VARIABLE LEFT AND/OR RIGHT VERTEBRAL ARTERY IN PREVERTEBRAL PART: A REVIEW OF FEATURES IN THE POSTNATAL PERIOD

Ljiljana Vasović1, Goran Radenković2, Milena Trandafilović1*, Gordana Đorđević3

Faculty of Medicine, University of Niš, 1Department of Anatomy, 2Department of Histology and Embryology, Niš, Serbia
3Health Center of Niš, Niš, Serbia

Abstract. The vertebral artery (VA), as the first upstream branch of the subclavian artery on both sides courses having four topographical parts — prevertebral, cervical, atlantic and intracranial to the interlocking connection into basilar artery. However, its amenability to the variations can be at the origin, and/or course and/or termination. The review of postnatal features of variable VA origin and its prevertebral part was performed according to the 171 literature case reports. Among them, 94 cases of variable left VA, 30 cases of variable left and right VAs and 47 cases of variable right VA have been analyzed. The left and/or right VAs were showed as simple or common vessels or segmentally duplicated at their origin from the aorta and/or subclavian or common carotid or external carotid artery or unusual arterial stems. Different patterns of single VA origin and/or arrangement associated with main supra-aortic arteries variants were presented as 30 primary (basic) and 32 complementary models. Nine different vascular and/or visceral pathological processes were common independently of unilateral or bilateral variability of the VA; however, there were only eight patients with pathological changes in variable VA.

Key words: Human vertebral artery, morphologic variants, postnatal status, associated disorders

Introduction

The cardiovascular system is the first system functioning in the developing animal or human embryo [1]. As cited by Bhatia et al. [2], the development of blood vessels is associated with local release of certain growth factors such as the placental growth factor, fibroblast growth factor-2, angiopoietins and vascular endothelial growth factor.

The development of the cardiovascular system is associated with the formation of the endocardial tube and paired primitive aortae. The endocardial tube begins to beat during the third week of gestation. It consists of four parts: (1) sinus venosus; (2) primitive atrium; (3) primitive ventricle; and (4) bulbus cordis that continues as the truncus arteriosus. Six primitive aortic arches bilaterally diverge from a dilatation of the truncus arteriosus (aortic sac) to the dorsal aortas that run through the entire length of the embryo and their segmental branches correspond to the somites. The dorsal aorta gives off thirty pairs of dorsal intersegmental arteries (DIAs), which supply the spinal cord and the developing somites. Each segment has the same number as the intersegmental artery bounding it caudally. The fusion of paired dorsal aortas could be seen just caudal to pharyngeal arches, during the 4th week.

The first pair of aortic arches embedded in the mandibular arch courses around the rostral part of the pharynx. Actually it is formed by the curving of a ventral segment of the primitive aorta (“ventral aorta”) into dorsal segment (“dorsal aorta”), between days 22–24. The first aortic arch will contribute to the development of maxillary and external carotid arteries. A second pair of aortic arches that embedded into tissue of the hyoid arch springs from the cephalic end of the heart dorsal to the ventral root of the first aortic arch. It participates in the formation of hyoid artery and its stapedial branch. The further course of development is followed by appearance of other aortic arches; five pairs (I–IV and VI) are developed between days 22–29. The development of the fifth aortic arch is followed by the disappearance of the first two arches. A proximal segment of the third pair will form the common carotid artery (CCA), whereas the distal part of the third arch together with some segments of the dorsal aorta will contribute to the formation of the internal carotid artery (ICA). The left fourth arch will form the segment of adult arch of the aorta between the left CCA and subclavian (SA) arteries; the right fourth arch will form the proximal right SA [3, 4].

There is a disagreement in the literature about the complete development of the SA. Some authors noted that the distal right SA will derive from a portion of the right dorsal aorta and the right sixth cervical intersegmental artery (CIA), whereas the left SA will be formed entirely from the left sixth CIA [5–16]. However, some embryologists [1, 3, 4], as well as most cited anatomists...
and clinicians in this paper described that the seventh CIA is a precursor of future SA and VA.

The segment of the ventral aortic roots between the fourth and third aortic arches will incorporate into the brachiocephalic trunk on the right and into the ascending aorta on the left side. The arch of the aorta will develop from the aortic sac, left 4th aortic arch, and a part of the left dorsal aorta. The left sixth aortic arch will participate to the formation of the pulmonary trunk, left pulmonary artery and ductus arteriosus; the right sixth arch will contribute to the right pulmonary artery. The branches of the arch of the aorta develop during the 5th and 6th weeks of gestation, and during the 8th week transformation of the aortic arch arteries leads to the development of an adult arterial system. This adult pattern is caused by degeneration or hypertrophy or Anastomosis of some embryonic vessels and/or separation of one primitive vessel into two and/or formation of new arteries [3, 4, 6]. However, isolated anomalies of the arch of the aorta and its branches with normal heart can associate with chromosome 22q11 deletion [17].

Summarizing the developmental changes from stereomicroradiographic images of timed-gestation embryos, Effman et al. [1] noted the following: (1) partitioning of the truncus arteriosus; (2) initial symmetry of primitive III, IV and VI aortic arches and dorsal aortae; (3) development of the SAs from seventh CIs caudally to their final location on the primitive aortic arch; (4) progressive decrease in the size of right IV and VI aortic arch derivatives; (5) attenuation of a segment of the right dorsal aorta distal to the right SA; (6) progressive rounding of the aortic arch; and (7) persisting large main pulmonary trunk and ductus arteriosus through late gestation.

