of stenosis or irregularity of vessel walls, (3) patients with a past history of radiotherapy or surgery around the ICA, and in cases of (4) multiple ipsilateral lesions, (5) single ipsilateral ICA, or (6) recurrent disease medial to the petrous ICA [16, 17]. A significant proportion of the mortality in TJP surgery, reported in earlier series, was due to injury of the artery and as a consequence of resection of the ICA [2]. ICA manipulation can be extremely dangerous resulting in spasm, thrombosis, rupture, massive stroke, and even death [3, 18]. To minimize such risks, PBO of the ICA in TJP surgery was first employed by Andrews et al. [5] and Zane et al. [19] in order to facilitate radical tumor removal and enable safe mobilization of the carotid. While PBO of the ICA allows safe removal of the lesion, this procedure cannot be used in cases of inadequate collateral circulation and is not inherently risk-free.

We have developed the application of preoperative stenting of the ICA in the management of TJPs since 2003 to avoid preoperative closure or bypass procedures and to protect and preserve integrity of the ICA during surgery [3, 11]. Preoperative stent insertion also allows an aggressive ICA dissection with significant reduction of the surgical risks [3, 10, 12]. In class C3 and C4 tumors, major encasement of the ICA is usually found at the inferomedial wall of the horizontal petrous segment. Curative treatment necessitates aggressive removal of the bone in the region of the carotid canal and dissection of the arterial wall in class C3 and C4 tumors. We have noted that most of the recurrences were localized to the area around and medial to the petrous ICA [8]. Preoperative endovascular intervention in the form of intra-arterial stents in the cervical and petrous (vertical and horizontal) segments of the ICA allows total tumor clearance in these areas without compromising the artery. In our experience of over 30 cases, the stenting of ICA has transformed the therapeutic management in cases of advanced TJPs, leaving very few or no TJPs inoperable.

Preoperative Assessment of the ICA

The aims of preoperative assessment are to (1) determine the degree and extent of involvement of the artery by the tumor and (2) determine the efficacy of the collateral circulation in maintaining the perfusion of the areas that would be affected by the manipulation or sacrifice of the artery. The investigations used for this purpose include high-resolution CT scan, MRI, magnetic resonance angiography (MRA), and digital subtraction angiography. Narrowing and irregularities of the arterial lumen are strongly suggestive of infiltration of the ICA wall. To determine the efficacy of the collateral circulation, four vessels angiography with manual cross compression test, xenon-enhanced computed tomography cerebral blood flow, single-photon emission computed tomography, and carotid stump pressure management are used.

The indications for preoperative endovascular intervention of the ICA are:

(1) Encasement of the distal cervical and petrosal vertical segments of the ICA between 270 and 360°, as shown by CT and MRI in the axial plane
(2) Evidence of stenosis and irregularities of the arterial lumen of the distal cervical and petrosal segments of the ICA as determined by angiography
(3) All class C3 and C4 TJPs, vagal and carotid body paragangliomas
(4) Extensive blood supply from ICA branches as seen on angiography
(5) Previous surgery with ICA manipulation and/or previous radiotherapy

In these situations, the options include preoperative PBO, external-internal carotid artery bypass followed by PBO or reinforcement with intra-arterial stents. In this chapter, we will briefly discuss PBO and stenting of the ICA.

Preoperative Endovascular Management of the ICA

Permanent Balloon Occlusion

A balloon occlusion test (BOT) is performed if there is good cross-filling from at least one of the two communicating systems. A PBO would be undertaken if the patient tolerated the BOT and angiographic data demonstrated good cross-flow.

The BOT-PBO procedure is performed under local anesthesia with mild sedation and systemic heparinization. A bilateral femoral approach is employed in which an 8F guiding catheter is inserted into one femoral artery and positioned in the ICA to be occluded. The contralateral femoral artery puncture is used for the angiographic evaluation. To permanently occlude the ICA, a GVB 16 balloon mounted on a CIF catheter (Minyvasis, Gennevilliers, France) is used. The first balloon is usually placed into the cavernous segment of the ICA just proximal to the origin of the ophthalmic artery and two more balloons at the carotid foramen and in the neck just distal to the bifurcation (Figs. 9.1, 9.2, and 9.3). After balloon inflation, occlusion of the ICA is confirmed angiographically by injection of contrast into the guiding

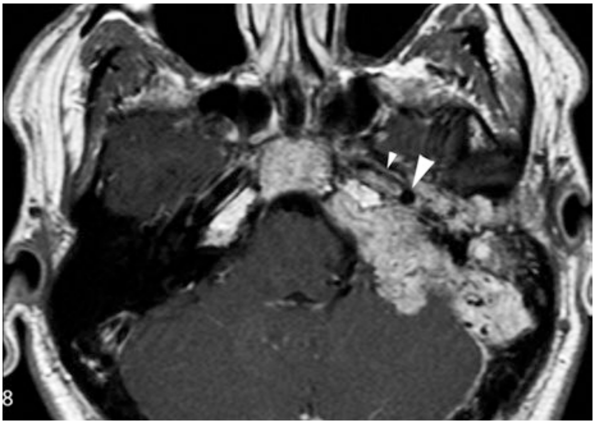

Fig. 9.1 MRI with gadolinium (axial view) of a case of right C3 TJP at the level of the horizontal segment (*small arrow head*) of the internal carotid artery. Note the encasement of the vertical segment (*big arrow head*) of the artery

