

The carotid and vertebral arteries discovery – initial findings

A descoberta das artérias carótidas e vertebrais – achados iniciais

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ABSTRACT

The studies on the vascular system, including the cervicocephalic arteries (carotid and vertebral arteries), present a long trajectory, having their deep roots in the far past, considering the Western authors, having as representatives the Greek sages Alcmaeon, Diogenes, Hippocrates, Aristoteles, Rufus, and Galenus. They produced pivotal knowledge dissecting mainly cadavers of animals, and established solid bases for the later generations of scholars. The information assembled from these six authors makes it possible to build a quite clear picture of the vascular system, here specifically focused on the cervicocephalic arteries, and mainly of the extracranial segments. Thus, the carotid system became fairly well identified, origin, course, and name, as well as the origin of the still unnamed arteries running through the orifices of the transversal processes of the cervical vertebrae, and entering into the cranium. Almost all that was then known about human anatomy, since this period, and then throughout the Middle Ages, was extrapolated from animal dissections. This state of affairs was maintained until the 14th century, when human corpses dissections were again allowed.

Keywords: arteries, cervicocephalic, carotid, vertebral, discovery

RESUMO

Os estudos do sistema vascular, incluindo as artérias cervicocefálicas (artérias carótidas e vertebrais), apresentam um longo percurso, tendo suas raízes profundas no passado distante, considerando os autores ocidentais, tendo como representantes os doutos gregos Alcmeón, Diógenes, Hipócrates, Aristóteles, Rufus e Galenus. Eles produziram conhecimento pivotal, dissecando principalmente cadáveres de animais e estabelecendo bases sólidas para as gerações futuras de estudiosos.

A informação reunida desses seis autores permite construir um quadro bastante claro do sistema vascular, aqui focado especificamente nas artérias cervicocefálicas e principalmente nos seus segmentos extracranianos. Assim, o sistema carotídeo ficou bastante bem identificado, origem, trajeto e nome, assim como a origem das ainda não nomeadas artérias que percorrem os orifícios dos processos transversos das vértebras cervicais e entrando no crânio.

Quase tudo que era conhecido sobre anatomia humana, desde esse período, e depois ao longo da Idade Média, foi extrapolado a partir de dissecções de animais. Esse estado de coisas foi mantido até o século 14, quando a dissecção de cadáveres humanos foi novamente permitida.

Palavras-chave: artérias, cervicocephalicas, carótidas, vertebrais, descoberta

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INTRODUCTION

The encephalic blood supply is delivered by the cervicocephalic arteries that comprise four vessels, two internal carotid and two vertebral arteries, which course in the neck and then ingress into the cranial cavity, where they ramify.¹ (Figure 1) (Box)

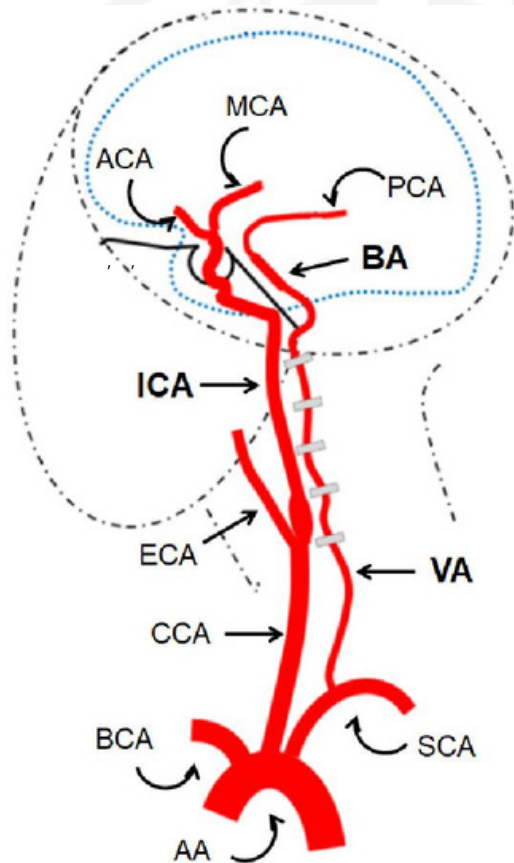


Figure 1. Simplified schema of the head and neck with projection of the cervicocephalic arteries [left side view].

