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PHD THESIS SUMMARY

Anatomo-imaging research on the cervical carotid system

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1 Summary General Part

In the general part of the PhD Thesis general concepts of carotid anatomy (chapter 1) and internal jugular anatomy (chapter 2) are presented. Concerning carotid anatomy the common, external and internal carotid arteries are documented. Details of the branches of the external and internal carotid arteries are also presented as follows.

The common carotid arteries (CCAs) have different origins. The right CCA originates from the brachiocephalic trunk (or *arteria inominata*), the first branch of the aortic arch [1]. The left CCA is the second branch of the aortic arch [1]. The CCA is free of collateral branches and ascends to the neck on the side of the trachea and larynx, deep to the sternocleidomastoid muscle [2]. The right CCA has an exclusively cervical course from the level of the right sternoclavicular joint to the upper limit of the bifurcation, and the left CCA initially has an intrathoracic course in the superior mediastinum from the level of the aortic arch to the left sternoclavicular joint, followed by the cervical course [3]. The CCAs are closer to each other inferiorly, each has a superior and lateral trajectory, so that they diverge from each other [3]. The cervical course of the common carotid artery can be divided into an initial deep cervical portion and a shallow cervical portion in the carotid trigon [3]. At the superior margin of the thyroid cartilage of the larynx the ACC bifurcates into the external (ACE) and internal (ICA) carotid arteries [4,5]. At the level of the carotid bifurcation (CB) is the carotid sinus, which has the carotid glomus in depth. The carotid sinus may also extend to the ACE and/or ACI 3. These two are reflexogenic areas [6,7]. The carotid sinus and glomus are stimulated in hypoxia or increased blood pressure and induce angio- and cardiodepressor reflexes [3].

The external carotid artery (ECA) extends from the CB to its terminal division into the superficial temporal (STpA) and maxillary (MA) arteries at the neck of the mandible [2]. The external carotid artery (ECA) may be missing uni- or bilaterally [8]. When unilateral, these branches arise from the superior continuation of the common trunk, or from the contralateral vessel [8]. The collateral branches of the ECA are the superior thyroid (STA), lingual (LA), facial (FA), ascending pharyngeal (APA), occipital (OA) and posterior auricular (PAA) arteries [2]. The segment of origin of the ECA is placed antero-medial to the ICA [9]. In the ascending trajectory the ECA is initially located in the carotid triangle, then passes deep to the posterior belly of the digastric m. and stylohyoid muscle and is disposed in the lateropharyngeal space [3]. It crosses the fork of the stylohyoid muscles, superficially having the stylohyoid muscle and deeply the styloglossus and stylopharyngeal muscles [3]. At this level it lies close to the palatine tonsil [3]. The ECA enters the parotid space and divides into its two terminal branches [25, 28]. The STA vascularises the thyroid gland, larynx and anterior cervical region [3]. It originates in the carotid triangle on the anterior aspect of the ECA, above the CB (or at or inferior to the carotid bifurcation in the CCA) [3]. Sometimes it has a common origin with the LA through the thyrolingual trunk, or with it and the FA through the thyro-linguo-facial trunk [3,10]. Very rarely, the STA may arise from the SA [3,11]. The collateral branches of the STA are the infrahyoid branch, the sternocleidomastoid branch, the superior laryngeal artery and the cricothyroid branch [12]. Near the upper pole of the thyroid gland, the terminal branches of the STA, the anterior and posterior glandular branches [3], branch off. The LA is usually the second anterior branch of the ECA [3]. It originates in the carotid triangle [3]. In the tongue the AL continues as the deep lingual artery [3]. The collateral branches of the LA are the suprahyoid branch, the dorsal lingual branches and the sublingual artery [3]. The FA is the third collateral branch of the ECA [3]. It has two portions: cervical and facial [3]. The cervical branches of the facial artery are: the ascending palatine artery, the submandibular glandular branches and the submental artery [3]. In the face, the FA gives the two labial arteries, inferior and superior and the terminal branch, the angular artery [3]. The OA is one of the two posterior branches of ECA [3]. The OA branches are: mastoid branch, auricular branch, sternocleidomastoid branches, meningeal branch, descending branches and occipital branches [3] The APA is the medial collateral branch of the ECA [3]. The APA branches are pharyngeal branches, inferior tympanic artery and posterior meningeal artery [3]. The PAA is the posterior collateral branch of ECA [3]. The collateral branches of the PAA are the stylomastoid artery and the posterior tympanic artery [3]. Then the PAA sends two terminal branches: the auricular artery and the occipital artery [3]. The MA is the terminal bifurcation branch of ACE [3]. It extends from its origin postero-internally from the neck of the mandible to the level of the sphenopalatine foramen where it continues as the sphenopalatine artery [3]. The ascending branches of the MA are [3] deep auricular artery, anterior tympanic artery, middle meningeal artery (MMA), accessory meningeal artery, posterior deep temporal artery and anterior deep temporal artery [6,13]. The descending branches of the MA are: the pterygoid branches, inferior alveolar artery, Juvara's lingual nerve artery, masseterine artery, buccal artery and descending palatine artery [3]. The two anterior branches of the MA are the posterior superior alveolar artery and the infraorbital artery [3]. The posterior branches of the MA are the artery of the pterygoid canal and the pharyngeal artery [3]. The STpA is the terminal branch of the PTA which continues its course [3]. The collateral branches of the STpA are the parotid branches, the transverse facial artery, the anterior auricular branches, the zygomaticoorbital artery and the middle temporal artery [3]. The terminal branches of the STpA are the frontal branch and the parietal branch [6,13]. The internal carotid artery is the second terminal bifurcation branch of the CCA. It has a cervical and a cranial portion [3]. The internal carotid artery sends intracavernous branches and intradural branches [3]. The intracavernous branches are the meningohypophyseal trunk, the widest branch, present in 100% of cases, the inferior cavernous sinus artery, present in 84% of cases and the capsular arteries of McConnell, present in 28% of cases [14]. Then the clinoid portion of the ICA reaches internally of the anterior clinoid process [3]. Between the arachnoid and pia mater the ICA sends the superior hypophyseal artery, ophthalmic artery, posterior communicating artery and anterior choroidal artery [3]. It further bifurcates into its two terminal branches, the anterior and middle cerebral arteries.