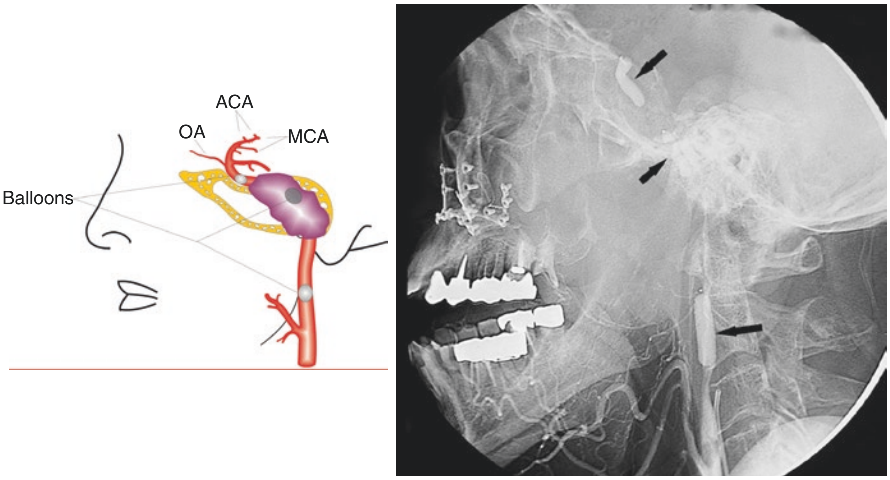

Fig. 9.2 Angiogram showing the balloons (*three arrows*). *ACA* anterior cerebral artery, *MCA* middle cerebral artery, *OA* ophthalmic artery

Fig. 9.3 Angiogram showing complete occlusion of the artery after placement of the balloons. The distal branches of the external carotid artery are not seen as they were closed in a previous surgery. The shadow of the vertebral artery can be appreciated (*two arrows*)

catheter, followed by confirmatory angiography to establish that adequate cross-flow is achieved, with special attention to the symmetry of the arterial, capillary, and venous phases on either side (Figs. 9.4 and 9.5). The patient's physical and mental status is then monitored for 20 min. The first balloon is then detached. If balloon occlusion is not tolerated, the balloon is deflated immediately. In most cases this is apparent very quickly, in the first few minutes after carotid occlusion. If asymmetry

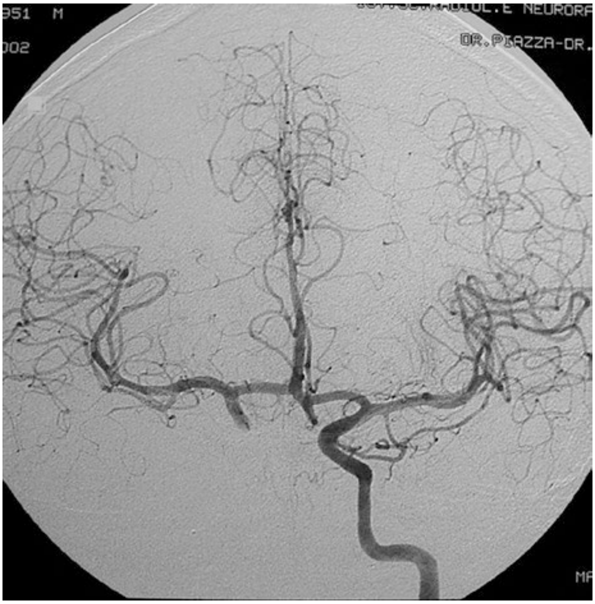

Fig. 9.4 Angiography (arterial phase) of a patient with injection of the left internal carotid artery after manual cross compression test of the right internal carotid artery showing patency of the anterior communicating and perfect symmetry of the arterial and venous phases of the two cerebral hemispheres

Fig. 9.5 Venous phase angiography of same patient as Fig. 13.41

(>1 s) in the capillary and venous phases of the angiogram is identified, angiography is repeated a few minutes later. If this asymmetry does not correct, the balloon is deflated and alternatives must be considered. After PBO, the patient is monitored for 24 h in an intensive care unit. Surgery is scheduled only after 3–4 weeks.

Intra-arterial Stenting

The introduction of preoperative reinforcement of the ICA with stents is a significant advancement in the surgical management of patients who are at risk of damage to the ICA. Stent insertion reinforces the artery and allows more aggressive carotid dissection while reducing the possibility of intraoperative injury to the ICA. To reduce the risk of thromboembolic complications, antiplatelet therapy is commenced 5 days before the stent insertion using a combination of clopidogrel (75 mg/day) and aspirin (100 mg/day). This therapeutic regimen is administrated for 1–3 months after stenting and then reduced to single-drug treatment with aspirin only. Antiplatelet agents are stopped and low molecular weight heparin (LMWH) commenced 5 days before surgery. Antiplatelet agents are introduced 2 days after surgery and LMWH is stopped 3 days after surgery. The patient then is placed on lifelong antiplatelet therapy (Fig. 9.6).

