Am J Transl Res 2021;13(12):14121-14132
www.ajtr.org /ISSN:1943-8141/AJTR0139129

Original Article

Diagnosis and treatment of carotid body tumors

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Received September 14, 2021; Accepted November 27, 2021; Epub December 15, 2021; Published December 30, 2021

Abstract: Purpose: To investigate the clinical diagnosis, treatment, and complication prevention of carotid body tumors (CBTs). Methods: The medical records of 24 patients with CBTs treated in the Department of Oral and Maxillofacial Surgery in Shandong Provincial Hospital Affiliated to Shandong First Medical University from 1999 to 2014 were reviewed. All the patients had unilateral CBTs and underwent preoperative B-mode ultrasound. Before surgery, CBT diagnosis was confirmed by digital subtraction angiography (DSA) in 8 patients, magnetic resonance imaging (MRI) in 9 patients, and computed tomography angiography (CTA) in 11 patients. All the patients had surgical intervention and preoperative Matas test. The retrograde stump pressure in the internal carotid artery was monitored in all the cases during surgery. Transcranial Doppler (TCD) inspection was performed on all patients before and during surgery. Simple tumor resection was performed in 8 patients, and excision of both the tumor and external carotid artery was performed in 11 cases. Five patients received intraluminal shunt after tumor resection and partial removal of internal, external, and common carotid arteries. Results: The diagnostic accuracy of B-mode ultrasound, DSA, MRI, and CTA was 75%, 100%, 88.9%, and 90.9%, respectively. In the enrolled 24 patients, tumors were completely removed with no postoperative death, hemiplegia, or blindness. There were 4 cases of transient hypoglossal nerve palsy and 1 case of transient vagus nerve involvement after surgery, which were recovered after 4-8 months of follow-up. No recurrence was found in the included patients during the followed-up, varied from 3 months to 4 years. B-mode ultrasound examination can be used as a preliminary screening method. DSA, CTA, and MRI are all effective diagnostic tools for CBTs. Among them, the diagnostic coincidence rate of DSA is 100%, making it the most effective means of inspection. Surgical resection is the first choice for the treatment of CBT patients who are willing to undergo surgery. Conclusions: Preoperative routine Matas test can improve the brain tolerance of patients with carotid artery occlusion, preoperative, and intraoperative TCD monitoring are beneficial to understand the intracranial circulation in the circle of Willis. Intraoperative monitoring of residual arterial pressure and intraluminal shunt can prevent or significantly reduce the incidence of serious postoperative complications.

Keywords: Carotid body tumor, imageological examination, surgical treatment

Introduction

A carotid body tumor (CBT), or a paraganglioma, is a chemodectoma and the most common type of paraganglioma derived from the neural crest [1]. It is a rare neck tumor located at the adventitia of the common carotid artery bifurcation [2]. CBTs are benign tumors with low incidence, slow growth, and low canceration rate, which are not significantly associated with age [3, 4]. Gender difference in the occurrence of CBTs has not been established. Most literature reports a slightly higher incidence of CBTs in women [5]. The pathogenesis of this disease remains unclear, but it is considered to be associated with chronic hypoxia of tissues and mutation of mitochondrial oxygen sensitive genes [6]. Due to the special occurrence site, complex anatomical structure, abundant blood supply of tumor, and non-specific clinical manifestations, the tumor often involves the neck nerves and blood vessels, resulting in a high clinical misdiagnosis rate and great difficulty in diagnosis and treatment compared with many other tumors [7]. Misdiagnosis and improper treatment will cause serious surgical complications and even endanger the lives of patients [8]. Increasing attention has been paid to the

clinical diagnosis and treatment of CBTs. At present, the preoperative diagnosis of CBTs mainly relies on imaging methods, such as Doppler ultrasound, magnetic resonance imaging (MRI), digital subtraction angiography (DSA), and computed tomography angiography (CTA) [9]. The current treatment modalities for CBTs include surgery, radiotherapy, embolization, and combination therapy, among which surgical resection is the one with the highest efficacy [10-12].

Tumor resection is the recommended strategy for the treatment of CBTs [13]. Improved vascular surgical techniques and adequate pre-operative preparations can significantly lower the risks of peri-operative complications such as carotid injury, stroke, and death [14]. The management of such tumors remains challenging because of the non-specific clinical presentations and the difficulties encountered during surgical excision, a standard treatment. In view of the clinical and pathological features of CBTs, surgery is hypothesized to be the optimal treatment that can resect the tumor completely. Diagnostic analysis of different cases and analysis of surgical treatment are helpful for the treatment of CBTs. Due to the rarity of the presentation, most studies about malignant CBTs were small case reports, leading to a lack of standard approaches for early recognition and appropriate surgical techniques. The innovation of this research lies in the introduction of a case series of 24 pathologically diagnosed benign CBTs at our department, and the comprehensive analysis of their preoperative imaging characteristics, to deepen the understanding about the clinical features of the disease and improve the surgical treatment for such lesions.

In this study, the medical records of 24 patients with CBTs diagnosed and treated in the Department of Oral and Maxillofacial Surgery in Shandong Provincial Hospital Affiliated to Shandong First Medical University from January 1999 to January 2014 were reviewed. We discussed our experience in the management of CBTs in these patients, with regard to the strategies in the preoperative diagnosis, reduction of intraoperative blood loss, and preservation of internal carotid circulation, aiming to share our experience in the diagnosis and management of CBTs.

Materials and methods

General information

This study was a retrospective analysis and was approved by the Institutional Board Review at Shandong Provincial Hospital Affiliated to Shandong First Medical University. The research participants were 24 patients with CBTs, with a male to female ratio of 10:14 and an average age of (38.0±9.9) years old (range: 20-65). All the patients had unilateral CBTs, with the tumor on the left side of the neck in 8 cases and on the right side in 16 cases. The course of illness ranged from 5 months to 11 years. Inclusion criteria: All the patients presented with a cervical mass with a sense of local pressure or tremors and vascular murmurs. All the cases were pathologically confirmed to have no malignant metastasis during the operation. All the patients had complete clinical data and follow-up records. Exclusion criteria: Patients with incomplete clinical data. Patients with serious cardio-cerebral vascular diseases. Patients with a history of mental illness. Patients who did not consent to the procedure.

