

Microsurgical anatomy of the external carotid artery: a stereoscopic study

Anatomia microcirúrgica da artéria carótida externa: um estudo estereoscópico

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Abstract

Background: Knowledge of the anatomical structures of the external carotid artery by means of stereoscopic study may yield better results in microsurgery of the external carotid artery.

Objective: To describe the structures of the external carotid artery under stereoscopic view, identifying its multiple aspects.

Methods: The cervical regions of twelve cadavers were dissected using a surgical microscope with 3 to 40 X magnification. The anatomical dissections were documented using the technique to obtain three-dimensional images (3D), aiming at producing stereoscopic images.

Results: The use of the stereoscopic technique allowed a tri-dimensional approach to the extracranial arterial circulation, and the performance of surgical dissections such the combined approach to the posterior fossa and infratemporal fossa, making microvascular surgery and neurosurgical procedures more precise.

Conclusion: The use of images obtained by the stereoscopic technique produced a more assertive result in relation to the anatomy study for microsurgical or neurosurgical procedures, allowing better analysis before performing complex neurosurgical procedures.

Keywords: stereoscopic vision; carotid artery, external; three-dimensional images.

Resumo

Contexto: O conhecimento das estruturas anatômicas da artéria carótida externa por meio do estudo estereoscópico pode determinar melhores resultados em microcirurgias da artéria carótida externa.

Objetivo: Descrever as estruturas da artéria carótida externa sob a visão estereoscópica, identificando seus múltiplos aspectos.

Métodos: Doze regiões cervicais foram dissecadas, utilizando-se microscópio cirúrgico com 3 a 40X de aumento. As disseções anatômicas foram documentadas utilizando-se a técnica para obtenção de imagens tridimensionais (3D), objetivando a produção de impressões estereoscópicas.

Resultados: O uso da técnica estereoscópica possibilitou a abordagem da circulação arterial extracraniana, sendo realizados estudos cirúrgicos do tipo combinado fossa posterior e fossa infratemporal, tornando as microcirurgias e os procedimentos neurocirúrgicos vasculares mais precisos.

Conclusão: O uso das imagens obtidas pela técnica estereoscópica produziu um resultado mais assertivo em relação ao estudo da anatomia para a microcirurgia e procedimentos neurocirúrgicos, facilitando melhor aprendizado previamente à realização de procedimentos complexos em neurocirurgia.

Palavras-chave: visão estereoscópica; artéria carótida externa; imagens tridimensionais.

Study carried out at the Microsurgery Laboratory of the University of Arkansas, Little Rock, USA.

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Introduction

The external carotid artery presents complex anatomy that should be known in depth by vascular surgeons, neurosurgeons, head and neck surgeons, among other professionals. When studied using conventional photographic images, such anatomy does not show the real depth of some structures. In order to mitigate this problem and to provide a tri-dimensional (3D) perspective in printed images, the 3D anaglyphic method was created. The purpose of this study is to present detailed results of microsurgical dissections of the external carotid artery by means of stereoscopic imaging.

Material and methods

This study was conducted at the Microsurgery Laboratory, University of Arkansas, Little Rock, United States. The cervical region of twelve cadavers were dissected using a surgical microscope of 3 to 40 X magnification. The cadavers were injected with color silicon and positioned with a Mayfield skull clamp; the head was stretched and rotated, simulating the surgical position to approach the extracranial arterial circulation. Then, combined posterior fossa and infratemporal fossa surgical dissections were performed, that simulated operations for jugular foramen tumors, as well the simulation of vascular neurosurgical procedures, such as: endarterectomy and extra- to intracranial arterial anastomosis.

The anatomical dissections were documented using the technique to obtain 3D images, aiming at the production of stereoscopic prints. In this technique, pictures are taken of the same object from two different positions, but on the same horizontal plane. The first position corresponds to the left eye view and the second position corresponds to the right eye view. The images were superimposed, using a previously defined software program, coordinated and printed. A Nikon D70 camera, 8.0 megapixels with macro lens was used to document the dissections. The device was adapted to a sliding bar assembled on a tripod. The lens and the shutter speed were set at f32 and 1/60 seconds, respectively. The stereoscopic technique employed by the authors is detailed in a previous study conducted by Ribas et al.¹. The prints made using the stereoscopic technique should be viewed with red-green stereoscopic glasses.

Results

The authors described the anatomy based on the studies conducted by Testut and Latarjet² and Rhoton³.

