Management of the cervico-petrous internal carotid artery in class C tympanojugular paragangliomas

1 Andrea Bacciu, MD,[1] Sampath Chandra Prasad, MS,[2*] Natalie Sist, MD,[3] Giulio Rossi, MD,[1] Paolo Piazza, MD,[4] Mario Sanna, MD[2]

[1]Department of Clinical and Experimental Medicine, Otolaryngology Unit, University-Hospital of Parma, Parma, Italy. [2]Department of Otology and Skull Base Surgery, Gruppo Otologico, Piacenza-Rome, Italy. [3]Department of Otolaryngology, Eastern Health, Box Hill, Victoria, Australia. [4]Department of Neuroradiology, University-Hospital of Parma, Parma, Italy.

Accepted 13 September 2015
Published online 00 Month 2015 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/hed.24264

ABSTRACT: *Background.* Management of the cervical and petrous internal carotid artery (ICA) is frequently required in Fisch class C tympanojugular paragangliomas (TJPs). The purpose of this study was to discuss the perioperative intervention of the ICA in patients who underwent surgical resection of a TJP.

Methods. A retrospective study of 237 patients surgically treated for Fisch class C TJPs was done to identify cases that required ICA management.

Results. Management of the ICA was required in 176 patients (74.2%). Forty-two patients required just an ICA decompression, 88 underwent a subperiosteal dissection, 19 underwent subadventitial dissection without intraluminal stenting, 17 underwent subadventitial dissection with intraluminal stenting, and 12 underwent arterial resection after permanent balloon occlusion. There were no complications associated with the endovascular procedures. Gross total tumor resection was achieved in 91.5% of the cases.

Conclusion. Preoperative endovascular intervention, in selected cases, facilitates gross total tumor removal and significantly reduces the risk of an intraoperative ICA injury. © 2015 Wiley Periodicals, Inc. *Head Neck* 00: 000–000, 2015

KEY WORDS: internal carotid artery (ICA), tympanojugular paragangliomas (TJPs), stenting, permanent balloon occlusion, infratemporal fossa approach

INTRODUCTION

Tympanojugular paragangliomas (TJPs) are predominantly benign and slow-growing tumors, which are locally aggressive and infiltrate the skull base.[1] The surgical management of TJPs is particularly challenging as a result of their complex anatomic location, the local major neurovascular structures, and the proximity of intracranial structures. The internal carotid artery (ICA) is often involved by the tumor in its upper cervical and petrous portions. Fisch and Mattox[2] classified temporal bone paragangliomas into 4 categories (class A, B, C, and D) according to location and extension based on high-resolution CT scan. On the basis of the extent of the ICA involvement, Fisch class C tumors are further subdivided into 4 subclasses: C1 tumors that erode the carotid foramen without involvement of the ICA; C2 tumors that erode the vertical segment of the petrous ICA up to the carotid genu; C3 tumors that involve the horizontal segment of the petrous ICA; and C4 tumors that reach the anterior foramen lacerum with extension into the cavernous sinus. Early attempts to resect tumors involving the ICA were associated with high rates of morbidity and mortality.[3] However, today, significant reduction in morbidity has been achieved in the surgical management of this subset of tumors because of advances in preoperative interventional neuroradiology and refinements in skull base microsurgery.[1] 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,[5,6] and intravascular reinforcement with stenting.[7–12] 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.[1,11] Preoperative stent insertion also allows an aggressive ICA dissection with significant reduction of the surgical risks.[1,10–12] This study details our experience with the management of ICA in TJP surgery over the last 2 decades.

*Corresponding author: S. C. Prasad, Department of Otology and Skull Base Surgery, Gruppo Otologico, Via Emmanueli 42, Piacenza, Rome, 29100 Italy. E-mail: sampathcp@yahoo.co.in

MATERIALS AND METHODS

The records of 237 patients with class C and D TJP (Fisch and Mattox[2] classification) surgically treated at the Gruppo Otologico between April 1988 and September 2012, were retrospectively reviewed to identify patients who underwent some form of ICA management. Patients with a follow-up of <1 year as well as those with

TABLE 1. Indications for preoperative endovascular intervention of the internal carotid artery in the management of tympanojugular paragangliomas.