Imagological diagnosis

B-mode ultrasound: Philps HD15 color ultrasonic diagnostic apparatus was used. The transducer frequency was set to 7.5 MHz. The patient remained supine with the head turned to the contralateral and the neck fully exposed. Two-dimensional ultrasonography was used to slide in all directions to examine the neck mass. A continuous multi-section scanning was performed to observe the location, morphology, size, boundary, and internal echo of the mass. Attention was paid to the location and adjacent relationship between the mass and the major cervical artery. Color Doppler ultrasound was performed to show the relationship between intratumor blood flow and the surrounding vessels and track the main source of the nutrient vessels. The presence of space occupying lesions or compression, damage to the vascular wall, and the distance and angle between the internal and external carotid arteries were observed. Pulse Doppler ultrasound was used to analyze the spectrum characteristics and collect the peak velocity of blood flow and the resistance index.

The vagus and sympathetic nerves were in the deep layer of carotid sheath. The carotid artery body was located behind the bifurcation of the common carotid artery. CBTs were closely adhered to the carotid artery. Schwannomas generated by vagus and sympathetic nerves were deeply seated in the carotid sheath. CBTs were closely connected to the carotid artery and surrounded the carotid artery during the continuous growth of the tumor, resulting in an increase in the angle of the carotid bifurcation. The mass could move horizontally but not vertically. Encircle carotid artery bifurcation plane, single (unilateral) or double (bilateral) masses, increased angle between the internal and external carotid arteries, widened distance, and the presence of blood flow signals in the mass are the typical sonographic manifestations of CBTs.

Ultrasonography observation: (1) All the masses were located at the bifurcation of carotid artery, and mostly, the boundaries between them and the major carotid artery were ill-defined. (2) The masses had irregular shape, clear boundary, low internal echo, and uneven distribution. (3) Most of the masses surrounded the major cervical vessels. (4) The tumor compressed the internal and external carotid arteries, which increased the distance between them, widened the included angle of the carotid bifurcation, and narrowed the vessels under compression. (5) The blood flow in the tumor was rich, distorted, and brightly colored, indicating that the feeding artery came from the internal and external carotid arteries. The pulse Doppler confirmed that it was the arterial spectrum with the characteristics of low speed and low resistance.

DSA: Advance LCV plus angiography machine from GE Company was used for DSA examination.

The patient was placed in the supine position and routinely sterilized with the towel. After local anesthesia, the right femoral artery was punctured with the modified Seldingers technique. Routine DSA was performed on bilateral common carotid arteries, internal carotid artery, vertebral artery, and intracranial artery with a 5F single-curved catheter. The contrast agent used was iodohyanol 300, the injection speed was 3-7 mL/s, the dose was 6-12 mL, and the acquisition speed was 3-6 frames/s. DSA in the front and side position was routinely performed. The oblique DSA was performed only when necessary. Contralateral angiography of the internal carotid artery on the healthy side was performed after compressing the common carotid artery on the affected side to observe the opening of the traffic artery and the cerebrovascular conditions. The main manifestations of DSA were: The tumor was located at the bifurcation of the carotid artery. The bifurcation angle of the carotid artery increased and was shaped like a goblet. Small tumors were spheroidal. The internal and external carotid arteries were significantly compressed and arc-shaped in patients with large tumors presenting eccentric growth.

The main blood supply artery was the external carotid artery, mainly including the pharyngeal artery, occipital artery, and superior thyroid artery. The tumor blood vessels were distributed in the form of network and plexus. The blood supply was abundant. Vascular lake and early display of the draining veins can be observed in larger tumors. If the carotid artery was surrounded by tumors, the carotid wall may be irregular, or the lumen narrowed.

MRI examination: The Magnetom Avanto1.5T, a full-body MRI scanner produced by Siemens was adopted.

Preoperative preparation

Transcranial Doppler (TCD) was performed on all 24 patients before surgery to observe the flow velocity of each intracranial artery and the symmetry of bilateral hemispheric flow velocity. The blood velocity of the total internal and external arteries of the extracranial segment of the neck was observed. Matas test was performed in all cases. Compression was performed for 30 minutes at a time for 15 to 20 days on the premise that the patient had no conscious symptoms, until the patients could tolerate for 30 minutes without appearing cerebral ischemia symptoms. After the Matas test, the functional compensation of collateral arteries of the circle of Willis at the base of the skull was detected.

Operative technique

All 24 patients underwent surgery in the Department of Oral and Maxillofacial Surgery in

Table 1. General data

Characteristic	Cases (n=24)
Gender (Male/Female)	10/14
Age [year, (min, max)]	20,65
Course of illness [month, (min, max)]	5,132
Distribution [n]	
Unilateral	24
Bilateral	0
Orientation	
Left	8
Right	16
Symptom [n]	
Pulsatile mass	24
Ache	3
Vocal hoarseness	4
Local tenderness	5
Size [cm, (min, max)]	2×1.5×1, 13.5×10×5
Shambin criterion [n]	
I	8
II	11
III	5

Shandong Provincial Hospital Affiliated to Shandong First Medical University after diagnosis and consent for surgical treatment. Simple tumor dissection was performed in 8 cases. The tumor was completely removed in 11 patients with ligation of the external carotid artery or its corresponding branches. In 5 cases with internal carotid artery adhesion, the tumor was removed by using the internal carotid artery bypass surgery.

Operative incision: The "フ", "丁" or straight line shaped incision was made at anterior to the sternocleidomastoid muscle. The "フ" shaped incision was the best to fully expose the tumor.

Operative procedures: For all the patients, local anesthesia was carried out under consciousness. The common carotid artery was dissected and ligated within 30 minutes. The patients' feelings (such as dizziness, numbness of limbs, and mobility of limbs) were evaluated. TCD was conducted to observe the blood flow velocity of each intracranial artery and whether the bilateral hemispheric velocity was symmetrical. The blood velocity of the total internal and external carotid arteries of the extracranial segment was observed and compared with the results before occlusion. If patients had no above symptoms, general anesthesia would be employed. All the masses were sectioned into paraffin sections for pathological examinations.

Postoperative observation and treatment: Postoperative routine anti-infection treatment and close monitoring of symptoms such as breathing difficulty, hoarse voice, tongue skewness, cough, swallowing difficulty, and hemiplegia were carried out. Patients were also closely monitored for changes in blood pressure and heart rate.

