Surgical Management of Giant Transdural Glomus Jugulare Tumors with Cerebellar and Brainstem Compression

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Abstract

Objective The objective of this study is to discuss the management of advanced glomus jugulare tumors (GJTs) presenting with intradural disease and concurrent brainstem compression.

Study Design This is a retrospective case series.

Results Over the last decade, four patients presented to our institution with large (Fisch D_2; Glasscock-Jackson 4) primary or recurrent GJTs resulting in brainstem compression of varying severities. All patients underwent surgical resection through a transtemporal, transcervical approach resulting in adequate brainstem decompression; the average operative time was 12.75 hours and the estimated blood loss was 2.7 L. All four patients received postoperative adjuvant radiotherapy in the form of intensity-modulated radiation therapy or stereotactic radiosurgery. Combined modality treatment permitted tumor control in all patients (range of follow-up 5 to 9 years).

Conclusion A small subset of GJTs may present with intracranial transdural extension with aggressive brainstem compression mandating surgical intervention. Surgical resection is extremely challenging; the surgical team must be prepared for extensive operating time and the patient for prolonged aggressive rehabilitation. Newly diagnosed and recurrent large GJTs involving the brainstem may be controlled with a combination of aggressive surgical resection and postoperative radiation.

Keywords
- glomus jugulare
- paraganglioma
- lateral skull base

Introduction

Glomus tumors, also termed paragangliomas, are typically benign nonsecreting indolent tumors that originate from the paraganglion cells of the jugular bulb or tympanic plexus.[1,2] Optimal management remains controversial with options including microsurgical resection (partial, subtotal, total resection), radiotherapy (stereotactic single fraction, or conventional large volume fractionation), or a combination thereof[2–5]; a third option includes careful observation with serial imaging and clinical examination.[6]

Although generally considered histologically benign, glomus jugulare tumors (GJTs) may present late with aggressive infiltrative disease resulting in considerable morbidity[7] and in rare circumstances, death.[8,9] Cranial base progression is typified by expansion through pneumatized air cell tracts, vascular channels, and foramina often manifesting with lower cranial nerve (CN) dysfunction. Up to 20% of tumors may

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develop intracranial extension with or without intradural involvement;[10] only in very rare circumstances do tumors present with symptomatic brainstem compression or hydrocephalus.[2,11]

Synchronous advancements in imaging and surgical technique have allowed for aggressive surgical resection with an improved morbidity profile. The evolution in surgical management of large GJTs has led to some commonly accepted tenants: preoperative angiography to identify feeding vessels with selective embolization,[12,13] the team approach utilizing the neurotologist and neurosurgeon,[4,14] wide surgical exposure permitting proximal large vessel control,[15] aggressive resection with preservation of vital structures (carotid artery system and functioning lower CNs), postoperative CN rehabilitation,[16] and close follow-up with a low threshold for surgery or adjunct radiation for recurrent or progressive residual disease.[5]

Over the last decade, we have evaluated ~40 GJT. We discuss four patients presenting with particularly advanced aggressive disease (Fisch D_2 or Glasscock-Jackson 4) with significant cerebellum and brainstem compression (►**Table 1**); herein, details regarding patient course and implemented management strategies are presented for each case.

Report of Cases

Patient 1

Over a period of 2 years patient 1 experienced hearing loss, progressive facial nerve weakness, and increasingly severe headaches. In 2001, at the age of 63 years she developed an abrupt worsening of head pain, gait imbalance, and decreased sensorium. She was then transported by ambulance to a local facility where computed tomography (CT) revealed a large (maximum diameter 6.5 cm) posterior fossa lesion with anterocephalad extension through the petrous apex and lateral clivus resulting in significant brainstem compression and obstructive hydrocephalus. She was started on intravenous dexamethasone and mannitol but despite treatment became obtunded. An external ventricular drain (EVD) was then placed resulting in improved alertness and orientation however over the following 3 days she again became increasingly lethargic. She was subsequently transferred to our facility while intubated and was largely unresponsive with only an intermittent capacity to follow commands. A limited preoperative examination revealed left CN VI and VII palsies and left hemiparesis; her intubated state precluded a preoperative vocal cord examination. An urgent CT was obtained which revealed a large posterior fossa tumor resulting in formidable brainstem compression with acute cerebellar and brainstem hemorrhage (►**Fig. 1**).

The patient subsequently underwent preoperative angiography and embolization of feeding vessels and subtotal resection through a combined transtemporal suboccipital approach (see "Discussion" section). Intraoperatively, the tumor was found to erode through dura and was adherent to and compressing the brainstem and cerebellum resulting in left-sided tonsillar herniation. The left lateral cerebellum

Table 1 Summary of Patients with Large Transdural Glomus Jugulare Tumors with Cerebellar and Brainstem Compression

Patient Number (Date)	Age Sex	Previous Treatments	Maximum Diameter; Intracranial Extension (cm)	Vessel Involvement (CS, ICA, ECA, VBS)	Preoperative Neurologic Deficits	Primary Treatment	Postoperative Neurological Condition	Recurrence/Progression of Residual Disease
1 (2001)	63 F	None	6.5; 3.3	Internal carotid, external carotid	CNs VI–VIII, SBSC/H, hemorrhagic stroke with hemiparesis, obtunded state	Subtotal resection	Resolution of hydrocephalus and improved mental status	Progression of residual disease 1.5 years later, treated with SRS
2 (2003)	71 F	External beam radiation (1958)	5.5; 3.8	Cavernous sinus, internal carotid, vertebrobasilar system	CNs VII–XII, SBSC/H	Subtotal resection	Progression of CN VII paresis, transient worsening of dysphagia	Progression of residual disease 2 years later, treated with IMRT
3 (2004)	57 F	Gross total resection (1984)	8.0; 4.7	Cavernous sinus, internal and external carotid, vertebrobasilar system	CNs VI–X, XII	Subtotal resection, IMRT	Progression of CN VII paresis	None
4 (2005)	28 M	None	4.8; 4.0	Internal carotid, vertebrobasilar system	CNs VI, IX–XI	Gross total resection	CN VII weakness (HB 3), CHL	Recurrence 2 years later, treated with SRS

CHL, conductive hearing loss; CN, cranial nerve; CS, cavernous sinus; female; HB, House–Brackmann; ICA, internal carotid artery; IMRT, intensity-modulated radiation therapy; M, male; SBSC/H, symptomatic brainstem compression with hydrocephalus; SRS, stereotactic radiosurgery; VBS, vertebrobasilar system.