The external carotid artery arises from the bifurcation of the common carotid artery, also called primitive carotid artery; there is one artery on the right and another on the left side of the neck. The right common carotid originates from the brachiocephalic trunk, at the lower part of the neck, while the common left carotid starts at the aortic arch, presenting a small intrathoracic segment, which makes it longer than the right common carotid. These arteries run from their origins to the upper border of the thyroid cartilage, where they bifurcate to form external and internal arteries.

The common carotid arteries are located in each side of the antero-lateral region of the neck (carotid region), and are related posteriorly with the cervical sympathetic chain and with the transverse apophysis of cervical vertebrae covered by the prevertebral muscles and the deep cervical aponeurosis.

The transverse apophysis (transverse process) of C₆ presents a voluminous and palpable tubercle, which is used as the surgical reference point to access the common carotid; this prominence is called Chassaignac tubercle. At this level, the common carotid artery is crossed posteriorly by the inferior thyroid artery. It is related to the esophagus and the trachea (tracheoesophageal axis) inferiorly, to the laryngotracheal axis superiorly, to the sternocleidomastoid muscle anteriorly, and in close contact with the internal jugular vein along all its extension. The vagus nerve is between these two large caliber vessels.

The common carotid artery, the internal jugular vein and the vagus nerve form the neurovascular bundle of the neck, which is wrapped by a very evident sheath, offering an excellent plane for surgical dissection. This artery bifurcates at the level of the upper border of the thyroid cartilage, forming the internal and external carotids. At the bifurcation, the common carotid artery presents a bulge, known as carotid bulb.

The external carotid artery starts at the level of the upper border of the thyroid cartilage lamina and ends behind the neck of the mandible, between the tip of the mastoid process and the angle of the mandible. It bifurcates inside the parotid gland forming the superficial temporal artery and the maxillary artery, also known as internal maxillary artery.

Figures 1 to 10 illustrate the external carotid artery anatomy. The external carotid artery branches are: superior thyroid artery, ascending pharyngeal artery, lingual artery, facial artery, occipital artery, posterior auricular artery, superficial temporal artery and (internal) maxillary artery.

Superior thyroid artery

The superior thyroid artery starts at the anterior aspect of the external carotid artery, at the level of the greater cornu of the hyoid bone. When the common carotid artery bifurcates

above the usual level, this artery can have its origin at the carotid bulb. Running a deep anterior and later downward course, it divides into small branches onto the upper pole of the thyroid lobe. Along its course, the superior thyroid artery is in contact with the pharynx and the larynx, below the infrahyoid muscles. In this course, it supplies the thyroid gland with its terminal (anterior and posterior) branches and the larynx with its collateral (superior laryngeal and cricothyroid) branches. The following branches have been identified:

- Infrahyoid branch: parallel to the lower border of the hyoid bone, it supplies the supra- and infrahyoid muscles.
- Middle sternocleidomastoid artery branch: 4 to 6 cm long, it starts and crosses the common carotid artery and the internal jugular vein, entering the deep portion of the sternocleidomastoid muscle, and it is accompanied by a large tributary of the internal jugular vein.
- Superior laryngeal artery: has its origin at the superior thyroid artery, following an anteroinferior course to subsequently bifurcate into two terminal branches, one external and one posterior. The external branch is behind the terminal branches of the superior laryngeal nerve and the upper portion of the branch behind the posterior nerve bundles. The posterior branch runs posteriorly, closely related to the arytenoid fold.
- Inferior and posterior laryngeal arteries: they run upwards posteriorly to the cricoarytenoid muscle, after anastomosing with the posterior portion of the superior laryngeal branch. They supply the inferior pharyngeal constrictor, the ary-arytenoid, posterior cricoarytenoid and the cricothyroid muscles.
- Terminal branches: an internal branch that accompanies the upper border of the thyroid body and that anastomoses at the midline with the branch from the opposite side; an external branch that runs downwards and bifurcates over the external portion of the corresponding thyroid lobe; and a posterior branch that crosses behind the thyroid gland, between this gland and the trachea⁴.

Figure 1 shows the side view of the external carotid artery branches and Figure 2 shows the same image, but using the stereoscopic technique.

Ascending pharyngeal artery

The ascending pharyngeal artery is the only branch that comes off the posterior face of the external carotid artery, near or at the same level of the lingual artery. It runs upwards in contact with the lateral wall of the pharynx and ends at the base of the skull, entering the jugular foramen and the hypoglossal canal⁵.