The internal jugular vein (IJV) is the main vein of the neck and extends from the jugular foramen to the jugulo-subclavicular venous angle or Pirogoff's angle [2,7]. It originally has a dilatation in the jugular foramen which is called the superior bulb of the IJV [2] or jugular bulb [15]. The pharyngeal plexus drains into the IJV and abuts the pharyngeal wall [4]. The meningeal veins drain into the upper end of the IJV blood from the dura [4]. The lingual vein is generally the LA satellite [4]. Lingual dorsal veins drain the lingual dorsum [4]. The comitant vein of the hypoglossal nerve accompanies that nerve [4]. The sublingual vein is located in the sublingual space on the lateral aspect of the hypoglossal nerve [4]. The deep lingual vein accompanies the deep lingual a. on the genioglossus [4]. The superior thyroid vein is the satellite of the STA and empties into either the facial vein or the IJV; receives the superior laryngeal vein [4]. The middle thyroid vein empties into the IJV and has no corresponding arteries [4]. Sternocleidomastoid vein drains into either IJV or superior thyroid vein [4]. The retromandibular vein receives several tributaries in the preauricular region and empties into the facial vein [4]. It arises from the superficial temporal and maxillary veins [4]. The superficial temporal veins are STpA's satellites; they receive the middle temporal vein and the transverse facial vein [4]. The maxillary veins drain the pterygoid venous plexus into the retromandibular vein [4]. This plexus is located between the temporalis muscle and the pterygoid muscles [4].

2 Summary Personal Part

The original research in the PhD Thesis led to the realisation and publication of studies on the vertical level of the BC, the axial rotation of the BC, the relationships between the carotid arteries and the hyoid bone, the external carotid vein, the persistence of the carotid duct in adults and the maxillofacial arterial trunk variant.

2.1 Research on the vertical level of the carotid bifurcation

Knowledge of CB levels is important for vascular neck surgery, radical neck dissections, carotid sinus stimulation, catheterisations and aneurysms [16]. Currently used human anatomy texts have very little precise information regarding the frequency of CB variations [17]. This is despite the fact that the most serious postoperative complication of radical cervical surgical dissection is haemorrhage from the carotid arterial system [18].

There were used 150 CT angiogram files in the study. Inclusion criteria were: good quality of the scans, adequate vertical travel and absence of pathological processes distorting the carotid anatomy. Exclusion criteria were: inadequate scans to observe carotid anatomy, pericarotid pathological processes distorting the carotid anatomical features, previous surgery in the cervical region, hyperextension or excessive lateral rotation of the neck during CT scan [19]. Three cases were excluded and determinations were performed in a retrospective group of 147 cases, 86 men and 61 women (sex ratio = 1:4). I followed the vertebral level of the CB, including the intervertebral disc levels 20. The vertical topography of the CB in relation to mandibulo-hio-laryngeal landmarks was classified into 7 anatomical types: type 1 - CB at the level of the upper margin of the thyroid cartilage; type 2 - CB in the interval between the hyoid bone and the thyroid cartilage of the larynx; type 3 – CB at the level of the hyoid; type 4 - CB located in the interval between the hyoid bone and the mandible; type 5 - CB at the level of the gonion (subgonial) or above it (supragonial); type 6 - CB at the lower cervical level; type 7 - intrathoracic CB.