Reinforcement with stents is performed under general anesthesia as a separate procedure following diagnostic angiography. Three different types of self-expanding nitinol stents are used: Xpert Stent System (Abbott Laboratories Vascular Enterprises, Dublin, Ireland), Neuroform 3 (Boston Scientific, Fremont, CA), and LEO (Balt Extrusion, Montmorency, France). We consider the Xpert stent the most suitable for reinforcement of both the cervical and intratemporal portions of the ICA because of its diameter (4 or 5 mm) and length (20, 30, or 40 mm). To reduce the possibility of injuring the ICA at the stent-tumor border, at least 10 mm of tumor-free vessel wall must be reinforced with the stent, both proximally and

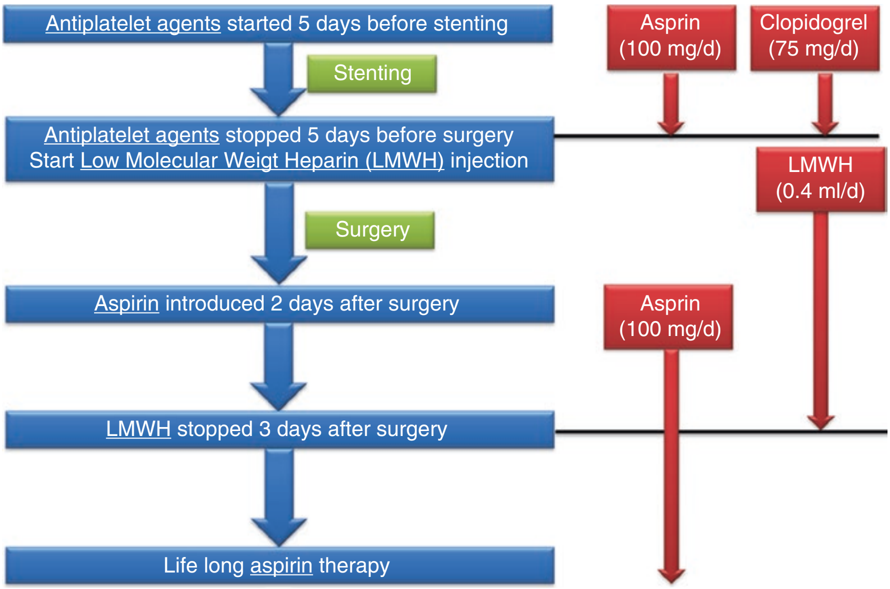

Fig. 9.6 Medication schedule associated with stenting into the internal carotid artery

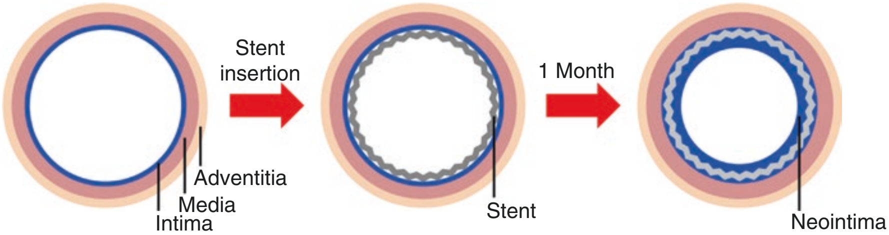

Fig. 9.7 Changes of anatomy of the internal carotid artery after stent insertion

distally. To achieve this, it is necessary to insert up to two or even three stents. Each stent is carefully selected and tailored to the individual patient. It is difficult to negotiate the stent between the vertical and horizontal portions of the carotid canal and in arteries that are coiled or kinked in the neck, and great care must be taken while this is being performed. In such situations, softer and more flexible stents must be chosen, to reduce the risk of dissection of the ICA. If a stent placement is technically impossible, a PBO is the next option.

The timing of reinforcement with stents also plays an important role; an interval of at least 4–6 weeks is advocated between stenting and surgery. This allows the formation of a stabilized neointimal lining (Fig. 9.7) on the luminal surface of the stent. In the presence of significant blood supply from the ICA, a bare stent is ineffective in reducing the vascular supply to the tumor. In such situations, the use of PBO, preoperative embolization with particles during temporary balloon occlusion of the ICA, and insertion of covered stents are possible alternative solutions. Present literature suggests that covered stents have several theoretical disadvantages, increased thrombogenicity, rigidity, and greater difficulty in positioning at arterial angles, when compared to bare stents.

One month after the stent insertion, the neointimal layer is developed and subsequent subadventitial dissection can be safely performed.

Intraoperative Management of the ICA

Intraoperatively, the ICA may require the following types of intervention, depending on degree of involvement: (1) decompression with or without partial mobilization of the artery, (2) subperiosteal dissection, (3) subadventitial dissection, (4) subadventitial dissection with stent coverage, and (5) arterial resection (after preoperative PBO).

Simple decompression—This technique is employed when the tumor is around the ICA but not adherent to the artery (i.e., Fisch class C1 TJPs). Decompression of the ICA is performed after identifying it medial to the Eustachian tube by drilling out the tympanic bone. A large diamond burr is used parallel to the course of the artery. Drilling is advanced both laterally and medially to the artery. By removing the bone anterior to the ICA, the artery can be displaced laterally or medially by manipulating it with the tip of the suction tube while drilling is being performed. If additional drilling around the ICA is required, a vessel loop is wrapped around the artery to enable a wider range and better control.