It supplies the dura-mater of the inferior clivus region, and at the same time, it anastomoses with branches of the dorsal meningeal artery, which starts at the meningohypophyseal trunk into the cavernous sinus. These branches supply the upper two-thirds of the clivus⁵ (Figures 3 and 4).

Lingual artery

The lingual artery has its origin at the medial aspect of the external carotid artery, on average 2 cm cephalad to the carotid bulb, and runs obliquely and anteriorly. It runs in front of and over the greater cornu of the hyoid

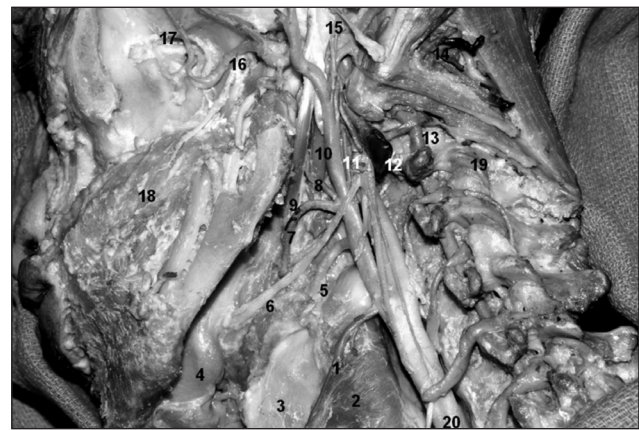


Figure 1. Side view of the external carotid artery branches. 1. superior thyroid artery; 2. inferior pharyngeal constrictor muscle; 3. thyroid cartilage; 4. submandibular gland; 5. lingual artery; 6. hypoglossal nerve; 7. facial artery; 8. ascending palatine artery; 9. stylohyoid muscle; 10. styloglossus muscle; 11. ascending pharyngeal artery; 12. internal jugular vein (sectioned); 13. vertebral artery; 14. suboccipital triangle; 15. styloid process and posterior auricular artery; 16. maxillary artery; 17. infraorbital nerve; 18. buccinator muscle.

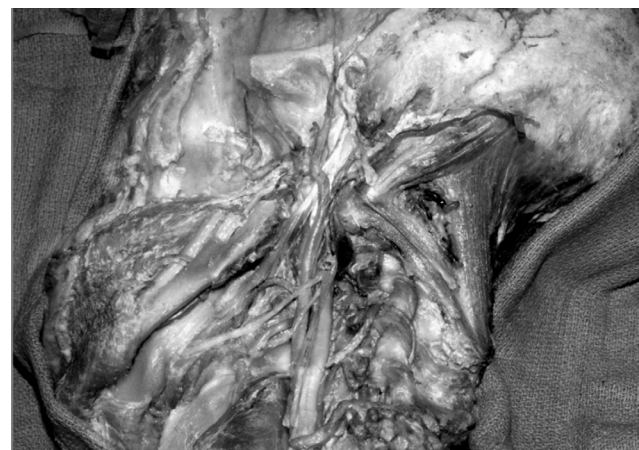


Figure 2. Side view of the external carotid artery branches using the stereoscopic technique.

bone and runs under the hyoglossal muscle to reach the anterior portion of the tongue through its terminal branch (deep lingual artery)^{5,6}.

Along its course, the lingual artery gives off three important collateral branches:

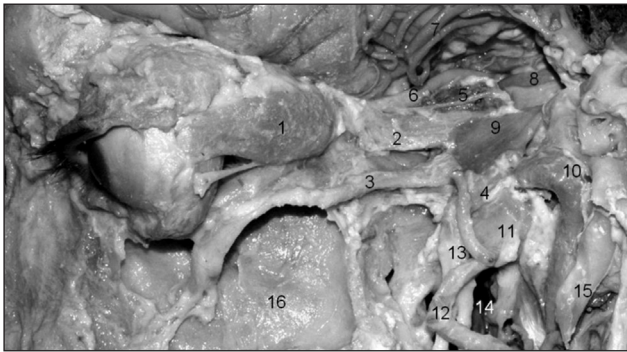


Figure 3. Advanced dissection of the skull base, showing the middle meningeal artery and its point of penetration into the middle fossa (12), as well as the cervical internal carotid artery entering the skull base, after which it is called intrapetrous portion of the internal carotid artery. 1. lateral rectal muscle; 2. V1; 3. V2; 4. V3; 5. trochlear nerve; 6. oculomotor nerve; 7. M2 branches of the middle cerebral artery above the insula; 8. posterior cerebral artery; 9. Gasserian ganglion; 10. ICA; 11. Eustachian tube; 12. middle meningeal artery; 13. V3; 14. oropharynx; 15. styloid process.