The CB was located, on either side of the median plane, from the level of the C2 vertebra to the level of the C5/C6 intervertebral disc. In men, the most common CB locations were, in order, at the C4 vertebra (29.07%), C3 vertebra (27.33%) and C3/C4 disc (26.16%) levels. In females, the most common locations of CB were, in order, at the C3 vertebra (27.05%), C3/C4 disc (26.23%) and C4 vertebra (20.49%) levels. In the overall group, the most common locations of CB were, in order, at the C3 vertebra (27.21%), C3/C4 intervertebral disc (26.19%) and C4 vertebra (25.51%) levels. In men (N_M=86), the CB showed bilateral symmetry to vertebral landmarks in 55.81%. In women (N_F=61), bilateral symmetry of CB to vertebral landmarks was recorded in 45.9% of cases. In the general group (N=147), bilateral symmetry of CB to vertebral landmarks was identified in 51.7%. There were no positive cases for bilateral symmetry of the C2 vertebral level of CB. No bilateral symmetry was detected for the C5/C6 level either. In the male subgroup (N_M=86), bilateral symmetrical CB at C3 was present in 15.12%, C3/C4 in 15.12%, C4 in 18.6% and C5 in 6.98%. In the female subgroup (N_F=61) bilateral symmetry was at C2/C3 in 3.28%, at C3 in 14.75%, at C3/C4 in 9.84%, at C4 in 8.2%, at C4/C5 in 6.56% and at C5 in 3.28%. No intrathoracic CB (type 7) was found in the investigated group. Only types 1-6 were identified. In men (172 CBs) type 3 (hyoid level) prevailed (45.35%); type 2 (inter-thyro-hyoid CB) was identified in 29.65%, type 1 (thyroid cartilage level) was present in 8.14%, type 4 (inter-hyo-mandibular level) in 11.63%, type 5 (gonial level) in 2.33% and type 6 (lower cervical level) in 2.91%. In women (122 CBs), type 3 (hyoid level) was also prevalent (30.33%); type 1 (CB at the upper border of the thyroid cartilage) was present.) in 22.13%, type 2 (inter-thyro-hyoid CB) was identified in 17.21%, type 4 (inter-hyo-mandibular level) in 16.39%, type 5 (gonial level) in 11.48% and type 6 (lower cervical level) in 2.46%. In the overall batch (294 CBs), the distribution of the respective types was type 3 (39.12%) – type 2 (24.49%) – type 1 (13.95%) – type 4 (13.61%) – type 5 (6.12%) – type 6 (2.72%). In men (N_M=86), the CBs showed bilateral symmetry to anterior cervical landmarks (types 1-6) in 55.81% of cases. In women (N_F=61), bilateral symmetry of CBs to anterior cervical landmarks was recorded in 65.57% of cases. In the general group (N=147), bilateral symmetry of CBs to anterior cervical landmarks was found in 59.86%. In men (N_M=86) in 44.19%, it was not detected bilateral symmetry for types 1-6; bilateral symmetrical type 1 was present in 2.33%, type 2 in 15.12%, type 3 in 29.07%, type 4 in 5.81%, type 5 in 1.16% and type 6 in 2.33%. It was not detected bilateral symmetry for types 1-6 in 34.43% of females (N_F=61); bilateral symmetrical type 1 was present in 16.39%, type 2 in 9.84%, type 3 in 21.31%, type 4 in 6.56%, and type 5 in 11.48%. This research revealed precise and statistically significant differences between sexes and both left and right types 1-6 and vertebral levels of CB. On the right, types 2 (inter-thyro-hyoid) and 3 (hyoid) are more often encountered in men, while types 1 (thyroid cartilage, typical) and 5 (gonial) – are more often encountered in women (Pearson Chi2=12.7, p=0.026). On the left, types 2 (inter-thyro-hyoid) and 3 (hyoid) are more often encountered in men, while in women, types 1-4, ranging from the thyroid to inter-hyo-mandibular level, are very close in range (from 11 to 17 cases). The association is statistically significant (Pearson Chi2=17.6, p=0.003). In men, there is a higher variability of vertebral level of right CB (from C2/C3 to C5, with a higher number of cases at C3 and C4), while in women, most cases had a C3-C4 level. The associations are highly statistically significant (Pearson Chi2=29.6, p<0.001). Similarly, on the left, there is a higher variability of vertebral level in men (from C2 to C5/C6) than in women (from C2 to C4). Also, in men, most cases by a wide margin are at the C4 level (30 v. 8 cases), while in women, most cases are at C3 and C3/C4). The association is highly statistically significant (Pearson Chi2=27.3, p<0.001). On the right side, types 1 (thyroid) and 2 (inter-thyro-hyoid) are most often encountered at the C2 level, type 3 (hyoid) – at the C3/C4 level, and type 5 (gonial) – at the C4 level. The associations, which are highly statistically significant (Pearson Chi2=147.4, p<0.001), underscore the importance of our findings. On the left side, type 1 is most often associated with a C2/C3 level, type 2 with C3 and C4 levels, and types 3, 4 and 5 with a C3/C4 level. The associations, also highly statistically significant (Pearson Chi2=135.5, $p<0.001$), further validate our research. Thus, the hyoid level could not be associated with a certain vertebral level. When comparing bilateral vertebral levels of CBs, it was observed that a C2/C3 level of the right CB is usually associated with a C3 level of left CB, and C3, C3/C4, C4 and C5 vertebral levels of the right CB with, respectively, the C3, C3/C4, C4 and C5 vertebral levels of the left CB. These associations suggest an important symmetry (Pearson Chi2=336.5, $p<0.001$). When comparing bilateral types of anterior cervical landmarks, symmetry was observed in types 1-5, with a highly significant association (Pearson Chi2=249.5, $p<0.001$).

From an anatomical point of view the vertebral level of the CB could illustrate the general concept of anatomical variability [20]. However, although the height of the CB is referred to the vertebrae, this definition is not practical for surgery because neither the patient is seated in anatomical position nor the vertebrae are accessible to the surgeon [21]. Anterior anatomical landmarks are more practical for localising CB during surgical procedures [21]. Although some authors have always found CBs localised posteroinferior to the greater hyoid horn [22], those results are contradicted by my results demonstrating how the greater hyoid horn should not be considered as an absolute landmark of CB [20].

Various studies have determined the vertical position of the BC bilaterally and found no bilateral CB asymmetry [23], or bilateral differences in CB level were not statistically significant [24]. Although not explicitly documented, such a vertical CB asymmetry results from the study of McAfee (1953) [25]. In 1979, Smith and Larsen documented the existing literature and found a lack of information on a possible CB symmetry, which is why they performed their original study on 100 angiograms [26]. These authors found that in 22% of cases the right CB was localised higher than the left and in 50% the left CB was higher localised [26]. Lo et al. (2006) found bilateral CB asymmetry in 48% of cases [27]. Woldeyes (2014) found bilateral asymmetric CB in 61.5% of cases [28]. Kurkcuoglu et al. (2015) found bilateral CB asymmetry in 33% of cases [16]. Mompeo and Bajo (2015) found bilateral CB asymmetry in 10.52% of 19 cases studied [29]. I in the present study found bilateral asymmetrical CB in 48.3% for vertebral level and 40.14% for anterior cervical landmarks [20]. However, we found bilateral CB symmetry to be significant for both vertebral and anterior cervical landmarks [20]. The anatomical correlation between these two sets of landmarks is less expected [20]. Other authors, however, have not appreciated the bilateral BC symmetry [30].

In the present study as well as in other studies different possibilities of vertical localisation of the CB have been identified [12,16,20,23-26,28-45]. Various anatomical studies have only followed the vertebral level of the CB, other studies have focused on the anterior cervical landmarks, and few studies have documented both vertebral and anterior levels of the CB [20]. Numerous studies were performed by dissection [20]. Few studies have used groups larger than 100 cases [20]. There are studies that have indicated the CB level as low, normal or high only by its reference to the superior margin of the thyroid cartilage [36,46].