Follow-up

After discharge, the patients were followed up by clinic visits for eight months to four years. The follow up indicators included complications, functional recovery, metastasis, and recurrence.

Complications included death, hemiplegia, blindness, transient hypoglossal nerve palsy, and transient vagus nerve involvement.

Functional recovery: The time for functional recovery of hoarseness, cough, dysphagia, hemiplegia, transient hypoglossal palsy, and transient vagus nerve involvement was observed.

Statistical analyses

All the collected data were analyzed by SPSS 21.0 (IBM Corp., Armonk, NY, USA). The measurement data were represented as mean ± standard deviation. The counting data were expressed as cases or percentages. Differences within groups were compared using paired t-test. The independent-sample t test and non-parametric Mann-Whitney U test were used to compare the continuous variables of normal distribution and non-normal distribution, respectively. The Chi-square test was used for comparison of category variables. Statistical significance was defined as $P<0.05$.

Results

General data and clinical symptoms

The general data of the patients are shown in **Table 1**. The clinical findings of these patients were similar: all 24 cases had palpable pulsatile masses in the neck, with 3 cases present-

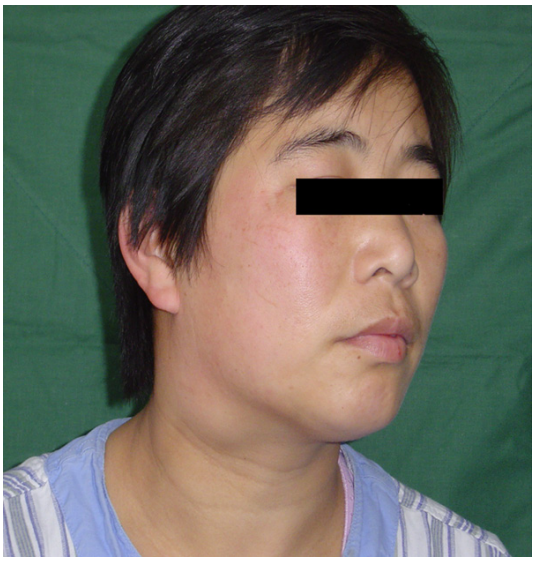

Figure 1. Clinical presentation of the carotid body tumor.

ing ache, 4 cases presenting vocal hoarseness, and 5 cases presenting local tenderness. The tumors, located at the carotid triangle area, were round or oval shaped and grew slowly and gradually. The neoplasms were laterally mobile but vertically fixed as they attached to the carotid bifurcation. The tumors had a firm consistency and were mobile and pulsatile (**Figure 1**). The artery pulse was palpable and mostly conductive. Blowing vascular murmurs were found in 9 cases. The minimum tumor size was 2 cm ×1.5 cm ×1 cm and the maximum was 13.5 cm ×10 cm ×5 cm. According to the Shamblin's classification [15], there were 8 cases of grade I, 11 cases of grade II, and 5 cases of grade III.

Presentations and diagnosis

All the patients received B-mode ultrasonography which showed solid and hypoechoic tumors close to the blood vessel. B-mode ultrasonography diagnosed 18 patients as CBTs, 4 patients as neurgenic tumors of the neck, and 2 patients as angiomas, with a diagnostic coincidence rate of 75%.

Eight patients underwent DSA examination and were all diagnosed as CBTs. The images showed bifurcation of the common carotid artery, and displacement of the internal and external carotid arteries under tumor compression. The blood vessels supplying the tumor can be clearly shown. Among the 8 patients, 4 cases were from the ascending pharyngeal artery, 2 cases from the superior thyroid artery, 1 case from the internal and external carotid artery, and 1 case from the internal carotid artery alone. In all the cases, staining was evident in the parenchymal phase and continued into the venous phase. In some cases, the tumor vein showed early and drainage veins were obvious (**Figure 2**). The diagnostic coincidence rate was 100%.

Out of the 9 cases receiving MRI examination, 8 were diagnosed as CBTs and 1 as jugular bulbar tumor. MRI showed that the tumor was located at the bifurcation of the carotid artery in three different sections, presenting a regular round or round-like mass with clear boundaries. T1-weighted image (T1-WI) showed low signal. T2-weighted image (T2-WI) showed heterogeneous or high signal. The mass straddled the bifurcation of the common carotid artery, and internal and external carotid artery displacement by compression was observed. After intravenous injection of GD-DTPA, the lesions were scanned and showed heterogeneous enhancement (**Figure 3**). The diagnostic coincidence rate was 88.9%.

Among the 11 patients with CTA examination, 10 cases were diagnosed as CBTs and one as cervical schwannoma. The tumors were regular round or circular-like masses with clear boundaries that spanned the bifurcation of the common carotid artery and presented displacement of the internal and external carotid arteries under compression (**Figure 4**). The diagnostic coincidence rate was 90.9%.

Operation indexes

The operation time of the whole group was (176.5±83.3) min, and the intraoperative blood loss was (1021.1±861.7) ml. Simple tumor resection was performed in 8 patients, and excision of both the tumor and external carotid artery was performed in 11 cases.

Postoperative pathological features

Some tumor cells were large, round, ovoid, or polygonal, with abundant cytoplasm, lightly stained or transparent nucleoli. Other tumor cells were smaller with darker nuclear staining or spindleshaped. The tumor cells were