AA=aortic arch, BCA=brachiocephalic artery, SCA=subclavian artery, CCA=common carotid artery, ICA=internal carotid artery, ACA=anterior cerebral artery, MCA=middle cerebral artery, VA=vertebral artery, BA=basilar artery, PCA=posterior cerebral artery

Box. Anatomic characteristics of the cervicocephalic arterial system (carotid and vertebrobasilar arteries).

The encephalic structures are supplied by the cervicocephalic arterial system (carotid and vertebrobasilar arteries), which arises directly or indirectly from the aortic arch.¹
 The carotid system is formed by the internal carotid arteries and their branches.
 The internal carotid arteries [ICA] arise in the neck, resultant from the bifurcation of the 'common carotid arteries' [CCA] (about the level of C4). The latter have different origin on each side – on the right, it stems from the brachiocephalic artery [BCA] (or innominate artery), ramification of the aortic arch [AA], while on the left, it arises directly from the aortic arch. At the origin, the internal carotid arteries are somewhat dilated – segment known as the 'carotid bulb' or 'carotid sinus'. Both arteries, from their origin, progress to the base of the skull [cervical segment], enter through the ostium that leads to the 'carotid canal', a passage localized inside the petrous part of the temporal bone [petrous segment], entering into the cranial cavity through the 'foramen lacerum', pierce the dura mater, and pass into the 'cavernous sinus' [cavernous segment], lateral to the sella turcica. Inside the cavernous sinus they present a sinuous route, leave the sinus perforating the dura-mater [cerebral segment]. There, after the ophthalmic artery is released, emerge in the suprachiasmatic cistern, emit the 'posterior communicating artery' [PCoA], and finally their two terminal branches, the 'anterior cerebral artery' [ACA] and the 'middle cerebral artery' [MCA].^{1,3}
 The vertebrobasilar system is established by the vertebral and basilar arteries, and their branches. The vertebral arteries [VA] have a similar origin on both sides – the subclavian arteries [SCA]. After a short course, they pass through orifices of the transversal processes from C6 (or C5) to C3 cervical vertebrae, then forming a loop, enter through the transverse foramen of C2 (axis), continue through the transverse foramen of C1 (atlas) [cervical segment], pierce the dura mater, and finally ingress into the cranial cavity through the occipital aperture [foramen magnum] [intracranial segment]. There, they progress anterolaterally to the medulla oblongata, and at the lower border of the pons merge to form the basilar artery [BA], which runs in the central groove of the pons, and behind the dorsum of the sella, bifurcates to form its two terminal branches, the 'posterior cerebral arteries' [PCA].^{1,3,4}
 Such is the usual pattern, existing also a number of variations of this configuration.^{3,2,33}
 Once at the base of the brain, the ramifications of the carotid and the vertebral-basilar systems anastomose, forming an arterial circle – the 'circle of Willis'.^{31,35}

These vascular systems have been studied since ancient times. Initially, such studies were performed mainly by animal dissections, and should be regarded as pivotal, as they laid the bases of this knowledge.