- Hyoid branch: it runs along the hyoid bone, first above and then below it. It anastomoses with the branch from the opposed side at the midline, forming an arch located between the genioglossus and geniohyoid muscles. It supplies the insertions of the infrahyoid muscles above and the stylohyoid branches, at the junction where the digastric and mylohyoid branches meet.
- Dorsal lingual artery: it is usually of small caliber and was identified in only one cadaver. It has an ascending branch that runs inferiorly, reaching both sides of the base of the tongue and ending at the mucosa that covers the caliciform papillae, the anterior arch, the soft palate and the epiglottis.

Sublingual artery: it is a flexible vessel in the anatomical dissections that runs in parallel to Wharton's duct, between the mylohyoid and genioglossus muscles. Along its course, it gives off branches to the sublingual gland and the hyoglossus muscle, branches above the genioglossus and branches below the geniohyoid muscle before bifurcating into terminal branches: one superior, towards to middle portion of the horizontal branch of the mandible and one inferior, which enters the middle mental canal through the sub and intragenian foramina.

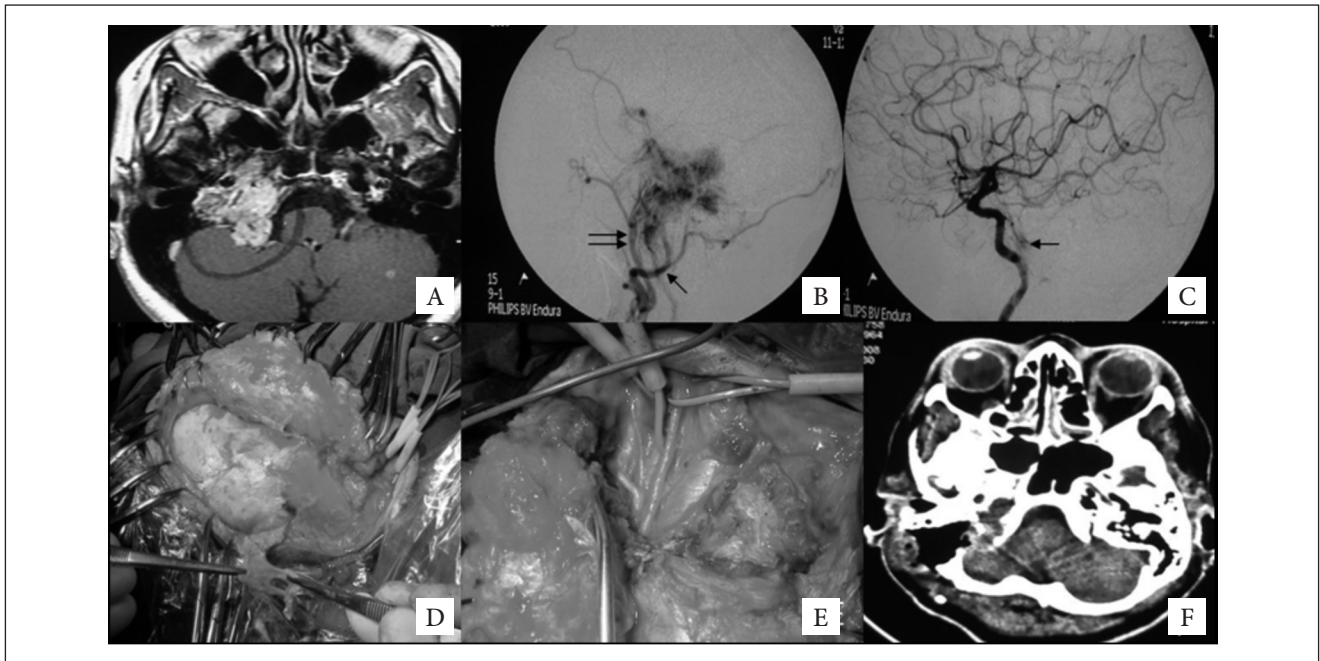


Figure 4. A) Axial magnetic nuclear resonance in T1 with gadolinium, showing an injury on the right jugular foramen surface, compatible with a paraganglioma; B) arteriography with injection of contrast into the right external carotid artery, showing filling across the occipital artery (single arrow) and ascending pharyngeal artery (dual arrow), the two vessels were embolized; C) cross-sectional arteriography with catheterization of the right internal carotid artery, showing a small tumoral blush originated in the carotid-tympanic branches of the intrapetrous portion of the ICA; D) surgical stage showing the previously separated temporalis muscle; E) dissection and exposure of the neurovascular structures of the neck; F) computed axial tomography in the immediate post-operative period, showing hypodense material compatible with fat graft inside the mastoid portion of the temporal bone during the skull base reconstruction.