Subperiosteal dissection—This technique is indicated when the tumor involves the periosteum of the carotid canal without reaching the adventitia. In this technique, a plane of dissection is developed between the adventitia of the ICA and the periosteum of the carotid canal [20] (Figs. 9.8–9.22). This is relatively easier and safer in the vertical petrous segment, as the ICA is thicker and more accessible when compared to the horizontal segment. The dissection of the tumor is started at the cervical level, from an uninvolved extratemporal segment of the ICA, where a good plane of dissection is easily identified. The bone of the carotid canal around the ICA from its entrance into the temporal bone is drilled out along with the

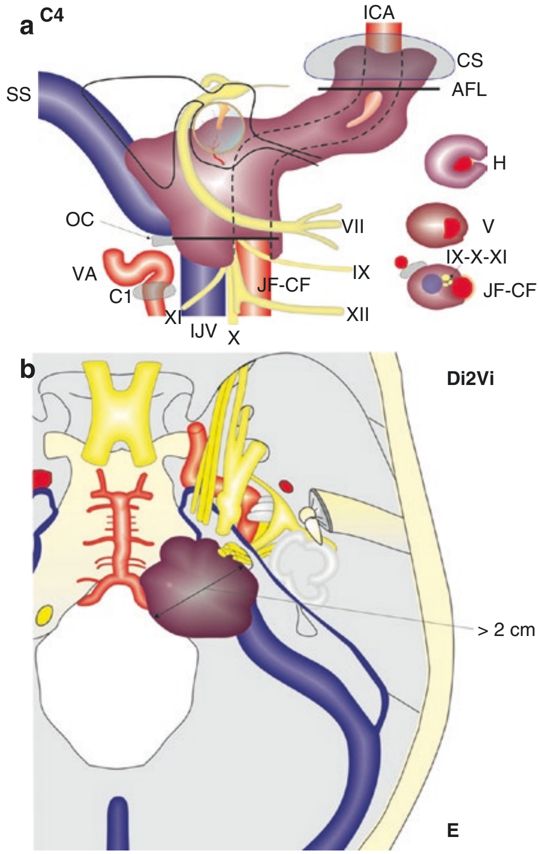

Fig. 9.8 (**a**, **b**) A class **C4Di2Vi** (right side) was operated in two stages. In the second stage, the remnant of the tumor that involved the ICA was excised and is shown here in pictorial steps. Angiography revealed inadequacy of the collateral circulation. A stent was placed in the artery preoperatively. *SS* Sigmoid Sinus, *OC* Occipital Condyle, *VA* Vertebral artery, *C1* C1 vertebra, *XI* XI cranial nerve, *IJV* Internal Jugular Vein, *JF-CF* Jugular foramen - cartid foramen, *XII* XII cranial nerve, *IX* IX cranial nerve, *VII* VII cranial nerve, *ICA* Internal carotid artery, *CS* Cavernous segment, *AFL* anterior foramen lacerum, *H* Horizontal carotid, *V* Vertical carotid

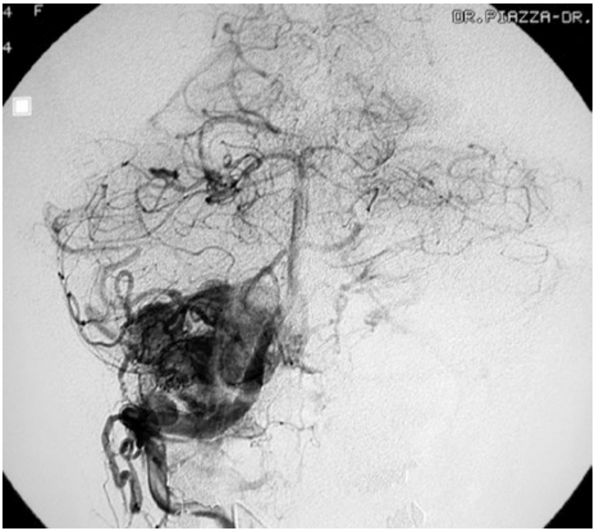

Fig. 9.9 Angiogram of the case shows the tumor blush and the massive involvement of the internal carotid artery

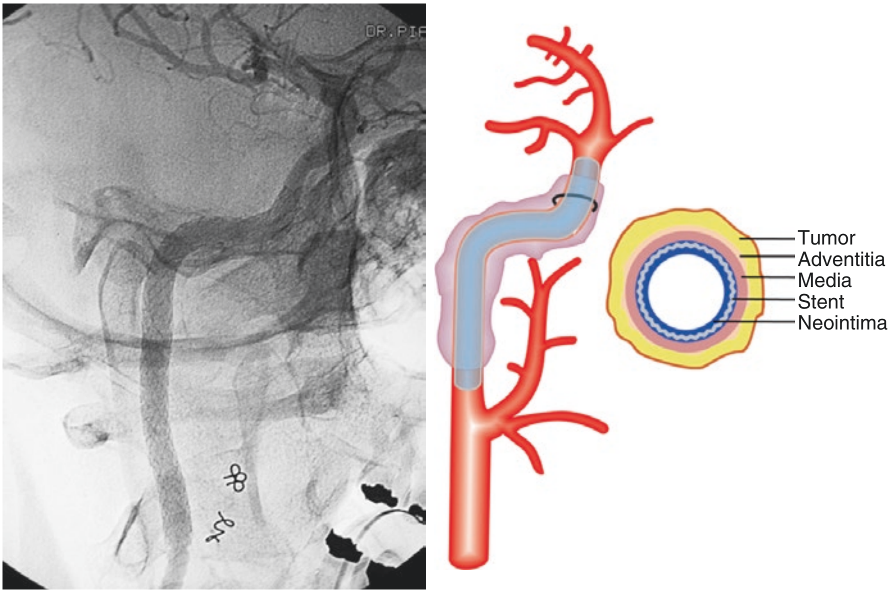

Fig. 9.10 Angiogram, lateral view, showing the stent inside the internal carotid artery