The present paper intends to review the discovery of the cervicocephalic arteries, from their origin, throughout the course in the neck, until the entrance into the skull, and finally their terminal intracranial branching, as seen by the early Western authors. The representative authors, for the present purpose, stem from the ancient Greek civilization, from the Archaic to the Roman period of its history.²

The late Archaic or pre-Classical period (ca 600-500 BCE) is best represented by the pre-Hippocratic scholars, Alcmaeon and Diogenes, who opened the paths of such studies.^{2,3}

Alcmaeon of Croton (born ca 540-510 [fl ca 490-450 BCE]), was a Greek physician whose apparently important anatomic production, including 'On Nature' (De Natura) (written between 500 and 450 BCE), was mostly lost. However, scanty extant fragments may be found in writings of later authors. There, it can be learned that he performed dissections, probably of animals only, and he is seen by some as the first one to perform such activity. Further, it is argued by some that in the course of dissections, he observed that in the dead animal certain vessels were bloodless, or contained very little blood, concluding that it was also so in the living animal. Thus, it was maintained that he drew a distinction between 'veins' ('blood-flowing vessels') and 'bloodless vessels' ['arteries']. Alternatively, others consider that he simply distinguished between larger and deeper blood vessels as opposed to smaller ones close to the surface, based on the differential blood flow in his theory of sleep.^{3,4,5,6,7}

Alcmaeon is credited by some for distinguishing between two kinds of vessels - 'veins' ('blood-flowing vessels') and 'bloodless vessels' ['arteries'].

Diogenes of Apollonia (5th century BCE [fl ca 440]), was a Greek natural philosopher, whose works, most of them, were also lost. But, in his extant fragments of 'On Nature' there is a description of the distribution of the blood vessels in the human body, later quoted by Aristoteles in the 'History of Animals' (On Veins). He did not distinguish between arteries and veins, both being called 'veins' (or 'vessels') (*phlebes* - φλέβες). He begins: "...the body contains two large veins [vessels] that stretch through the abdomen along the vertebral column, on the right ['cava?'] and on the left ['aorta?'], extending to the corresponding leg and reaching to the head". Then: "The blood-vessels that run to the head along the throat can be seen as large ones in the neck ['internal jugular?']; and from each of the two, at the point where it terminates, a number of blood-vessels branch off to the head...and each set finishes up beside the ear ['external jugular?']. There is another blood vessel in the neck running nearby the large one, on either

side of the neck, but it is a little smaller [CCA?], and the majority of vessels coming from the head converge on it, and these [two vessels] extend inward through the throat and from each of them vessels branch off, passing underneath the shoulder blade [SCA?] in the direction of the hands...".^{3,8,9,10}

Diogenes identified two main vessels coursing along the body, one at the right side ('cava') and another at the left ('aorta'), and vessels which they gave origin, some to the head (jugular? and carotid?), and others to the arms (subclavian). Apparently, he was the first to make the initial description of the vascular system.

The above authors were followed by Hippocrates, and Aristoteles, of the Classical period, and then by Rufus and Galenus, of the early Roman period, obligatory names to be cited as fundamental of this period of achievements.

Hippocrates of Kos (ca 460-370 BCE), Greek physician (and Corpus Hippocraticus), described aspects of the blood circulation in his numerous writings, as the 'Epidemics II and V', 'Nature of Man', 'On Anatomy', and others. His Epidemics II (section IV - chapter 'On Veins' [*Περι φλεβων*]) mentions that the 'hepatic' [vein] (*ιπατιτες*) (*ήπατιτις*) ('cava vein', according to Galenus' interpretation) ascends [descends?] until the heart, and from there some [branches] go to the neck ['jugulars?'], while others go to the shoulder blade ['subclavians?'].^{11,12,13} The 'Nature of Man' (chapter XI) deals with veins [and/or arteries], as follows: "The large veins [comprise]... There are four pairs in the body. One pair extends from behind the head through the neck, and on either side of the spine externally reaches to the loins and legs, and then stretches through the shanks to the outside of the ankles and to the feet ['cava vein' and 'aorta']...The other pair of veins extend from the head by the ears through the neck, and are called jugular (throat, neck) veins ['jugular veins?' 'carotid arteries?']. They stretch right and left by the side of the spine [vertebral column] internally ['cava' and 'aorta'] along the loins...The third pair of veins passes from the temples through the neck under the shoulder-blades, then they meet in the lungs and reach, the one on the right the left side, and the one on the left the right. The right one reaches from the lungs under the breast both to the spleen and to the kidneys [branches of the cava?], and the left one [branches of the aorta] to the right from the lungs under the breast both to the liver and to the kidneys...The fourth pair begin at the front of the head and eyes [external 'jugular' or 'carotid'], under the neck and collarbones ['brachiocephalic' and 'subclavian'], passing on the upper part of the arms to the elbows, then through the forearms to the wrists and fingers...".^{14,15}