Facial artery

The facial artery has its origin on average 1.5 cm above the lingual artery. It runs an ascending and oblique course anteriorly; initially in contact with the pharyngeal wall, it passes under the posterior belly of the digastric muscle and the stylohyoid muscle, entering the anterior groove of the masseter muscle and crossing the horizontal ramus of the mandible⁷. Finally, it runs obliquely upward and forward, following the nasolabial crease. It ends at the internal angle of the eye, under the name of angular artery, which anastomoses with one of the branches of the ophthalmic artery⁷. The collateral branches of the facial artery are: the cervical and facial branches (Figures 6 and 7).

Cervical branches

The inferior ascending palatine artery arises from the facial artery 4 to 5 cm distally to its origin. It runs anterior e superiorly, passing between the fibers of the styloglossus muscle. It ascends through the lateral aspect of the pharynx, gives off a branch to the tongue muscles and branches off distally to the palatine tonsil, superior pharyngeal constrictor muscle and stylopharyngeal muscle. It anastomoses with the superior palatine and inferior pharyngeal arteries. The internal pterygoid muscle artery arises from the inferior palatine, and rarely from the facial artery, and supplies the internal pterygoid muscle. The submental artery is a larger vessel, that has its origin at the facial artery at the level of the submandibular gland. It runs horizontally along the lower border of the mandible, between the mylohyoid muscles and the anterior belly of the digastric muscle, supplying several small branches to these muscles along its course. It ends in the mental region, where it anastomoses with the terminal ramifications of the inferior dental arch.

Facial branches

The inferior masseteric artery has this name to be distinguished from the masseteric artery, which arises from the internal maxillary artery and is the main supplier to the masseter muscle. The inferior labial artery arises from the facial artery at the level of the lips. It runs horizontally into the muscles of the lower lip and it anastomoses at the midline with the same artery from the opposite side. The superior labial artery starts at the same level as the inferior labial artery, but it runs to the upper lip, where it anastomoses at the midline with the same artery from the opposite side. The lateral nasal artery

arises from the facial artery at the level of the nose side and runs forward and inside and bifurcates, almost immediately after its origin, in the three branches, resulting in slender ramifications to the alae, to the dorsum and to the lobe. The terminal branches of this artery anastomoses with the same arteries from the opposite side.



Figure 5. Posterior cervical region showing the occipital artery and vein (single arrows). Contralateral occipital artery (dual arrow) and C2 dorsal branch.

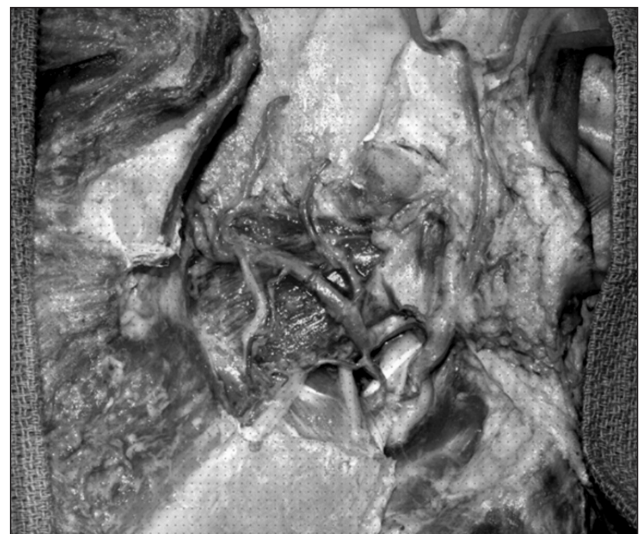


Figure 6. Side view of the intratemporal fossa. The zygoma and part of the mandible were removed. 1. facial artery; 2. buccinator muscle; 3. superior posterior alveolar artery; 4. sphenopalatine artery; 5. deep temporal arteries (anterior and posterior); 6. lateral pterygoid muscle (upper head); 7. maxillary artery; 8. medial pterygoid muscle (lower head); 9. buccal nerve; 10. buccal artery; 11. styloid process; 12. medial pterygoid muscle; 13. lingual nerve; 14. inferior alveolar nerve; 15. external carotid artery; 16. posterior auricular artery; 17. posterior belly of the digastric muscle; 18. angle of the mandible; 19. condylar process.

