Annals of Anatomy 238 (2021) 151789

Contents lists available at ScienceDirect

Annals of Anatomy

journal homepage: www.elsevier.com/locate/aanat

RESEARCH ARTICLE

Anatomic mapping of the collateral branches of the external carotid artery with regard to daily clinical practice

Rosana Cobiella[a,1], Sara Quinones[a,1], Paloma Aragones[a,c], Xavier León[d], Anto Abramovic[b,e], Teresa Vazquez[a], José Ramón Sanudo[a], Eva Maranillo[a], Lukasz Olewnik[f], Clara Simon de Blas[g], Ian Parkin[h], Marko Konschake[b,*]

[a] Department of Anatomy and Embryology, School of Medicine, Complutense University of Madrid, Madrid, Spain
[b] Department of Anatomy, Histology and Embryology, Institute of Clinical and Functional Anatomy, Medical University of Innsbruck (MUI), Innsbruck, Austria
[c] Department of Orthopedics, Hospital Universitario Santa Cristina, Madrid, Spain
[d] Department of ORL, Hospital de la Santa Creu i Sant Pau, UAB, Spain
[e] Department of Neurosurgery, Medical University of Innsbruck (MUI), Innsbruck, Austria
[f] Department of Anatomical Dissection and Donation, Medical University of Lodz, Poland
[g] Department of Computer Science, Universidad Rey Juan Carlos I, Madrid, Spain
[h] University of St. Andrews, School of Medicine, Scotland, United Kingdom

ARTICLE INFO

Article history:
Received 28 April 2021
Received in revised form 8 June 2021
Accepted 8 June 2021
Available online 30 June 2021

Keywords:
External carotid artery
Arterial variations
Interventional radiology
Vascular surgery

ABSTRACT

Background: To identify the anatomical variations of the main branches of the external carotid artery (lingual, facial, occipital, ascending pharyngeal and sternocleidomastoid), giving information about the calibers and origins with the aim of creating a new classification useful in clinical practice.
Material and methods: 193 human embalmed body-donors were dissected. The data collected were analyzed using the Chi^2 test. The results of previous studies were reviewed.
Results: The majority of the anterior arterial branches (superior thyroid, facial and lingual artery) were observed with an independent origin, respectively, classified as pattern I (80.83%, 156/193). In 17.62% (34/193) a linguofacial trunk, pattern II, has been observed, only in 1,04% (2/193) a thyrolingual trunk, pattern III, has been found and in one case (1/193, 0.52%) one thyrolinguofacial trunk, pattern IV, was found. Depending on the posterior branches (occipital and ascending pharyngeal), four different types could be determined: type a, the posterior arteries originated independently, type b, the posterior arteries originated in a common trunk, type c, the ascending pharyngeal artery was absent, type d, the occipital artery was absent.
Conclusion: Anatomical variations in these arteries are relevant in daily clinical practice due to growing applications, e.g., in Interventional Radiology techniques. Knowledge of these anatomical references could help clinicians in the interpretation of the carotid system.

1. Introduction

Nowadays, the anatomical knowledge of the carotid vascular axis is important from a diagnostic as well as from a therapeutic point of view in diverse medical fields e.g., Otolaryngology, Interventional Radiology and Vascular Surgery. A major injury of the great cervical vessels during surgery can have direct consequences for the patient's life (Hollinshead, 1954), entailing one of the main causes of morbidity and, above all, mortality. Furthermore, in the field of Interventional Radiology, it is not currently limited to diagnosis, but also extends to the endoluminal therapeutic approach to vascular pathology. In this case, in a subtraction radiological technique, which enhances the arterial vessels by means of a contrast agent, all the external anatomical references are lost except for the bone limits. Therefore, the anatomical domain of the vascular elements is essential for a clear identification of each vessel in Interventional Radiology, especially as a preoperative evaluation for techniques such as extracranial-intracranial bypass procedures and carotid endarterectomies (Germans and Regli, 2014; Rajamani and Chaturvedi, 2011).

* Corresponding author at: Institute of Clinical and Functional Anatomy, Medical University of Innsbruck (MUI), Müllerstr. 59, 6020 Innsbruck, Austria.
E-mail address: Marko.konschake@i-med.ac.at (M. Konschake).
[1] Denotes co-first authorship.

https://doi.org/10.1016/j.aanat.2021.151789

Anatomic variability of the external carotid artery has been reported in previous literature with an incidence of 2.5%–21% (Adachi and Kihara, 1928; Gluncic et al., 2001; Lucev et al., 2000; Mata et al., 2012; Ozgur et al., 2008; Sanjeev et al., 2010; Shintani et al., 1999; Zumre et al., 2005). To date, 2 previous studies referred to a classification of the branches of the carotid arterial axis into arterial patterns (Livini, 1903a, b).

Previously, we studied the anatomical variations of the superior thyroid and superior laryngeal arteries (Vazquez et al., 2009). Therefore, the aim of this study was to complete the identification for all anatomic variations within the main branches of the external carotid artery and to establish a new classification for simple clinical handling.

2. Material and methods

A total sample of 193 human embalmed body-donors (386 hemi-necks) from the Department of Anatomy, University of Cambridge, UK, were dissected by preclinical medical students and recorded during a period of four years.

We have undertaken this study with a sample that previously has been partially dissected by medical students. Most of the students did not dissect the suprahyoid region, however, some touched and cut some branches of the ECA. Due to this circumstance, some of them are partially deteriorated. Even so, 386 hemi necks were dissected. The results found were out of a total of 207, although in some cases (due to failures in previous dissections) the number of sample size was lower. Therefore, these cases were not included in the present study. The main sample considered was a total of 207 hemi necks. Detailed dissections of arteries were done by experienced anatomists.

The individuals had given their written consent to body donation and use of their bodies for scientific and educational purposes prior to death. According to National Law, scientific institutions (in general Institutes, Departments or Divisions of Medical Universities) are entitled to receive the body after death mainly by means of a specific legacy, which is a special form of last will and testament. No bequests are accepted without the donors having registered their legacy and been given appropriate information upon which to make a decision based upon written informed consent (policy of ethics); therefore, an ethics committee approval was waived (Konschake and Brenner, 2014).

The gender distribution was 74 male and 91 female body-donors, with an age range of 60–103 years. Clinical histories were available; no case contained any reference to previously performed vascular surgical intervention.

The dissections were completed and distances between main collateral branches and external diameters were measured with digital calipers (Mitutoyo Absolute Digimatic Caliper, UK). These measurements were independently verified by two experienced anatomists.

The initial descriptive data presentation was performed using a Windows Excel sheet (Microsoft Office, Version 1908, Microsoft, Inc., Redmond, WA, USA), the subsequent statistical analysis was performed with SPSS (IBM SPSS Statistics, version 24.0, IBM Corporation). After initial testing for normal distribution using Kolmogorov–Smirnov test, variances between individual groups compared with the population were analyzed using Chi^2 test. P values of <0.05 were considered statistically significant.

Following the measurements and statistical evaluation, the results were compared with previously published studies. This resulted in a new classification system with special regard to clinical practice and usability.

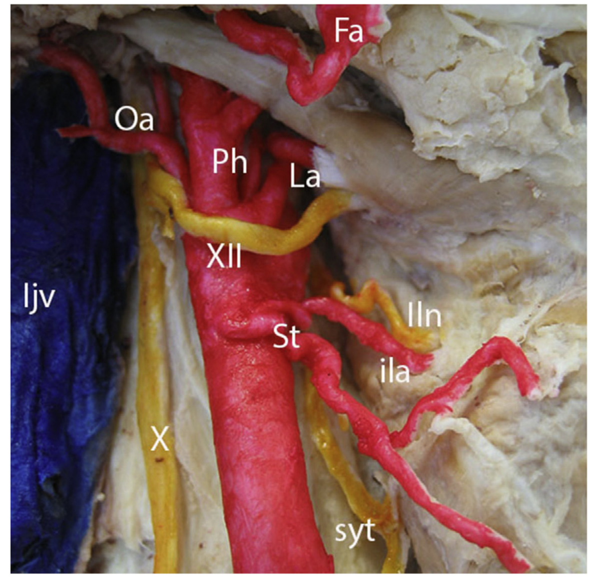

Fig. 1. Right lateral view of Area II after decline the sternomastoid muscle (carotid triangle). Dissection of the main collateral arteries of the external carotid artery and its relationships with the sympathetic trunk, vagus nerve, hypoglossal nerve and internal laryngeal nerves.
The concept of Area II is clinical used in ENT surgery, is the suprahyoid region behind the digastric muscle and occupied by the internal jugular vein, external carotid artery and accessory, vagus and hypoglossal nerves.
Ijv, internal jugular vein, St: superior thyroid artery, ila: internal laryngeal artery, Iln: internal laryngeal nerve, La: lingual artery, Fa: facial, Oa: occipital artery. Ph: ascending pharyngeal artery, X: vagus nerve, XII: hypoglossal nerve.