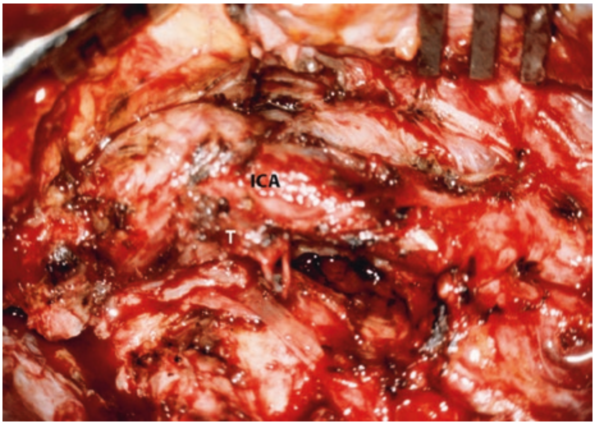

Fig. 9.11 Intraoperative view showing the internal carotid artery completely encased by the tumor. *ICA* internal carotid artery, *T* tumor

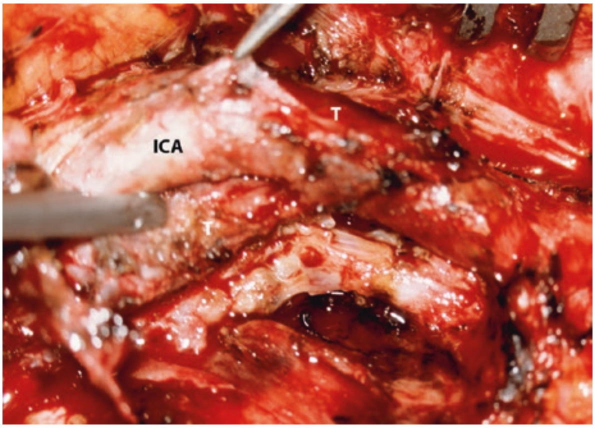

Fig. 9.12 Establishment of the plane of cleavage. *ICA* internal carotid artery, *T* tumor

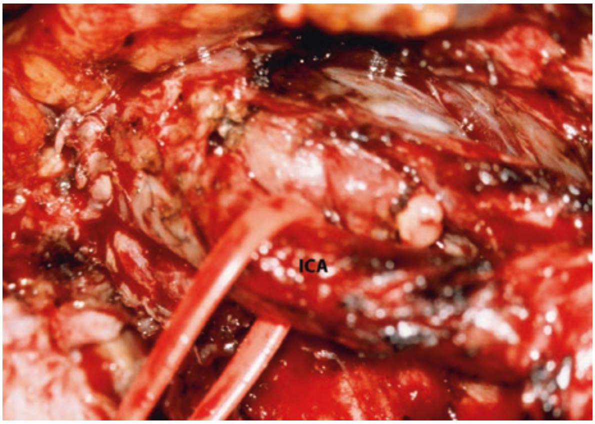

Fig. 9.13 The artery (posteriorly displaced by an umbilical tape) has been partially dissected from the tumor. Note that the tumor is anteriorly placed. *ICA* internal carotid artery, *T* tumor

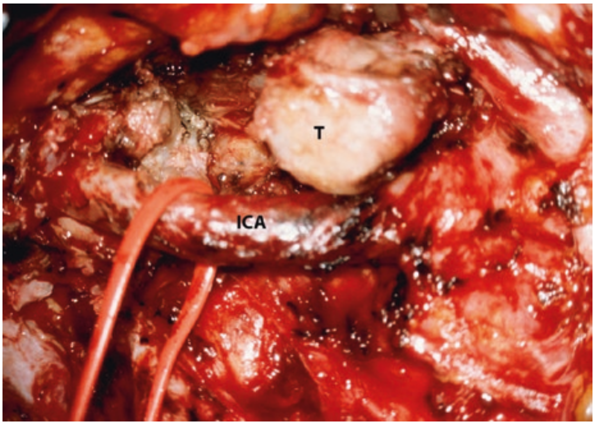

Fig. 9.14 Further dissection of the tumor. The internal carotid artery (ICA) is posteriorly displaced, *T* tumor

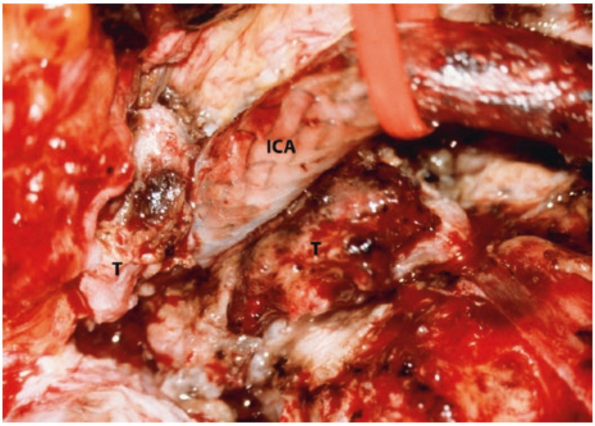

Fig. 9.15 Here the ICA has been anteriorly displaced. Note that the stent appears clearly through the thinned arterial wall. *ICA* internal carotid artery, *T* tumor