Indications	Stenting	Permanent balloon occlusion
Related to tumor extension:		
Advanced stags (Fisch class C3 and C4)	+	+
Circumferential encasement of more than 180° of the cervical, and petrous (vertical and horizontal) segments of the ICA as shown by CT and MRI in the axial plane	+	+
Related to angiographic findings:		
Evidence of stenosis and irregularities of the ICA lumen as determined by angiography	+	+
Poor compensation of contralateral cerebral blood flow through the Circle of Willis	+	−
Absence or minimal contribution from ICA branches to the tumor		
Compensation of contralateral cerebral blood flow through the Circle of Willis	−	+
Extensive contribution from ICA branches to the tumor		
Related to patient characteristics:		
Previous surgery with ICA manipulation and/or previous radiotherapy	+	+
Patients with single ipsilateral ICA	+	−

Abbreviation: ICA, internal carotid artery.

incomplete records were excluded from the study. This yielded a study population of 176 patients who required some form of ICA management. To determine the degree and extent of involvement of the cervical and petrous portions of the ICA, all patients underwent preoperative evaluation, including high-resolution CT and gadolinium-enhanced MRI. All patients underwent 4-vessel digital subtraction angiography to detect the vascular supply from the ICA branches and to detect signs of ICA infiltration (ie, irregularities or stenosis of the arterial lumen). Functional evaluation of the Circle of Willis was performed in each case during angiography using manual cross compression testing. Preoperative endovascular treatment, either with stent reinforcement or permanent balloon occlusion, was carried out in cases that had a serious degree of ICA involvement. The indications for endovascular intervention of the ICA were based on tumor extension, MRI and angiographic findings, and clinical findings (Table 1). Details on the methods of endovascular intervention of the ICA have been described elsewhere.[1,10,11,13] Preoperatively, all patients also underwent superselective tumor embolization 2 to 4 days before surgery. At the time of discharge from the hospital, an ultrasound Doppler study of the cervical ICA, together with an angio-CT and angio-MRI of the brain were performed in all cases with a stented vessel. Postoperatively, all patients underwent an annual radiological follow-up (high-resolution CT and MRI) to detect any recurrence. In addition, yearly ultrasound and angiographic sequences (using both CT and MRI) have been performed.

Technique of preoperative endoluminal stenting of the internal carotid artery

Reinforcement of the ICA with endoluminal stenting is performed with the patient under general anesthesia. The decision regarding what type of stent and whether multiple stents are needed is based on the site and the length to be stented (cervical and/or petrous) and on the technical features of the individual stent. At present, we consider the Xpert (Abbott Vascular, Ireland) and Astron (Biotronik SE, Berlin, Germany) bare stents to be the most suitable for reinforcement of both the cervical and petrous portions of the ICA because of their diameter (4 or 5 mm), length (20, 30, or 40 mm), flexibility (during endovascular deployment), and resilience during surgical dissection. To reduce the possibility of injuring the ICA at the stent-tumor interface, we suggest that at least 10 mm of tumor-free vessel wall may be reinforced with the stent, both proximally and distally. Occasionally, to achieve this, it is necessary for 2 or even 3 stents.[1,11] An interval of at least 4 to 6 weeks is recommended between stenting and surgery to allow the formation of a stabilized neointimal lining on the luminal surface of the stent.[13–15]

Anticoagulation therapy. To reduce the risk of thromboembolic complications, antiplatelet therapy is commenced 5 days before stent insertion using a combination of clopidogrel (75 mg/day) and aspirin (100 mg/day). This therapeutic regimen is administered for 1 to 3 months after stent insertion and then reduced to single-drug treatment with aspirin only. Antiplatelet agents are stopped and low molecular weight heparin is commenced 5 days before surgery. Antiplatelet agents are resumed 2 days after surgery and low molecular weight heparin is stopped 3 days after. The patient is then placed on life-long antiplatelet therapy.[10,11,13]

Technique of preoperative permanent balloon occlusion of the internal carotid artery