3. Results

Firstly, the origin and calibers of the main collateral arteries (lingual, facial, occipital, ascending pharyngeal and sternocleidomastoid) were studied (Fig. 1). Secondly, a new classification of the branches of the external carotid artery was developed while comparing our findings with those published previously.

3.1. Lingual artery

The lingual artery was the largest artery that originated immediately cranial to the superior thyroid artery. The investigation of this artery was performed in 207 hemi-necks. The artery was observed arising from four different levels: external carotid artery (164/207, 79.23%), common origin in form of an arterial trunk (37/207, 17.4%) either with the superior thyroid artery, with the facial artery or with both of them, carotid bifurcation (2.41%) and the common carotid artery (0.48%) (Fig. 2). The localization of the artery's origin was variable, the anterior surface of the carotid being the most common in 76.6% of cases (Fig. 3), followed by the anteromedial (14.3%), medial (6.5%), anterolateral (1.3%), and lateral (1.3%) side.

In our sample, 37 trunks were found: 34/37 linguofacial trunks (91.89%) (Fig. 4 B), 2/37 thryrolingual trunks (Fig. 4A) and 1/37 thyrolinguofacial trunk (rare variation included in (Vazquez et al., 2009)).

Linguofacial trunks were found in 40.54% (15/37) on the left-hand side originating from the external carotid artery. On the right side, two thyrolingual trunks (2/37, 5.4%) were found, one of them originating from the common carotid and the other from the external carotid. The rest of the arterial trunks on the right side were linguofacial trunks (19/37, 51.35%) arising at the level of the external carotid artery in the majority of cases, except one starting from the carotid bifurcation. In five cases the linguofacial trunks were

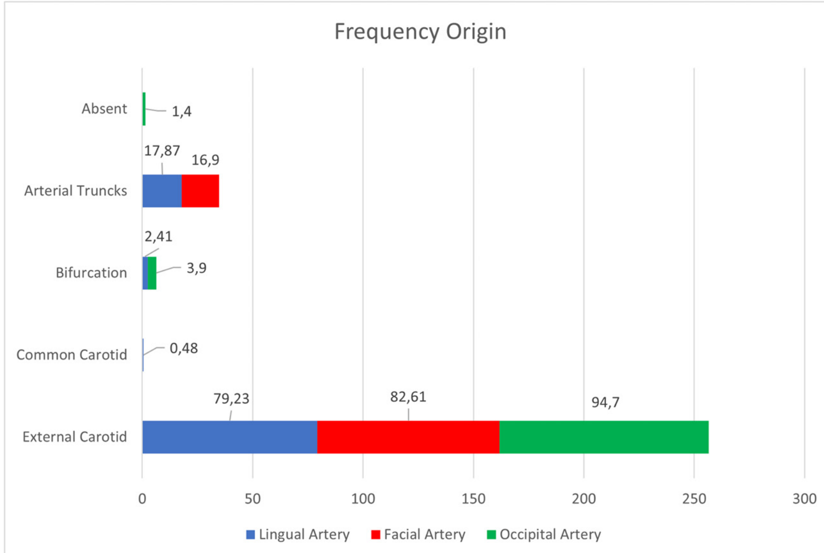

Fig. 2. Frequency origin of the lingual, facial and occipital artery.

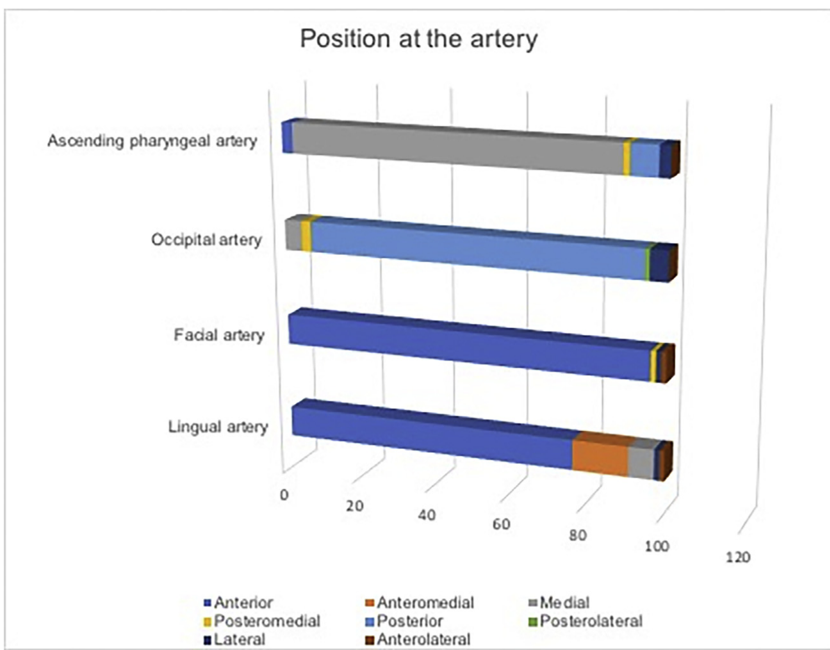

Fig. 3. Position at the artery in the case of the ascending pharyngeal, occipital, facial and lingual.

registered bilaterally. Compared to an isolated origin of the lingual artery, the common arterial trunk showed a 0.7 cm higher origin with no significant difference ($p > 0.05$).

No significant differences were observed regarding the origin of the lingual artery, neither by side nor by gender ($p > 0.05$).

The mean distance between the independently originating lingual arteries and the carotid bifurcation was 1.32 cm with a standard deviation of 0.76 cm. The range was established between 0.1 and 4.1 cm.

The mean distance between the origin of the linguofacial trunk and the carotid bifurcation amounted to 1.39 cm with a standard deviation of 0.82 cm and a range of 0.2–4.0 cm. In six body-donors (2.9%; 6/207) the lingual artery originated from the bifurcation itself, of which five were in isolation and one in form of a linguofacial trunk (Fig. 5).

In two cases, the lingual artery originated at the level of the common carotid artery, one in isolation and the other in the form of a thyrolingual trunk. These two subtypes had distances between the origin and the carotid bifurcation of 0.3 cm and 2.0 cm, respectively (Fig. 5).

We have not observed statistically significant differences in the distance of origin of the lingual artery, both in isolation and in the form of the arterial trunk, neither by side nor by gender ($p > 0.05$).

The caliber found for the lingual artery ranged from 0.1 cm to 0.8 cm, with a mean caliber of 0.3 cm and a standard deviation of 0.08 cm (Fig. 6). In the distribution of arterial caliber by side, we have not observed statistically significant differences ($p > 0.05$). However, when evaluating gender differences, we have observed that the diameter of the lingual artery has been significantly greater in men ($p = 0.027$).

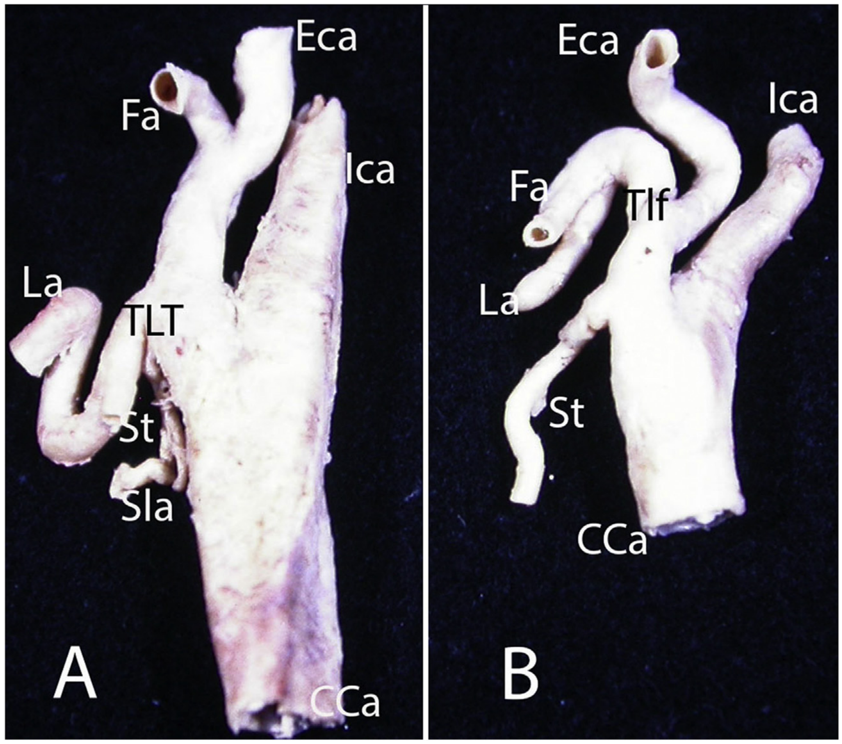

Fig. 4. Isolated block of the carotid arteries to show two of the common patterns observed in this study. A. Left view of a thyrolingual trunk formed by the superior thyroid with the lingual artery. B. Left view of a linguofacial trunk constituted by the lingual and facial artery.
CCa: common carotid artery, Ica: internal carotid artery, Eca: external carotid artery, TLT: thyrolingual trunk, St: superior thyroid artery, La: lingual artery, Fa: facial, Tlf: linguofacial trunk, Sla: superior laryngeal artery.