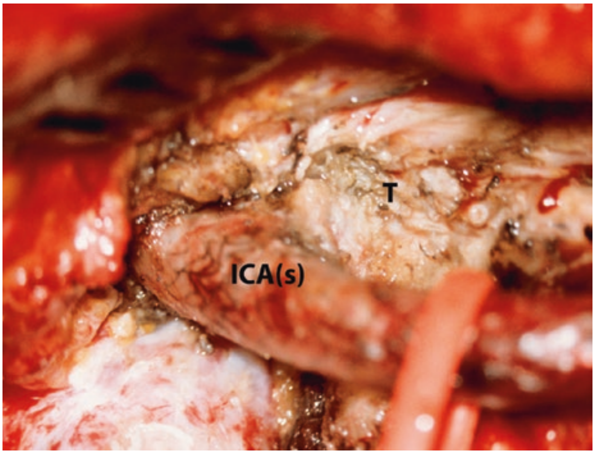

Fig. 9.16 The horizontal segment of the ICA was made free from the tumor (T). Note that the tumor extended to the foramen lacerum

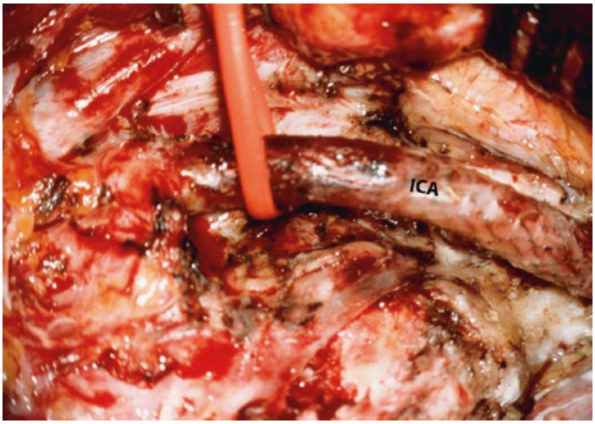

Fig. 9.17 Final view at the last procedure. Most of the internal carotid artery in the petrous bone had been freed from the tumor. Note the bloodless surgical field and the reinforcement of the internal carotid artery with a stent. To avoid postoperative cerebrospinal leak, the recurrent intradural lesion was left in place and removed in another stage (see Case 3 in Chap. 17)

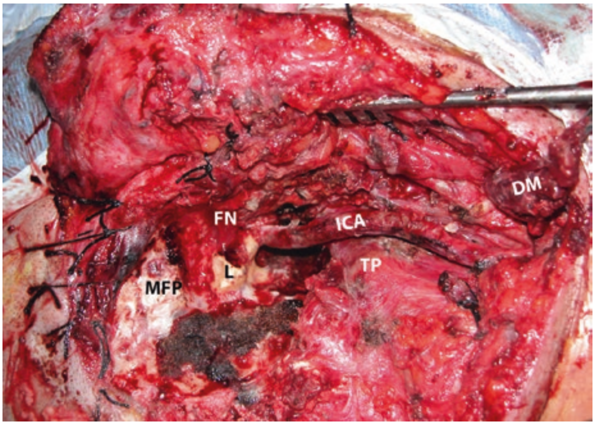

Fig. 9.18 Note the fully exposed internal carotid artery after complete tumor removal. *DM* posterior belly of the digastric muscle, *FN* facial nerve, *ICA* internal carotid artery, *L* labyrinth, *MFP* middle fossa plate, *TP* transverse process of the atlas

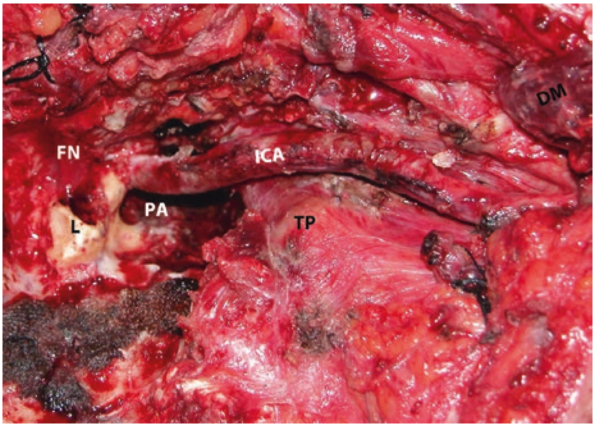

Fig. 9.19 Higher magnified view. *DM* posterior belly of the digastric muscle, *FN* facial nerve, *ICA* internal carotid artery, *L* labyrinth, *PA* petrous apex, *TP* transverse process of the atlas

Fig. 9.20 CT scan, axial view showing the stent inserted into horizontal portion of the internal carotid artery