In cases in which stent placement is technically impossible (ie, kinking of the cervical portion of the ICA or in the presence of a significant blood supply from the ICA), a permanent balloon occlusion is an alternative option.[10,13] Permanent balloon occlusion can be undertaken if the patient has tolerated the balloon occlusion test and angiographic data demonstrates good cross-filling from at least 1 of the 2 communicating systems.[6] The balloon occlusion test-permanent balloon occlusion procedure is performed with the patient under local anesthesia with mild sedation and systemic heparinization. A bilateral femoral approach is used in which an 8F guiding catheter is inserted into one of the femoral arteries 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 gold valve latex 16 balloon (Cathnet Science, Paris, France) mounted on a continuous indwelling Foley's catheter (Minyvasis, Gennevilliers, France) is used. Three detachable balloons are used in each case to occlude the ICA. The balloons are placed in the distal cavernous segment just proximal to the origin of the ophthalmic artery, at the carotid foramen, and in the neck just distal to the bifurcation. The procedure has been described in detail elsewhere.[10] After permanent balloon occlusion, the patient is monitored for 24 hours in an intensive care unit to detect and prevent hypotension. With a successful permanent balloon occlusion, surgery is scheduled 3 to 4 weeks later.

Intraoperative management of the internal carotid artery

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 permanent balloon occlusion).

Simple decompression. This technique is used when the tumor is around the ICA but not adherent to the artery (ie, Fisch class C1 TJP). 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.[15] 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 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 to 2.0-mm thick with the adventitia being approximately 1-mm thick. The adventitia is absent at the horizontal portion.[16] 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.

This study was approved by the Ethics Committee of the Casa Di Cura Privata Hospital. All the patients involved in the study gave their consent for their clinical data to be used for the study.

RESULTS

Of the 237 patients with TJPs, tumor involvement and, therefore, management of the ICA was required in 176 patients (74.2%). Fifty-nine patients (33.5%) were men and 117 (66.5%) were women. The mean age at the time of surgery was 46.6 ± 12.3 years (range, 16–75 years). Twenty-five patients (14.2%) had multicentric paragangliomas. The patients were divided into 5 procedure-specific groups: (1) ICA decompression; (2) ICA subperiosteal dissection; (3) ICA subadventitial dissection without intraluminal stenting; (4) subadventitial dissection with intraluminal stenting; and (5) permanent balloon occlusion. These groups contained 42, 86, 19, 17, and 12 patients, respectively. Relevant information on the patients is provided in Table 2. The infratemporal fossa T2
approach type A was used in 166 cases (94.3%) and a combination of infratemporal fossa approach with other approaches was used in 10 cases (5.7%). The details of the surgical approaches used for excision of TJPs have been described elsewhere.[1,13,14] Staged surgical resection was used in 19 cases (10.8%) with a large intradural extension (class Di2 TJPs) to avoid the risk of postoperative cerebrospinal fluid leak resulting from the wide neck exposure. The extradural portion was removed first, leaving the intradural portion for subsequent removal 3 to 6 months after primary surgery. In these cases, the intradural portion was removed through a petro-occipital transsigmoid approach in 12 cases (63%), a transcochlear approach in 6 cases (31.6%), and an extreme lateral approach in the remaining case (5.3%). The mean follow-up was 33.6 ± 29.5 months (range, 12–156 months). In this series, there was requirement for any perioperative blood product transfusion and no perioperative mortality.

Outcomes of perioperative management of the internal carotid artery

Decompression. Forty-two patients (23.9%) underwent decompression of the ICA: 34 patients underwent simple

TABLE 2. Patient characteristics.

Characteristics	Decompression (n = 42)	Subperiosteal dissection (n = 86)	Subadventitial dissection without stenting (n = 19)	Subadventitial dissection with stenting (n = 17)	Arterial resection after permanent balloon occlusion (n = 12)	Total (n = 176)
Age, y						
Mean ± SD	49 ± 13.1	47.8 ± 11.8	43.5 ± 13.7	42.4 ± 9	39.7 ± 13.2	46.6 ± 12.3
Range	23–71	17–75	16–60	30–59	17–60	16–75
Sex, no.						
Male	9	28	5	9	8	59
Female	33	58	14	8	4	117
Carotid involvement						
C1 TJP	35	7	0	0	0	42
C2 TJP	6	76	2	10	3	97
C3 TJP	1	3	17	6	7	34
C4 TJP	0	0	0	1	2	3
Intradural extension						
De1	2	19	1	2	0	24
De2	0	5	3	1	2	11
Di1	0	18	8	6	4	36
Di2	1	0	4	6	8	19
Other associated tumors						
VP	0	4	3	3	2	12
CBT	0	4	1	4	1	10
VP + CBT	0	2	0	1	0	3
Surgical approach						
Infratemporal fossa approach-A	42	82	16	17	9	166
Infratemporal fossa approach-TLA	0	3	1	0	0	4
Infratemporal fossa approach-TCA	0	1	2	0	2	5
TCA	0	0	0	0	1	1
Second stage approach						
Petro-occipital transigmoid	1	0	3	4	3	11
TCA	0	0	1	1	4	6
Extreme lateral	0	0	0	1	1	2
Removal						
Total	41	86	15	10	9	161
Subtotal	1	0	4	7	3	15
Recurrence	1	2	0	2	1	6
Follow-up	35.1 ± 33.4 (12–156)	33.2 ± 27.5 (12–120)	25 ± 16.7 (12–148)	32.9 ± 31.8 (12–144)	44.1 ± 38.6 (12–120)	33.6 ± 29.5 (12–156)