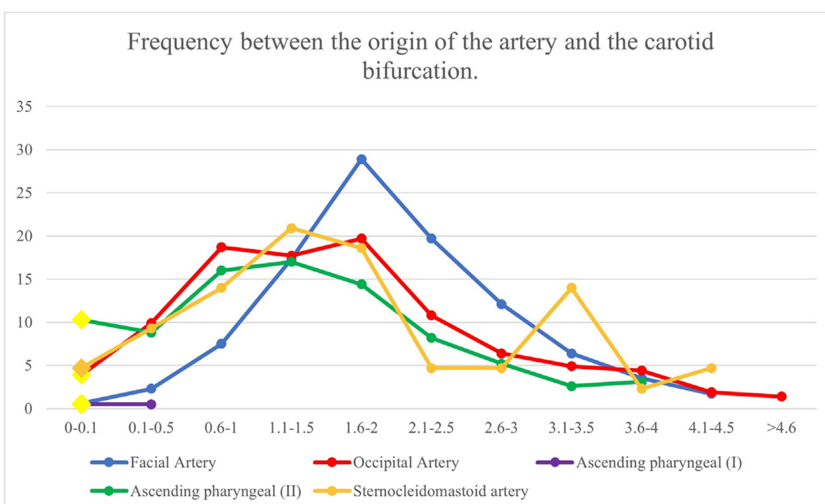

Fig. 5. Frequency between the origin of the studied artery and the carotid bifurcation (distance in mm in the X-axis). Studied arteries: facial, occipital, ascending pharyngeal (I), ascending pharyngeal (II) and sternocleidomastoid artery.

3.2. *Facial artery*

The facial artery was the largest artery that originates immediately cranial to the lingual artery.

The artery was observed arising from three different levels, mainly from an independent branch originating isolated from the external carotid artery (171/207, 82.61%), as arterial trunks (35/207, 16.9%) or isolated at the carotid bifurcation (1/207, 0.48%). In the case of the origin of the facial artery as an arterial trunk (16.9%), it always arose together with the lingual artery except a unique thyrolinguofacial trunk. All these trunks originated from the external carotid artery except for one that did so at the level of the carotid bifurcation. Therefore, the most frequent origin was the external carotid artery (99.03%; 205/207 [$p < 0.01$]) either independently or in the form of an arterial trunk (Figs. 7 and 8).

The origin of the facial artery was investigated in a total of 77 samples. Its origin was variable, being the most common with a 96.1% (74 cases) in the anterior face of the artery, the remaining three cases were in an antero-lateral, lateral, and postero-medial position (1.3% each) (Fig. 3).

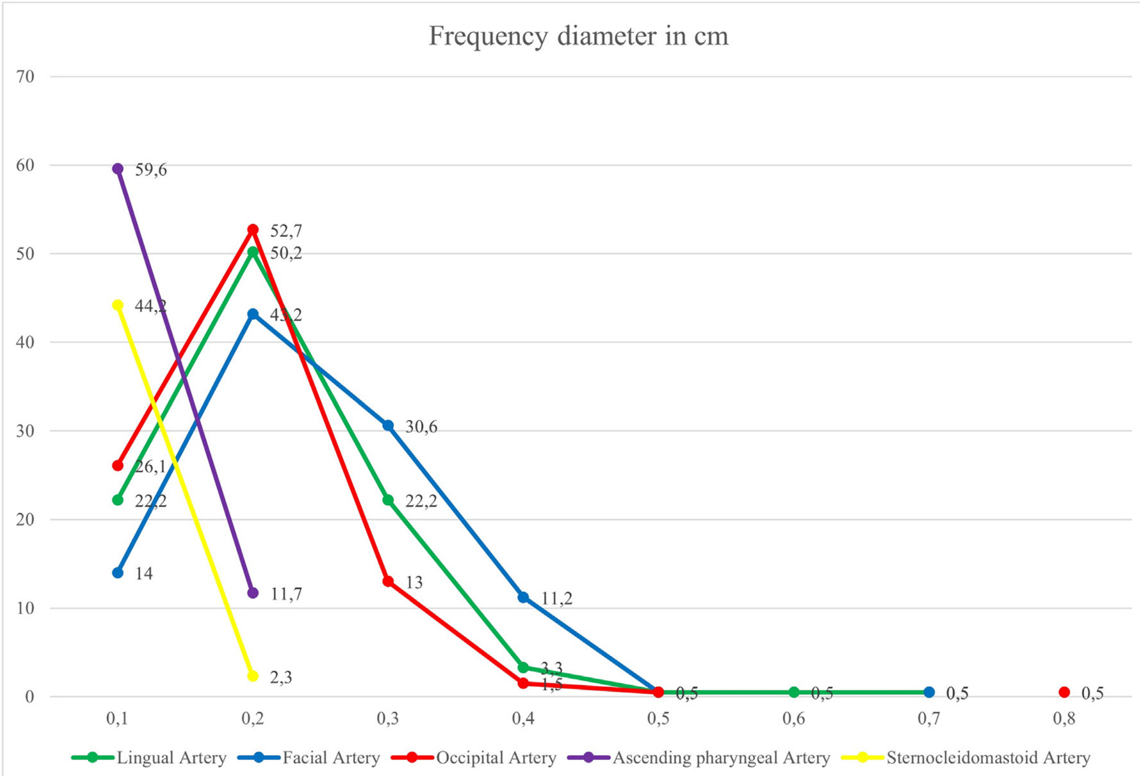

Fig. 6. Frequency diameter in cm of the lingual, facial, occipital, ascending phayngeal and sternocleidomastoid artery. cm, centimeters.

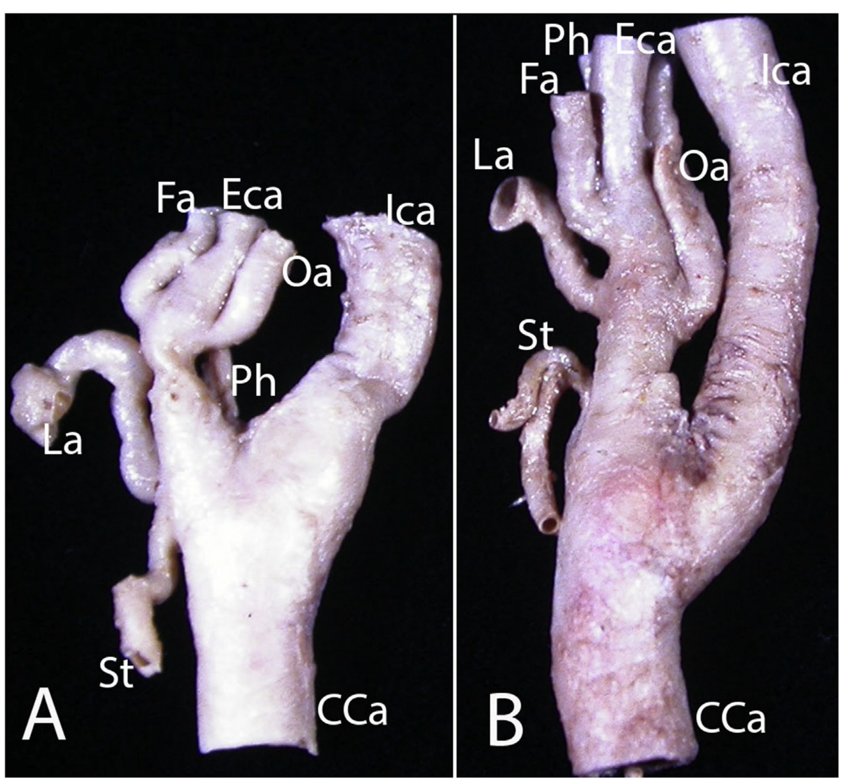

Fig. 7. Isolated block of left carotid arteries showing the variability of origin of different arteries.
CCa: common carotid artery, Ica: internal carotid artery, Eca: external carotid artery, St: superior thyroid artery, La: lingual artery, Fa: facial, Oa: occipital artery. Ph: ascending pharyngeal artery.