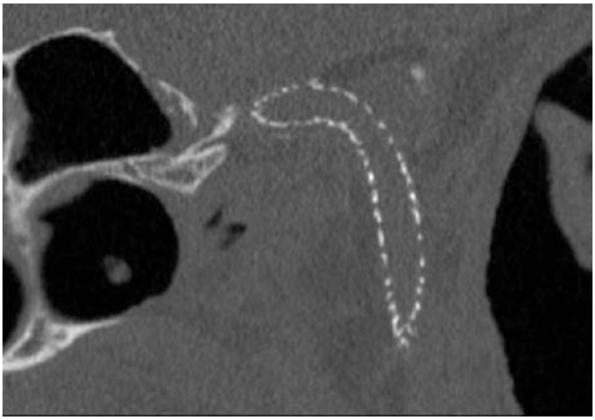

Fig. 9.21 CT scan, axial view showing the stent inserted into vertical portion of the internal carotid artery

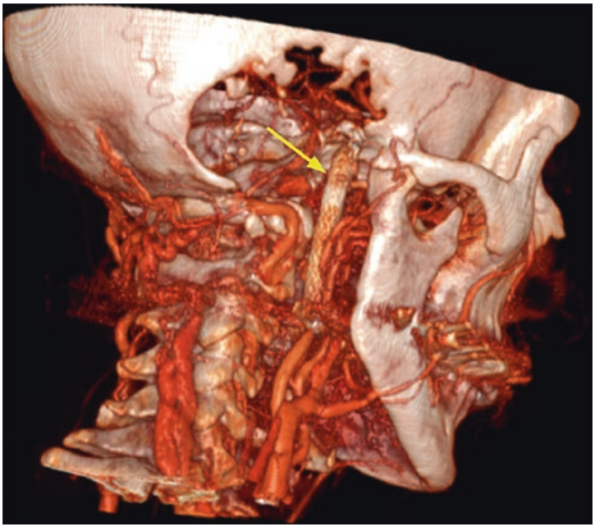

Fig. 9.22 Color 3D angioCT: view from below. Note the large bone removal and the stented artery (*arrow*)

tumor infiltrating the bone and periosteum. Gentle displacement of the ICA, from its entrance in the skull base to at least the genu of the horizontal segment, is required if the tumor has extended anterior to the artery. There could be areas where the tumor may extend into the adventitia of the artery, and subadventitial dissection may be required.

Subadventitial dissection—This technique is applied to tumors that infiltrate the adventitia without reaching the muscular layer (media) of the ICA. Subadventitial dissection consists of separating the adventitia from the muscular layer. The wall of the ICA at the level of the vertical segment is 1.5–2.0 mm thick with the adventitia being approximately 1 mm thick. The adventitia is absent at the horizontal portion [21]. Therefore, subadventitial dissection can only be executed at the vertical portion. The intraoperative risk of a vascular injury is especially high in irradiated or previously operated cases. Small lacerations to the arterial wall, or any avulsion of the caroticotympanic branches, can often be controlled with judicious use of the bipolar cautery. For small to medium defects, direct suture repair is recommended. Double-armed vascular sutures are used while temporary occlusion is applied. Care to evert the edges of the artery while suturing is important to avoid stenosis. The postoperative risks of subadventitial dissection include weakening of the vessel leading to subsequent blowout or to dilatation and delayed aneurysm formation.

Dissection and Resection Following Permanent Balloon Occlusion

Following balloon occlusion of the artery, dissection is started from cervically upward. It is ligated immediately proximal to the proximal balloon using a large vascular clip, followed by en bloc resection of the artery with the surrounding tumor. Care must be taken to identify the distal segment of the occluded artery and perform transection here, to avoid excess traction on the cavernous sinus segment during final tumor removal (Fig. 9.23).

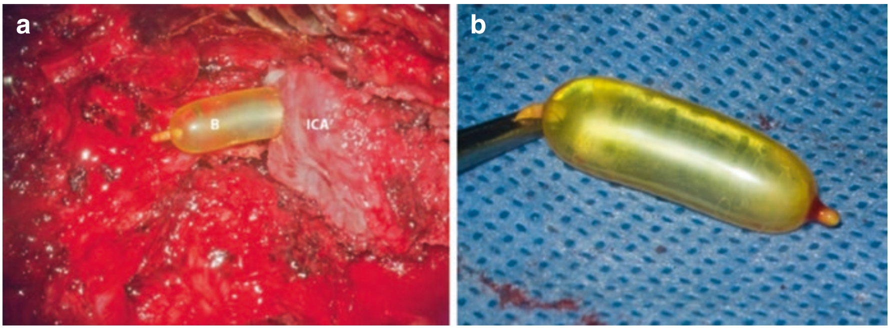

Fig. 9.23 (**a**) Latex balloon inserted into the internal carotid artery. (**b**) The harvested balloon