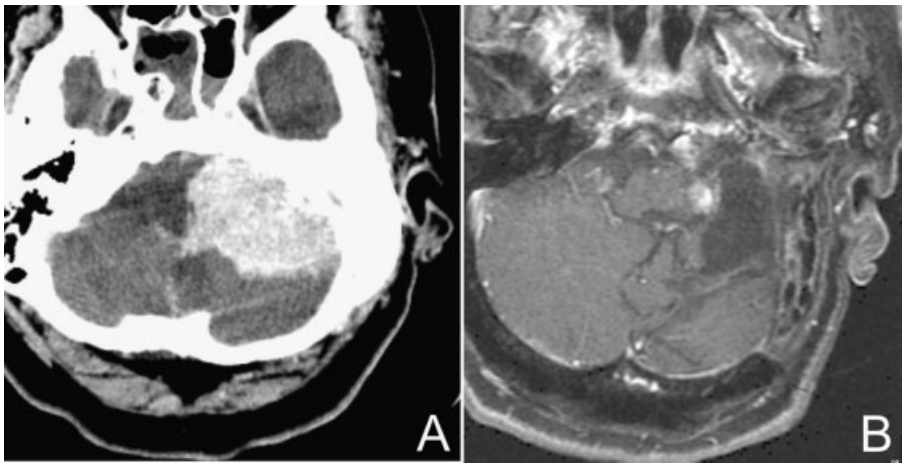

Figure 1 (A) Axial computed tomography images demonstrating a large (6.5 cm maximum diameter) left-sided skull base lesion resulting in considerable posterior fossa compression of the brainstem and cerebellum. (B) Postoperative axial T1-weighted magnetic resonance images with gadolinium enhancement demonstrating subtotal resection and posterior fossa neural decompression.

was grossly pale, avascular, and nonviable and was therefore resected with the tumor. The facial nerve was grossly encased within the middle ear and mastoid segment as well as in the posterior fossa and was also sacrificed. In all, the operative time was ~15 hours with 4.8 L of blood loss requiring transfusion. On postoperative day 2, she began to follow commands and was extubated on postoperative day 6 with her EVD removed on day 7. Postoperatively, she was found to have left-sided paralysis of CNs VI to XII and persistent left hemiparesis. A percutaneous endoscopic gastrostomy (PEG) tube was placed 3 weeks after surgery for worsened dysphagia and was subsequently removed 3 months later. She later underwent a left lateral tarsorrhaphy and tensor fascia lata static sling to improve her facial function and appearance. After 18 months of initial resection, the patient was treated with stereotactic radiosurgery (18.2 cm^3, 15 Gy marginal, and 30 Gy maximal dose) for progressive residual disease near the brainstem. Through intense occupational and physical therapy the patient regained some functional strength of her left torso and extremities allowing her to ambulate with the use of a walker. The patient is now 72 years of age living independently and has been followed for 9 years without any radiographic or clinical evidence of disease progression.

Patient 2

In 1956, patient 2 first experienced left hearing loss, facial weakness, dysphonia, and dysphagia at the age of 26. After 2 years, a biopsy was obtained confirming the diagnosis of a left GJT. She subsequently underwent primary external beam radiotherapy (3450 cGy) resulting in stable symptomatology for over three decades. In 1992, at the age of 61 she presented to The Mayo Clinic with complaints of mild worsening dysphagia and dysphonia. CT demonstrated a large destructive (5.5 cm maximum diameter) calcified mass occupying much of the left posterior fossa extending through the petrous ridge to the clivus and cavernous sinus with encasement of the internal carotid artery (ICA); there was cerebellar and brainstem abutment without hydrocephalus. Otoscopy

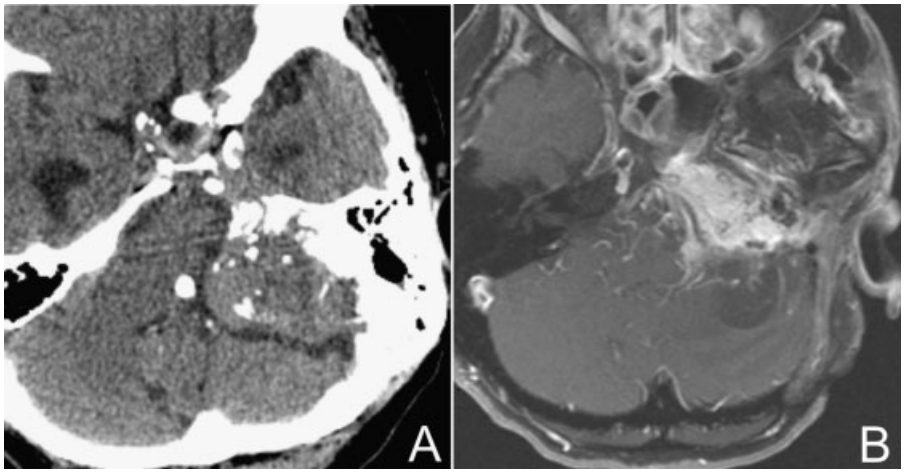

Figure 2 (A) Axial computed tomography image demonstrating a large (5.5 cm maximum diameter) left-sided skull destructive skull base lesion extending from the posterior fossa to the left lateral clivus. (B) One year postoperative axial magnetic resonance imaging with gadolinium demonstrating subtotal resection with posterior fossa decompression and residual disease along the petrous apex and clivus.

demonstrated a left-sided pulsatile middle ear mass and neurological examination found multiple left-sided CN deficits (VII to XII) including House–Brackmann[17] (HB) grade 5 of 6 facial paresis and audiometric evaluation revealed profound sensorineural hearing loss (SNHL) in the left ear.