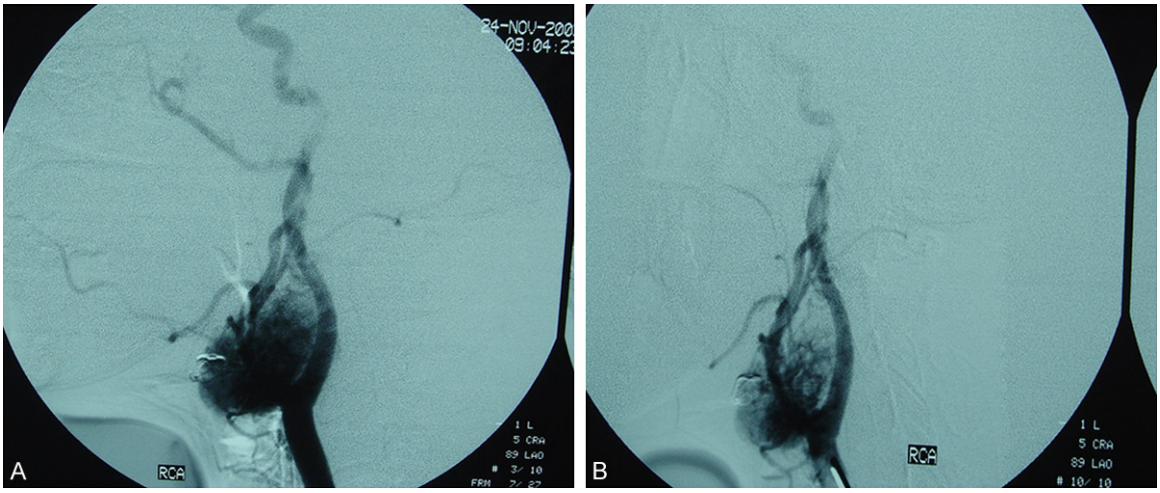

Figure 2. A: DAS showed hypervascularization of the carotid body tumor; B: DSA showed the carotid body tumor, mainly from the external carotid artery.

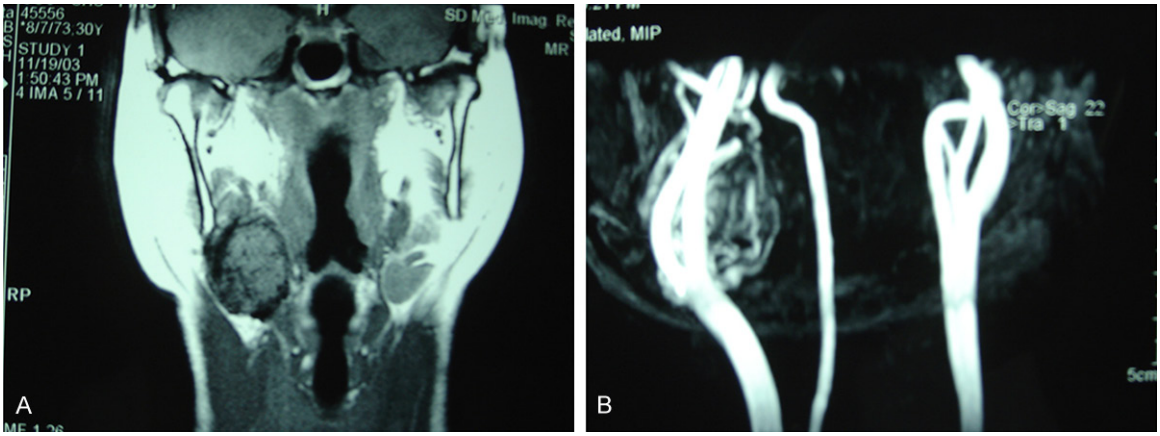

Figure 3. A: MRI showed the carotid body tumor; B: MRI showed heterogeneous signal distribution in a carotid body tumor.

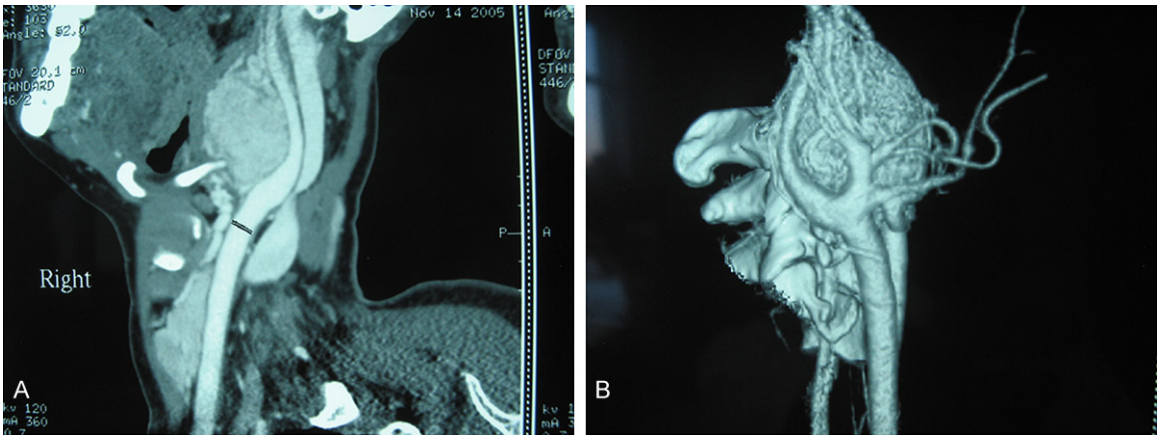

Figure 4. A: CTA showed the carotid body tumor; B: CTA imaging demonstrated the typical separation of external and internal carotid arteries of a carotid body tumor.

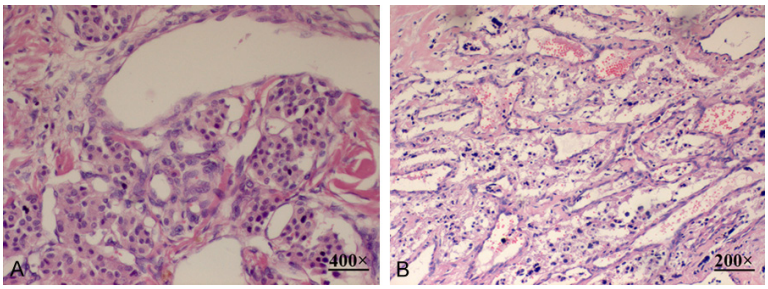

Figure 5. A: Alveolar-like nests of tumor cells (400 mo); B: Surrounding these cell nests is a dense network of thin-walled sinusoidal capillaries; some nuclear pleomorphism can be seen (200 nb).

arranged in clumps, cords, or alveoli, interspersed with connective tissue rich in thin-walled vessels and sinuses (**Figure 5**).

Postoperative complications and follow-up results

The operation was a complete success in the 24 patients without hemiplegia or death. Temporary hypoglossal nerve involvement occurred in 4 patients and vagus nerve involvement was found in 1 patient. After the operation, the patients were followed up for 4-8 months and gradually returned to normal function. Postoperative pathological findings were all CBTs. The 24 patients were followed up for 3 months to 4 years. No postoperative recurrence or metastasis was detected by color Doppler ultrasound or CT.