From the present study [20] the following results were obtained: (1) inter-tiro-hyoidian and hyoidian CB levels are more common in males on either side of the median plane; (2) on the right side, normal and gonial types occur more frequently in females and on the left side in females CB is more frequently localised in the interval between the upper border of the thyroid cartilage and the mandible; (3) the vertebral level of CB in males is highly variable and in females most cases present a C3-C4 level on the right side and a C2-C4 level on the left side. We found in our study significant associations between certain vertebral levels and anterior cervical landmarks [20]: level C2 with types 1 and 2, level C3/C4 with type 3, level C4 with type 5 on the right side, and on the left side, level C2/C3 with type 1, levels C3 and C4 with type 2, and level C3/C4 with types 3, 4 and 5. With regard to the usual anatomy, these associations might be surprising when referring the hyoid and thyroid cartilage to a particular cervical vertebra [20]. However, the vertical position of the laryngeal apparatus as well as the geometry of the cervical vertebrae must be considered variable [20]. Mirjalili's study [37] showed that the correspondence between the anatomical position of the anterior cervical landmarks and the vertebral landmarks is not absolute; both the hyoid and the thyroid cartilage can be located anywhere in the interval between the C3 vertebral and the C5/C6 disc. These authors, however, found no significant sex or age correlations and did not determine the topography of the CB relative to the gonial angle [37]. Demirtas et al. recently identified a statistically significant correlation between CB levels and CB angles on both sides of the midplane: the CB angle decreases with descending vertical CB level [47].

2.2 Research on axial rotation of the carotid bifurcation

The common carotid artery typically bifurcates at the superior margin of the thyroid cartilage into the ICA and ECA [4,19]. Conventional anatomical treatises describe that the initial segment of the ECA is localised anterior and medial to the ICA, but at the level of the gonion the ECA crosses the ICA and reaches external to it [19,48]. Any significant anatomical variation from the usual relationships of the ECA is defined as aberrant anatomy [49]. However, the concept of anatomical normality is paradoxical because the boundaries between what is considered normal and what is abnormal are blurred [50]. Surprisingly, the attention of anatomists has not previously been focussed on the different patterns of CB torsion. I therefore aimed in the present study to investigate anatomical patterns of CB axial rotation on CT angiograms [19].

I utilised 153 CT angiogram records in the study. Three cases were excluded. I assessed axial CB rotation (S - sagittal CB, C - coronal CB, O - oblique CB). We correlated these types with Kamide types: K1 - ICA lateral, ECA medial; K2 - ICA and ECA overlapping in the sagittal plane (with subtypes "a" - ECA anterior to ICA and "b" - ICA anterior to ECA); K3 - ECA lateral and ICA medial. This resulted in the types we documented: CK1 (CB in coronal plane, with lateral ICA and medial ECA), CK3 (CB in coronal plane, with medial ICA and lateral ECA), OK1 (CB with oblique orientation, with antero-medial ECA and postero-lateral ICA, the normal anatomical variant), OK3a (CB with oblique orientation, with antero-medial ICA), OK3b (CB with oblique orientation, with postero-medial ICA), and SK2a (CB with sagittal orientation, with anterior ECA of ICA). Statistical analyses were performed using SPSS v.29 for MacOS. I used the Pearson Chi2 test to assess significant associations between qualitative variables. A p value less than 0.05 was considered statistically significant.

We carried out the research on a sample of 150 angioCT files, 88 male and 62 female. In the overall batch (N=150, 300 CB) OK1 type was identified in 40% of CB, OK3a type in 1%, OK3b type in 2%, CK1 type in 9%, CK3 type in 5.67% and SK2a type in 42.33% of the bilateral CB batch. We did not identify type SK2b. On the right side in the overall group (N = 150, 150 CB) type OK1 was identified in 33.33% of CB, type OK3a in 2%, type OK3b in 2%, type SK2a in 46.67%, type CK1 in 6% and type CK3 in 10%. On the left side in the overall group (N = 150, 150 CB) we did not identify type OK3a; type OK1 was identified in 46.67% of CB, type OK3 in 2%, type SK2a in 38%, type CK1 in 12% and type CK3 in 1.33%. In males (NM=88), bilaterally (n=172 CBs) we found 16 CBs with CK1 type, 9 CBs with CK3 type, 71 CBs with OK1 type, 1 CB with OK3a type, 4 CBs with OK3b type, and 75 CBs with SK2a type. In women (NF = 62), bilaterally (n = 124), CK1 type was detected in 11 CB, CK3 type in 8 CB, OK1 type in 49 CB, OK3a type in 2 CB, OK3b type in 2 CB, and SK2a type in 52 CB. Bilateral right/left comparison of the identified CB types resulted in the following distribution in males: type CK1 - 7/9, type CK3 - 7/2, type OK1 - 29/42, type OK3a - 1/0, type OK3b - 2/2 and type SK2a - 42/33. A bilateral right/left comparison of the identified CB types resulted in the following distribution in females: type CK1 - 2/9, type CK3 - 9/0, type OK1 - 21/28, type OK3a - 2/0, type OK3b - 1/1 and type SK2a - 28/24. Out of 150 cases, 54% had bilateral symmetry of axial rotation of CB. In males 50/88 cases had bilateral symmetry of axial rotation of the CB and in females 31/62 cases had bilateral symmetry of this morphological variable. There was no statistically significant association between sex and the left or right subtypes (Pearson Chi2=4.82, $p=0.30$ for the right side and Pearson Chi2=0.887, $p=0.926$ for the left side. There is a very strong symmetry between left and right side (Pearson Chi2=53.93, $p<0.001$), especially for OK1 and SK2a types, with antero-medial and anterior ECA and anterior ECA, respectively. Bilateral asymmetry of CB axial rotation types occurred in different combinations. One male case with bilaterally symmetrical OK3b type and three other cases with bilaterally symmetrical CK1 type were found.