Occipital artery

It arises from the posterior aspect of the external carotid artery, near the origin of the facial artery, and runs posteriorly and upwards to supply the neck region. The collateral branches of the occipital artery are:

- superior sternocleidomastoid branch: runs to the deep sternocleidomastoid muscle;
- muscular branches in variable number that are given off at different levels of the occipital artery and go to neighboring muscles;
- stylomastoid branch: enters the stylomastoid foramen, in close relation with the facial nerve along its course. Its ramifications go to the eardrum, mastoid cavity and semicircular canals.
- meningeal artery: enters the mastoid foramen, supplying the dura-mater of the mastoid region (Figure 5).

Posterior auricular artery

Also named retroauricular artery, it arises right above the occipital artery and runs a posterosuperior oblique course, passing beneath the posterior belly of the digastric muscle, finally reaching the posterior border of the mastoid^{8,9}. It has the following terminal branches: an anterior branch that supplies the internal face of the ear and supplies the external face with small distal branches, called perforators, which supply the skin of the helix, antihelix, concha and earlobe; one posterior branch, which spreads in the region behind the ear, anastomosing with branches from the occipital and superficial temporal arteries.

Superficial temporal artery

The superficial temporal artery is one of the terminal branches of the external carotid artery. It arises right above the mandibular condyle, inside the parotid gland and goes upward, anterior to the tragus. In its most superficial course, it passes (between the two fascias of the temporalis muscle) above the temporalis muscle and the anterior auricular muscle, and divides into two terminal branches: frontal and parietal. The superficial temporal artery is accompanied along all its course by the superficial temporal vein and partially by the auriculotemporal nerve^{5,6} (Figure 8).

Maxillary artery

The maxillary artery is one of the terminal branches of the external carotid artery (the other one is the superficial



Figure 7. Stereoscopic side view of the intratemporal fossa.

temporal artery), which arises at the level of the neck of the mandible and its initial course is inside the parotid gland⁵. The maxillary artery is divided into three portions: mandibular (or retromandibular), pterygoid and pterygopalatine. These subdivisions of the maxillary artery are established in relation to the lateral pterygoid muscle⁵. From lateral to medial direction, the first portion is laterally, the second is at the same level and the third is medially located in relation to the muscle. In our dissections, the maxillary artery was lateral to the buccal and lingual arteries and to the inferior alveolar nerve in all specimens⁵.

The branches of the first portion penetrate into foramina of base of the skull. This segment of the maxillary artery passes between the mandibular condyle and the sphenomandibular ligament, running alongside the auriculotemporal nerve. Its branches are: the deep auricular artery, closely related to the wall of the external acoustic meatus⁴; the anterior tympanic artery, which runs parallel to the chorda tympani nerve and enters the petrotympanic fissure; and the middle meningeal artery, the first maxillary artery branch that runs superficially to the lateral pterygoid muscle. It may start at a trunk in common with the inferior alveolar artery, but this pattern was not observed in our dissections. It ascended to enter the spinal foramen; the accessory meningeal artery may start at the medium meningeal artery and ascends next to the tensor veli platini and levator