Discussion

CBTs, which grow and evolve from the tissue of hemangioma [16], are chemoreceptor tumors or non-chromaffin gangliomas that arise from the third branchial cleft neural crest [17]. This kind of tumor contains a large number of microarteriovenous fistulas with rapid intratumor blood circulation. The blood supply is abnormally rich [18]. Such tumors are rare and were first described and reported by Vou Haller in 1743 [19]. CBTs are relatively rare and account for only 0.4-1.0% of arterial tumors and 0.1-2.0% of cervical arterial tumors [20]. Most of them are benign and unilateral, with a slightly higher incidence in women than men [21]. Its incidence is low and the etiology remains to be defined. Long-term chronic hypoxia exposure in high-altitude regions may be associated with the disease [22]. CBTs are located at the branch of the carotid artery, adjacent to many important tissues and vital organs such as the common carotid artery, the internal carotid artery, the vagus nerve, the hypoglossal nerve and the recurrent laryngeal nerve, that seriously interfere with the blood supply of brain tissue during the operation, resulting in a certain risk of intraoperative and postoperative complications [23, 24].

Most patients see a doctor because of the neck mass, usually without symptoms of discomfort. A few patients developed symptoms such as syncope, tinnitus, and blurred vision [25]. Dysphagia, hoarseness, ipsilateral, displacement of the tip of the tongue towards the affected side during tongue extension and Horner's syndrome may occur if the ninth, tenth and twelfth nerves in the brain are compressed [26]. If the tumor grows toward the pharynx, the pharynx may be found bulging on oral examination [27]. About 3% of patients with CBTs are associated with carotid sinus syndrome, an allergic reaction to the carotid sinus caused by the tumor pressing on the carotid body [28]. The main manifestations are cardiac function inhibition, sudden slow heartbeat, blood pressure drops, leading to cerebral ischemia and hypoxia and fainting [29].

In this study, physical examination showed that the tumor was in the trigonometry area of the carotid artery, presenting as a round or ovoid mass, which was laterally mobile but vertically fixed. The surface was often smooth, and the texture was medium soft. The arterial pulse can be touched and mostly conductive. Blood vessel murmurs can be heard by auscultation. CBTs are mostly benign [30]. According to the reports from Kliewer et al. [31] and Barnes et al. [32], the incidence of malignant lesions is about 2%-9%, and a malignant conversion rate of 5%-10% has recently been reported. The postoperative pathological examination of the 24 patients enrolled in this study indicated benign tumors. Clinically, CBTs can be divided into the following two types: family type (6.5%), mostly bilateral; and sporadic, mostly unilateral. All 24 patients had unilateral CBTs. Shamblin et al. [15] classified CBTs into three categories: Grade I: The tumor is confined to the bifurcation of carotid artery without adhesion to the

wall of internal and external carotid arteries; Grade II: The tumor extends below the bifurcation of the carotid artery, partially enveloping the vessels at the bifurcation of the carotid artery and adhering to the wall of the internal and external carotid arteries; Grade III: The tumor completely envelops the bifurcation of the carotid artery and its superior and inferior carotid arteries, and closely adheres to the carotid artery. The surgical methods of CBTs with different grades also vary greatly. It is necessary to clarify the classification of tumors and their relationship with carotid artery and surrounding tissues before surgery. According to the Shambin's classification [15], there were 8 cases of grade I, 11 cases of grade II, and 5 cases of grade III among the 24 patients included in this study.

The incidence of CBTs is low, resulting in a high misdiagnosis as most clinicians lack relevant experience [33]. In addition to the preoperative diagnosis according to the clinical manifestations, it is particularly important to choose the examination method with high diagnostic value [34]. B-ultrasonography can be used as a preliminary screening test, which can clearly reflect the blood supply, size and location of the tumor and the carotid artery, contributing to diagnosis. It is difficult to understand the relationship between tumor and blood vessels because it cannot provide multidirectional images [35]. The diagnostic coincidence rate of B-mode ultrasound was found to be 75% (18/24) in this study. It is necessary to differentiate the disease from other tumors that occur in this area. In our series, neurogenic tumors of the neck were diagnosed in 4 cases by B-mode ultrasound and hemangiomas were diagnosed in 2 cases. (1) Neurogenic tumor: After comprehensive analysis, the neurogenic tumors and their characteristics were not well understood. The tumors in these cases had clear boundary, low echo, and large volume, all squeezing the major cervical artery, they were located deep behind the carotid artery. There was no major carotid artery surrounding the neck, and the angle at the bifurcation of the carotid artery was not increased. Color doppler ultrasound showed that the tumor had sparse blood flow, no thick dendritic blood flow signal inside the CBT; (2) Angioma: Most of them were not closely related to the large vessels of the neck. Color doppler ultrasound showed relatively sparse blood flow signals inside the tumor, which were mostly starshaped.

MRI has a high ability of tissue resolution, which can clearly show the size, morphology, range, and location of the tumor. It can intuitively display the relationship between the tumor and blood vessels by means of fluid-space effect, which has high diagnostic value [36]. The diagnostic coincidence rate of MRI in these patients was 75% (8/9).

As to DSA, it can observe the changes of the carotid artery, locate the tumor, determine the blood supply status of the tumor, and confirm the location relationship between the tumor and the carotid artery. It can display the traffic of the bilateral cerebral arteries and clearly show the collateral circulation of the circle of Willis, which is one of the exact diagnostic methods of CBTs [37]. DSA can show the diameter and blood flow patency of the common carotid artery and its branches, including the circle of Willis, the size and location of the tumor, and the relationship with the common internal carotid artery [38]. For those with large tumors, DSA can show the bifurcation of the common carotid artery showing cube-like enlargement and nourishing vessels from the external carotid artery [39]. Nourishing vascular embolization can be performed preoperatively according to the results of DSA to promote tumor shrinkage and reduce intraoperative bleeding. DSA can be the gold standard for diagnosing this disease [10, 40]. All 8 patients in this group were diagnosed as CBTs by DSA. The diagnostic coincidence rate was 100%. DSA is a traumatic examination, which has certain risks such as iodine allergy, vascular injury, arterial thrombosis, and embolism.