Abbreviations: TJP, tympanojugular paraganglioma; VP, vagal paraganglioma; CBT, carotid body tumor; TLA, translabyrinthine approach; TCA, transcochlear approach.

decompression without mobilization of the ICA and 8 had decompression with partial mobilization of the artery in the presence of bony infiltration anterior to the vertical segment. No perioperative or postoperative ICA-related complications occurred in this group. Total tumor removal was achieved in 41 patients (97.6%). A small tumor remnant was left in place in the area of the jugular foramen in 1 patient to avoid injuring the dominant jugular bulb. The residual tumor was unchanged after 16 months of follow-up. In 1 patient, recurrence was detected 16 years after surgery.

Subperiosteal dissection. Subperiosteal dissection was carried out in 86 patients (48.9%), 19 (22.1%) of whom required mobilization of the ICA. Seventy-six of the 86 patients (88.4%) had class C2 tumor, 7 (8.1%) had class C1 tumors, and 3 (3.5%) had class C3 tumors. Forty-two lesions (48.8%) had intracranial extension, 18 of which had intradural involvement. No perioperative ICA-related complications have been encountered in this group. Total tumor removal was achieved in all cases. Two patients (2.3%) experienced recurrence, 30 and 68 months after the initial procedure. The first patient developed recurrence in the internal auditory canal and the tumor was successfully resected via a combined infratemporal fossa approach and translabyrinthine approach. The second patient had recurrence in the petrous apex and was treated with stereotactic radiotherapy. One patient developed a facial nerve paresis (HB grade IV) as a result of embolization; this recovered to normal function by the 1-year follow-up.

Subadventitial dissection without stenting. Nineteen patients (10.8%) underwent ICA subadventitial dissection of the ICA without endoluminal stenting. One patient (5.3%) experienced an ICA injury during tumor dissection, which was successfully sutured. Total tumor removal was achieved in 15 patients (78.9%) and subtotal removal in 4 patients (21.1%). In these 4 patients, small tumor remnants around the ICA were left behind to avoid injuring the artery. Remnants of tumors were either treated by stereotactic radiotherapy (1 patient) or monitored with observation (3 patients). All residual tumors remained unchanged after an average follow-up of 25.5 ± 17.2 months (range, 12–84 months).

Subadventitial dissection after reinforcement with endoluminal stenting. Subadventitial dissection was performed in 17 patients (9.7%) after reinforcing the ICA with stenting
F1 (see Figure 1). The indications for stent placement were: (1) absence of a contralateral ICA in 2 patients (11.8%); (2) previous surgical manipulation of the ICA in 4 patients (23.5%); and (3) severe encasement and or/stenosis of the intrapetrous ICA in 11 patients (64.7%). The 4 patients with previous surgery had undergone the infratemporal fossa approach with subadventitial dissection of the ICA and had recurrent or residual lesions.

In 14 cases (82.3%), 2 stents were deployed in a serial fashion covering the ICA from the distal cervical segment to the petrous segment. In 2 patients (11.7%), a single stent was placed along the petrous ICA, and 1 patient (5.9%) received a single stent in the cervical ICA. During stent insertion, 1 patient developed vasospasm, which was treated with intra-arterial vasodilators. In 1 case, a residual tumor in the petrous apex could directly be associated with disappointing results after stent deployment. Severe intraoperative bleeding arose from large ICA feeders that were affected by the stent and a risk-free arterial mobilization was impossible because of the use of an inadequately stiff stent with large mesh size. This patient could not receive permanent balloon occlusion because of an absence of a valid contralateral cerebral compensation. There were no postoperative vascular events in this group of patients.