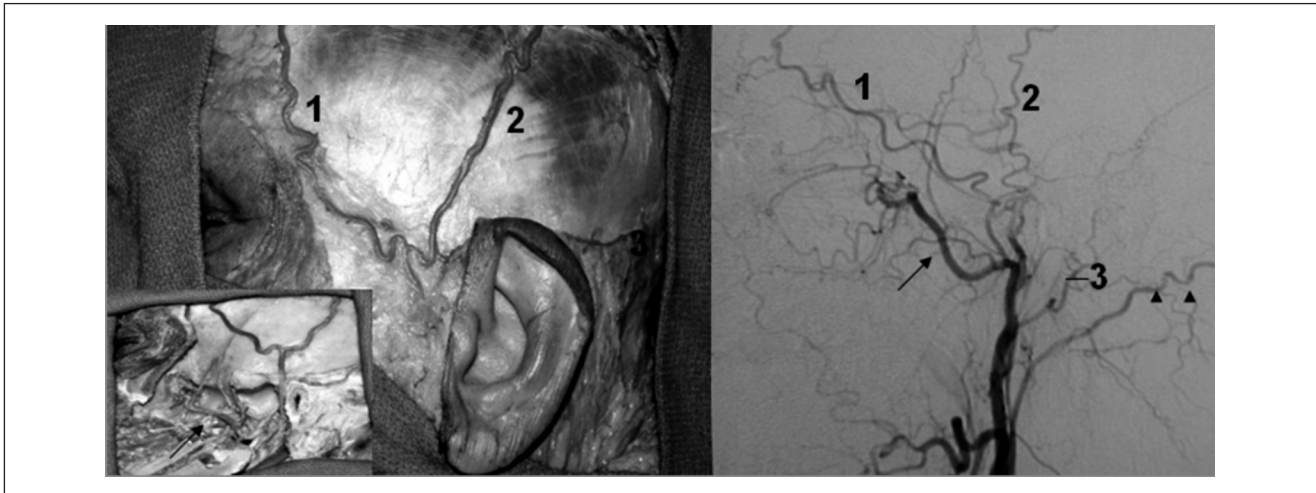


Figure 8. Anomato-radiologic correlation of the superficial temporal artery. 1. frontal branch; 2. parietal branch. The arrow in the smaller figure indicates the maxillary artery.

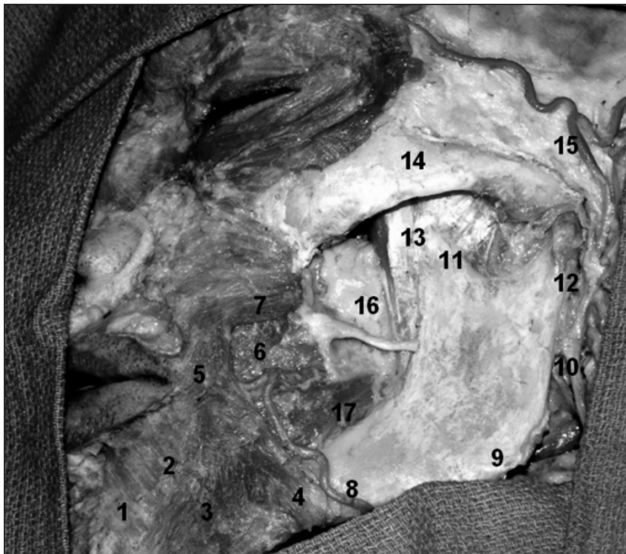


Figure 9. Side view of the left face with dissection of deeper tissues. The masseter muscle was removed. The insertion of the temporalis muscle tendon was inserted in the coronoid process of the mandible. 1. *mentalis* muscle; 2. *depressor labii inferioris*; 3. *depressor anguli oris*; 4. platysma muscle fibers; 5. *orbicularis oris* muscle; 6. *risorius* muscle; 7. greater zygomatic muscle; 8. facial artery; 9. angle of the mandible; 10. retromandibular vein; 11. coronoid process; 12. condylar process; 13. temporalis muscle tendon inserted in the coronoid process; 14. zygoma; 15. superficial temporal artery; 16. perioral fat.

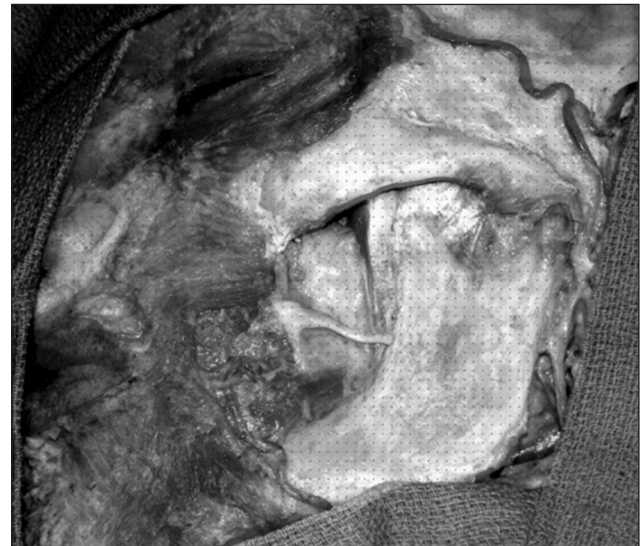


Figure 10. Side view of the left face with dissection of deeper tissues, using the stereoscopic technique.

veli palatine muscles and to reach the foramen ovale, which was observed in two cadavers. The mandibular artery enters the mandibular foramen through the medial surface of the mandible to supply the mandible and the teeth of the inferior dental arch¹⁰.