As cited [16], primary VA stem contains three parts: (1) cervical VA with prevertebral and transversal segments; (2) atlantic part; and (3) subarachnoid part—a metencephalic longitudinal anastomosis in the direction of primitive ICA caudal branch. Any interruption or regression and reformation in the developmental process of VA can give rise to anomalies such as fenestration or duplication [12, 16, 18], as well as the variable origin [12, 16], and/or involvement of only one VA in the BA origin [19].

Although these VA anomalies can be found both in the fetal [12, 16, 20] and adult period, in continuation of review of morphological features of the VA from prenatal to the postnatal age 21 [16], anatomo-pathological specificities of VA in a special sample of left and/or right VA variants will be highlighted.

**Material and Methods**

Case reports of the left and/or right VA variants from online available articles and library archives at the Faculty of Medicine of Niš dated from year 1928 to 2015 have been examined. These variants in 171 adult cases—patients and cadavers of (unknown) gender that were investigated in 32 countries have been reviewed (Table 1).

Systematization of variable VAs was performed according to the location and relationships of variable VA with other supra-aortic arteries in the form of primary and complementary models. The capital letter — M (or M*) with corresponding Arabic number was used for labeling the patterns of variable left (or right) VA origin, respectively; two letters — MM* (with corresponding Arabic number) were used for marking different patterns of variable origin of both VAs. Marking of complementary model (variable VA origin associated with variation of the main supra-aortic arteries) was as follows: appropriate characters of primary models (M1… or M*1… or MM*1…) received a small letter of the alphabet. All models were personally sketched.

**Unilateral and bilateral VA variability**

Routine anatomy dissection of human cadavers during students’ exercises, as well as surgical interventions and/or some radiological methods (aortography, or cerebral angiography, or selective vertebral angiography, or retrograde brachial angiography, or computer tomography angiography, or magnetic resonance angiography, or digital subtraction angiography, or color Doppler sonography) were applied as therapeutic and/or diagnostic procedures in patients because of different diseases during which variable VA and other vascular and/or visceral (ab)normalities were detected.

**Left VA**

**General data**

Only on the left side, a variable VA was found in 94/171 or 54.97% of cases (52 of male, 25 of female and 17 of unknown gender), from age 6 [21] to 95 [22]. Variable left VA was discovered in patients with different initial symptoms—headache [11, 13, 18, 23, 24], or motor weakness in the right upper limb [25, 26] and lower limb [27], or weakness and vertigo [23, 28], or dizziness [29] and gait instability [30, 31], or tingling on one side of the body [23] followed by cardiac murmur [21], or paresthesia in the left arm [32] and left limb [33], or chest pain [34, 35], or presyncope [36], or stroke [37, 38], or known presence of arterial aneurysm [38, 39], or transient ischemic attack [40], or dysphagia, dehydration and respiratory distress [7]. However, this VA variability was also discovered during health screening [41–43], or preoperative examination [9, 44], or suspected pacemaker failure [45], as well as in single angiographic images [15, 46–49].

**Status of vessel stem**

The left VA was presented as a simple or common vessel or total and segmentally duplicated at the origin from different vascular sources—the left SA and/or the arch of the aorta, or left CCA, or left external carotid artery (ECA), or left thyrocervical trunk, or so-called left brachiocephalic artery, or special left lateral SA (Fig. 1).
A single left VA of aortic origin was found between a brachiocarotid trunk and left SA [34, 46, 50], distally from the left CCA and left SA in most cases. Although infrequently, the left VA was found between the brachiocephalic trunk (BT) and left CCA [51], between the right SA and bicarotid trunk [24], between the left CCA and left internal carotid artery (ICA) and left SA [52], and between the left CCA and left internal thoracic artery (InTA) [53] in single cases. Such unique cases were also the origins of the left VA from the left CCA [27] or so-called left brachiocephalic artery [45] or special left lateral SA [54]. The left VA had a common origin with the left SA at the arch of the aorta [53, 55–57], and with the left inferior thyroid artery (ITA) originating from ipsilateral SA or the arch of the aorta [41].

The left VA was totally duplicated in a female case described by Poonam et al. [58]. Namely, the authors discovered one hypoplastic VA of SA origin that coursed only in the V1 and V2 parts, and entered the C VI foramen transversarium, whereas the second VA of ECA origin was dominant and took the course through V3 and V4 parts without entering any foramen transversarium. The left VA was segmentally duplicated while both segments originated from ipsilateral SA [28, 29, 47, 59], or SA and the arch of aorta [9, 13, 23, 25, 30, 32, 36–38, 40, 43, 49, 53, 59, 60], or the thyrocervical trunk and aorta [61]. The patterns of the variability of 93 left VAs and its association with variable main supra-aortic arteries are presented by 12 primary and 12 complementary models, respectively (Table 2).