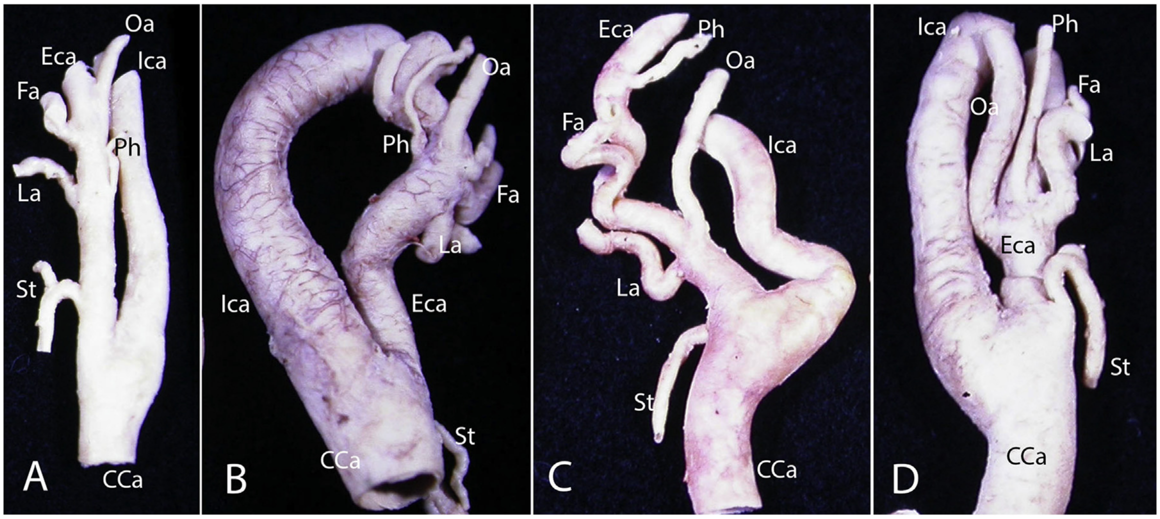

Fig. 8. Isolated block of the carotid arteries showing the variability of origin of different arteries. A, C, left lateral views and B, D, right internal views. CCa: common carotid artery, Ica: internal carotid artery, Eca: external carotid artery, St: superior thyroid artery, La: lingual artery, Fa: facial, Oa: occipital artery. Ph: ascending pharyngeal.

No statistically significant differences were observed regarding the origin of the facial artery with regards to the location, neither by side nor by gender ($p > 0.05$).

The distance between the origin of the facial artery and the carotid bifurcation in the external carotid, in isolation, is shown in Fig. 5.

The maximum distance at which the origin of the facial artery occurred, in the external carotid artery, was 4.5 cm of the carotid bifurcation while the minimum was 0.2 cm away from the carotid bifurcation. The mean was 2.08 cm with a standard deviation of 0.82 cm.

The caliber of the facial artery was observed in 206 cases, 95 in male and 111 in female with results ranging from 0.2 cm to 0.8 cm. The mean value obtained was 0.36 cm with a standard deviation of 0.23 cm (Fig. 6).

In the distribution of arterial caliber by side and gender we have not observed statistically significant differences ($p > 0.05$).

3.3. Occipital artery

The artery was observed arising from two different levels: external carotid artery (94.7%, 195/206) and carotid bifurcation (3.9%, 8/206, $p < 0.01$) (Figs. 7 and 8). Exceptionally, on the right side, the artery was not identified in three samples (1.4%, 3/206).

Analyzing the origin of the occipital artery according to the side, there was a predominance of origin of the artery at the level of the bifurcation on the right side ($p = 0.033$).

No statistically significant difference was observed regarding gender ($p > 0.05$).

Differing from the origin location of the upper mentioned lingual and facial artery, the location of the origin of the occipital artery, in any of its levels, was the posterior face of the vascular axis in most cases (74/85 87.1%). In the remaining cases, the origin was observed in a lateral position (4/85 4.7%), medial (4/85 4.7%), postero-medial (2/85, 2.4%) and in a postero-lateral position (1/85, 1.2%, Fig. 3).

The distance from the origin of the occipital artery to the carotid bifurcation in the external carotid is shown in Fig. 5. In 8 samples (3.9%; 8/203) the occipital artery originated at the level of the carotid bifurcation itself.

The mean distance at which the origin was established was 1.8 cm with a standard deviation of 1.15 cm and a range of 0.1–6.7 cm.

Table 1
Distances of the origin of the ascending pharyngeal artery regarding the occipital artery.

Origin of the ascending pharyngeal artery.		Total (n = 174)	
	cm	(n = 23) N	%
Regarding the occipital artery	≤0.5	14	60.9
	0.6−1	5	21.7
	1.1−1.5	1	4.3
	1.6−2	2	8.7
	2.1−2.5	1	4.3

N, sample size and cm, centimeters.

The occipital artery's origin was observed in 199 cases (90 in men and 109 in female), finding values that ranged between 0.1 cm and 0.9 cm. The overall mean diameter obtained was 0.27 cm with a standard deviation of 0.09 cm (Fig. 6).

In the distribution of arterial caliber as well as origin by side and gender, we have not observed statistically significant differences ($p > 0.05$).

3.4. Ascending pharyngeal artery

It is the last of the great arteries described, classically located in the carotid triangle and has the most variable origin of all collateral branches (Figs. 7 and 8).

The origin of the ascending pharyngeal artery was studied in 207 cases (95 men and 112 female), being observed at up to eight different levels: external carotid (70.5%), occipital (13.5%), carotid bifurcation (9.7%), internal carotid (1.4%), common carotid artery (1%), facial (1%), lingual (0.5%) and superior laryngeal arteries (0.5%); in 4 samples (1.9%), the ascending pharyngeal artery was not identifiable.

In sum, the most frequent origin was observed at the level of the carotid arterial axis in 81.2% of the cases. No significant differences were observed in the origin of the ascending pharyngeal artery neither by side nor by gender ($p > 0.05$). The distance of origin of the ascending pharyngeal is shown in Table 1.

The ascending pharyngeal artery origin location was observed on the medial face of the vascular axis in most cases (60/70, 85.7%), the remaining 10 cases were distributed as follows: posterior (5/70, 7.1%), lateral (2/70, 2.9%), anterior (2/70, 2.9%) and, finally, postero-medial (1/70, 1.5%) (Fig. 3). The distance from the origin of the ascending pharyngeal artery to the carotid bifurcation in the arteries that arise from the common and external carotid, is shown in Fig. 5.

In 13.5% of cases (28/207), the ascending pharyngeal artery arose in a common trunk with the occipital artery.

The caliber of the ascending pharyngeal artery, measured in 198 cases (92 men, 106 female) showed a range of 0.05 cm to 0.3 cm. The overall mean diameter obtained was 0.17 cm with a standard deviation of 0.06 cm (Fig. 6).

We have not observed statistically significant differences for the distance of origin or the caliber of the ascending pharyngeal artery neither as a function of the side nor as a function of gender ($p > 0.05$).

3.5. Sternocleidomastoid artery

Despite the bibliography defined that there are actually two sternocleidomastoid arteries, in the present study no distinction was made between superior and inferior. Furthermore, only the cases when its origin was located in the carotid axis have been studied (the rest were not considered). The total number of sternocleidomastoid arteries measured amounted to 43 cases (43/207, 20.7%). 40 arteries originated at the level of the external carotid artery (40/43; 93.02%), 2 cases (2/43, 4.7%) at the level of the carotid bifurcation and 1 case (1/43, 2.3%) at the level of the common carotid artery.

The mean distance at which the origin was established, in the external carotid artery, was 2 cm with a standard deviation of 1.11 cm and a range of 0.4–4.5 cm (Fig. 5). The only case originating at the level of the common carotid was at 0.3 cm distance.

Most of the cases in which the sternocleidomastoid artery originated from the external carotid artery did so in the territory where the occipital artery usually originated and not in the territory of the superior thyroid artery.

The mean diameter of the sternocleidomastoid artery amounted to 0.13 with a standard deviation of 0.04 cm as well as a range of 0.05 cm to 0.3 cm (Fig. 6).

3.6. Proposal of a new classification

After the initial dissection, measuring procedure and statistical analysis, a thorough literature review with regard to currently available classification systems for the topography of the external artery's branches was performed. As a result, a new classification system was developed dividing the collateral branches of the external carotid artery into two groups: anterior branches (superior thyroid, lingual and facial artery), and posterior branches (occipital and ascending pharyngeal artery), not including the superior laryngeal artery and sternocleidomastoid due to their lower incidence.