Given relatively stable symptoms, advanced age, and the absence of hydrocephalus or symptomatic brainstem compression, the patient was observed over 9 years with stable serial radiography and clinical examinations. In 2001, at the age of 70 years she experienced an acute worsening of laryngeal function and over 6 months lost ~12 kg despite essentially no radiographic progression. Later that year she underwent a left vocal cord medialization procedure (type 1 thyroplasty with arytenoid adduction) and cricopharyngeal myotomy resulting in good glottic closure, improved voice, and stabilization of weight.

Nearly 2 years later (2003), at 71 years of age she presented to the emergency room with a 6-hour history of brisk left external auditory canal (EAC) hemorrhage and worsening symptoms. Physical examination revealed tumor growing out of the external ear canal. Bleeding was temporarily managed by pressure packing and repeat CT found rapid interval enlargement with tumor involving the entire temporal bone and cavernous sinus with obstructive hydrocephalus. Magnetic resonance angiography demonstrated multiple supplying vessels from the carotid and vertebrobasilar systems (►**Fig. 2**). In preparation for surgery, the patient underwent balloon occlusion testing and carotid angiography with superselective embolization of feeding vessels. The patient subsequently underwent subtotal resection through a combined left transtemporal suboccipital craniotomy with tracheostomy and EVD placement. There was significant radiation-associated scarring and calcifications and in total there was ~3.3 L of blood loss requiring blood bank and autotransfusion spanning 12 hours of operative time. The tumor grossly invaded dura in the posterior fossa and was adherent to the brainstem and cerebellum. The facial nerve was encased in tumor and given near-complete long-term preoperative paralysis, the nerve was sacrificed. After 2 weeks, she developed a purulent wound infection necessitating operating room drainage and debridement, and ultimately a trapezius myocutaneous flap was used for defect reconstruction. Postoperatively, she experienced progression from HB grade 5 to 6 and worsening dysphagia necessitating temporary (3 months) PEG tube placement. Her tracheostomy tube was decannulated after approximately 1 month without complication. A year after surgery, she underwent a facial reanimation procedure including temporalis muscle transfer and upper eyelid gold weight application.

The patient was followed with serial magnetic resonance imaging (MRI) for approximately 2 years until she represented in 2005 with trigeminal nerve (V1 and V2) hypoesthesias and pain with corresponding radiographic tumor progression. Because of the original extensive tumor involvement and concerns with poor wound healing, intensity-modulated radiation therapy (IMRT) was pursued (4500 cGy). She is now 78 years old (7 years following surgery) living independently without clinical or radiographic evidence of tumor progression.

Patient 3

Patient 3, at the age of 37 years (1984) experienced right-sided tongue weakness, hearing loss, and right lateral gaze diplopia, which led to the diagnosis of a large right-sided GJT. She subsequently underwent gross total resection through a translabyrinthine approach outside the United States. Postoperatively, she experienced new facial nerve weakness (recovering to HB grade 5) but otherwise remained neurologically unchanged. She was subsequently followed for ~12 years with serial CT and clinical examinations in Mexico without any reported radiographic recurrence or change in examination. After immigrating to the United States, she presented to our institution for the first time at the age of 57 (2004) with new dysphagia and an 8-kg weight loss over the previous 6 months. On clinical examination, she had a large pulsatile mass in her right upper neck, stable CNs VI to VIII and XII weakness and a new paretic right soft palate and vocal cord. MRI showed a homogeneously enhancing

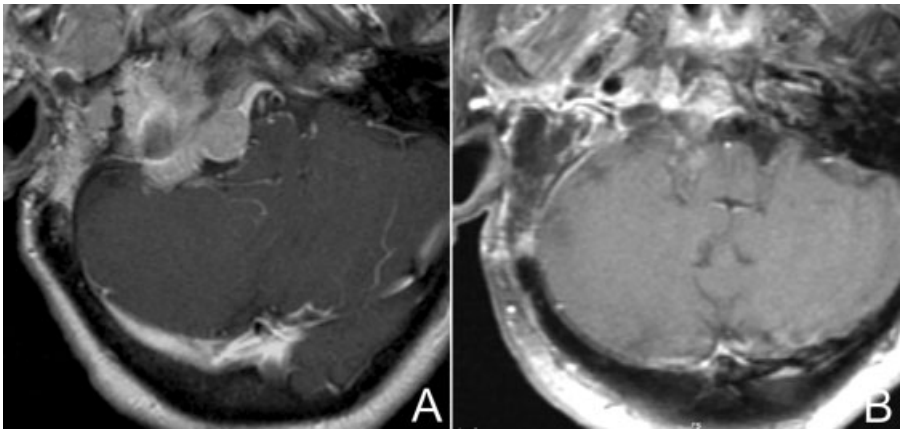

Figure 3 (A) Axial T1-weighted magnetic resonance image with gadolinium enhancement demonstrating a large destructive right-sided skull base lesion extending from the posterior fossa to the cavernous sinus and parapharyngeal space with encasement of the right internal carotid artery and posterior fossa brainstem compression. (B) Three months postoperative axial T1-weighted image demonstrating subtotal tumor resection with decompression of posterior fossa contents.