The description is complex, and far from unambiguous, revealing a mix-up of arterial and venous vessels, as he did not (clearly) distinguish between them. The large vessels have an upper segment (superior cava, and ascending and arch of the aorta), and a lower one (inferior cava, and descending aorta), the first related to

the head, neck, and upper limbs, the second to the rest of the body. Thus, it is possible to infer that these vessels (veins and arteries), passing along the neck to supply the head, could be understood as the 'jugular veins' (external and internal) and 'carotid arteries' (common, external, and internal). The vessels passing throughout the neck under the collarbones could represent the 'brachiocephalic'/'subclavian' veins/arteries.¹⁵ Additionally, the short treatise 'On Anatomy' also contains information about the vascular system. There, he describes the heart, and a vein that rises from its base, which trembles loudly [pulsation?], and courses to the liver, named the 'large vein' ['aorta artery?'], which nourishes the entire body, descending further to the kidneys, ureters, and bladder. Next, in "On the Heart", he mentions that from this organ arise two veins ('cava vein' and the 'large artery' ['aorta']). Further, in 'On Veins', he describes that the 'aorta' artery leaves the heart, and divides into an ascending and a descending segment.¹⁵

It should be considered that Hippocrates knowledge on anatomy was probably based on observation on animals [kind not specified], possibly corroborated by some human dissection, perhaps aborted foetus, or exposed infants, in conjunction with opportunistic observation of war wounded and accident victims.¹⁶ There is a great difficulty in understanding Hippocrates' description of the vascular system, as he did not distinguish (clearly) between 'arteries' and 'veins', using the same term frequently for both. It should be highlighted that the term 'artery' (*άρτηριη*) is used more often, in his writings, for the 'rough artery' (*τραχειία αρτηρία*) ('tracheia-arteria') [trachea] and 'bronchi' [Note 1]. The term 'vessels' (*αγγεία* [*αγγεία*]) was usually preferred, as they carry blood, air, and possibly other fluids. Finally, the starting point and direction of these vessels (e.g., 'come from the heart' and "come from the head") is varied, derived only by a simple observation, sometimes seen as originating from the heart, other times, from the head, liver, and/or spleen.^{11,16,17}

Aristoteles of Stagira (384-322 BCE), Greek philosopher and biologist, obtained his anatomical knowledge dissecting animals. In his 'The History of Animals' (*Historia Animalium*) and 'The Parts of Animals' (*De Partibus Animalium*), he considers aspects of the circulatory system. In the *Historia* he writes: "There are two blood-vessels in the thorax by the backbone [vertebral column], and lying to its inner side, and of these two the larger one is situated to the front, and the lesser one is to the rear of it, and the larger is situated rather to the right-hand side of the body ['cava vein'], and the lesser one to the left, and by some this 'vein' ['artery'] is termed the 'aorta' [*ἀορτή*]...". Further: "These blood-vessels have their origins in the heart, for they traverse the other viscera, in whatever direction they happen to run, without in any way losing their distinctive characteristic as blood-vessels...owing to the fact that these two veins are above and below ['cava' and 'aorta'], with the heart lying midway". Proceeding:

"...the parts of the lesser vein, named the 'aorta', branch off, accompanying the branches from the large vein ['cava'] And: "...the vein that emerges from the heart ['superior cava'] branches off in two directions ['brachiocephalic veins']...extend to the sides and to the collarbones ['subclavian veins']...The 'jugular veins' ...run alongside the trachea-arteria... they branch off into four veins...each branch of the other pair ['internal jugular'] stretches from the region of the ear to the brain ... the remaining veins that branch off from the last-mentioned vein, some encircle the head ['superficial temporal vessels'], others ['maxillary vessels'] end their courses...at the teeth... ['external jugular veins' and 'external carotid']".^{18,19,20} In *Partibus* (II and III), there are additional information: "... however, that it [the brain] may not itself be absolutely without heat, but may have a moderate amount, branches run from both blood-vessels, that is to say from the 'large vessel' ['cava'] and from what is called the 'aorta', and end in the membrane [meninges] which surrounds the brain... [internal 'jugular veins' and 'carotid arteries']..."^{20,21}

Aristoteles did not discriminate (clearly) between veins and arteries, both being called veins (*phlebes*), but recognized the different natures of the vessels, those being larger and membranous and those narrower and sturdy, and also those that contained or not blood. He acknowledged two main blood vessels - the 'large vein', corresponding to the 'cava', and the lesser veins, or 'aorta'. However, he did not distinguish between their functions, holding that both alike nourish the body by carrying the blood to all parts of it. Branches from the 'large vein' and 'aorta' accompany each other throughout the entire body, emitting twigs to the head ('jugulars' and 'carotids'), supplying the external structures ['external jugular' and 'external carotid'] and the brain ['internal jugular' and 'internal carotid'], and both providing branches to the upper limbs ('brachiocephalic veins' and 'subclavian artery').^{20,21}

Aristoteles writings are somewhat clearer, in comparison to those of Hippocrates. He introduced the term 'aorta' to designate the 'lesser vein' [Note 2]. The excerpts above permit to suspect that Aristoteles meant, arising from the 'aorta', and ascending in the direction of the head, the existence of cervicocephalic arteries (carotid and vertebral arteries), and also those directed to the upper limbs (subclavian arteries).

[Note 1: arteria= from Greek *arteria* ('windpipe')]

(<https://www.etymonline.com/word/artery>) [28-04-2022]

[Note 2: aorta=from Greek *aorte* 'a strap to hang (something by)', a word applied by Aristoteles to the large artery of the heart, literally 'what is hung up', probably from *aeirein* 'to lift, heave, raise'. Used earlier by Hippocrates to designate the bronchial tubes] (<https://www.etymonline.com/word/aorta>) [28-04-2022]

Rufus of Ephesus (fl late 1st and early 2nd centuries CE), Greek physician, acquired most of his knowledge on anatomy by dissecting varied animals (mainly monkey cadavers). He wrote numerous books, but most of his works were lost. However, preserved writings and fragments were rescued and published, including his principal work on anatomy, 'On Names of the Parts of the Human Body', where information about the state of pre-Galenic anatomy may be found. He distinguished veins from arteries, arguing that veins are vessels that contain blood, while arteries contain a certain amount of blood and a larger amount of 'spirit' (*pneuma*). He mentions that Aristoteles named the large artery which runs down the spine as 'aorta'. Regarding the origin of the term 'carotid' he affirms: "In the past, the name 'somniferous' (*carotides*) (*καροτίδες*) was applied to the vessels which ascend through the neck, because by compressing them, drowsiness [stupor] (*karódeis*) (*καρώδεις*) (derived from the Greek word *karos* [*κάρος*], meaning 'to stun, stupefy, or fall into deep sleep') is produced. ..." ['carotid artery' (common? internal?)]. And added: "The carotid [artery] (*καρωτίδας*) provides blood to the brain, and interruption to its flow results in loss of consciousness (*καρώδεις*)".^{19,22,23}

Rufus' contribution is important, as he reminds the origin of the term 'carotid', and clarifies that the term was in use for a relatively long time. However, it was not possible, until now, to trace the ancient origin of this term.