CTA of the neck can help understand the size and range of CBTs and the relationship between tumor and surrounding tissue structure [41]. Three-dimensional imaging technology can clearly display the three-dimensional image of CBTs, carotid artery and its branches, which is of great value in diagnosis and surgical decision [42]. Compared with DSA, CTA has the advantages of simple operation, low cost, low relative risk, and less pain, which is worthy of promotion in clinical practice. Its disadvantage is that it cannot perform local embolization on the main nourishing vessels of the tumor body [43]. In our series, 11 patients underwent CTA

examination. It was found that their tumors were regular round or circular-like masses with well-defined boundaries that spanned the bifurcation of the common carotid artery and presented displacement of internal and external carotid arteries under compression. With CTA, 10 cases were diagnosed as CBTs and 1 case as cervical schwannoma, with a coincidence rate of 90.9%. CTA can be used as a non-invasive examination method in clinical practice, and multiple post-treatment techniques can be applied simultaneously to fully display the anatomical relationship between the tumor and carotid arteries. It can clearly show the tumor's nourishing artery, which helps to understand the relationship between the tumor and surrounding tissues and the vascular involvement in detail. CTA has unique advantages in the diagnosis of CBTs and can be used as the preferred method for clinical diagnosis and preoperative evaluation. From our point of view, when we find a solid mass located at the bifurcation plane of the carotid artery, we should first observe whether the angle between the internal and external carotid arteries has increased or whether the distance has widened. If the blood flow signals in the mass are abundant, it is not difficult to determine that the mass is a CBT. If the blood flow signals are not abundant, it is necessary to determine the mass and the surrounding tissues. We also need to observe whether the mass is closely related to the peripheral nerves. The possibility of schwannomas in the neck should be considered.

Before surgery, it is advised to make early judgments about the flow velocity of each intracranial artery, to observe the symmetry of blood flow velocity of both hemispheres, and to determine the blood flow velocity of the total, internal and external carotid arteries, and the functional compensation of collateral arteries in the circle of Willis at the base of the skull [44]. The preoperative Matas test was performed, each time lasting 30 minutes for 15 to 20 days. After the test, TCD examination was performed to observe the functional compensation of collateral arteries of the circle of Willis at the skull base and compared with that before the experiment. This test is not infallible, and the compression may not be completely correct. Even though the test may be negative, there may still be serious postoperative reactions. B-ultrasound examination of distal internal carotid artery was performed during carotid artery compression to monitor blood flow velocity and observe whether the blood flow direction was from intracranial regurgitation. B-ultrasound may be used as an auxiliary examination to evaluate the effectiveness of Matas test.

Patients that have been diagnosed or highly suspected to have CBTs should be treated with surgery as early as possible to prevent tumor progression, avoid invasion of adjacent nerves or blood vessels, and reduce postoperative complications. The key to the operation is to protect the carotid artery and prevent cerebral ischemia. During the operation, obstruction of the common carotid artery should be avoided as much as possible, or intermittent blocking should be used. If revascularization or transplantation is performed, systemic use of heparin before blocking the common carotid artery can prevent thrombosis. Intraoperative blood pressure should be kept stable to ensure a certain intracranial perfusion pressure. According to the size of the tumor and the relationship with the carotid artery, surgery is mainly divided into the following ways: (1) Simple tumor dissection: In the early stage, the tumor grows in the external sheath of the carotid artery and is not closely adhered to the carotid artery, so it is easy to be separated and removed. In our series, 8 cases were treated with this method, among which the tumors in 2 cases could still be removed after the internal carotid artery had been circumscribed. (2) Tumors resection and ligation of the external carotid artery: Due to the large size of the tumor and the close adhesion between the tumor and the external carotid artery, the corresponding branches of the adhered external carotid artery or the main trunk of the external carotid artery should be removed during the operation. Eleven of the 24 patients enrolled in this study were treated with this method. During the operation, 4 patients had tumors adhered to the ascending pharyngeal artery, 5 patients had tumors adhered to the superior thyroid artery, and 2 patients had tumors directly supplied by the external carotid artery. (3) Excision of the tumor, external carotid artery and part of the internal carotid artery: For patients with Shamblin grade II or grade III CBTs, the common carotid artery-internal carotid artery diversion operation is required. The

tumor can be removed together with part of the internal carotid artery and external carotid artery. During the operation, the distal end of the internal carotid artery was separated and incised. One side of the shunt tube was inserted into the common carotid artery and the other side was inserted into the incision of the distal internal carotid artery of the tumor. In this way, intracranial blood supply could not be interrupted, and the tumor body could be shrunk to reduce the bleeding during tumor resection, greatly improving the safety of the operation. In our series, 5 patients received this procedure, with no postoperative symptoms of cerebral ischemia. There was no stroke or cerebral ischemia during 3 months to 4 years of follow-up.

Due to the specific location of CBTs, the incidence of postoperative complications is relatively high, mainly including cranial nerve injury, cerebrovascular accidents, and bleeding, among which cranial nerve injury and cerebrovascular accidents are the most serious [45]. Nerve injury mainly involves hypoglossal nerve, vagus nerve and its branches, and the mandibular ramus of the facial nerve. Preoperative and intraoperative positive brain tissue protection, which is significantly associated with success or failure of CBT surgery, can significantly reduce brain tissue damage, and lower the risk of hemiplegia and death [46]. We have taken the following measures for brain tissue protection: (1) Preoperative CVD was performed to examine the circle of Willis and collateral branches of cerebral artery. In clinical practice, we found that both DSA and CTA had a good display effect. (2) Preoperatively, the affected common carotid artery was treated with Matas test for 30 minutes for 15 to 20 days. (3) Preoperative TCD examination was performed to observe the blood flow velocity of each intracranial artery and whether the bilateral hemispheric velocity was symmetrical. The total, internal, and external carotid blood velocity of the extracranial segment was observed. Before and after the carotid artery compression test, an observation was conducted regarding whether the collateral arteries of the circle of Willis at the base of the skull were well compensated. TCD monitoring is of great significance for brain tissue protection. (4) Extracranial segment of internal carotid artery countercurrent pressure was measured after intraoperative common carotid artery occlusion. A value greater than 70 mmHg indicated that carotid artery occlusion was safe. A residual arterial pressure less than 50 mmHg indicated a greater risk of artery occlusion, requiring bypass surgery. (5) The use of common carotid artery-internal carotid artery bypass surgery, without interrupting the intracranial blood supply, can make the tumor body shrink and reduce the bleeding during tumor resection, which can effectively protect brain tissue and greatly improve the safety of surgery. (6) Surgical operation should strive for fine, gentle, and rapid to reduce minimize bleeding during operation. In this study, 4 patients presented with temporary hypoglossal involvement and 1 with vagus nerve involvement, which gradually returned to normal after 4-8 months of follow-up. It was related to intraoperative traction, postoperative edema, and scar adhesion, but not to the brain area. In conclusion, preoperative B-mode ultrasound can be used as a preliminary screening test, which is helpful for CBT diagnosis. DSA, CTA, and MRI have obvious diagnostic value. The diagnostic coincidence rate of DSA is 100%, which is the most effective means of inspection. CTA can be used as a non-invasive examination method in clinical practice, using multiple post-treatment techniques simultaneously. It has unique advantages in the diagnosis of CBTs and can be used as the preferred method for clinical diagnosis and preoperative evaluation. After a solid mass is found in the bifurcation plane of the common carotid artery in the actual imaging examination, the bifurcation angle of the common carotid artery should be observed. If the angle increases and the blood flow inside the mass is abundant, it can be determined as a CBT. If the blood flow signal is not abundant, it is necessary to determine the mass and the surrounding tissues. The possibility of cervical schwannomas should also be considered.