The distribution of the anterior branches with regard to its distance from the carotid bifurcation was constant throughout the entire sample: superior thyroid artery followed by lingual and facial artery. The only observed variation, which maintains the previously mentioned sequence, was the association of the different branches in arterial trunks, either linguofacial (lingual and facial artery), or thyrolingual (superior thyroid and lingual artery).

This fact determined 3 main patterns: (Fig. 9)

- Pattern I: the three anterior branches originate independently. It is the most frequent pattern, which was present in 80.83% 81.35% of our study cohort.
- Pattern II: The superior thyroid artery arises separately, while the lingual and facial artery form a common trunk (linguofacial trunk). This type was observed in 17.62% of our study cohort.
- Pattern III: The superior thyroid artery forms a common trunk with the lingual artery (thyrolingual trunk) while the facial artery remains with an isolated origin. This pattern was observed in 2 of the 193 cases (1,04%).
- Pattern IV: A common trunk formed by the superior thyroid, lingual and facial artery (thyrolinguofacial trunk). This pattern was observed only in one case (0.52%).

On the other hand, the distribution of the origins of the posterior arteries (occipital and ascending pharyngeal) raised four different possibilities, being classified as types (these could appear on each pattern):

- Type a: The posterior arteries originate independently. In our study, this was the most frequent type (159/193, 82,4%).
- Type b: The posterior arteries originate in a common trunk (27/193, 13.99%).
- Type c: The ascending pharyngeal artery is absent (4/193, 2.07%).
- Type d: The occipital artery is absent (3/193, 1,55%).

To analyze if there are significant differences among authors in the incidence of variations of the superior thyroid artery origins, we have compared the observed data by means of the Fisher homogeneity test with a significance level alpha = 0.05. When comparing authors with data obtained, results show that there are significant differences (p-value = 6.65e-06) when considering the four variation types. Anomalous larger percentages for pattern I and smaller for pattern II were reported by Ozgur et al. (2008), extremely larger percentages por pattern III and anomalous smaller for pattern II were reported by Aaron and Chawaf (1967) and extremely large for pattern IV by Zumre et al. (2005) and Adachi and Kihara (1928) (Aaron and Chawaf, 1967; Adachi and Kihara, 1928; Ozgur et al., 2008; Zumre et al., 2005). The confidence interval for each variation type is given in Table 4. Fig. 10 shows the compared data within a box plot.

4. Discussion

The course of the main branches of the external carotid artery is of great relevance for both diagnostic and therapeutic approaches. The variability of these structures has been described several times, but a large cohort was lacking a classification of defined variations and a categorization according to its prevalence. With the help of this study, which dealt with anatomical dissection as well as statistical elaboration and literature research, this gap could be closed for the first time.

4.1. Lingual artery

The most frequent origin of the lingual artery was the external carotid artery (Adachi and Kihara, 1928; Hollinshead, 1954; Livini, 1903a, b; Quain, 1844; Tubbs et al., 2016), being present in 95.7% of our study cohort.

In 19.18% of the cases, the origin of the lingual artery was joined by other branches, mainly the facial artery, forming a linguofacial trunk, (17.62%), less frequently, the superior thyroid artery, thyrolingual trunk (1.04%), and exceptionally the thyrolinguofacial trunk (0.52%).

The percentage obtained in our series, although somewhat lower, is similar to that reported by previous literature (Adachi and Kihara, 1928; Hollinshead, 1954; Livini, 1903a, b; Quain, 1844; Tubbs et al., 2016). On the contrary, our literature review found no study describing a bilateral linguofacial or thyrolingual trunk. However, in our sample, this bilaterality was observed in up to 27.8% of the linguofacial or thyrolingual trunk subtypes. The distance of the

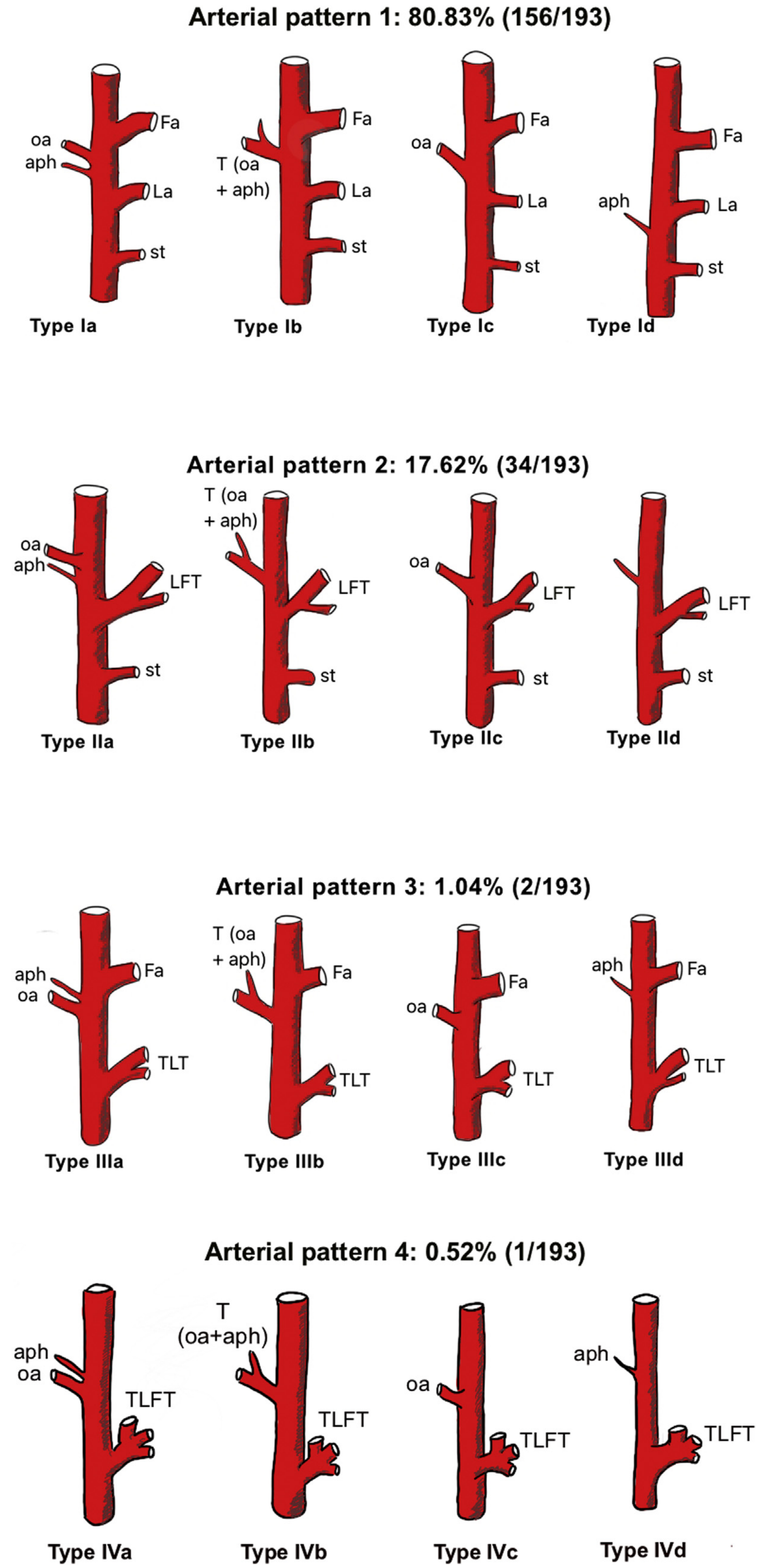

Fig. 9. Drawing of the arterial patterns observed in this study. Four different patterns regarding the bifurcation of the anterior branches (superior thyroid, lingual and facial) and types of origin of the occipital and pharyngeal ascending arteries.
TLT: thyrolingual trunk, LFT: linguofacial trunk, TLFT: thyrolinguofacial trunk, T: trunk La: lingual artery, st: superior thyroid artery, Fa: facial, oa: occipital artery, aph: ascending pharyngeal artery.

Table 2
Arrangement of the origin of the ascending pharyngeal artery in the carotid arterial axis and in the occipital artery. Comparison with the bibliography consulted. In the case of Livini (1903a,b) the percentage of cases of the internal carotid artery, carotid bifurcation, external carotid artery and absent cases (3%) amounted to 100% of the sample. n = sample size.

Ascending pharyngeal	Intern carotid	Common carotid	External carotid	Carotid bifurcation	Occipital
Quain (1844) (n = 144)	6.2%	–	73.6%	4.1%	13.2%
Livini (1903a,b) (n = 200)	3%	–	81%	10%	16.3%
Adachi and Kihara (1928) (n = 128)	8%	–	66%		26%
Czerwinski (1981) (n = 240)	–	2%	74%	–	24%
Our sample (2020) (n = 207)	1.4%	1%	70.5%	9.7%	13.5%

Table 3
Situation of origin. Comparison of our results with those of Livini (1903a,b) if we analyze the terminology assigned for the different faces of the carotid arterial axis.