Claudius Galenus of Pergamon (ca 130-ca 210 CE), Greek physician and philosopher, explained in his varied books aspects of the circulatory system. He recognized the differences between arteries and veins, and argued that not only the veins but also the arteries contain blood. He described the arterial system [mostly in monkeys, preferentially the tailless Barbary ape (*Macaca inuus*)], beginning with the 'large artery' or 'aorta' (according to Aristoteles), which rises from the left ventricle of the heart and soon forms the arch and the descending segment. From the arch emerge two unequal branches. One, which ascends to the sternum [right side] where it splits into two unequal divisions, a lesser at the left side, form the left [common] 'carotid artery' [left CCA], and the other sturdier, at the right side [BCA], ascends obliquely, and form the right [common] 'carotid artery' [right CCA] (*carotides* - "term according to the old times", as he affirmed), and the remaining part runs to the right shoulder and upper limb [right SCA]. Another, slimmer branch arising from the arch, at the left side, goes to the shoulder and upper limb [left SCA].^{19,24,25,26} Each [common] 'carotid artery', in the neck, divides into two branches - one posterior, and one anterior. Each 'posterior branch' divides to supply external parts of the head [ECA]. The internal branch [ICA] runs through a 'channel' [carotid canal] in the 'petrous bone' [part of the temporal bone], where it makes a bend like a 'spun', and ramifies into minute twigs to form the 'retiform plexus' (*rete mirabile*). Further, an artery runs to the brain, providing the 'choroid plexus', another to the

ocular orbit [‘ophthalmic artery’], and the extremities of the posterior ramifications [PCoA?] join with those [branches] that came from the orifices of the cervical vertebrae [VA] (see below). From there, he explained, that out of the ‘retiform plexus’, the small ramifications, are again reunited, and constitute ‘two larger arteries’ that ascend and encircle the brain together with the delicate meninx [pia-mater], “in the fashion of a ‘girdle’ [ACA? and MCA?].^{24,25,26,27,28} He also detailed the origin and course of other deep seated arteries, describing that the branches destined to the upper limb [SCA] emit rami that run to the vertebral column, and route through the lateral vertebral [transvers processes] orifices of the lower six cervical vertebrae [VA], ascending in the direction of the cranium. There, after crossing over the 1 vertebra, each divide into two branches, one of them enters the cranium [intracranial VA], and course in the direction of the posterior encephalon.^{24,25,26,29}

Galenus studies were performed mainly by dissecting and vivisectioning varied kinds of animals (monkeys, oxen, pigs, sheep, dogs). He also obtained information from injured gladiators, as he acted as physician to this class of wrestlers.^{20,25,26,29}

Galenus provided the first detailed description of the cervicocephalic arteries, including the extra- and intracranial segments of the carotid and vertebral arteries, from their origin in the cervicothoracic region, their course in the neck, and their arrival and branching in the intracranial cavity (Figure 2). Despite some inaccuracies derived from the fact that his studies were performed mostly in animals [monkeys, oxen, etc.], and that he attributed to one animal the structures found in another, and extrapolated his findings to the human body, as he claimed that there were no marked differences between them, his findings were influential for more than one and a half millennium, even when, in the 14th century, human corpses dissection was reinstated.³⁰

COMMENTS

The studies on the vascular system, including the cervicocephalic (carotid and vertebral arteries), have a long trajectory, having their deep roots in the far past, considering the Western civilization. Thus, it can be stated, without perpetrating a mistake, that initially Alcmaeon and Diogenes, then Hippocrates and Aristoteles performing their studies many centuries later, still BCE, and later Rufus and Galenus, flourishing in the first centuries of the CE, are obligatory names to be cited. They produced pivotal knowledge on this (and other subjects), dissecting mainly cadavers of animals, and laid solid bases for the next generations of scholars. It should be stressed, that the above-mentioned pioneers, mainly Galenus, continued to be cited, and their teachings continued to be followed during the Middle Ages, and at the Renaissance, and further, even with the reinstatement of human corpses