The second portion of the maxillary artery was located superficially to the lateral pterygoid muscle in all specimens. The anterior and posterior branches of the deep temporal artery supply the temporalis muscle. The masseter artery runs inside the mandibular incisure to reach the masseter muscle^{7,9}. The pterygoid artery presents a variable number and supplies the pterygoid muscle. The buccal artery runs parallel to the buccal branch of the mandibular nerve and supplies the skin and mucous membrane above the buccinator muscle^{7,9} (Figures 9 and 10).

Discussion

The external carotid artery supplies most of the soft tissues of the head and neck, as well as the meninges, giving off six branches before dividing into the superficial temporal artery and the maxillary artery.

Studies on the external carotid artery are extremely important, due to the anatomical structures found there. Poor knowledge of this artery surgical anatomy may lead to inadvertent injuries. At operation, two parameters are used to identify the external carotid artery: it runs more anteriorly than the internal carotid artery and gives off several branches in the neck, while the internal carotid artery has none.

Carotid endarterectomy is the surgical procedure with the highest number of co-operative studies demonstrating its effectiveness. The selection criteria for symptomatic patients were determined particularly by the co-operative study called NASCET (North-American Symptomatic Carotid Endarterectomy Trial)¹¹, according which the neurologically stable patients with carotid stenosis of 70% or above benefit from the surgery in the services where the morbimortality is below 6%. The higher the stenosis degree, the higher the surgery benefit. But, in patients with stenosis between 50 and 69%, the surgery should be indicated only in services where the morbimortality is below 2%¹².

When exposing the cervical spine for cervical spine discectomy through an anterior approach, after opening the superficial fascia and retracting laterally the sternocleidomastoid muscle, the pre-tracheal fascia was observed, which involves the muscles from the lower portion of the hyoid (of which the most important is the omohyoid muscle), the vasculo-nervous bundle, the esophagus and trachea. This bounded region is called the carotid triangle^{12,13}.

The occipital artery is the main branch used for arterial bypass in the posterior fossa and it is usually anastomosed to the posterior inferior cerebellar artery (PICA).

The ascending pharyngeal artery is the main blood supply to the paragangliomas of the jugular foramen and other tumors located in it.

For reconstruction of the base of the skull after resection for carcinoma, the facial artery is the main artery used to supply the flap to be grafted. In juvenile nasopharyngeal angiofibromas, the maxillary artery is the main artery to be embolized. In some cases, the posterior auricular artery supplies the glomic tumors of the jugular foramen, and it may be embolized in the preoperative period or ligated during the operation.

The superficial temporal artery is the main vessel that can be anastomosed in the M4 branch of the middle cerebral artery, in the low-flow bypass¹².

The brain processes the stereoscopic view by observing an object captured from two different points (retina of each eye), providing a notion of depth. The stereoscopic photographic documentation provides this notion of depth which, otherwise, would not be conceived with conventional 2D images. Currently, 3D images have been increasingly produced, not only for medical publications, but especially for general media, which can be seen in 3D movies and animations produced in the last years. However, it should be noted that this technology is not new. Since the publication of Bassett Stereoscopic Atlas¹³, originally published in 1961 and reedited in 1994, up to two recently published microsurgery atlas, one edited by Poletti and Ojemann in 1985¹⁴ and one by Kraus and Bailey in 1994^{15,16}, stereoscopic images have been presented.

Recently, surgical and anatomical stereoscopic videos have been used for pedagogical purposes in projectors, computer displays and printed (anaglyphic) method. Besides offering a better anatomical illustration and a better 3D understanding, the use of stereoscopic images can also enhance the individual's familiarity with his/her own three-dimensionality and promote the spatially related skills. The article of Ribas et al.³ already highlighted that the form is the primitive unit of perception and that stereoscopic images have definitive advantage in the production of illustrations. Virtual environments for surgery planning and training, which are being developed through telesurgical systems, will also require stereoscopic visualization and the individual's familiarity with the 3D concepts and stereoscopy.

Conclusion

The study of the external carotid artery, under the perspective of microsurgical anatomy, provides a 3D view to the surgeon, due to the fact that an anatomical region can be studied in different angles and according to the surgical position of the patients. The stereoscopic documentation is useful, as it adds the sense of depth of the documented anatomy. Studies of this type can be more didactical in the teaching of anatomy.

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All figures are available in color at: <http://www.jvascbr.com.br/>
Figures 6 and 10 need 3D glasses.