destructive mass (8 cm maximum diameter) involving the right posterior fossa, most of the right temporal bone, clivus, sphenoid sinus, cavernous sinus, and invading the retro- and parapharyngeal spaces. Inferiorly, it extended down into the neck, displacing the ICA anteriorly. There was clear encasement of the right ICA, external carotid artery, and vertebrobasilar system with posterior fossa transdural extension and compression of the medulla and pons (►**Fig. 3**). Options were reviewed and the patient elected for surgery with probable postoperative external beam radiation. Preoperatively, a balloon occlusion study of the right ICA was performed with embolization of feeding vessels. The patient was brought to the operating room and underwent a combined transtemporal suboccipital approach with subtotal resection. During exploration, the facial nerve was encased in tumor and given poor preoperative function it was removed with the specimen without grafting. There was clear broad transdural invasion in the posterior fossa and the tumor was found to be intimate with the cerebellum. The tumor was meticulously removed from the cerebellum with all involved dura. The total operative time was 12 hours with 1.7 L of blood loss requiring transfusion.

Postoperatively, the patient remained on the ventilator over 4 days and was then extubated without event. She experienced progression of her facial nerve weakness (HB 5 to 6) and continued dysphagia requiring PEG tube placement 2 weeks later. After 4 months of surgery, she underwent a right upper eyelid gold weight placement, a right temporalis muscle transfer to the upper and lower lip, and a right vocal cord medialization thyroplasty with arytenoid adduction for CNs VII and X rehabilitation. After 3 months of surgery, she underwent IMRT (4500 cGy) for the treatment of residual disease. She is now 62 years of age, 6 years following surgery, living independently and continues to be followed without any clinical or radiographic evidence of disease progression.

Patient 4

Patient 4 first presented to our institution at the age of 28 (2005) after experiencing a 4-year progression of symptoms including intermittent headaches, right neck pain, hoarseness, pulsatile tinnitus, hearing loss, and dysphagia with liquids. Examination demonstrated multiple right-sided cranial neuropathies (VI and IX to XII) and otoscopy revealed a right vascular appearing middle ear mass. Audiometry revealed an isolated conductive deficit without SNHL. CT found a large (4.8 maximum diameter) destructive inhomogeneous right temporal bone mass extending from the upper neck and posterior fossa to the petrous apex and lateral clivus. There was gross transdural infiltration, medullary compression, encasement of the right ICA, and vertebral artery. Additionally, there was extension into the right upper neck with destruction of the right occipital condyle and mild displacement of the occipitocervical junction (►**Fig. 4**).

Options were reviewed and the patient elected to proceed with surgical resection with a probable second stage operation for occipitocervical fusion and possible postoperative radiotherapy. The patient tolerated presurgical ICA balloon occlusion and selective feeder embolization and subsequently underwent gross total resection using a combined transtemporal suboccipital approach with facial nerve transposition. The occipital condyle was found to be free floating within the bulk of the tumor and there was a considerable intradural component encasing CNs VI to XII and compressing the brainstem and cerebellum; all diseased dura was removed with the specimen allowing for adequate decompression. Since the patient had good preoperative hearing, the CN VII-VIII complex was preserved and the EAC was not oversewn. The tumor was completely resected over a period of 12 hours, with ~1 L of blood loss requiring transfusion. On postoperative day 3, he developed cerebrospinal fluid (CSF) leakage from the temporal incision and EAC and was taken back the following day for wound revision and oversewing of the EAC and eustachian tube occlusion. He was then kept in a cervical collar and occipitocervical fusion was performed 1 week later using a right iliac crest graft. Postoperatively, he experienced worsening dysphagia, and initially a complete facial nerve paralysis (HB 6/6) improving to a HB grade 3 over the following year. A PEG tube was placed 2 weeks after initial surgery for worsening swallow function and 6 months later he underwent a type 1 thyroplasty with arytenoid adduction

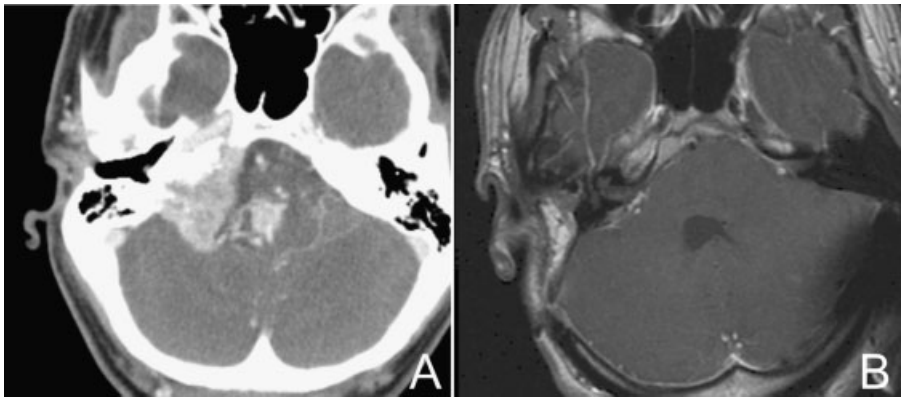

Figure 4 (A) Axial computed tomography images demonstrating a (4.8 cm maximum diameter) right-sided skull base lesion with significant intracranial growth. (B) One year postoperative axial T1-weighted magnetic resonance imaging with gadolinium enhancement demonstrating gross total tumor resection.

and cricopharyngeal myotomy for voice and swallow rehabilitation; he was subsequently liberated of his PEG tube less than 6 months later.