**Caliber**

Some authors described that variable left VA was hypoplastic [26] and had 0.9 mm diameter [58], or was small with mild ostial narrowing [23, 45], or dilated [34, 81]. The diameter of the left VA of aortic origin ranged from 2 mm [62] to 8.4 mm [77]. A 9.5 mm diameter

### Table 1. Distribution of single cases of the variable vertebral artery origin

<table>
<thead>
<tr>
<th>Country*</th>
<th>Case numbers</th>
<th>Side</th>
<th>Left</th>
<th>Right</th>
<th>Left + Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>2 (2u)</td>
<td>Patients + Cadavers (m / f / u)</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>Austria</td>
<td>1 (m)</td>
<td>1 (f)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>1 (m)</td>
<td>1 (m)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>1 (m)</td>
<td>1 (m)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>2 (2f)</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Croatia</td>
<td>1 (f)</td>
<td>1 (f)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethiopia</td>
<td>1 (m)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>France</td>
<td>2 (m+f)</td>
<td>2 (2f)</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>6 (2m+4f)</td>
<td>2 (m+f)</td>
<td>1 (f)</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Greece</td>
<td>1 (u)</td>
<td>1 (u)</td>
<td>2</td>
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<tr>
<td>Grenada</td>
<td>1 (m)</td>
<td>1</td>
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<tr>
<td>India</td>
<td>32 (18m+3f+11u)</td>
<td>7 (2m+3f+2u)</td>
<td>5 (3m+1f+1u)</td>
<td>44</td>
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<tr>
<td>Iran</td>
<td>1 (m)</td>
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<td>Ireland</td>
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<tr>
<td>Italy</td>
<td>1 (f)</td>
<td>2 (m+f)</td>
<td>3</td>
<td></td>
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</tr>
<tr>
<td>Japan</td>
<td>12 (5m+7f)</td>
<td>8 (5m+3f)</td>
<td>1 (m)</td>
<td>21</td>
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</tr>
<tr>
<td>Korea</td>
<td>3 (2m+1f)</td>
<td>4 (2m+2f)</td>
<td>2 (2f)</td>
<td>9</td>
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<tr>
<td>Lithuania</td>
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<tr>
<td>South Africa</td>
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<td>1 (m)</td>
<td>7</td>
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<td>Spain</td>
<td>1 (m)</td>
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<td>Tanzania</td>
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<tr>
<td>Trinidad and Tobago</td>
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<tr>
<td>Turkey</td>
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<td>4 (3m+1f)</td>
<td>3 (3f)</td>
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<td></td>
</tr>
<tr>
<td>UK</td>
<td>2 (f+u)</td>
<td>2 (m+u)</td>
<td>1 (f)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>12 (7m+5f)</td>
<td>10 (5m+4f+1u)</td>
<td>5 (2m+3f+1u)</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Σ</td>
<td>94 (52m+25f+17u)</td>
<td>47 (25m+17f+5u)</td>
<td>30 (9m+18f+3u)</td>
<td>171 (85m+60f+26u)</td>
<td></td>
</tr>
</tbody>
</table>

*Alphabetical order

m, male; f, female; u, unknown gender
was noted in a common stem of the left VA and SA in the first [56], and 10.08 mm in the second case [57].

Sikka and Jain [81] revealed that the diameters of the left VA at origin and at the entry of the corresponding cervical foramen transversarium were different — 4.9 mm and 3.9 mm, respectively. Ikegami et al. [64] described a pyramidal commencement of the left VA on the arch of the aorta with 8 mm in diameter, and its decrease to 4 mm at a point about 2 cm away from the origin.

Course in V1 part

There was no note about some special course of the variable VA in V1 part in relation to the course of the normal VA. There were descriptions that the left VA of aortic origin ascended upward and backward lying behind the left vagus, left brachiocephalic vein and left CCA [84], or in close to the left vagus and the apex of the left lung [56], sometimes of tortuous course [81]. The VA was crossed anteriorly by ITA [71], or by sympathetic trunk [77], or by thoracic duct [74]. Posteriorly, the VA was related to the longus cervicis muscle before entering the foramen transversarium of the cervical (C) vertebra at a higher level than that of the sixth [71].

There were reports about different levels of the single (left) VA entry at the foramen transversarium of cervical vertebra — C VII [49, 56], C VI [54, 58, 65, 68–70, 72, 74, 75, 80, 82, 84], C V [11, 33, 62, 64, 71, 77], C IV [49, 55, 71, 81], C III [76, 87] and C I [27]. Moreover, in a case described by Poonam et al. [58], the left VA of aortic origin bifurcated at V1 part, where one vessel entered C VI, whereas the second vessel entered C V foramen transversarium. Unusual extension of the left VA of thyrocervical origin outside of the transverse foramina and penetration of dura in the level of foramen magnum was described in a 36-year-old woman [44].