Our sample (2020)	Situation of origin		Livini (1903a,b)
Thyroid, lingual and facial	Anterior	Internal	Thyroid, lingual and facial (30%)
Ascending pharyngeal	Medial	Posterior	Ascending pharyngeal and occipital
Occipital	Posterior	External	Occipital (30%)
	Lateral	Anterior	Facial

Table 4
Arrangement of the anterior branches (superior thyroid, lingual and facial arteries), expressed in percentages.

Authors	Pattern I: independently	Pattern II: linguofacial trunk	Pattern III: thyrolingual trunk	Pattern IV: thyrolinguofacial trunk
Quain (1844) (n = 302)	79.3	20	0.7	0
Livini (1903a,b) (n = 200)	73.5	25	1.5	0
Adachi and Kihara (1928) (n = 300)	76.3	18.7	2	3
Aaron and Chawaf (1967) (n = 187) (anatomical)	73.2	20.9	5.9	0
Aaron and Chawaf (1967) (n = 100) (radiological)	65	26	9	0
Poisel and Golth (1974) (n = 156)	72.69	23.1	3.21	0.64
Czerwinski (1981) (n = 240)	80.9	17.5	1.6	0
Shintani et al. (1999) (n = 58)	65.5	31	3.5	0
Lucev et al. (2000) (n = 40)	80	20	0	0
Zumre et al. (2005) (n = 40)	75	20	2.5	2.5
Ozgur et al. (2008) (n = 40)	90	7.5	2.5	0
Sanjeev et al. (2010) (n = 37)	78.38 (29/37)	18.92 (7/37)	2.7 (1/37)	0
Mata et al. (2012) (n = 36)	77.8	19.4	2.8	0
Yonenaga et al. (2011) (n = 56)	69.6	28.6	1.8	0
Our study (2020) (n = 193)	80.82	17.62 (34/193)	1.04 (2/193)	0.52 (1/193)
$IC_{95\%}$ (p)	[73.98;77.75]	[19.16;22.74]	[2;3.43]	[0.15;0.74]

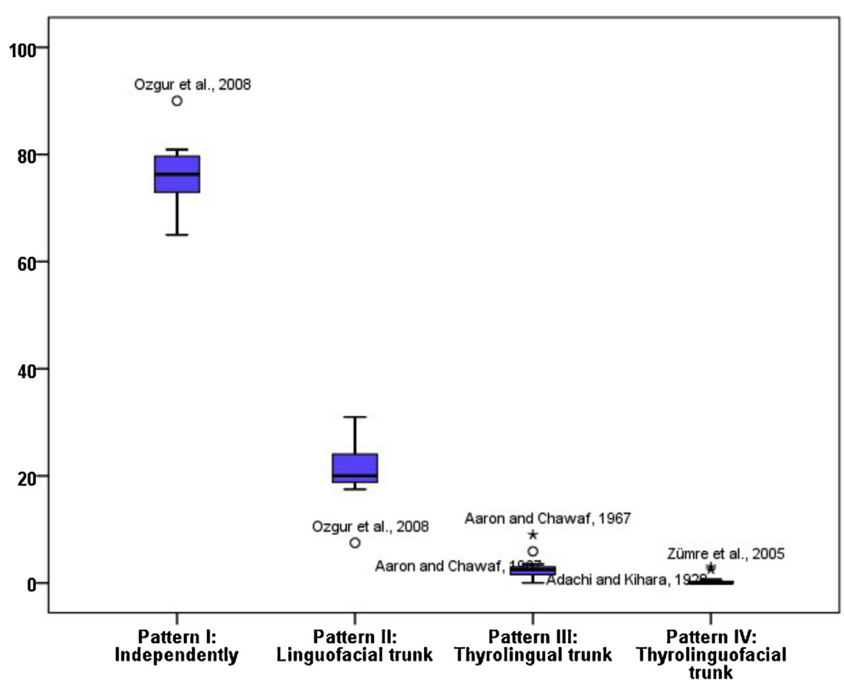

Fig. 10. Box plot comparing authors. Results show that there are significant differences (p-value = 6.65e-06) when consider the four variation types.

linguofacial trunk origins was similar to the origin of the lingual artery although more caudal to the usual facial artery's origin.

From a surgical point of view, alterations in the course of the lingual artery are highly important, since the ligation of this artery depends on the identification of it in certain classical cervical triangles (Pirogoff triangles, Lesser and Beclard) (Adachi and Kihara, 1928).

As for other authors, the origin at another level of the carotid axis was very infrequent with seven cases at the level of the carotid bifurcation mentioned as the lowest level by Livini (Livini, 1903a, b) in three cases; two cases in the series by Adachi and Kihara (1928), one case in the series by Lucev et al. (2000), and one case described by Troupis et al. (2014) and four cases at the level of the common carotid artery (three cases in the series by Adachi and Kihara (1928) and one case by Ambali and Jadhav (2012)).

The lingual artery arises from the anterior (Hollinshead, 1954) or internal (Tubbs et al., 2016) aspect of the external carotid artery, above the superior thyroid artery. In our series the most frequent situation for the lingual artery was at the anterior level of the carotid arterial axis with 76.6% of the cases. This is not consistent with the results from previous studies by Livini, where the medial origin was shown to be the most common at 75% (Livini, 1903a, b).

Previously, the origin of the lingual artery was considered to be at a distance of approximately 2 cm from the carotid bifurcation (Livini, 1903a, b; Tubbs et al., 2016) or 1 cm from the superior thyroid artery, respectively (Tubbs et al., 2016). The measurements of our study show only congruent results concerning the distance to the superior thyroid artery at 0.85 cm.

In the present study, the distance between the origin of the lingual artery at the external carotid artery and the carotid bifurcation ranged from 0.1 to 4.1 cm with a mean distance of 1.34 cm. These results are similar to previous findings of Lucev et al. (2000) and Lins et al. (2005) where the range was 0.5–3.7 cm and 0.5−4 cm, respectively.

Concerning the superior thyroid artery, our mean diameter (0.32 cm) was slightly greater than that evaluated by Czerwinski (1981) in his series, which was 0.28 cm. In this work, performing the analysis in relation to side and gender, no significant differences were observed in its origin, but in terms of arterial caliber, the diameter of the lingual artery was significantly greater in male ($p = 0.027$).

4.2. Facial artery

The usual origin of the facial artery was located at the external carotid artery (Hollinshead, 1954; Livini, 1903a, b; Quain, 1844; Tubbs et al., 2016) with a frequency of 99% in our study cohort.

There were two cases originating at the level of the carotid bifurcation, one isolated and another one in the form of a linguofacial trunk. Our literature review showed no similar variabilities; hence we firstly describe these two types of a facial artery origin.

It should be noted that the case of the lingual artery originating in the common carotid artery as well as the facial artery originating at the level of the carotid bifurcation were observed at the same body-donor, on the left side. The superior thyroid artery arose 0.6 cm below from the bifurcation, the lingual 0.3 cm below the bifurcation too and the facial artery directly at the bifurcation. The occipital and the ascending pharyngeal arteries originated from the external carotid at 0.1 cm and 0.6 cm above the bifurcation, respectively.

Classically, the origin of the facial artery was described with an anterior localization on the carotid vascular axis (Hollinshead, 1954; Tubbs et al., 2016). In the studies published by Livini (Livini, 1903a, b) the two most frequent origins were antero-internal with 70% and internal with 30%. In our series, in 96.1% of the cases, the origin was established in an anterior face of the artery (Table 3).

Classically, the origin of the facial artery was referred to in different ways: at the level of the lower border of the digastric muscle and slightly covered by the angle of the mandible (Hollinshead, 1954), 2.5 cm from the carotid bifurcation (Livini, 1903a, b) and 0.5 cm of the lingual artery (Tubbs et al., 2016).

The mean distance of the facial artery's origin from the carotid bifurcation was 2.08 cm, compared to 3.08 ± 1.18 cm as published by Yonenaga et al. (2011).

In terms of arterial caliber, the differences of the results compared to Czerwinski (1981) were more evident with 0.36 cm versus 0.2 cm, respectively. No justification for such a wide difference, up to 0.15 cm, was found; an artery that was always represented with a caliber equal to or greater than that of the lingual artery (Hollinshead, 1954; Janfaza, 2011; Tubbs et al., 2016).