After 2 years of surgery (2007), three small foci of recurrent tumor were identified, one in the right prevertebral space near the C1-C2 junction, and two in the right cerebellopontine angle (CPA). Over the course of 1 year, these were found to enlarge and the patient underwent a single session treatment of all three lesions with stereotactic radiosurgery (16.5 cm^3, 15 Gy marginal, and 33.3 Gy maximal dose). He is now 33 years of age, 5 years following surgery, and continues to be followed by serial imaging and examination without evidence of tumor progression.

Discussion

With the earliest descriptions, lateral skull base glomus tumors were classified as tympanicum and jugulare lesions.[18,19] With improvements in imaging and surgical technique, it became apparent that a more detailed classification scheme was required. In 1978, Fisch devised the first practical classification system (types A to D) whereby tumors could be classified by area of involvement and treated with particular consideration directed toward intrapetrous ICA involvement (type C) and intracranial extension (type D).[15] In 1982, Jackson et al adopted a new classification (I-IV) taking into account the management of larger lesions, stressing the importance of collaboration between the neurotologist and neurosurgeon.[4] Later, Green et al proposed a novel classification system (1–7) with associated surgical approaches that officially recognized the issue of transdural disease.[20] Particularly relevant to the presented cases, in 1987 Al-Mefty et al described the combined infratemporal and posterior fossa approach for the removal of giant GJTs with considerable intracranial extension.[21] Before this, such tumors were largely considered inoperable or at least requiring multiple stage operations. To date, there have been few reports focusing on intracranial transdural disease[10,22–24] and none have specifically addressed the management of patients having transdural disease with brainstem compression. The general management of glomus tumors is well described in the literature[4,7,20,25] and we have largely limited our discussion to management strategies and postoperative issues in patients with very large GJTs with special consideration given to broad transdural disease with concurrent brainstem compression.

Evaluation

Preoperative imaging with high-resolution CT is the most useful study for establishing tumor extent and determining its relationships to key surgical bony landmarks required for surgical planning.[26] MRI should be considered in all cases with intracranial extension to determine the relationship to critical neurovascular structures, the status of the tumor-dura interface, and the relationship of the tumor to vulnerable intradural anatomy.[11] When imaging reveals carotid or vertebrobasilar artery involvement or intracranial extension, we routinely employ four-vessel angiography to define the vascularity of the tumor, extent of ICA involvement, survey for multifocal disease (present in up to 10% of patients), and partially devascularize the tumor through selective embolization of accessible feeding vessels. Additionally, cerebral cross-perfusion studies using temporary balloon occlusion should be performed to determine the risk of stroke in the event that a carotid or vertebral artery must be sacrificed intraoperatively. Audiometric evaluation is consistently performed to determine degree of hearing loss to guide preoperative counseling and to help establish whether hearing preserving approaches are warranted. Preoperative serum assays for functional or secreting tumors are only performed in patients with a suggestive history.

Treatment

Management options for large primary or recurrent GJTs include surgical resection (subtotal or total), radiotherapy, or a combination of the latter. Radiation has little direct effect on GJT cells and works primarily through vascular endothelial injury resulting in fibrosis of feeding vessels.[27,28] Initial tumor swelling is common and osteoradionecrosis and injuries to radiosensitive structures may be severe;[29,30] while very uncommon, radiation-induced malignancy remains a concern.[31] While primary radiation therapy may provide local tumor control in up to 96% of large GJTs (type C and/or D),[32] we caution against the use of primary radiation in tumors with considerable brainstem compression since radiation may cause considerable swelling resulting in worsening compression and renders any subsequent surgery more difficult. In such cases, radiotherapy (large volume or stereotactic delivery) should be limited to postoperative management in cases with residual progressive disease. While "watchful waiting" remains a viable option in elderly patients with stable radiographic disease and minimal symptomatology, all patients that demonstrate progressive brainstem compression should undergo surgical debulking and at a minimum partial resection.

Surgical resection for large extensive GJTs is extremely demanding and the surgical team must be physically and psychologically prepared for extended operations around vital neurovascular structures. The complementing expertise afforded by the neurotologist/neurosurgeon team has proven invaluable in the setting of a long operation. In the four presented cases, the total operative time ranged from 12 to 17 hours. Despite aggressive presurgical embolization, blood loss ranged from 1 to 4.8 L and all patients required intraoperative transfusion. To this end, the surgical team and anesthesia provider must be prepared with preoperative blood typing in the anticipation of intraoperative transfusion requirements. Gross total resection of extensive tumors may be difficult and can be associated with unnecessary morbidity, particularly in cases of recurrent disease following surgery or radiation. In such cases, subtotal resection followed by stereotactic or fractionated radiation may be warranted. Advancements in surgical strategy using combined approaches have allowed for improved access and in many cases, single stage gross total extirpation of large tumors with intradural components.[2] Despite such developments,

many still favor a two-stage removal citing a decreased risk of a subarachnoid communication and easier removal with a second operation.[7]

Large GJTs with intradural involvement and brainstem compression require adequate posterior fossa access similar to other large primary CPA tumors; for this purpose, generally, a suboccipital craniotomy is combined with either a transtemporal or infratemporal approach. Proximal large vessel control in the upper neck is obtained before any "bone work" and we place EVDs in all cases with significant brainstem compression and hydrocephalus for intraoperative and postoperative monitoring and management. In cases requiring extensive dural resection and free graft reconstruction, we generally oversew the EAC, occlude the eustachian tube with bone wax and overlying fascia, and pack the wound void with an abdominal fat graft to decrease the risk of postoperative CSF leak and meningitis.