Surgical excision is the preferred treatment for CBTs. Routine preoperative Matas test can improve the cerebral tolerance of carotid artery occlusion. Preoperative and intraoperative TCD monitoring can be used to understand the intracranial circulation in the circle of Willis. Intraoperative monitoring of residual arterial pressure and common carotid artery and internal carotid artery bypass surgery can prevent or significantly reduce the occurrence of serious postoperative complications.

Disclosure of conflict of interest

None.

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References

[1] Fathalla AE and Elalfy MA. Clinical outcome of carotid body paraganglioma management: a review of 10-year experience. J Oncol 2020; 2020: 6081273.

[2] Fan D, Luster S, Eid IG and Saied Calvino A. A multidisciplinary approach to carotid body tumors surgical management. J Surg Case Rep 2020; 2020: rjaa030.

[3] Han T, Wang S, Wei X, Xie Y, Sun Y, Sun H, Zhu J, Wu Y, Zhou J and Zhao Z. Outcome of surgical treatment for carotid body tumors in different Shambling type without preoperative embolization: a single-center retrospective study. Ann Vasc Surg 2020; 63: 325-331.

[4] Robertson V, Poli F, Hobson B, Saratzis A and Naylor AR. A systematic review and meta-analysis of the presentation and surgical management of patients with carotid body tumours. Eur J Vasc Endovasc Surg 2019; 57: 477-486.

[5] Ikeda A, Shiga K, Katagiri K, Saito D, Miyaguchi J, Oikawa SI, Tsuchida K, Asakage T, Ozawa H and Nibu KI. Multi-institutional survey of carotid body tumors in Japan. Oncol Lett 2018; 15: 5318-5324.

[6] Knight TT Jr, Gonzalez JA, Rary JM and Rush DS. Current concepts for the surgical management of carotid body tumor. Am J Surg 2006; 191: 104-110.

[7] Jiang X, Fang G, Guo D, Xu X, Chen B, Jiang J, Dong Z and Fu W. Surgical management of carotid body tumor and risk factors of postoperative cranial nerve injury. World J Surg 2020; 44: 4254-4260.

[8] Sevil FC, Tort M and Kaygin MA. Carotid body tumor resection: long-term outcome of 67 cases without preoperative embolization. Ann Vasc Surg 2020; 67: 200-207.

[9] Jin ZQ, He W, Wu DF, Lin MY and Jiang HT. Color Doppler ultrasound in diagnosis and assessment of carotid body tumors: comparison with computed tomography angiography. Ultrasound Med Biol 2016; 42: 2106-2113.

[10] Ma D, Liu L, Yao H, Hu Y, Ji T, Liu X, Zhang C and Qiu W. A retrospective study in management of carotid body tumour. Br J Oral Maxillofac Surg 2009; 47: 461-465.

[11] Jones HG and Stoneham MD. Continuous cervical plexus block for carotid body tumour excision in a patient with Eisenmenger's syndrome. Anaesthesia 2006; 61: 1214-1218.

[12] Casarim AL, Tincani AJ, Del Negro A, Aguiar CG, Fanni RV and Martins AS. Carotid body tumor: retrospective analysis on 22 patients. Sao Paulo Med J 2014; 132: 133-139.

[13] Bobadilla-Rosado LO, Garcia-Alva R, Anaya-Ayala JE, Peralta-Vazquez C, Hernandez-Sotelo K, Luna L, Cuen-Ojeda C and Hinojosa CA. Surgical management of bilateral carotid body tumors. Ann Vasc Surg 2019; 57: 187-193.

[14] Alqaim M, Puri AS, Vaezi AE and Schanzer A. Carotid body tumor resection utilizing a covered stent graft to enable resection of the tumor en bloc with the internal carotid artery. J Vasc Surg Cases Innov Tech 2019; 5: 481-484.

[15] Shamblin WR, ReMine WH, Sheps SG and Harrison EG Jr. Carotid body tumor (chemodectoma): clinicopathologic analysis of ninety cases. Am J Surg 1971; 122: 732-739.

[16] Xing J, Cheng Y, Ying H, Guan M, Jia N and Bai C. Systemic treatment of a metastatic carotid body tumor: a case report and literature review. Medicine (Baltimore) 2020; 99: e22811.

[17] Lebbe I, Bosmans F, Verheyen L and Duchateau J. Unilateral carotid body tumor: case report and implications report and pre-operative management. Ann Clin Case Rep 2020; 5: 1782.

[18] Snezhkina AV, Lukyanova EN, Kalinin DV, Pokrovsky AV, Dmitriev AA, Koroban NV, Pudova EA, Fedorova MS, Volchenko NN and Stepanov OA. Exome analysis of carotid body tumor. BMC Med Genomics 2018; 11: 5-19.

[19] Hoang VT, Trinh CT, Lai TAK, Doan DT and Tran TTT. Carotid body tumor: a case report and literature review. J Radiol Case Rep 2019; 13: 19-30.