4.3. Occipital artery

In our series, the most frequent origin for the occipital artery was the external carotid artery, with 95% of the cases, which coincides with the majority of previous studies (Adachi and Kihara, 1928; Czerwinski, 1981; Hollinshead, 1954; Livini, 1903a, b; Quain, 1844; Tubbs et al., 2016). The percentage of cases (3.9%) originating at the level of the carotid bifurcation was higher than that observed in literature with frequencies of 0.7% (Quain, 1844), 0.5% (Livini, 1903a, b) and 0.3% (Adachi and Kihara, 1928). In most of our cases, the origin at the carotid bifurcation was identified on the right side (7 versus 1), obtaining a trend although no statistical significance has been reached ($p = 0.06$).

Also, in three cases (2.8%) no occipital artery was identified, this finding is similar to Livini's series (1.5%) (Livini, 1903a, b).

As in our results, where in 88% of cases the occipital artery originated at the posterior face of the carotid arterial axis, most of the evaluated works in literature agree, establishing this surface as the most frequent (Hollinshead, 1954; Livini, 1903a, b; Tubbs et al., 2016).

In our series, the mean distance from the carotid bifurcation was 1.8 cm, similar to previously published findings by Livini (Livini, 1903a, b) and Alvernia et al. (2006). These results are in accordance with previous findings reported in Livini's series (Livini, 1903a, b), with a distance maximum of 6 cm in Livini's series compared to 6.7 cm in our result. However, Alvernia et al. differed radically with both series, showing a range from 0.7 to 2.8 cm (Alvernia et al., 2006).

As with the lingual artery, the mean diameter obtained in our results, 0.27 cm was clearly higher compared to results obtained by Czerwinski (1981) of 0.16 cm.

With the exception of the difference observed in the origin of the occipital artery at the level of the bifurcation, which is more prevalent on the right side ($p = 0.06$), no other differences, either as a function of side or gender, were found.

4.4. Ascending pharyngeal artery

The most common origin was the external carotid artery being in our sample 70.5%. However, characteristically, it was a highly variable artery in terms of its origin, arising from other collateral branches of the external carotid artery, especially the occipital artery (Table 2).

In addition, two cases of an ascending pharyngeal artery originating from the facial artery have been found. This result is consistent with previously described cases in the literature (Adachi and Kihara, 1928; Tubbs et al., 2016). Exceptionally, one case originating from the lingual artery and the other from the superior laryngeal artery previously described by Livini (Livini, 1903a, b).

The frequency distribution obtained in our results was comparable to previous literature, with the exception of cases that arose from the internal carotid artery, in which a less percentage was found coinciding with Czerwinski (1981) (Table 2).

In four cases (1.9%) the pharyngeal ascending artery was not identified, similar results were found in studies published by Quain (1844) (one case, 0.7%) as well as Livini (Livini, 1903a, b) (six cases, 3%).

Similar to the occipital artery, the ascending pharyngeal artery is defined as a posterior collateral branch of the external carotid artery (Hollinshead, 1954; Tubbs et al., 2016). For Livini this situation was observed in up to 90% of his sample (Livini, 1903a, b). In our results, in 85.7% of the cases the origin of the ascending pharyngeal artery was observed on the internal face of the carotid arterial axis.

We believe that it might be possible that in clinical practice there were no such marked discrepancies between our results and those of Livini (Livini, 1903a, b) and that rather the difference is found in the way in which the different faces of the carotid arterial axis have been cataloged, as represented in Table 3.

Looking at it this way, there were practically no differences in the situation of origin as such, except for a discrepancy in the frequency distribution of the facial and occipital artery. In these two arterial branches, the congruence regarding the distribution frequency compared to the results by Livini is 30% (Livini, 1903a, b).

Regarding the distance of origin, the ascending pharyngeal artery is defined as the most variable collateral branch, which was described in various locations including the artery being close to the carotid bifurcation (Hollinshead, 1954; Janfaza, 2011) or at the same height as the lingual artery, at 2 cm distance to the carotid bifurcation (Livini, 1903a, b; Tubbs et al., 2016).

The mean arterial caliber of the ascending pharyngeal artery was 0.17 cm, and therefore, if we eliminate occasional collateral branches of the carotid arterial axis (sternocleidomastoid arteries), it was the branch with the smallest caliber of the group studied. In the literature consulted, we did not find any previous studies reporting on the arterial diameter of the ascending pharyngeal artery.

Given the great variability regarding the origin of the ascending pharyngeal artery, which was highlighted previously, it should be noted that from a surgical point of view the identification of this artery is not predictable based on its origin. Alternatively, the identification of the ascending pharyngeal artery should be provided using the location and the caliber; that is, a small-caliber artery located on the inner side of the carotid arterial axis. The high variability of 18.8% in the origin of this artery should be noted with regards to its identification, especially because of the clinical relevance, such as during an intraoperative ligation. Tumor lesions located in the pharynx or at the skull base, such as glomus tympanicum and jugulare or nasopharyngeal angiofibroma, may be mainly supplied by this artery (Lins et al., 2005), whose treatment may be a surgical approach, if a "watch and wait" option or other approaches, such as endovascular embolization or radiosurgery is not applicable.

4.5. Sternocleidomastoid artery

All authors recognized that there are two different sternocleidomastoid arteries, superior and inferior (Hollinshead, 1954). The superior sternocleidomastoid artery arose from the occipital artery and the inferior from the superior thyroid artery (Hollinshead, 1954), however, a direct origin from the external carotid artery was reported in 42% of cases or 37% of cases, respectively (Livini, 1903a, b). Our results only show an origin from the external carotid artery in 19.3%. Moreover, our result show origins arising from the carotid bifurcation (2/43, 4.65%) and one from the CCA (1/43, 2.33%), these cases we did not find in the literature consulted.

In the same way we did not find any reference to the distance of the superior sternocleidomastoid artery from the carotid bifurcation, that in our results was of 2 cm meanwhile the occipital was at 1.8 cm in 20% of cases. Very similar with the location that must be taken into account to avoid confusion of these two arteries.

4.6. Arrangement and classification

Looking at the anterior arterial branches studied in this cohort, 80.83% (156/193) of the superior thyroid, lingual and facial arteries originated separately from the external or common carotid artery, which is in accordance with previous studies (Adachi and Kihara, 1928; Lucev et al., 2000; Mata et al., 2012; Ozgur et al., 2008; Poisel and Golth, 1974; Sanjeev et al., 2010; Shintani et al., 1999; Zumre et al., 2005). Among the combined artery trunks, the linguofacial trunk was always observed most frequently, except for the study conducted by Adachi hence a linguofacial trunk was not detected in his case series. In this study, the linguofacial trunk was observed in 17.62% cases (34/193), while the previously reported linguofacial trunk frequency ranges from 7.5 to 31% (Lucev et al., 2000; Mata et al., 2012; Ozgur et al., 2008; Poisel and Golth, 1974; Sanjeev et al., 2010; Shintani et al., 1999; Zumre et al., 2005) (Table 4).

The thyrolingual trunk was reported by other authors with a prevalence ranging from 2.5 to 3.5% (Mata et al., 2012; Ozgur et al., 2008; Poisel and Golth, 1974; Sanjeev et al., 2010; Shintani et al., 1999; Zumre et al., 2005), while the prevalence observed in the present study was 1.4%. (2/193) (Table 4). Only one thyrolinguofacial trunk was found (0.52%), a very rare variation, evaluated in our previous article (Vazquez et al., 2009); other authors reported a frequency up to 3% (Adachi and Kihara, 1928; Mata et al., 2012; Ozgur et al., 2008; Poisel and Golth, 1974; Sanjeev et al., 2010; Shintani et al., 1999; Zumre et al., 2005) (Table 4).

To our knowledge, from the previous literature reviewed, only two authors, Livini and Aaron, performed classifications of arterial patterns in the branches of the external carotid artery (Aaron and Chawaf, 1967; Livini, 1903a, b). Based on the established classification system, this study intended to obtain similar patterns, from which comparisons could be made.

The studies by Livini (Livini, 1903a, b) consists of an exposition of the different combinations of arterial branches, which were observed in the study cohort although no distribution frequency was shown, which limits the applicability of the classification for daily clinical work.

Aaron and Chawaf (1967) developed another classification, using the distance of the origin as a variable. However, in our results, this character was the most variable and the one with the most dispersion, hence, this parameter is neither applicable for a sufficient usability.

In our case, the arterial patterns were developed based on the origin of the collateral branches emitted by the carotid arterial axis at the upper carotid triangle level, allowing a new point of view compared with these previous classifications. These results provide clearer guidelines for orientation against possible variations compared with the classical pattern.