Gross total removal was achieved in 10 patients (58.8%). Subtotal removal was performed in 7 cases (41.2%); leaving intradural tumor in the posterior cranial fossa (2 patients), around the intradural vertebral artery (1 patient), in the petrous apex and pericarotid area (1 patient), and in the cavernous sinus (2 patients). In 1 case, it was not possible to establish a plane of dissection between the artery and a recurrent tumor. Residual lesions in the 7 patients were treated by observation (2 patients), stereotactic radiotherapy (4 patients), and surgery followed by stereotactic radiotherapy (1 patient). Six of the residual lesions demonstrated no growth at the last radiological evaluation (average follow-up, 25.1 ± 13.4; range, 12–48 months). One patient, with a posterior fossa residual tumor, had evidence of growth at 30 months after surgery and was managed with stereotactic radiotherapy. Two patients (20%) who had gross total removal experienced recurrence. One patient with a class C2Di1 tumor had recurrence at the level of the petrous apex 1 year after surgery and was subjected to stereotactic radiotherapy. The second patient with a class C3Di1 tumor experienced recurrence at the level of the hypoglossal canal 4 years after surgery and the tumor was resected via the previously performed infratemporal fossa approach with transcondylar-transtubercular extension.

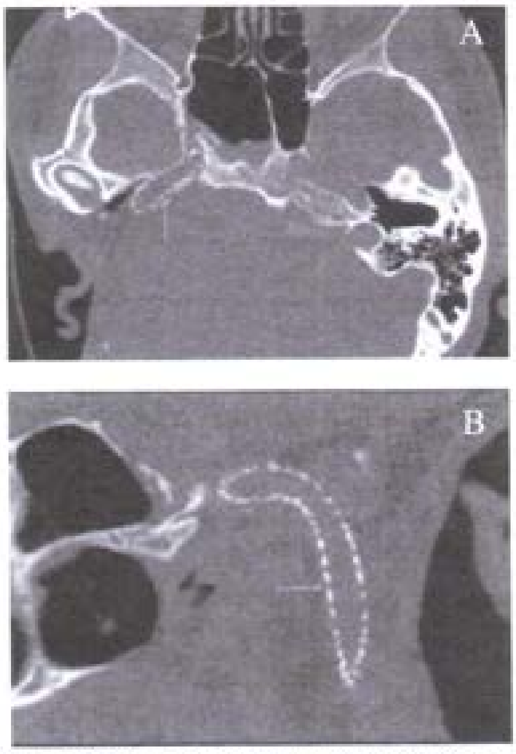

FIGURE 1. CT scan of the skull base showing the stent inserted into the horizontal (A) and vertical (B) portions of the internal carotid artery. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Internal carotid artery resection after permanent balloon occlusion. Twelve of the total 176 patients (6.8%) underwent permanent balloon occlusion of the ICA. In our early experience, before the introduction of arterial stenting in 2003, permanent balloon occlusion was attempted in 9 cases with severe encasement of the ICA. Eight patients had previous incomplete surgery and 1 patient had previous radiotherapy. From 2003, only 3 patients had permanent balloon occlusion. Our present policy is to perform permanent balloon occlusion only in those tumors where there is extensive blood supply from ICA branches with compensation of contralateral cerebral blood flow through the Circle of Willis. No complications occurred during endovascular intervention or during surgery as a consequence of the permanent balloon occlusion in any case. None of the 12 patients experienced any long-term untoward effects from permanent balloon occlusion in a mean follow-up period of 44.1 ± 38.6 months (range, 12–120 months). Total removal was achieved in 9 cases (75%), whereas in 3 cases the removal was subtotal. Two cases involved the cavernous sinus and the patients were subjected to postoperative stereotactic radiotherapy. In both cases, radiological imaging showed no growth of the residual lesion after 8 and 10 years postoperatively. Subtotal removal was also accomplished in a patient with a tumor extending into the foramen magnum. To remove this lesion, a second-stage surgery was performed through an extreme lateral transcondylar approach. Surgery was abandoned as persistent bleeding obscured the surgical field. An MRI after surgery showed a small tumor remnant at the foramen magnum, which remained stable at the 4-year follow-up. One patient (11.1%) had a recurrence 10 years after his primary surgery; the patient subsequently died of disease recurrence despite 5 episodes of intratumoral embolization.