Prendes et al. considered as aberrant anatomy any significant anatomical variation from the usual ratio of the ECA, as a structure localised anterior and medial to ICA [49]. Thus, the OK1 variant in my study is regarded as normal; here we identified it in only 40% of cases. Thus, 60% of cases had aberrant anatomical variants. Carotid vascular anomalies may have important surgical implications, particularly in terms of the incidence of cranial nerve damage [9]. Torsionised carotid artery (TCA), or transposition of ECA and ICA, or torsionised carotid bifurcation (TCB), is a variant in which the internal carotid artery (ICA) is medial to the ECA [9,51]. Ueda et al. note that the first description of a lateralised ECA was by Hyrtl in 1841 [52].

Various studies indicate that TCB occurs more frequently on the right side [53-55]. TCBs are usually asymptomatic and are not clinically significant except in carotid endarterectomies [53]. The epidemiological evaluation of TCB is controversial [9]. Various studies have reported a high incidence of TCB [9,23,56,57]. This is due to the absence of strict criteria to define the degree of axial rotation of the CB to consider ECA to be lateral to ICA [9]. Thus, the definition of a lateralised ECA is usually operator-dependent and subject to bias, and the actual incidence remains elusive [9]. A lateralised ECA is defined by the fact that its anterior collateral branches should cross the ICA, and the ECA should be placed lateral or postero-lateral to the ICA [9]. All these branches, STA, LA and FA should be ligated [9]. Katano and Yamada observed that carotid torsion is clockwise [57]. Kamide et al. (2016) found the three types with certain prevalences: type 1 was present in 24 cases (41.4%), type 2 - in 30 cases (51.7%), and type 3 was identified in 4 cases (6.9%) [58]. Seven cases (12.4 %) had TCB, three with type 2 (10 %) and four with type 3 (100 %); these were found on the right side in all cases [58]. The authors found TCB intraoperatively in 10 per cent in type 2 and 100 per cent in type 3 [58]. Twisted carotid bifurcations could be preferentially found in carotids with severe atherosclerosis in cases with diabetes or hypertension [57]. TCB endarterectomy can be performed safely, sometimes after correction of carotid position [57]. Circumferential dissection and medial mobilisation of the ECA allow adequate exposure for carotid endarterectomy [56]. A case-by-case three-dimensional assessment should address specific anatomical possibilities of axial rotation of the CB, such as those determined in this study [19]. Imaging sections are important to identify different abnormalities and to plan surgical and non-surgical treatments [59].

2.3 Raporturile carotico-hioidiene

Current anatomical descriptions contain little accurate information on the frequency of anatomical variations of BC [17]. I thus aimed in this research to provide details of possible carotid-hyoid relationships and to establish their prevalence.

The determinations were performed on a retrospective group of 147 cases, 86 male and 61 female (sex ratio = 1:4). In the personal study of the carotico-hyoid (greater hyoid horn) relationships, on the group of 147 cases, 86 male and 61 female, we followed 12 anatomical types for direct carotico-hyoid relationship. In 57.14%, no direct carotico-hyoid (types I-XII) relationships were identified in the overall, bilateral group (N=294 CB). In 42.86%, were identified different types of carotico-hyoid relationships, except for type VII - ICA lateral to the greater hyoid horn.

Type I (ECA medial to the greater hyoid horn) was evidenced in 0.34%, type II (ICA medial to the greater hyoid horn) was present in 0.34%, type III (ECA and ICA medial to the greater hyoid horn) in 1.02%, type IV (CCA medial to the greater hyoid horn) was present in 1.02%, type V (CB medial to the greater hyoid horn) - in 0.34%, type VI (ECA lateral to the hyoid) was identified in 20.41%, type VIII (ECA and ICA lateral to the hyoid) in 3.74%, type IX (CCA lateral to the hyoid) in 8.5%, type X (CB lateral to the hyoid) in 6.46%, type XI (ICA medial to the hyoid greater horn and ECA lateral to it) in 0.34%, type XII (ECA medial to the greater horn and ICA lateral to it) in 0.34%. In males we did not identify carotid-hyoid relationships in 54.65%. We did not find types VII and XII in the male sublot. In females (122 of left/right sides) we did not identify carotico-hyoid relationships in 60.66%. In the female sublot we did not find types I, II, III, V, VII and XI. We determined the types of ratios comparatively by sex. In males, on the right side (n=86), in 50% we did not find carotico-hyoid ratios; type VI (ECA lateral to the greater hyoid horn) was identified in 24.42% and types IX (CCA lateral to the hyoid) and X (CB lateral to the hyoid) were each present in 6.98%. In females, on the right side (n=61), in 57.38% we found no carotid-hyoid relationships; type VI (ECA lateral to the greater horn hyoidis) was identified in 16.39% and types IX (CCA lateral to the hyoid) and X (CB lateral to the hyoid) were present in 9.84% each. In males, on the left side (n=86), in 59.3% we found no carotico-hyoid relationships; type VI (ECA lateral to the greater hyoid horn) was identified in 19.77% and type IX (CCA lateral to the hyoid horn) was present in 10.47%. In females, on the left side (n=61), in 63.93% we found no carotico-hyoid relationships; type VI (ECA lateral to the greater hyoid horn) was identified in 19.67% and types IX (CCA lateral to the hyoid) and X (CB lateral to the hyoid) were present in 6.56% each. A total of 104/147 cases (70.74%) with bilateral symmetry were identified, distributed as follows. For the null types, without carotid-hyoid ratio, 73/104 (70.19%) as well as in types IV (medial CCA of hyoid, 0.96%), VI (lateral ECA of hyoid, 17.31%), VIII (both ECA and lateral ICA of hyoid, 1.92%), IX (lateral CCA of hyoid, 6.73%) and X (lateral CB of hyoid, 2.88%). There is a highly significant association between left and right variants of carotid-hyoid ratio, with a Pearson Chi2 value of 466592, significant at a p-value below 0.001. In males we found 55/86 cases with bilateral symmetry, 39 of them with no carotid-hyoid ratio, 10 with type VI, 2 with type VIII and 4 with type IX. In the female sublot there were 49/61 cases with bilateral symmetry of the carotico-hyoid ratio, 34 with no such ratio, 1 case with type IV, 8 cases with type VI, 3 cases with type IX and 3 cases with type X.