Medial and lateral segments of duplicated left VA also penetrated foramen transversarium at different levels [9, 28, 30, 38]. Their fusion differed from case to case — C VII [36], C VI [37], C V [13, 18, 23, 30, 32, 49], C IV [38, 43], or above C II [28].
<table>
<thead>
<tr>
<th>Vascular source(s)</th>
<th>Schemes and description of primary models of variable left VA</th>
<th>Schemes and description of complementary models of variable left VA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subclavian stern (S)</td>
<td>M1: Segmental duplication of the left VA of SA origin.</td>
<td>M1a: Additionally, fenestration of the left common carotid a. (CCA) and segmental duplication of the right CCA</td>
</tr>
<tr>
<td></td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>Left subclavian a (SA)</td>
<td>M1(M1a): Vf / S + Vm / S</td>
<td>M2a: V / Sf</td>
</tr>
<tr>
<td>Sub-clavian branch</td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>So-called lateral left subclavian a (S)</td>
<td>M2a: Left VA origin from so-called left lateral SA associated with a presence of a left medial SA.</td>
<td></td>
</tr>
<tr>
<td>Vertebral -inferior thyroid trunk (V-i)</td>
<td>M3: Common trunk of the left VA and inferior thyroid artery of SA origin.</td>
<td>M3: V-i / S</td>
</tr>
<tr>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
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</tr>
<tr>
<td>Thyro-cervical trunk (T)</td>
<td>M4: Left VA originates from the left thyro-cervical trunk (TT).</td>
<td>M4: V / T</td>
</tr>
<tr>
<td>Subclavian stem and aortic arch (S + A)</td>
<td>M5: V/A + V/S</td>
<td>M6a:</td>
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<tr>
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<tr>
<td></td>
<td>Left VA originates with two separate vessels from the arch and left SA.</td>
<td>Additionally, common stem of brachiocephalic trunk (BT) and left CCA–brachiocephalic trunk [36].</td>
</tr>
<tr>
<td></td>
<td>[9, 13, 23, 25, 30, 32, 37, 38, 40, 43, 49, 53, 59]</td>
<td>[36]</td>
</tr>
<tr>
<td>Thyrsovascular trunk and aortic arch (T + A)</td>
<td>M6: Segmental duplication of the left VA of SA and aortic origin.</td>
<td>M7: Segmental duplication of the left VA of TT and aortic origin.</td>
</tr>
<tr>
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<td>[61]</td>
<td>[61]</td>
</tr>
<tr>
<td>Arch of the aorta</td>
<td>M8: Left VA originates from the arch as the second branch.</td>
<td>M8b: Additionally, brachiocephalic trunk [24, 46, 50].</td>
</tr>
<tr>
<td></td>
<td>[51]</td>
<td>[24]</td>
</tr>
<tr>
<td></td>
<td>M9: Left VA originates from the arch as the third branch.</td>
<td>M9b: Additionally, absence of both CCAs; left ICA as the second branch of the arch [52].</td>
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<tr>
<td></td>
<td>[7, 11, 15, 31, 32, 41, 49, 53, 58, 62–88]</td>
<td>[52]</td>
</tr>
</tbody>
</table>
## Variable Left and/or Right Vertebral Artery in Prevertebral Part: a Review of Features in the Postnatal Period

<table>
<thead>
<tr>
<th>M8 (M9a–b); M9 (M9a–c); M10: V/A</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
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<tr>
<td>M10: Left VA originates from the arch as the fourth (last) branch. [21, 23, 26, 35, 39, 48, 49]</td>
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</table>

<table>
<thead>
<tr>
<th>M11 (M11a): V-S/A</th>
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<tbody>
<tr>
<td><img src="image2.png" alt="Diagram" /></td>
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<tr>
<td>M11: Common beginning of the left VA and SA from the arch. [53, 55]</td>
</tr>
<tr>
<td>M11a: Additionally, brachiocarotid trunk [56, 57].</td>
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</tbody>
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<table>
<thead>
<tr>
<th>M12a: V-I/A</th>
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<tbody>
<tr>
<td><img src="image3.png" alt="Diagram" /></td>
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<tr>
<td>M12: Common beginning of the left VA and internal carotid a. Additionally, right SA as the first branch of the arch; right external carotid and internal carotid aa. as separated branches of the arch [42].</td>
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<thead>
<tr>
<th>M13: V-I/A</th>
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<tbody>
<tr>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>M13: Common stem of the left VA and inferior thyroid artery originates from the arch. [41]</td>
</tr>
</tbody>
</table>

| So-called left brachiocephalic a. (B') |

<table>
<thead>
<tr>
<th>M14a: V/B'</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5.png" alt="Diagram" /></td>
</tr>
<tr>
<td>M14a: Left VA is a branch of so-called left brachiocephalic artery trifurcation; additionally, common stem of the left and right brachiocephalic arteries is the only branch of the arch. [45]</td>
</tr>
</tbody>
</table>
Collaterals

Although normally VA does not distribute collaterals in V1 part, some authors noted side branches of the variable left VA as follows: (1) suprascapular artery [44]; (2) InTA [35]; and (3) bronchial artery [31, 62]. An early bifurcation of VA of aortic origin in two vessels was also evidenced, but without description about their further course and termination [58].

Additional vascular variants

VA. A fenestration of the left VA stem after fusion of its initial double segments in 42-year-old woman [25] and 73-year-old man was also reported [30].

Distal duplication of the right VA at the craniocevical region [38], or ectatic diameter of the right VA followed segmental left VA duplication of aortic and subclavian origin [25] in two separate cases.

Aorta. There was variable number (1–6) and/or arrangement of branches of the arch (and descending aorta). The arch of the aorta with four branches of different arrangement was the most frequent in cases of variable left VA.

Rare cases of these patterns were as follows: (a) one branch—a common trunk of so-called brachiocephalic arteries [45]; (b) two branches—a brachiocarotid and left VA-SA stems [56, 57]; (c) three (variable) branches—brachiocarotid stem, a medial segment of the left VA and left SA in one [36], and BT, left CCA and left VA-SA stem in two cases [53, 55]; (d) five branches—right CCA, left CCA, left VA, left SA and lusoria right SA in the first [89], and BT, left CCA, left VA, left InTA and left SA in the second case [53]; (e) six branches—right SA, right ECA, right internal carotid artery (ICA), left ICA-VA stem, and left SA in the one case [42].

In addition, a mild dilatation of ascending aorta [26], or kinked and elongated arch of the aorta [21], or dilated arch and descending aorta [39] were associated with aortic origin of left VA distally from the left SA. Hypoplastic descending aorta was associated with segmental duplication of the left VA in one case [60].

Brachiocephalic trunk (BT). There were some cases of absence of normal BT [24, 45, 89], or the presence of a brachiocarotid stem [34, 36, 46, 50, 56, 57]. One case of BT aplasia was especially characteristic because of the presence of unusual common brachiocephalic stem that divided into two so-called brachiocephalic arteries, while the left vessel distributed the left CCA, VA and SA, whereas the right vessel bifurcated in the right CCA and SA [45].