DISCUSSION

One of the most intricate steps in the surgical treatment of TJPs is the management of the cervico-petrous ICA. Fisch class C TJPs require an accurate preoperative neurovascular evaluation taking into consideration the degree of ICA involvement, the anatomic and functional integrity of the Circle of Willis, previous surgery or radiotherapy, and the patient's age and the general condition of the patient.[1,10,17–19] Patients can be considered as having a high-risk of intraoperative ICA injury if: (1) encasement of the ICA reaches more than half (ie, 180–360°) of the arterial circumference; (2) there is evidence of stenosis or irregularity of the vessel walls; (3) there is a medical history of radiotherapy or surgery around the ICA; (4) in cases of multiple ipsilateral lesions; (5) in cases of single ipsilateral ICA; or (6) the recurrent disease is medial to the petrous ICA.[20,21]

A significant proportion of the mortality in TJP surgery, reported in an earlier series, was due to injury of the artery and as a consequence of resection of the ICA.[3] ICA manipulation can be extremely dangerous resulting in spasm, thrombosis, rupture, massive stroke, and even death.[1,22] Insufficient vessel displacement, on the other hand, increases the risk of leaving behind tumor. In our experience, we have noted that most of the recurrences were localized to the area around and medial to the petrous ICA.[8]

To avoid possible surgical morbidity related to ICA injury, some authors recommended radiotherapy for large tumors in which surgery would require ligating or reconstructing the artery.[23,24] Others have advocated partial resection of tumors[22,25] when the ICA was encased. Although this policy seems entirely justified in older patients, it is hard to justify this treatment in younger and healthier patients who have a greater life expectancy and in whom these tumors are usually more aggressive. Another school of surgeons advocate a more aggressive behavior and management plan for surgical removal without any form of preoperative endovascular neuroradiological treatment of the ICA.[21] They demonstrated that it is possible to identify a plane of dissection between the tumor and the ICA even when the tumor encases the ICA or received a blood supply from it. They found it unnecessary to sacrifice or reconstruct the ICA. In a series of 12 cases of extensive TJPs, Patel et al[26] encountered vascular problems in 5 cases (3 ICAs had been repaired and 2 were resected) without any complications. However, they concluded that these patients were certainly at a greater risk of cerebrovascular complications. An analysis of the results of Leonetti et al[27] demonstrated a complication rate of 16% (4 of 25 cases) in patients undergoing intraoperative ICA management (3 cases of decompression and 1 case of decompression with mobilization). This included 3 deaths and 1 stroke that were caused by trauma or spasm of the artery. This signifies the fact that excessive manipulation of the ICA may weaken its wall, leading to intimal dissection or thromboembolic episodes. In this regard, efforts were made to incorporate some form of preoperative endovascular neuroradiological treatment of the ICA to reduce the surgical risks of arterial damage. Permanent balloon occlusion of the ICA in TJP surgery was first used by Andrews et al[5] and Zane et al[28] in order to facilitate radical tumor removal and enable safe mobilization of the carotid. Permanent balloon occlusion of the ICA allows safe removal of the lesion without any limitations. However, this procedure cannot be used in cases of inadequate collateral circulation and is not risk-free. Zane et al[28] reported the largest series of permanent balloon occlusion of the ICA in TJPs. They treated 31 patients and noted 2 major neurologic complications; 1 complication occurred after intraoperative permanent balloon occlusion (a stroke with longstanding hemiplegia) and the other complication was attributed to early surgery after preoperative permanent balloon occlusion (hemispheric stroke with permanent hemiplegia). Their follow-up of 10 years did not show any development of delayed complications.