Bilateral symmetry, strongly statistically significant, was identified for cases without carotico-hyoid relationships and for types IV, VI, VIII, IX and X. No bilateral symmetry was found for types I, II, III, V, VII, XI and XII. They can thus be regarded as unilateral anatomical variations. Any cervical surgical approach that involves intraoperative identification of the hyoid bone should be done with caution because it is not excluded that this bone may have direct, direct, direct relationship with the carotid arteries, either laterally or medially. Bilaterally symmetric carotid symmetrical carotid bifurcation was identified in only 28/100 previously studied cases [26]. In the present study bilateral symmetry of carotid-hyoid relationships was found in 70.74% [60]. However, it should be kept in mind that the hyoid bone has heterogeneous morphological characteristics related to sex, height and weight [61]. Thus, carotid variability is superimposed on an individually variable hyoid morphology [60].

Types with medial ICA of the greater horn, have been rarely reported [62-65]. Kolbel et al. (2008) reported one such case, with neurological symptoms that disappeared after resection of the respective hyoid greater horn [62]. In that case the carotico-hyoid relationships were type XI on the right and type VI on the left [62]. Martinelli et al. (2019) identified in one case also a type XI carotico-hyoid ratio [64]. A type XI was also identified in one case by Liu et al. (2020), the apex of the greater hyoid horn interposed between the ECA, laterally, and the ICA, medially, presses the carotid sinus or bulb [66]. Plotkin et al. (2019) also report a case with type XI, with the tip of the hyoid greater horn interposed between the ICA, medial, and ECA, lateral [63]. Kho et al. (2019) report a case with ICA and ECA medial to the greater horn, thus type III [65]. A type II carotid-hyoid relationship is presented by Tokunaga et al. (2015) [67]. Renard and Freitag (2012) report a case in which the tip of the greater horn was located immediately anterior, 1.6 mm, to the anterior tubercle of the transverse process of the C3 vertebra, and the ECA and ICA were located lateral to the greater horn, thus a type VIII [68].

Mori et al. (2011) identified in one case the localisation of ICA and ECA lateral to the greater horn, thus type VII; it is anatomically interesting that a consistent linguofICAal trunk started from the respective ECA, ascending anterior to the ECA and lateral to the greater horn (3 arteries located lateral to the hyoid greater horn) [69]. Hong et al. (2011) identify in one case the localisation of ICA and ECA lateral to the greater horn, thus a type VIII [70]. Also a type VIII carotico-hyoid relationship was reported by Renard et al. (2011) [71]. Yukawa et al. (2014) reported a case having on one side ICA and ECA lateral to the hyoid greater horn, thus a type VIII, and contralateral BC was lateral to the greater horn, thus a type X [72]. Type X with CCA lateral to the greater horn was also reported by Liu et al. (2021) [73]. Schneider and Kortmann (2007) reported localisation of ACC lateral to the greater horn, thus a type IX [74].

The hyoid bone is a remote cause of atherosclerotic lesions of the carotid arteries [64]. However, a retrospective cross-sectional and longitudinal cohort study has concluded that the presence and progression of atherosclerotic plaque and ICA stenosis do not depend on the distance between the hyoid and ICA [75]. Mechanical arterial compression can also lead to ICA dissection [68,72]. Also, chronic compression of the ICA with repetitive vascular trauma can lead to cerebral thromboembolic events in young patients [63]. Compression of the CCA can evolve with perforation of its wall 76,77 and pseudoaneurysm formation of this artery [74]. As pseudoaneurysms can form in the CCA as well as in the ECA or ICA [78], mechanical compression by the hyoid may be considered and investigated in such cases. A case with mechanical compression of the ICA by the hyoid and frequent non-atherothrombotic occlusion and recanalisation of the ICA [69] has been reported. ICA stenosis or occlusion may occur directly, through mechanical compression of the hyoid, or indirectly, through atheromatous plaque formation [71]. Fractures of the hyoid in cases positive for carotid-hyoid ratio may cause significant haemorrhage. Hyoid fractures may also cause pseudoaneurysms of the ECA [79].

2.4 Launay's external carotid vein

Typically, the retromandibular vein (RVM) is formed from the temporal and maxillary veins in the parotid space [80]. The anterior branch of the RMV joins with the facial vein (FV) proper to form the common FV, which in turn drains into the internal jugular vein (IJV) [81]. The retromandibulbar vein is useful for predicting the intraparotid course of the facial nerve (VII) [82]. Deep to the RMV runs the ECA which typically lacks a satellite vein [81].

The external carotid vein has been documented by Caroline Mage in her PhD thesis [83] who noted Rouvière and Delmas' (1985) textbook where the ECV is drawn [84]. Mage (2016) documented that ECV is the ECA’s satellite and could either replace or duplicate the RMV [85,86]. According to the drawing in Paturet's textbook, the ECV joins a superior parotid venous confluent that receives the superficial temporal and maxillary veins with an inferior hyoid venous confluent joined by the facial and lingual veins [83,86]. As drawn in Paturet, the ECV could also connect directly to the VJI [83,86]. Therefore, the aim of this study was to document the anatomy of the ECV [81].