The right ITA [64], and a variable thyroid ima artery of BT origin [86] were found in two separate cases of aortic origin of the left VA.

Common carotid artery (CCA). A common trunk of the left CCA and BT or brachiocarotid trunk was revealed in association with single left VA of aortic origin [34, 36, 46, 50, 56, 57], and segmental VA duplication [36].
The right CCA was the first branch of the arch of the aorta in a case of BT aplasia and aortic origin of left VA [89].

Fenestration of the left CCA and initial segmental duplication of the right CCA were followed by segmental duplication of the left VA [29]. Bilateral absence of CCA was discovered in two cases of aortic origin of VA [42, 52].

Subclavian artery (SA). A very interesting case was a seemingly normal left SA of aortic origin that immediately bifurcated into medial SA that gives most of the branches and the lateral ones that continue as the axillary artery [54]. The right SA as the first branch of the arch of the aorta was found in two cases of aortic origin of the left VA [24, 42]. So-called lusoria right SA (last branch of the arch of the aorta) persisted only in a case of BT aplasia and associated with aortic origin of the single VA [89].

In three separate cases of aortic origin of the left VA, InTA was revealed from the left VA [35], or the arch of the aorta [53], or the right SA about 1 cm before its continuation into axillary artery [85]. A bronchial artery was noted as a variable branch of the left SA in one case of aortic left VA origin [62]. There were two cases of variable ITA origin in the shape of ITA-VA common trunk originated from the arch of the aorta and from the left SA [41], and the third case of the right ITA branching from BT and in the presence of aortic origin of the left VA [64]. Aplasia of both ITAs was associated with aortic origin of single VA [75], and in a case of persistent thyroid ima artery [86].

Anterior cerebral artery (ACA). Right ACA branch supplying right MCA territory was associated with a common trunk of the left VA and ITA of SA origin [41]. Aplasia of the precommunicating part of the right ACA was associated with CCA origin of the left VA [27].

Posterior cerebral artery (PCA). There were two reports with data about fetal origin of the right PCA associated with segmental duplication [36], and single aortic origin of the left VA [15].

Persistent primitive arteries. Vasević et al. [7] and Lotfi et al. [24] discovered persistent left primitive trigeminal artery (PPTA) in association with aortic origin of the left VA, whereas Meila et al. [38] discovered the persistent right lateral spinal artery in a case of segmental duplication of the left VA.

Veins. Duplicate left vertebral veins at C V level [62] and between C III–IV and C V–VI [28] were revealed in cases of single aortic origin and segmental duplication of the left VA, respectively. Kawate et al. [62] also found a draining of these veins into venous angles on both sides. Ikegami et al. [64] noted enlarged veins in the neck and abdominal region in association with aortic origin of the left VA. Nathan and Seidel [89] revealed a termination of the thoracic duct in the right venous angle associated with aortic origin of left VA in a 64-year-old male. An arteriovenous fistula between the right VA and ipsilateral veins was discovered in a 42-year-old female with a segmental duplication of the left VA [25].

Associated disorders

Basic congenital anomalies

1. Ehlers–Danlos syndrome (a group of inherited disorders that affect primarily skin, joints and blood vessel walls) and segmental left VA duplication of SA origin were presented in a 43-year-old male [18].

2. Chiari malformation (malformation of the skull) was associated with an absence of C IV foramen transversarium and VA origin from the left thyrocervical trunk in a 36-year-old female [44].

3. Dumbell neurofibroma (a type of tumor that can involve both the spinal canal and the posterior thoracic cavity) and a finding of a common trunk of left VA and ITA of aortic origin (between the left CCA and left SA) were found in a 33-year-old male [41].

Acquired pathological disorders

1. Dissections of some arteries — left VA [11], or both CCAs [34], or the right ICA [18] in a case of segmental duplication of the left VA of SA origin [18], or aortic origin of single left VA [11, 34] were noted.

2. Cerebral infarction (of different localization) was followed by segmental duplication of the left VA [18, 49], or by aortic origin of the left VA distal to the left SA [23], or by CCA origin of the left VA [27].

3. Aneurysms of different arteries — left VA and both ICAs [13], left PCA [23], left anterior temporal artery [43], ICA [38] were associated with segmental VA duplication, whereas an aneurysm of the descending aorta [39], or anterior communicating artery [41], or unnamed artery [49] was followed by aortic origin of single VA.

4. Partial thrombotic occlusion of different arteries — left ICA followed by a common trunk of the left VA and ITA [41], or the right VA and both ICAs followed by origin of the left VA from so-called left brachiocephalic artery [45].

5. Stenosis of some arteries of different grade — so-called left brachiocephalic artery [45], or the left VA [11, 37], or ICAs and/or left VA [23], or the right VA [51] was also noted.

6. Coarctation of the aorta (distally to the left SA origin) followed by segmental VA duplication was found in a 15-year-old girl [60]; pseudocoarctation of the aorta and perimembranous ventricular septal defect was associated with aortic origin of the left VA (distally to the left SA) in a 6-year-old boy [21].

7. Cerebral hemorrhage was presented in a 60-year-old woman with aortic VA origin distally to the left SA [49], whereas ventricular hemorrhage was diagnosed in a 46-year-old man with aortic origin of the left VA (between the right SA and bicarotid trunk) [24].

8. Subarachnoid hemorrhage was presented in a 52-year-old female with aortic origin of the left VA between the left CCA and left SA [41].

9. Angiomatous formation and segmental duplication of the left VA were revealed on the left side of the neck in a 15-year-old girl [60].
10. Tumor at the left cerebellopontine angle and segmental duplication of the left VA were discovered in a 27-year-old female [9].