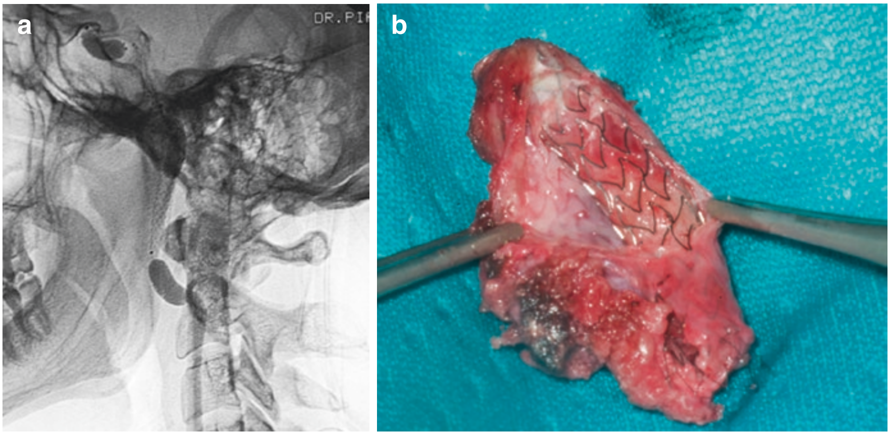

Fig. 9.24 (**a**) Angiography, lateral view. Three balloons are seen in the course of the internal carotid artery. (**b**) The stent is seen in the harvested internal carotid artery

In rare cases with failed tumor embolization due to high flow of tumor blood supply, permanent balloon occlusion can be performed even in cases with stent insertion (Fig. 9.24).

Intraoperative Internal Carotid Artery Injury

Prevention of injury to the ICA must be achieved at all costs. However, on rare occasions, a vascular injury may be encountered [22, 23]. In such case, the presence of proximal and distal control allows temporary occlusion, while a primary repair is carried out. A primary principle in such a situation is to achieve adequate visualization. Temporary compression or occlusion is achieved quickly by using previously placed control tapes. A variety of atraumatic vascular clips can also be used. Back-bleeding is a reassuring sign indicating some degree of collateral flow and allowing repair to be carried out in a timely fashion. Once the controls are achieved proximally and distally, small lacerations to the arterial wall or avulsion of the caroticotympanic branches can often be controlled with judicious use of the bipolar. Fine tips are used to approximate the edges in the longitudinal direction of the laceration. A low energy pulse is applied, and the forceps are advanced, and the process is repeated until the laceration is sealed. The occlusion is partially and then fully released to ensure closure. A layer of Surgicel® is placed over the repair and reinforced with fibrin glue. For small to medium defects, direct suture repair is recommended. Double armed vascular sutures are used while temporary occlusion is applied. Care to evert the edges is important as to avoid significant stenosis. Patch grafting and bypass using saphenous vein are options in extreme situations. In case of a stented ICA, the greatest risk is potential injury is at the transition point of the stented and non-stented artery. It is imperative to use minimal traction at this point. Facilities for rapid transfer of the patient to the neuroradiology suite once temporary control is gained are essential, with the options of emergency balloon occlusion or covered stent placement [24]. Apart from repair of the artery, important resuscitation principles must also be adhered to. Judicious volume replacement, estimation of blood loss, and consideration of component therapy were made. Following repair, normotension and adequate circulating volume must be maintained to ensure adequate repair and maintain neuroprotection. Any injury to the internal carotid artery or subadventitial dissection must be followed up radiographically due to the risk of pseudo-aneurysm formation.

Vasospasm of the ICA can also occur while manipulating the ICA. The etiology can be multifactorial but includes mechanical trauma, thermal changes, desiccation, and prolonged exposure to blood [25]. Therefore, irrigation with warmed saline and a gentle technique are essential to minimize this risk. It has been reported that younger patients are more prone to this complication due to increased vascular tonicity and reactivity [25, 26]. If the surgeon notices any segmental reduction in the ICA, manipulation must stop, and papaverine is placed onto the artery. The surgeon must wait till normotension or mild hypertension is achieved.

Representative Cases

Hints and Pitfalls

- A preoperative assessment of the ICA is of paramount importance.
- Determine the degree and extent of involvement of the artery by tumor with CT, MRI, MRA, and digital subtraction angiography.
- Determine the efficacy of collateral circulation.
- Do not use a PBO if the angiographic phase has a delay of more than 1 s.
- Use intraluminal stents when possible. It avoids closure of the ICA and facilitates subadventitial dissection of the tumor.
- It is advisable to wait 4–5 weeks after stenting before operating on these patients.
- Start dissection of the tumor inferiorly at a point not invaded by the tumor
- Exposure of the cervical segment of the ICA is an essential step in the management of these tumors.
- Gentle displacement of the vertical segment of the artery is often required in order to remove tumor extending to the medial and anterior portion to the artery.
- Dissection of the tumor must be accomplished parallel to the artery.
- Dissection of the occluded ICA is started at the cervical level.
- The ICA is closed proximal to the preoperative balloon using a large vascular clip.
- Avoid traction of the cavernous sinus segment during final tumor removal.

Conclusion

ICA involvement is no longer considered a limiting factor in TJP surgery, but requires an accurate preoperative neuroimaging evaluation of the extent of ICA invasion by the tumor and appropriate perioperative management. Decompression of the ICA and subperiosteal dissection are relatively simple surgical procedures that can be employed in cases where the adventitia of the ICA is free of involvement. Preoperative endovascular intervention in the form of intra-arterial stents in the cervical and petrous segments of the ICA has transformed the therapeutic management in cases of advanced TJPs. Stenting of the ICA avoids the need for potentially troublesome maneuvers like PBO, bypass procedures, and arterial repair or reconstruction. PBO is currently limited to those patients in which stent placement is technically impossible or in patients with tumors that derive significant blood supply from the ICA. No major perioperative complications, related either to preoperative stenting or intraoperative surgical management of the ICA, have been reported to date in our series of patients.

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