As mentioned before, the ICA may require the following types of treatment: (1) simple decompression; (2) decompression with partial mobilization; (3) subperiosteal dissection; (4) subadventitial dissection; (5) subadventitial dissection with endoluminal stenting; and (6) arterial resection (after preoperative permanent balloon occlusion) depending on various degrees of ICA involvement. As a matter of policy, we proceed to subadventitial dissection only in the presence of an intraluminal artery stent, which reduces the risk of arterial injury. The presence of the stent greatly facilitates dissection and mobilization of the ICA. This is of particular importance when working at the level of the carotid genu and/or the horizontal segment of the petrous ICA, where the access and the mobility of the artery are limited and the direct control of the anteromedial wall is particularly demanding. Use of vessel loops allows back and forth displacement of the vessel to achieve greater control of the medial wall of the carotid canal and the surrounding involved bone. The presence of the metallic frame of the stent provides protection against accidental rupture and can be used as the deep limit of dissection.[18] Minor bleeding can be encountered from the ICA, but is controllable with bipolar coagulation and hemostatic agents. The greatest risk is a potential injury at the transition point of the stented and nonstented artery, and minimization of traction is essential at this point. Potential complications associated with lifelong antiplatelet therapy (ie, gastrointestinal ulcers, mucosal bleeding) are the main drawbacks associated with arterial reinforcement with stents. However, the risk is diminished with the low dose of aspirin prescribed. To date, with a follow-up ranging from 12 to 144 months, there have been no adverse events related to the stenting, even with patients maintained on life-long antiplatelet therapy.

Permanent balloon occlusion of the ICA represents an alternative to stent placement in the following situations: (1) presence of extensive blood supply from branches of the ICA; (2) severe luminal stenosis; (3) massive parietal infiltration; (4) vessel wall weakness because of previous treatment (surgery or radiotherapy); or (5) tortuous course or kinking of the ICA at the skull base.[23] Permanent balloon occlusion carries the risk of delayed ischemia. To avoid such devastating complications, thorough investigations are available to assess the long-term influence of permanent balloon occlusion. The guiding principle of all these investigations is the same: to assess the efficacy of the collateral circulation in maintaining the perfusion of the areas that would be affected by the manipulation of the ICA. In our practice, the patient's collateral circulation is assessed using the 4-vessel angiography and the manual cross-compression test, combined with the study of the bilateral cortical angiographic phases. In the presence of good cross-filling, from one or both the anterior and posterior communicating arteries, we proceed with the balloon occlusion test followed by permanent balloon occlusion. After permanent balloon occlusion of the artery, dissection of the ICA is started at the cervical segment. The artery is ligated immediately proximal to the proximal balloon and at the distal segment of the occluded artery with large vascular clips. Care is taken to avoid excess traction on the cavernous sinus segment during the final component of tumor removal. The petrous portion of the ICA with the surrounding tumor is resected en bloc. Despite this, there is the persistent surgical problem of inadequate access to the medial wall of the ICA at the level of the anterior foramen lacerum, which until now is unreachable with the available lateral surgical approaches.

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 used 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 permanent balloon occlusion, bypass procedures, and arterial repair or reconstruction. Permanent balloon occlusion 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.