**Left and right VAs**

**General data**

An association of variable left and right VAs, single or associated with supra-aortic arteries’ variants was found in 30/171 (9 of male, 18 of female and 3 of unknown gender) or 17.54% of cases from age 4 [90] to 83 [91].

Variable left and right VAs were discovered in patients with different initial symptoms or reasons of investigation — a headache [25, 92, 93], followed by vertigo [94, 95], or cognitive impairment [91], or pain in the left eye and ear [8], or hemisensory disturbance [10], or trauma [96, 97], or subarachnoid hemorrhage [38], or personality change [98], or right-sided numbness [99], or right upper and lower limb weakness [90], or stroke [100], or central chest pain [101], or myocardial infarction [102], or carcinoma [103, 104], or spondyloepiphyseal dysplasia [105], or angiographic evaluation [106–109], or aortic valve replacement [110] or swallowing difficulties [111].

**Status of vessels’ stems**

Variable left and right VAs were presented as simple or common vessels or segmentally duplicated at their origin. Vascular sources of variable VAs were SAs, arch of the aorta and descending aorta, BT and its common stem with the left CCA—brachiocarotid trunk, and right CCA (Fig. 2).

There were some cases of similar vascular sources—left and right SA in 2/28 cases [8, 91] and aorta in 5/28 cases [92, 96, 97, 104, 105]. Different vascular sources were found in other 21 cases while aorta and right common carotid artery were more frequent vascular sources of the left and right VAs, respectively. Only Takasato et al. [8] described an association of double left (rudimentary and accessory) VAs with segmentally duplicated right VA of SA origin.

A variability of both VAs is presented by nine primary and nine complementary models (Table 3).

**Caliber**

Very interesting finding in some papers was relatively larger caliber of the variable right VA in relation to the same of the left VA. Namely, Rameshbabu et al. [108] noted that medial segment (2.2 mm in diameter) and lateral segment (2.4 mm in diameter) of the left VA united into single vessel of 3.2 mm in diameter. Simultaneously, medial segment (3.9 mm in diameter) and lateral segment (2.4 mm in diameter) of the right VA fused to form a single vessel of 4.4 mm in diameter. Diameter of the left VA of aortic origin was 3.3 mm, whereas the one of the right VA of CCA origin was 3.8 mm [114]. Diameter of the left VA of aortic origin was 6 mm, whereas the one of the right VA of BT origin was 7 mm [112].

Karcaltincaaba et al. [97] described a widening or so-called Kommerell’s diverticulum at aortic origin of the right VA.

**Course in V1 part**

Special course of variable (left or right) VA related to the unusual retroesophageal course of the right VA in cases of aortic origin of both VAs [96, 97, 102, 104]. They were also related to a location of the right VA in retrothyroid area and close to the thyroid gland in cases of its CCA origin [107] or segmental duplication of both VAs [38, 91, 100].

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**Fig. 2.** Eighteen patterns of relationships of variable both vertebral and main supra-aortic arteries.  
V (V), left (right) vertebral a.; V′(V′), lateral and medial segments of duplicated left (right) vertebral artery at prevertebral part; S (S), left (right) subclavian a.; LuS*, so-called lasoria right subclavian a.; A, arch of the aorta; DA, descending aorta; B, brachiocephalic trunk; C (C), left (right) common carotid a.; E, left external carotid a.
<table>
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<th>Vascular source(s)</th>
<th>Schemes and description of primary models of variable left and right VAs</th>
<th>Schemes and description of complementary models of variable left and right VAs</th>
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</thead>
<tbody>
<tr>
<td>(Left subclavian a...) + (Right subclavian a...) (S + S*)</td>
<td><strong>MM*1:</strong> Bilateral segmental duplication of vertebral aa. of subclavian (SA) origin.</td>
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<td></td>
<td><strong>MM*1:</strong> (V_l/S + V_m/S) + (V<em>_l/S</em> + V<em>_m/S</em>)</td>
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<tr>
<td>(Left thyrocervical trunk) + (Right subclavian a...) (T + S*)</td>
<td><strong>MM*2:</strong> Total duplication of the left VA of SA origin and segmental duplication of the right VA of SA origin.</td>
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<td></td>
<td><strong>MM*2:</strong> (V_l/T) + (V<em>_l/S</em> + V<em>_m/S</em>)</td>
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<tr>
<td>(Arch of aorta) + (Right subclavian a...) (A + S*)</td>
<td><strong>MM*3:</strong> Bilateral segmental duplication of vertebral aa. of aortic origin on the left and SA origin on the right side.</td>
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<td><strong>MM*3:</strong> (V_l/A + V_m/A) + (V<em>_l/S</em> + V<em>_m/S</em>)</td>
<td></td>
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<tr>
<td>(Arch of aorta + left subclavian a...) + (Right subclavian a...) (A + S) + (S*)</td>
<td><strong>MM*4a:</strong> Aortic origin of single left VA and segmental duplication of the right VA of SA origin. Additionally, common stem of brachiocephalic trunk (BT) and left common carotid artery (CCA) — brachiocarotid trunk.</td>
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<td><strong>MM*4a:</strong> (V / A) + (V<em>_l/S</em> + V<em>_m/S</em>)</td>
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<tr>
<td>(Arch of aorta) + (Brachiocephalic trunk + right subclavian a...) (A) + (B + S*)</td>
<td><strong>MM*5:</strong> Bilateral segmental duplication of vertebral aa. of aortic and SA origin on the left and SA origin on the right side.</td>
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<td></td>
<td><strong>MM*5:</strong> (V_l/S + V_m/A) + (V<em>_l/S</em> + V<em>_m/S</em>)</td>
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<tr>
<td>(Arch of aorta) + (Brachiocephalic trunk + right subclavian a...) (A) + (B + S*)</td>
<td><strong>MM*6a:</strong> Aortic origin of single left VA and segmental duplication of the right VA of SA origin of brachiocephalic origin. Additionally, brachiocarotid trunk.</td>
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<td><strong>MM*6a:</strong> (V / A) + (V<em>_l/S</em> + V*_m / BC)</td>
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<tr>
<td>MM*7: (Arch of aorta + Brachiocephalic trunk) (A + B))</td>
<td>MM*7a: Aortic origin of single left VA and BT origin of the right VA.</td>
<td>MM*7a: Additionally, brachiocephalic trunk.</td>
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<tr>
<td>MM<em>7: (V / A) + (V</em> / B)</td>
<td>MM<em>7a: (V / A) + (V</em> / BC)</td>
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**MM*8a:** Aortic origin of single left VA (second branch) and CCA origin of the right VA. Additionally, common stem of the left and right CCA — bicarotid trunk; right SA is the last branch of the arch [93, 99, 101].