Archived CT angiograms from 100 patients, 48 men and 52 women [81], were used. In three cases (3%, one male and two female patients), unilateral presence of ECV was documented and no pathological vascular changes were detected in these patients. However, there were important differences between these three cases, all of which were positive for the vein of Launay. In the first case, a fenestrated RMV with two unequal arms, one superficial thin and one deep thick, was identified for the first time. The RMV arms were supplied by an intricate venous network constructed by posterior pharyngeal veins and superficial temporal, maxillary, posterior auricular and occipital veins. The terminal segment of the ECA and its branches were intricate with this venous network. The two arms of the RMV merged to continue as the EJV, with course on the sternocleidomastoid muscle. On this muscle, the EJV was fenestrated, with the anterior arm of this fenestration united with the FV. From the posterior arm of the RMV left the ECV which continued on the anterior flank of the ECA and emptied into the IJV. In the second case, on the right side of the head there were two veins passing through Juvara's buttonhole (medial to the base of the neck of the mandible), a larger vein above the maxillary artery and another thin vein inferior to the maxillary artery. These were considered maxillary veins. The thinner, inferior maxillary vein had its course applied to the infraincisural triangle of the mandibular ramus and was supplied by the masseteric vein and the pterygoid venous plexus. The superior maxillary vein was supplied by the pterygoid venous plexus. Postero-inferior to the mandibular neck was the superior maxillary vein, which joined with the superficial temporal vein to form a short RMV that rapidly divided into two dichotomic veins, posterior and anterior. The posterior vein was the EJV, which continued to the sternocleidomastoid muscle and united with the FV. The anterior division of the RMV was the ECV of Launay. The latter crossed on the anterior side of the ECA towards the carotid triangle. In the carotid triangle the ECV united with a thyrolingual venous trunk to eventually terminate in the IJV. The ECV and the thyrolingual venous trunk formed a venous fork traversed by the ECA. In the third case, on the right side of the head, the EJV resulted from the superficial temporal and maxillary veins and was located posterior to the masseter muscle and posterolateral to the posterior border of the mandibular ramus. The superficial temporal vein was 1.87 cm in length and originated from a frontal and a parietal tributary, which joined inferiorly to the zygomatic root.

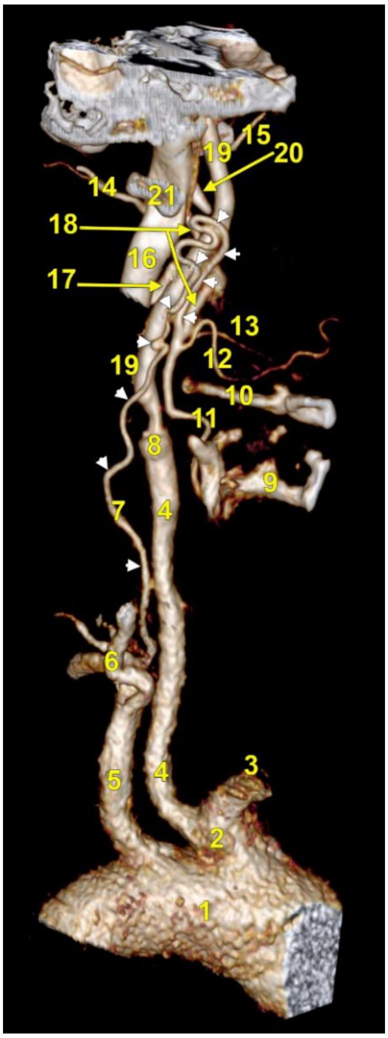
Although each of these three cases with ECV had a specific venous pattern, they shared a common feature: the usual tributaries of the RMV (i.e., the superficial temporal and maxillary veins) contributed equally to the origin of the EJV. Moreover, the RMV, when formed, contributed to the formation of Launay's ECV.

Rouvière and Delmas presented a variant of the ECV different from all those we have found and reported here: this variant presented the origin of the ECV from the maxillary vein, as in the third case above, but the maxillary vein continued further to a venous trunk that sent branches to both the RMV and the EJV. In Rouvière and Delmas' presentation, the RMV and FV formed the common FV, which joined the ECV before emptying into the IJV. Therefore, this variant presents the ECV as an "accessory RMV" that passes deep under the stylohyoid muscle. The ECV that we found in the present study appears as a "substituted RMV" with a deep tract.

The retromandibular vein is the most widely used landmark for predicting the course of the facial nerve within the parotid gland, based on the assumption that the nerve branches laterally from the RMV [82,87]. Because the facial nerve branches terminally within the parotid gland on the lateral side of the intraparotid veins, a ECV variant would apparently not alter the venous surgical landmark [81]. However, because ECV is applied to the ECA, care must be taken during their surgical dissection [81]. In this regard, when deciding and performing ECA ligation, care should be taken whether there is a ECV applied to the ECA [81]. Furthermore, surgical approaches to the palatine tonsil should spare not only the carotid arteries but also the vein of Launay, if present [81].

2.5 Persisting carotid duct (CD) in adult

Isolated unilateral persistence of unilateral DC has not been previously reported in adults, nor has it been found in association with segmental agenesis of the proximal segment of the proximal segment of CEA [88]. In a 71-year-old female case from the group studied in my PhD thesis I found a persisting CD [88].