REFERENCES

1. Sanna M, Khrais T, Menozi R, Piaza P. Surgical removal of jugular paragangliomas after stenting of the intratemporal internal carotid artery: a preliminary report. *Laryngoscope* 2006;116:742–746.
2. Fisch U, Mattox D, editors. *Paragangliomas of the temporal bone. Microsurgery of the skull base.* Stuttgart, Germany: Georg Thieme–Verlag; 1988.
3. Sanna M, Flanagan S. Surgical management of lesions of the internal carotid artery using a modified Fisch type A infratemporal approach. *Otol Neurotol* 2007;28:994.
4. Miyazaki S, Fukushima T, Fujimaki T. Resection of high-cervical paraganglioma with cervical-to-petrous internal carotid artery saphenous vein bypass. *Report of two cases. J Neurosurg* 1990;73:141–146.
5. Andrews JC, Valavanis A, Fisch U. Management of the internal carotid artery in surgery of the skull base. *Laryngoscope* 1989;99:1224–1229.
6. Sanna M, Piazza P, Ditrapani G, Agarwal M. Management of the internal carotid artery in tumors of the lateral skull base: preoperative permanent balloon occlusion without reconstruction. *Otol Neurotol* 2004;25:998–1005.
7. Cohen JE, Ferrario A, Ceratto R, Miranda C, Lylyk P. Covered stent as an innovative tool for tumor devascularization and endovascular arterial reconstruction. *Neurol Res* 2003;25:169–172.
8. Sanna M, De Donato G, Piazza P, Falcioni M. Revision glomus tumor surgery. *Otolaryngol Clin North Am* 2006;39:763–782.
9. Piazza P, Di Lella F, Menozzi R, Bacciu A, Sanna M. Absence of the contralateral internal carotid artery: a challenge for management of ipsilateral glomus jugulare and glomus vagale tumors. *Laryngoscope* 2007;117:1333–1337.
10. Sanna M, Piazza P, De Donato G, Menozzi R, Falcioni M. Combined endovascular-surgical management of the internal carotid artery in complex tympanojugular paragangliomas. *Skull Base* 2009;19:26–42.
11. Piazza P, Di Lella F, Bacciu A, Di Trapani G, Ait Mimoune H, Sanna M. Preoperative protective stenting of the internal carotid artery in the management of complex head and neck paragangliomas: long-term results. *Audiol Neurotol* 2013;18:345–352.
12. Konishi M, Piazza P, Shin SH, Sivalingam S, Sanna M. The use of internal carotid artery stenting in management of bilateral carotid body tumors. *Eur Arch Otorhinolaryngol* 2011;268:1535–1539.
13. Sanna M, Piazza P, Shin S-H, Flanagan S, Mancini F, editors. Microsurgery of skull base paraganglioma. Stuttgart, Germany: Georg Thieme–Verlag; 2013.
14. Sanna M, Jain Y, De Donato G, Rohit, Lauda L, Taibah A. Management of jugular paragangliomas: the Gruppo Otologico experience. *Otol Neurotol* 2004;25:797–804.
15. Cejna M, Virmani R, Jones R, et al. Biocompatibility and performance of the Wallstent and the Wallgraft, Jostent, and Hemobahn stent-grafts in a sheep model. *J Vasc Interv Radiol* 2002;13:823–830.
16. Farrior JB. Infratemporal approach to skull base for glomus tumors: anatomic considerations. *Ann Otol Rhinol Laryngol* 1984;93(6 Pt 1):616–622.
17. Van den Berg R, Rodesch G, Lasjaunias P. Management of paragangliomas. *Clinical and angiographic aspects. Interv Neuroradiol* 2002;8:127–134.
18. Valavanis A, Christoforidis G. Applications of interventional neuroradiology in the head and neck. *Semin Roentgenol* 2000;35:72–83.
19. Zanella FE, Valavanis A. Interventional neuroradiology of lesions of the skull base. *Neuroimaging Clin N Am* 1994;4:619–637.
20. Sanna M, Shin SH, De Donato G, et al. Management of complex tympanojugular paragangliomas including endovascular intervention. *Laryngoscope* 2011;121:1372–1382.
21. Al-Mefty O, Teixeira A. Complex tumors of the glomus jugulare: criteria, treatment, and outcome. *J Neurosurg* 2002;97:1356–1366.
22. Jackson CG, McGrew BM, Forest JA, Netterville JL, Hampf CF, Glasscock ME III. Lateral skull base surgery for glomus tumors: long-term control. *Otol Neurotol* 2001;22:377–382.
23. Elshaikh MA, Mahmoud-Ahmed AS, Kinney SE, et al. Recurrent head-and-neck chemodectomas: a comparison of surgical and radiotherapeutic results. *Int J Radiat Oncol Biol Phys* 2002;52:953–956.
24. Hinerman RW, Mendenhall WM, Amdur RJ, Stringer SP, Antonelli PJ, Cassisi NJ. Definitive radiotherapy in the management of chemodectomas arising in the temporal bone, carotid body, and glomus vagale. *Head Neck* 2001;23:363–371.
25. Witiak DG, Pensak ML. Limitations to mobilizing the intrapetrous carotid artery. *Ann Otol Rhinol Laryngol* 2002;111:343–348.
26. Patel SJ, Sekhar LN, Cass SP, Hirsch BE. Combined approaches for resection of extensive glomus jugulare tumors. *A review of 12 cases. J Neurosurg* 1994;80:1026–1038.
27. Leonetti JP, Smith PG, Grubb RL. The perioperative management of the petrous carotid artery in contemporary surgery of the skull base. *Otolaryngol Head Neck Surg* 1990;103:46–51.
28. Zane RS, Aeschbacher P, Moll C, Fisch U. Carotid occlusion without reconstruction: a safe surgical option in selected patients. *Am J Otol* 1995;16:353–359.