**MM*8b:** Common stem of the left VA and SA (second branch) of aortic origin, and CCA origin of the right VA. Additionally, bicarotid trunk and right SA as the last branch of the arch [115].

**MM*9a:** Aortic origin of single left VA (third branch) and CCA origin of the right VA. Additionally, right SA is the last branch of the arch [93, 99, 101].

**MM*10a:** Aortic origin of single left VA (fourth branch) and CCA origin of the right VA. Additionally, right SA is the first branch of the arch. Left CCA aplasia; left external carotid artery originated from the arch [94].

**MM*10b:** Aortic origin of single left VA (fourth branch) and CCA origin of the right VA. Additionally, right SA is the last branch of the arch [98, 111].

**MM*9a:** (V / A) + (V* / C*)

**MM*10a-b:** (V / A) + (V* / C*)
Variable Left and/or Right Vertebral Artery in Prevertebral Part: a Review of Features in the Postnatal Period

MM*11a: Aortic origin of the left (second branch) and right VAs (fourth branch). Additionally, brachiocephalic trunk.

MM*12: Aortic origin of the right (third branch) and left VAs (fourth branch).

MM*13: Aortic origin of the left (third branch) and right VAs (fifth branch).

MM*14: Aortic origin of the left (fourth branch) and right VAs (fifth branch).

MM*15: Origin of the left VA (third branch) from the arch and right VA from descending aorta.

Abbreviations of arteries in the text are explained during description of each pattern; abbreviations of same arteries in schemas include only the first capital letter from corresponding previous because of practical reasons. The current relationship of VA and the main supra-aortic arteries is personally presented by “mathematical relation” in the row below corresponding pattern.

Patterns are based on 29 cases because one report was without data about precise location of variable left and right VAs on the arch of the aorta [109]

Abbreviations of arteries in inserts: V (V*), left (right) vertebral a.; Vl(V*l) + Vm (V*m), lateral and medial segments of duplicated left (right) vertebral artery at prevertebral part; VC (VC*), left (right) subclavian a.; LuS*, so-called lusoria right subclavian a.; A, arch of the aorta; DA, descending aorta; B, brachiocephalic trunk; C (C*), left (right) common carotid a.; E, left external carotid a.
Ionete and Omoloja [91] and Mordasini et al. [100] described the course of both segmentally duplicated VAs as follows: The right medial segment originated proximally beyond the origin of SA and after a short loop it entered the carotid space, whereas the right lateral segment emanated from SA, coursed straight and entered the foramen transversarium of C VII vertebra. Both vessels joined in C IV–C V disk level to continue as the single right VA. On the left side, medial segment began from SA, looped slightly forward, and coursed straight up behind the left CCA, whereas lateral segment emanated just distal to the medial segment and entered the foramen transversarium of C VII vertebra; both vessels joined at C V–C VI disk level into single left VA. Meila et al. [38] presented the right lateral and medial segments at entry of the foramen transversarium of C VI and C IV vertebrae, respectively. They also found that left lateral segment entered the foramen transversarium of C V vertebra, whereas the medial segment entered it at C IV vertebra. Pauliukas [109] noted aortic origin of both VAs, but the left VA was the one which was strangulated by the sympathetic trunk and compressed at the entrance into C V foramen transversarium by longus colli muscle tendon.

Some variable VAs of single stems entered the foramen transversarium of the same cervical vertebra on both sides [103, 105, 107, 112, 115], whereas some VAs entered the foramen transversarium at different levels [58, 102, 109]. So, the right VA of CCA origin penetrated CVI foramen transversarium, whereas the left VA of aortic origin penetrated C VII [109]; the left VA of aortic origin penetrated C VI foramen transversarium, whereas the right VA of aortic origin penetrated C IV foramen transversarium [102] or the left VA of aortic origin penetrated C IV, while the right VA of aortic origin penetrated C VII foramen transversarium [58].

Collaterals

Schwarzacher and Krammer [102] described ITA as a side branch of the left VA in a case of aortic origin of both VAs.

Additional vascular variants

Aorta. There was a variable number (3–5) and/or arrangement of branches of its arch and descending part. In addition, cervical location of the arch of the aorta above the level of the manubrium of sternum was found in a 77-year-old woman [102].