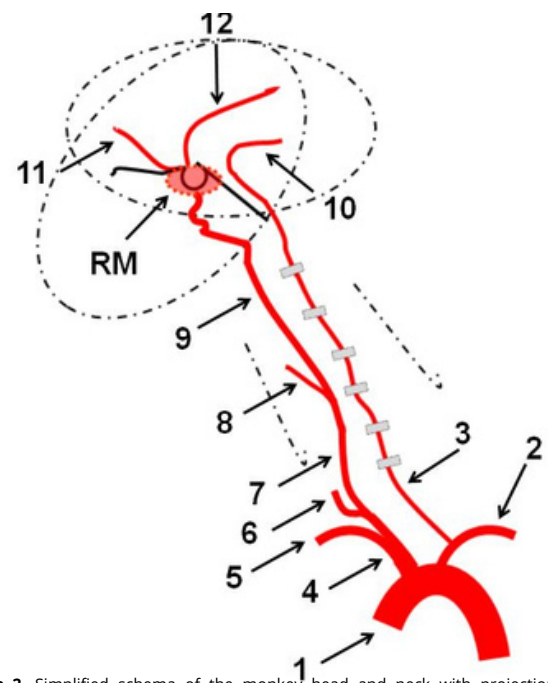


Figure 2. Simplified schema of the monkey head and neck with projection of the cervicocephalic arteries [left side view], drawn according to Galenus description^{24,27,29}. Observation. The carotid RM is inexistent in the monkey.

1=aorta, 2=small branch to the left upper limb [left SCA], 3=branch that ascends to the head through the transversal process orifices of the lower six cervical vertebrae [VA], 4=large common trunk that ramifies into 5=branch to the right upper limb [right SCA], and a trunk that bifurcates to form the 6=right [common] carotid artery [right CCA] (cut), and 7= left [common] carotid artery [left CCA], which divide to form 8=a posterior branch [ECA], 9=an anterior branch [left ICA], 10=branch to the posterior encephalon of the [intracranial VA], RM=plexiform net (*rete mirabile*), 11=[anterior] branch resulting from the reunion of the small vessels of the RM [ACA?], 12=[posterior] branch resulting from the reunion of the small vessels of the RM [MCA?]

dissection, by the pre-Vesalian anatomists, and by Vesalius proper, who relied on or criticized Galenus, as well as by anatomists that appeared later.^{3,9,31}

Almost all that was then known about human anatomy, since Alcmaeon until Galenus, and then throughout the Middle Ages, with exception of the recovered information of the Alexandrian anatomists, was extrapolated from animal dissection and vivisection - the distinction between non-human animal and human anatomy was probably not regarded as significant. This state of affairs was maintained until the 14th century, when human corpses dissections were again allowed.^{26,32}

The writings on the vascular anatomy of pre-Classical and Classical authors are not clear, as they did not distinguish clearly between veins and arteries. Thus, some descriptions are confusing, and it is necessary to ‘decode’ what they meant. The few extant writings of Rufus, and the many books of Galenus, which appeared centuries later, show a clearer description, and nomenclature.

Summing-up the information gathered from these six authors, native of varied regions of an extended Greece (Figure 3), makes it possible to build a quite clear picture of the vascular system, here specifically focused on the cervicocephalic arteries, and mainly of the extracranial

segments. Thus, the carotid system became fairly well identified, with its components (common, external, internal), origin, course, and name, as well as the origin of the still unnamed arteries that run through the transversal processes of the cervical vertebrae [VA], and enter into the cranium.

These studies lasted more than a half millennium, from Alcmaeon to Galenus, and laid solid bases for the forthcoming authors, one and a half millennium later, to begin the final steps for the obtention of the present-day knowledge on the subject.



Figure 3. Map of the Mediterranean Sea region, where the cities [red circles] of the six authors [between square brackets] are localized in an extended Greece. Present day names of the countries and the sea written in blue colour, and in simple quotation marks.

Blank map (part):

https://commons.wikimedia.org/wiki/File:Blank_Map_of_Mediterranean_Sea_region.svg

Localization of the cities: varied sources

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