The goal of resection (total vs. subtotal) is matched to the patient's perioperative fitness and expectations of longevity. Our primary goal in all patients with transdural disease and concurrent brainstem compression is an adequate removal of encroaching tumor and neural decompression. Initially, extradural posterior fossa tumor is removed and areas of involved dura are identified. After resection of diseased dura, intradural tumor is removed. Owing to its benign character, even in cases of extensive intradural invasion with postradiation changes, we are able to locate a safe plane between tumor and brain. Depending on the extent of resection, dura is then generally reconstructed with a fascia lata graft or less commonly a pericranial flap. The decision to proceed with further extradural resection depends on patient condition and extent of disease. In younger, otherwise healthy patients (patient 4), we endorse gross tumor removal when possible; however, in patients of advanced age (patient 2), those with a poor perioperative condition (patients 1 and 2), and patients with cavernous sinus involvement (patients 2 and 3), subtotal resection with postoperative radiotherapy and close follow-up is warranted.

Pathological and immunohistochemical markers do not predict clinical behavior and the diagnosis of malignant disease can only be determined after discovering metastasis to nonendocrine tissue. The presence of large tumor size, necrosis, nuclear polymorphism, abundant mitosis, and adjacent tissue invasion may be seen in benign and malignant GJTs alike and are therefore not distinguishing features.[33] While more common among vagal paragangliomas, malignant GJTs are exceedingly rare.[34] In the four presented cases of aggressive infiltrate disease, histological analysis failed to demonstrate any "aggressive" histopathological features. No significant degree of cytomorphologic atypia was observed, mitotic activity was uniformly low ($\leq$2 per 10 hpf) and atypical mitoses were not encountered. No perineural or angiolymphatic invasion was identified in any of the four cases (►**Fig. 5**). Furthermore, lymph node sampling and radiographic staging did not find evidence for metastatic disease.

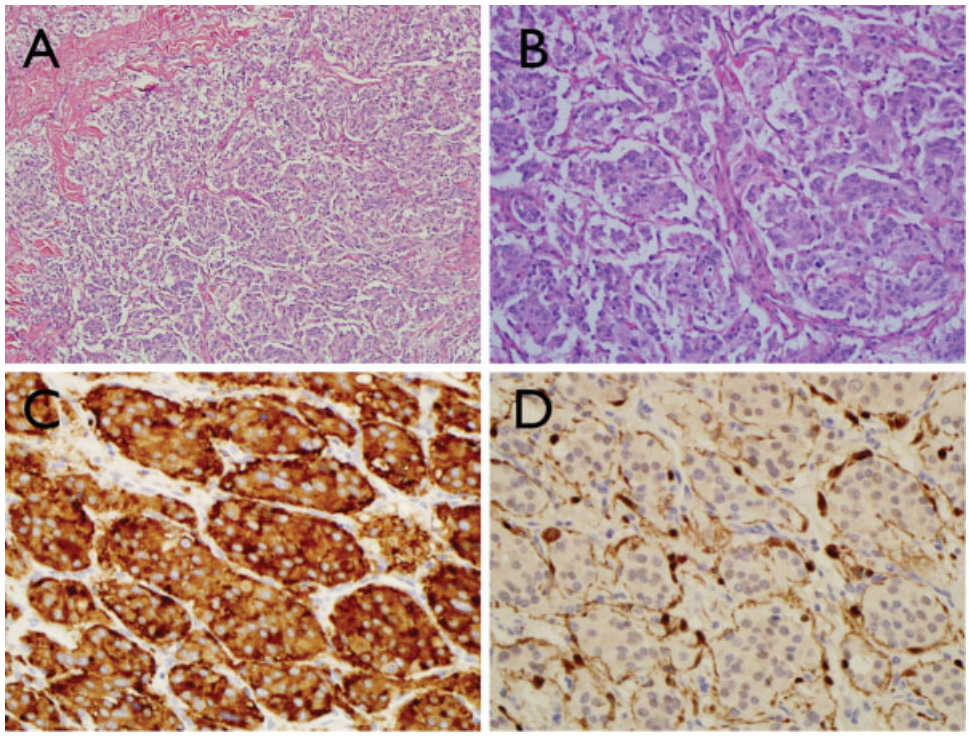

Figure 5 (A) Intermediate power (H&E, 100 ×) microscopic examination reveals a nested or organoid distribution of tumor cells embedded within a rich fibrovascular stroma. (B) At higher power (H&E, 200 ×), one can appreciate centrally located chief cells with monotonous round to oval nuclei, widely dispersed chromatin and a modest amount of eosinophilic or granular cytoplasm. The outer sustentacular cells are largely imperceptible. (C) An immunohistochemical stain for synaptophysin (200 ×) highlights the cytoplasm of tumor cells both strongly and diffusely. (D) An immunohistochemical stain for S-100 (200 ×) emphasizes the peripheral distribution of sustentacular cells around tumor cell nests (nuclear and cytoplasmic staining).

Lower CN management deserves particular attention as it relates to the presence intradural disease. The most common route for early intradural extension is through the medial wall of the jugular bulb.[7] Therefore, the presence of intradural disease generally correlates closely to preoperative lower CN dysfunction and their need for resection. Others corroborate this idea and have found that the presence of intracranial extradural disease does not predict lower CN involvement, however once spreading intradurally the prospect of CN preservation becomes disappointing.[7,8,26] In the four presented cases, tumor had grossly involved all lower CNs and given their poor preoperative function, they were resected to facilitate tumor removal. Facial nerve management has been extensively reviewed by previous authors[25,35–37] and we will limit our discussion only to mention that with planned subtotal resection, we favor the fallopian bridge technique whereas in cases of extensive GJT in which gross total removal is sought (patient 4), facial nerve rerouting is routinely incorporated. Finally, in patients with chronic poor preoperative facial nerve function (HB 5–6) with gross tumor involvement (patients 1 to 3), we favor resection followed by rehabilitative procedures such as upper eyelid gold weight placement, tarsorrhaphy, and temporalis muscle transposition since under these circumstances facial nerve grafting and other reinnervation procedures are often unsatisfactory.[38]