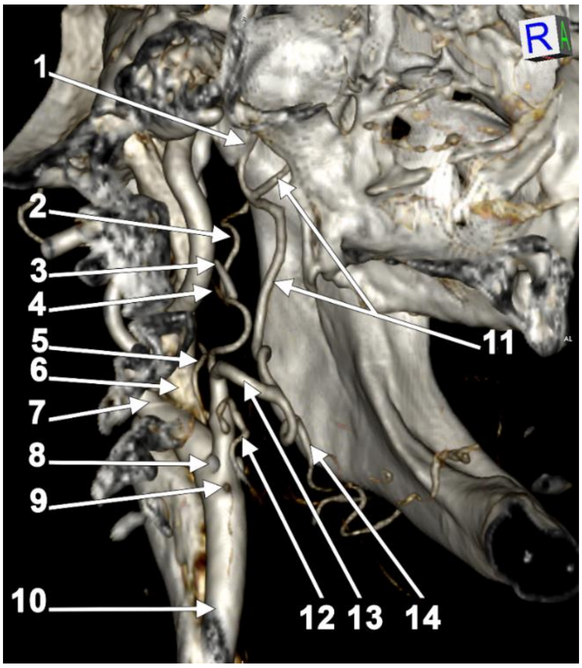
Three-dimensional volumetric rendering, left side, medial view of the carotid system. 1. aortic arch; 2. common trunk at the origin of the brachiocephalic trunk and left common carotid artery; 3. brachiocephalic trunk; 4. left common carotid artery; 5. left subclavian artery; 6. vertebral artery; 7. carotid duct (arrowheads); 8. blunt trunk at the origin of the left external carotid artery; 9. thyroid cartilage; 10. greater horn of the hyoid bone; 11. superior thyroid artery; 12. lingual artery; 13. facial artery; 14. occipital artery; 15. maxillary artery; 16. internal jugular vein; 17. retromandibular vein; 18. external carotid artery; 19. internal carotid artery; 20. styloid process; 21.tip of the transverse process of the atlas.

Foarte puţină informaţie se cunoaște despre DC persistent [89]. Pe baza cazului prezentat, se poate specula următorul mecanism: (1) agenezia segmentară a segmentului proximal al ACE indică faptul că extremitatea ventrală a AA3 nu a dat naștere ACE în morfogeneză; (2) un DC stâng persistent ar trebui să conecteze derivatele AA3 și AA4, deci AS stângă și axul ACC-ACI; (3) DC din cazul prezentat aici continua superior până la nivelul atlasului, apoi cobora și se insera într-un segment normal anatomic al ACE mai sus de osul hioid.

Very little is known about persistent CD [89]. Based on the presented case, the following mechanism can be speculated: (1) segmental agenesis of the proximal segment of the ECA indicates that the ventral end of AA3 did not give rise to the ECA in morphogenesis; (2) a persistent left CD should connect the derivatives of AA3 and AA4, thus the left SA and the CCA-ICA axis; (3) the CD in the case presented here continues superiorly to the level of the atlas, then descends and inserts into an anatomically normal segment of the CEA above the hyoid bone.

2.6 Maxillofacial arterial trunk

The anatomical variations reported here were uncovered during a retrospective study of angioCT records from 52 adult patients, in a 68-year-old woman (Case #1) and a 57-year-old man (Case #2).



Three-dimensional volume rendering, infero-medial view, left side. Left maxillofacial trunk. 1. middle meningeal a.; 2. superficial temporal a.; 3.stylo-hyal bone; 4. posterior auricular a.; 5. posterior auricular a.; 5. ascending pharyngeal a.; 6. internal jugular v.; 7. posterior kink of internal carotid a.; 8.apex of the greater hyoid horn; 9. origin of the superior thyroid a.; 10. common carotid a.; 11.maxillary a.; 12.lingual a.; 13. maxillofacial trunk; 14. facial artery.

The adult MFT presents morphologically as the common trunk of external carotid origin of the MA and FA [90]. This differs from the embryonic maxillofacial trunk which is the primordium of the definitive MA [90]. Quain (1844), cited in [91], appears to have been the first to report an adult MFT, occurring in 1/302 cases [92].

3 Conclusions of the PhD thesis

1. The vertical topography of the carotid bifurcation is highly variable and sex-dependent. This detail can be included in anatomy textbooks. Surgery and interventional medicine should carefully document each individual case.
2. Mechanical compression of the hyoid on the carotid arteries has various undesirable effects on ICA and cerebral circulation. Underlying these are several variational anatomical patterns of carotid-hyoid relationships, which can be accurately documented on CT angiograms.

3. Correlating the possibilities of variation in carotid-hyoid ratios with individual hyoid variability, a case-by-case judgement of the carotid artery-hyoid bone ratios is preferable to a preoperative assumption of a single anatomical-topographical possibility.
4. Any cervical surgical approach that involves intraoperative identification of the hyoid bone should be done with caution because it is not excluded that this bone may have a direct, direct, direct relationship with the carotid arteries, either lateral or medial.
5. A variable axial spin of the CB may be encountered at different times in the same patient and preoperative evaluation of the carotid anatomy should be considered even if the patient has been previously scanned.
6. Normal variants of axial rotation of the CB are rather bilaterally symmetric.
7. The maxillofacial arterial trunk is a rare adult arterial morphology. However, it is important in mandibular and retromandibular surgery, and its preoperative imaging documentation may help to avoid iatrogenic haemorrhagic accidents.
8. The external carotid vein runs along the external carotid artery. Care must be taken when planning surgical dissection of the external carotid artery to avoid injury to the vein of Launay and, consequently, haemorrhage.
9. Surgeons should be aware that an external carotid vein could contribute to the formation of a common facial vein, requiring either surgical ligation or careful surgical dissection.
10. Retromandibular venous variations are a common anatomical event; therefore, parotid dissections should be performed carefully.

11. A venous path through the mandibular notch could unite the deep temporal veins with the parotid space veins.

12. The external carotid vein should be better promoted during anatomical teaching.

13. A preoperative imaging evaluation of the carotid system could be extremely useful to identify adult persistence of a carotid duct and prevent haemorrhagic or ischaemic events.

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