Therefore, a thorough understanding of the branches of the ECA might lead to significant benefits in new techniques, e.g., external carotid and internal carotid (EC-IC) minimally invasive surgery (Fischer et al., 2016) or new intervention methods for chronic subdural hematoma via embolization of branches of the ECA (Al-Mufti et al., 2021). The absence of a thyrolinguofacial trunk in our samples, being a very rare variation, should be mentioned here again due to the fact that, although a rarity, it should be kept in mind for safe interventional procedures (Vazquez et al., 2009). Furthermore, the anatomy and classification of the different branches, especially facial artery, lingual artery, ascending pharyngeal artery are of high relevance for ENT approaches and surgeries or reconstruction plastic surgeries.

5. Conclusions

All the different variables studied as the origin and calibers of the main collateral arteries of the external carotid (lingual, facial, occipital, ascending pharyngeal and sternocleidomastoid arteries) have a substantiable importance in daily clinical practice due to growing applications e.g., in Interventional Radiology techniques. The new classification proposed could allow a more precise knowledge and control of these anatomical variations, aiming to support clinicians in the interpretation of imaging modalities.

Author contribution

Cobiella R: Project development, data collection, Manuscript writing.

Quinones S: Data analysis, Manuscript writing, Manuscript editing.

Aragones P: Manuscript writing, Manuscript editing.

León X: Data analysis.

Abramovic A: Data collection, Data analysis, Manuscript editing.

Vazquez T: Data collection, Data analysis, Manuscript editing.

Sanudo J: Data collection, Data analysis, Manuscript writing, Manuscript editing, Supervision.

Maranillo E: Data collection, Data analysis, Manuscript writing, Manuscript editing.

Olewnik L: Data analysis, Manuscript editing.

Simon de Blas C: Data analysis, Manuscript editing.

Parkin Ian: Project development, data collection.

Konschake M: Data analysis, Manuscript writing, Manuscript editing, Supervision.

Ethical approval details

The individuals had given their written informed consent for their use for scientific purpose prior to death. According to National Law, scientific institutions (in general Institutes, Departments or Divisions of Medical Universities) are entitled to receive the body after death mainly by means of a specific legacy, which is a special form of last will and testament. No bequests are accepted without the donor having registered their legacy and been given appropriate information upon which to make a decision based upon written informed consent (policy of ethics); therefore, an ethics committee approval was not necessary (Konschake and Brenner, 2014).

Consent to publish

Not applicable.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

All authors have nothing to declare. No outside funding was received.

Acknowledgements

The authors wish to express their sincere gratitude to the anatomical body-donors, who bequeathed their bodies for medical education and basic science research. Results from such research can potentially increase mankind's overall knowledge that can then improve patient care. Therefore, again, these donors and their families deserve our highest gratitude (Iwanaga et al., 2021).

References

Aaron, C., Chawaf, A., 1967. Variations de la carotide externe et de ses branches. Bull. Assoc. Anat. 13, 125–133.

Adachi, B., Kihara, T., 1928. Das Arteriensystem der Japaner. Verlag der Kaiserlich-Japanischen Universitat, zu Kyoto, pp. 26–46, Kommission bei Maruzen Co.

Al-Mufti, F., Kaur, G., Amuluru, K., Cooper, J., Dakay, K., El-Ghanem, M., Pisapia, J., Muh, C., Tyagi, R., Bowers, C., 2021. Middle meningeal artery embolization using combined particle embolization and n-BCA with the dextrose 5% in water push technique for chronic subdural hematomas: a prospective safety and feasibility study. Am. J. Neuroradiol. 42, 916–920.

Alvernia, J.E., Fraser, K., Lanzino, G., 2006. The occipital artery: amicroanatomical study. Oper. Neurosurg. 58, ONS–114-ONS-122.

Ambali, M., Jadhav, S., 2012. Variations in bifurcation point and branching pattern of common carotid arteries: a cadaveric study. J. Pharm. Biomed. Sci. 25, 147–151.

Czerwinski, F., 1981. Variability of the course of external carotid artery and its rami in man in the light of anatomical and radiological studies. Folia Morphol. (Warsz) 40, 449–453.

Fischer, G., Senger, S., Sharif, S., Oertel, J., 2016. Superficial temporal artery to middle cerebral artery bypass via a minimized approach: operative nuances and problem-solving aspects. World Neurosurg. 88, 97–103.

Germans, M.R., Regli, L., 2014. Posterior auricular artery as an alternative donor vessel for extracranial-intracranial bypass surgery. Acta Neurochir. 156, 2095–2101.

Gluncic, V., Petanjek, Z., Marusic, A., Gluncic, I., 2001. High bifurcation of common carotid artery, anomalous origin of ascending pharyngeal artery and anomalous branching pattern of external carotid artery. Surg. Radiol. Anat. 23, 123–125.

Hollinshead, W.H., 1954. Anatomy for Surgeon. Cassell.

Iwanaga, J., Singh, V., Ohtsuka, A., Hwang, Y., Kim, H.J., Moryś, J., Ravi, K.S., Ribatti, D., Trainor, P.A., Sañudo, J.R., 2021. Acknowledging the use of human cadaveric tissues in research papers: recommendations from anatomical journal editors. Clin. Anat. 34, 2–4.

Janfaza, P., 2011. Surgical Anatomy of the Head and Neck. Harvard University Press.

Konschake, M., Brenner, E., 2014. "Mors auxilium vitae"—causes of death of body donors in an Austrian anatomical department. Ann. Anat. 196, 387–393.

Lins, C.C.S.A., C.J, Nascimento, D.L.D., 2005. Extraoral ligature of lingual artery: anatomic and topographic study. Int. J. Morphol. 23, 271–274.

Livini, F., 1903a. L'arteria carotis externa. Richerche Arch. Ital. Anat. Embriol. 2, 653–741.

Livini, F., 1903b. The type and normal variations della carotis externa. Arch. Ital. Biol. 39, 487.

Lucev, N., Bobinac, D., Maric, I., Drescik, I., 2000. Variations of the great arteries in the carotid triangle. Otolaryngol. Head. Neck Surg. 122, 590–591.

Mata, J.R., Mata, F.R., Souza, M.C., Nishijo, H., Ferreira, T.A., 2012. Arrangement and prevalence of branches in the external carotid artery in humans. Ital. J. Anat. Embryol. 117, 65–74.

Ozgur, Z., Govsa, F., Ozgur, T., 2008. Anatomic evaluation of the carotid artery bifurcation in cadavers: implications for open and endovascular therapy. Surg. Radiol. Anat. 30, 475–480.

Poisel, S., Golth, D., 1974. Variability of large arteries in the carotid trigone. Wien. Med. Wochenschr. (1946) 124, 229–232.

Quain, R., 1844. The Anatomy of the Arteries of the Human Body: and Its Applications to Pathology and Operative Surgery with a Series of Lithographic Drawings. Taylor and Walton.

Rajamani, K., Chaturvedi, S., 2011. Stroke prevention—surgical and interventional approaches to carotid stenosis. Neurotherapeutics 8, 503–514.

Sanjeev, I., Anita, H., Ashwini, M., Mahesh, U., Rairam, G., 2010. Branching pattern of external carotid artery in human cadavers. J. Clin. Diagn. Res. 4, 3128–3133.

Shintani, S., Terakado, N., Alcalde, R.E., Tomizawa, K., Nakayama, S., Ueyama, Y., Ichikawa, H., Sugimoto, T., Matsumura, T., 1999. An anatomical study of the arteries for intraarterial chemotherapy of head and neck cancer. Int. J. Clin. Oncol. 4, 327–330.

Troupis, T., Michalinos, A., Dimovelis, I., Demesticha, T., Vlasis, K., Skandalakis, P., 2014. Bilateral abnormal origin of the anterior branches of the external carotid artery. Ann. Vasc. Surg. 28, 494.e5–494.e7.

Tubbs, R.S., Shoja, M.M., Loukas, M., 2016. Bergman's Comprehensive Encyclopedia of Human Anatomic Variation. John Wiley & Sons.

Vazquez, T., Cobiella, R., Maranillo, E., Valderrama, F.J., McHanwell, S., Parkin, I., Sanudo, J.R., 2009. Anatomical variations of the superior thyroid and superior laryngeal arteries. Head Neck 31, 1078–1085.

Yonenaga, K., Tohnai, I., Mitsudo, K., Mori, Y., Saijo, H., Iwai, T., Yonehara, Y., Ota, Y., Torigoe, K., Takato, T., 2011. Anatomical study of the external carotid artery and its branches for administration of superselective intra-arterial chemotherapy via the superficial temporal artery. Int. J. Clin. Oncol. 16, 654–659.

Zumre, O., Salbacak, A., Cicekcibasi, A.E., Tuncer, I., Seker, M., 2005. Investigation of the bifurcation level of the common carotid artery and variations of the branches of the external carotid artery in human fetuses. Ann. Anat. 187, 361–369.