One additional aspect that is infrequently discussed requires special attention as it relates to large GJTs. In our experience, wound complications including CSF leak (patient 4), breakdown and infection (patient 2) occur more frequently after large resections particularly when treating recurrent disease. Despite the concentrated vascularity and extensive collateral flow of the head and neck and in particular the scalp, wound breakdown and/or infection may be more common for the following five reasons: (1) extensive preoperative embolization diminishes tumor vascularity but will also secondarily devascularize the local wound bed; (2) long operative times with prolonged wound retraction may compromise local tissue quality; (3) larger incisions lead to decreased vascularization of the flap pedicle; (4) ligation of the sigmoid sinus and feeding tributaries may lead to venous congestion and elevated intracranial pressure; (5) in the case of tumor recurrence/progression following surgery or radiation, the local tissue quality is already substantially compromised from earlier insult.

CSF otorhinorrhea and wound leakage may also be more prevalent in large intracranial GJTs for several reasons: first, with broad intracranial disease, free graft dural reconstruction is usually required thereby increasing the likelihood of CSF fistulization; second, even in the face of longstanding unilateral sigmoid sinus occlusion, resection of the tumor, surrounding dura, and the sigmoid sinus with its tributaries may lead to venous hypertension and resulting increased intracranial pressure; and finally for reasons mentioned above, wound integrity may be compromised resulting in a weakened barrier to CSF leakage. The rate of postoperative CSF leak may be diminished by oversewing the EAC and occluding the eustachian tube orifice, meticulous dural defect repair, tension-free multilayer wound closure and potentially the use of a lumbar drain or EVD.

Description of Surgical Technique

The patient is placed in the supine position and the head is fixed in rigid three-point pinion fixation; intraoperative electromyography of CNs VII and X to XII is routinely employed using the VikingQuest module (Nicolet. Biomedical Inc., Madison, WI, USA). The surgical site is shaved and prepped in the standard fashion and a large postauricular C-shaped incision extending into the upper neck is created. The EAC is then transected and oversewn. The mastoid tip is freed of the inserting sternocleidomastoid muscle and the posterior tendon of the digastric muscle is transected to allow for improved high cervical exposure. Neck exploration is then performed to identify the proximal internal jugular vein (IJV), ICA, and CNs IX to XII; vessel loops are then loosely applied for proximal vascular control. A wide mastoidectomy is then performed and the facial nerve is identified. In cases of long-term poor preoperative function and gross tumor encasement (patients 1 to 3), the facial nerve is routinely transected however with normal preoperative function (patient 4) facial nerve rerouting or a fallopian bridge technique is employed. Since most patients with extensive GJTs have significant preoperative SNHL, a combined translabyrinthine transcochlear approach is often used to allow for broad exposure from the clivus to the CPA. Next, the sigmoid sinus is decompressed and the surgical field is extended to include retrosigmoid dural exposure (►**Fig. 6A**). The proximal sigmoid sinus is oversewn with a running double-armed monofilament suture, and the IJV is ligated and divided. At this point, tumor involving the temporal bone and clivus is painstakingly removed in a piecemeal fashion and depending on the extent of petrous carotid involvement, the ICA can be followed anterior and medially as needed.

After extradural tumor has been removed, the retrosigmoid dura is opened medial to the tumor and CSF is drained from the cisterna magna to allow for brain relaxation. The proximal sigmoid sinus is then divided, the presigmoid dura is opened, and the incision is carried inferiorly to include the jugular bulb; all diseased dura is then resected. Depending on preoperative function an attempt at lower CN preservation can be attempted, however with aggressive intradural disease, CNs IX to XI are invariably involved necessitating sacrifice. At this point, a clear view of the tumor-brainstem interface allows for safe intradural tumor removal (►**Fig. 6B**). The dural defect is reconstructed with a free fascia lata graft,[39] the eustachian tube orifice is packed with several round pieces of bone wax and overlying fascia, and the void is filled with an abdominal fat graft. The wound is closed in layers and a pressure head dressing is placed. Generally, regional pedicled or autologous vascularized free tissue transfer is not required for reconstruction. However, for patients with extensive defects or poor wound healing, the regional pedicled pectoralis major myocutaneous flap or the trapezious myocutanous flaps are viable options that afford relatively quick harvest with minimal donor site morbidity. Alternatively, free tissue transfer including the radial forearm, rectus abdominis, or scapular/parascapular free flap may be used depending on bulk and tissue type requirement.