[20] Pacheco-Ojeda LA. Carotid body tumors: surgical experience in 215 cases. J Craniomaxillofac Surg 2017; 45: 1472-1477.

[21] Maxwell JG, Jones SW, Wilson E, Kotwall CA, Hall T, Hamann S and Brinker CC. Carotid body tumor excisions: adverse outcomes of adding carotid endarterectomy. J Am Coll Surg 2004; 198: 36-41.

[22] Wang YH, Zhu JH, Yang J, Ma W, Zhong H, Zhang WS and Wu JY. The characteristics of carotid body tumors in high-altitude region: analysis from a single center. Vascular 2021; 4: 17085381211005238.

[23] Kim GY, Lawrence PF, Moridzadeh RS, Zimmerman K, Munoz A, Luna-Ortiz K, Oderich GS, de Francisco J, Ospina J and Huertas S. New predictors of complications in carotid body tumor resection. J Vasc Surg 2017; 65: 1673-1679.

[24] Selim M, AlJehani SH, Aljuhani AB and Albayomy AA. Preoperative super-selective emboliza-

tion of carotid body tumor and multidisciplinary approach. Cureus 2021; 13: e12879.
[25] Jin ZQ, He W, Wu DF, Lin MY and Jiang HT. Color doppler ultrasound in diagnosis and assessment of carotid body tumors: comparison with computed tomography angiography. Ultrasound Med Biol 2016; 42: 2106-2113.
[26] Finocchiaro M, Benvegna S, Finocchiaro N, Alfano M and Benvegna G. Chemodectoma: case report. Chirurgia 2017; 30: 73-77.
[27] Mokin M, Dumont TM, Kass-Hout T and Levy EI. Carotid and vertebral artery disease. Prim Care 2013; 40: 135-151.
[28] Ghali MG, Srinivasan VM, Hanna E and DeMonte F. Overt and subclinical baroreflex dysfunction after bilateral carotid body tumor resection: pathophysiology, diagnosis, and implications for management. World Neurosurg 2017; 101: 559-567.
[29] Li X, Zhang W, Shu C, Li Q, Zhang L and Zhu J. Diagnosis and outcomes of surgical treatment of carotid bifurcation tumors. J Int Med Res 2020; 48: 300060520976495.
[30] Grotemeyer D, Loghmanieh S, Pourhassan S, Sagban T, Iskandar F, Reinecke P and Sandmann W. Dignity of carotid body tumors. Review of the literature and clinical experiences. Chirurg 2009; 80: 854-863.
[31] Kliewer KE, Wen DR, Cancilla PA and Cochran AJ. Paragangliomas: assessment of prognosis by histologic, immunohistochemical, and ultrastructural techniques. Hum Pathol 1989; 20: 29-39.
[32] Barnes L and Taylor SR. Carotid body paragangliomas: a clinicopathologic and DNA analysis of 13 tumors. Arch Otolaryngol Head Neck Surg 1990; 116: 447-453.
[33] Tong Y. Role of duplex ultrasound in the diagnosis and assessment of carotid body tumour: a literature review. Intractable Rare Dis Res 2012; 1: 129-133.
[34] Law Y, Chan Y and Cheng S. Surgical management of carotid body tumor-is shamblin classification sufficient to predict surgical outcome? Vascular 2017; 25: 184-189.
[35] Demattè S, Di Sarra D, Schiavi F, Casadei A and Opocher G. Role of ultrasound and color Doppler imaging in the detection of carotid paragangliomas. J Ultrasound 2012; 15: 158-163.
[36] Arya S, Rao V, Juvekar S and Dcruz A. Carotid body tumors: objective criteria to predict the Shamblin group on MR imaging. AJNR Am J Neuroradiol 2008; 29: 1349-1354.
[37] Wu J, Liu S, Feng L, Du W, Cui M, Wang J and Zhao M. Clinical analysis of 24 cases of carotid body tumor. Zhonghua Er Bi Yan Hou Tou Jing Wai Ke Za Zhi 2015; 50: 25-27.
[38] Bercin S, Muderris T, Sevil E, Gul F, Kılıcarslan A and Kiris M. Efficiency of preoperative embolization of carotid body tumor. Auris Nasus Larynx 2015; 42: 226-230.
[39] Li MQ, Zhao Y, Sun HY and Yang XY. Large carotid body tumor successfully resected in hybrid operating theatre: a case report. World J Clin Cases 2019; 7: 2346.
[40] Ma D, Liu M, Yang H, Ma X and Zhang C. Diagnosis and surgical treatment of carotid body tumor: a report of 18 cases. J Cardiovasc Dis Res 2010; 1: 122-124.
[41] Lozano-Corona R, Anaya-Ayala JE, Martínez-Martínez R, López-Rocha S, Rivas-Rojas MA, Torres-Machorro A, Laparra-Escareno H and Hinojosa CA. Usefulness of preoperative three-dimensional volumetric analysis of carotid body tumors. Neuroradiology 2018; 60: 1281-1286.
[42] Becher T, Riascos-Bernal DF, Kramer DJ, Almonte VM, Chi J, Tong T, Oliveira-Paula GH, Koleilat I, Chen W and Cohen P. Three-dimensional imaging provides detailed atherosclerotic plaque morphology and reveals angiogenesis after carotid artery ligation. Circ Res 2020; 126: 619-632.
[43] Zhao H, Wang J, Liu X, Zhao X, Hippe DS, Cao Y, Wan J, Yuan C and Xu J. Assessment of carotid artery atherosclerotic disease by using three-dimensional fast black-blood MR imaging: comparison with DSA. Radiology 2015; 274: 508-516.
[44] Kaygusuz I, Karlidag T, Keles E, Yalcin S and Yüksel K. Carotid body tumor: clinical features. J Craniofac Surg 2015; 26: e586-e589.
[45] Gwon JG, Kwon TW, Kim H and Cho YP. Risk factors for stroke during surgery for carotid body tumors. World J Surg 2011; 35: 2154-2158.
[46] Hassanein AG, Hassanein KAM, Fadle KN, Al-Eslam AS and Al Qahtani FN. The outcome of multidisciplinary management of carotid body tumors: retrospective cohort study. J Maxillofac Oral Surg 2019; 18: 610-616.