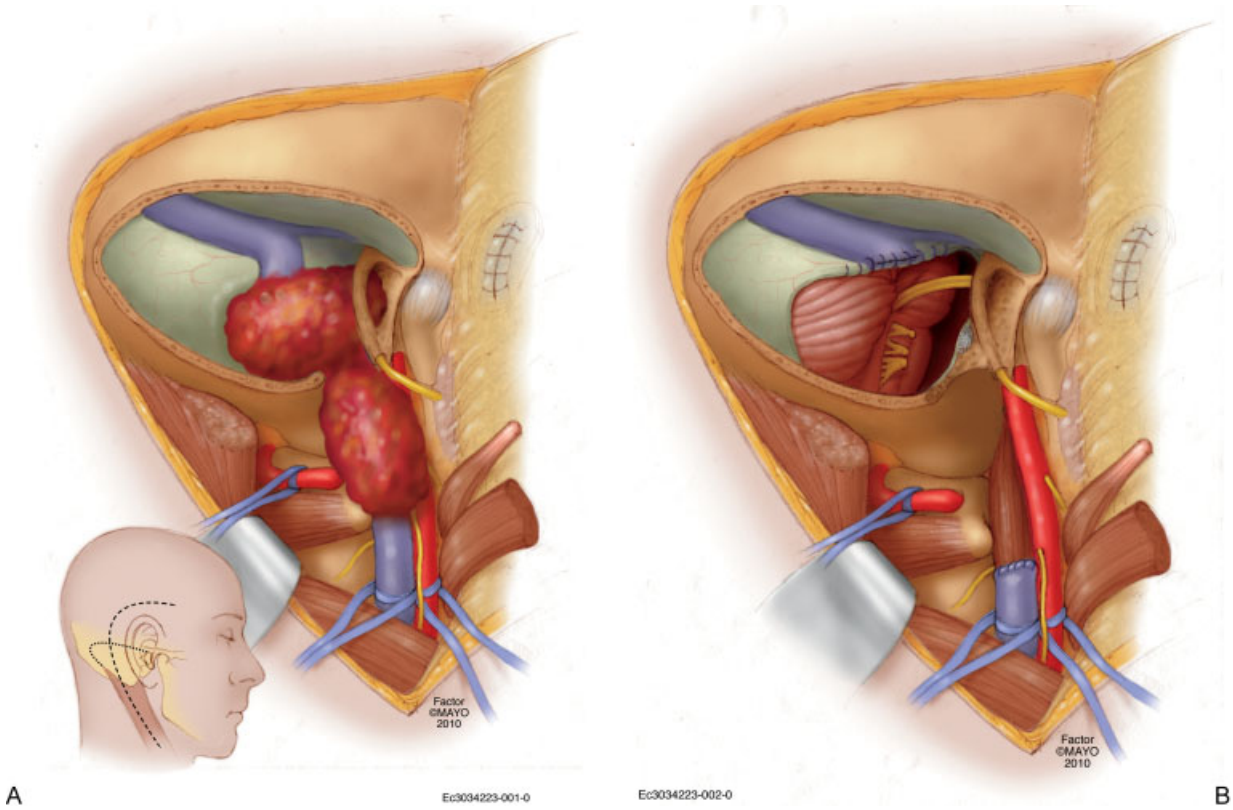

Figure 6 (A) Combined transotic retrosigmoid approach for exposure of a large right-sided glomus jugulare tumor with intracranial extension. The sternocleidomastoid muscle has been partially mobilized and retracted posteriorly, and the stylohyoid and posterior belly of the digastric muscle have been released to allow for high cervical exposure of the internal carotid artery, IJV, and vertebral artery. (B) Surgical view after removal of large tumor. The sigmoid sinus and IJVhave been removed, the lower cranial nerves divided, and the posterior fossa dura opened for access to intradural disease. The facial nerve was preserved in a fallopian bridge. IJV, internal jugular vein.

Postoperative Care and Surveillance

Postoperatively, all patients should be monitored in the neurosurgical intensive care unit. Early enteral nutrition through a nasogastric feeding tube and mobilization is recommended when possible to obviate rapid deconditioning and complications associated with prolonged immobilization. Generally, within 10 days following surgery, we recommend a videofluoroscopic swallow study to guide diet advancement. In cases of gross aspiration beyond 3 weeks, a PEG tube is usually placed for short- or long-term nutrition.

Postoperative rehabilitation for patients with large GJTs requires an aggressive multidisciplinary approach. Even though all patients with large tumors will have some degree of preoperative CN X dysfunction, virtually all will experience worsening postoperative swallow function. Postoperative dysphagia is generally multilevel and may involve oral incompetence from facial nerve weakness, oral and pharyngeal deficiencies from tongue, soft palate and pharyngeal constrictor paralysis, and glottic insufficiency from poor vocal cord mobility. Additionally, airway protective mechanisms might be hampered from a weak cough or an insensate larynx. Younger patients and those with long-term poor preoperative function generally compensate better postoperatively than patients with abrupt iatrogenic changes.[16] In the four presented cases, three patients underwent a type 1 thyroplasty with arytenoid adduction; only one patient has required long-term PEG tube use for ongoing dysphagia. While GJTs are very hypervascular, spontaneous intratumoral hemorrhage is extremely rare. Case 1 represents only the second published report of a patient presenting with acute intracranial hemorrhage secondary to a large GJT.[40] Clearly, patients with more devastating disease may require additional extended rehabilitation.

The literature supports the need for life-long follow-up for all patients with GJTs,[7,8] particularly following primary radiation treatment. When a tumor has reached an advanced stage, it has already proven itself as an aggressive subtype.[2,9] Two of the discussed patients presented to our institution with recurrent disease; patient 2 was found to have progression nearly 40 years following primary external beam radiotherapy, and patient 3 presented with aggressive recurrent disease approximately 20 years following reported gross total removal. After treatment with subtotal or gross total resection, tumor progression/recurrence was seen in three of the four presented cases. We endorse the need for long-term, if not life-long, follow-up for all patients with GJTs, particularly in those with known residual disease.

Conclusion

The mainstay therapy for giant GJTs with brainstem impingement remains surgical with or without adjunct radiotherapy. Surgical resection (gross total or subtotal) is challenging; the surgical team must be prepared for extended operating time and significant blood loss and the patient for prolonged recovery and intensive rehabilitation. Patients with large primary or recurrent GJTs present additional challenges including an increased risk for CSF leak and wound breakdown.

While intracranial extension may occur in up to 20% of patients,[10] significant brainstem compression remains uncommon. In newly presenting surgically fit patients, our preferred management strategy remains gross total resection regardless of intradural status; however, in the medically infirm patient with significant brainstem compression, neural decompression should be the primary goal and the benefit of complete single stage resection must be weighed against the potential harm of prolonged surgery. In such patients, subtotal resection with adequate decompression and either a staged secondary resection or postoperative radiotherapy should be considered. In the present series, the combination of surgical resection and postoperative radiation therapy allowed for tumor control in all subjects for periods ranging from 5 to 9 years.

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