BT. Its aplasia [90, 93–95, 98, 99, 101, 103, 106, 107, 110, 114–116] was noted in 14/29 or 46.4% of the cases, whereas a common trunk of the BT and left CCA (brachiocarotid trunk) [10, 104, 111, 113] was found in 4/29 or 14.2% of the cases. BT was a vascular source of the thyroid ima artery in one case [102].

SA. So-called lusoria right SA (LuS) was found in previously mentioned 12 cases of BT aplasia, except in a case described by Abas et al. [94], when right SA was the first branch of the arch of the aorta. Besides, LuS coursed retroesophageally in most of these cases.

An early bifurcation of the left SA in two axillary arteries was associated with aortic origin of the left VA and segmental duplication of the right VA in a 46-year-old man [111]. Aplasia of the left thyrocervical trunk was revealed in an 83-year-old woman with aortic origin of both VAs [102].

CCA. A common trunk of BT and left CCA (brachiocarotid trunk) at the arch of the aorta was described in four cases [10, 104, 111, 113], a common trunk of left and right CCAs (bicarotid trunk) at the arch of the aorta was also found in four cases [93, 99, 101, 114]. Right CCA was the first single branch of the arch of the aorta in nine cases [90, 95, 98, 103, 106, 107, 110, 115, 116]. Both ECAs supplied intracranial collaterals through their dural branches in a 4-year-old girl with Moyamoya disease [90].

Aplasia of the left CCA and ICA followed by the aortic origin of the left VA and CCA origin of the right VA were discovered in a 43-year-old woman [94].

Posterior cerebral artery (PCA). Fetal origin of both PCAs associated with aortic origin of the left and right VAs was found in a 53-year-old man [92].

Associated disorders

Basic congenital anomaly

1. Down syndrome (trisomy 21) was a known congenital anomaly in a 4-year-old girl where an aortic origin of the left VA and CCA origin of the right VA was discovered [90].

2. Klippel-Feil syndrome (congenital fusion of any two of seven cervical vertebrae) was presented in a 43-year-old woman with aortic origin of the left VA and CCA origin of the right VA [94].

Acquired pathological disorders

1. Pseudocoarctation of aorta associated with aortic origin of both VAs was discovered in a 35-year-old woman after trauma [96].

2. Aneurysms of different arteries—right anterior cerebral artery [92], posterior communicating artery [38, 115], and descending aorta [101] were proved in 4/28 cases.

3. Partial stenosis of the left ICA [91, 100], or right SA [98, 99] was also associated with variable VA origin.

4. Partial occlusions of the right VA [101], or left internal jugular vein and sigmoid sinus [93] were proved in 40-year-old and 50-year-old women, respectively.

5. Cerebral infarct was developed in a 60-year-old woman with aortic origin of the left VA and CCA origin of the right VA [10].

6. Thyroid carcinoma was primary reason of a preoperative evaluation in a 67-year-old woman when aortic origin of the left VA and CCA origin of the right VA were discovered [107].

7. Pial siderosis along the sulci of the right cerebral hemisphere were proved by MRI in a 68-year-old female with aortic origin of the left VA and CCA origin of the right VA [116].
Right VA

General data

Only unilaterally, variable right VA was found in 47/171 (25 of male, 17 of female and 5 of unknown gender) or 27.48% of cases from age 2 [118] to 76 [49, 119]. Variable right VA was discovered in patients with different initial symptoms or reasons of investigations—headache [26, 120, 121], or dizziness [30, 115, 122], or weakness [36], or blurred vision dizziness [123], or paresthesias [124], or transitory ischemic attacks [38, 125–128], or shortness of breath [118], or loss of consciousness [129], or progressive memory loss with incoherent behavior [130], or retrosternal chest pain [131], or carotid stenosis [132], or left hemiplegia [98], as well as after trauma [133, 134], or during preoperative evaluation [106, 135], or evaluation of mediastinal enlarged lymph nodes [136], or doubt for the left middle cerebral artery infarction [137] or by angiographic images [15, 49, 138–140].

Status of vessel stem

The vascular sources of variable right VA were the right SA and its (in)direct branches, the arch of the aorta, ascending and descending aorta, the brachiocephalic trunk, right CCA and right ECA (Fig. 3).

Segmentally duplicated right VA was revealed in seven cases [30, 38, 49, 122, 134, 141, 142]. Single right VA as a side branch of ipsilateral CCA was found in 10 cases [23, 49, 107, 115, 120, 125, 138, 143–145], whereas it was terminal branch of the right CCA in a case described by Morasch [140].

The right VA was of aortic origin in most cases; among them, it originated from the ascending aorta in one [131], and from descending aorta in another case [118].

In three cases the right VA originated singly from the brachiocephalic trunk [15], right thyrocervical trunk [146] and right supreme intercostal artery [147].

The right VA was presented as a simple or common vessel or segmentally duplicated at its origin; there were 9 primary and 9 complementary models (Table 4).

Caliber

Single right VA of aortic origin was described as “small” [131], or hypoplastic [26], or dilated with so-called Kommerell’s diverticulum at its beginning [133, 135, 136]. Right VA originating from the supreme intercostal artery [146], and thyrocervical trunk [147], measured 1 mm and 1.8 mm in diameter, respectively. Thomas et al. [134] described that the medial segment of duplicated right VA measured 1.3 mm in diameter and had a beaded appearance, whereas the lateral segment was of regular lumen and measured 3.1 mm in diameter.

Course in V1 part

There were some examples of unusual course of the variable right VA from the beginning to the entry at the foramen transversarium of cervical vertebra. So, Higashi et al. [119] observed that the right VA of aortic origin coursed into the first intercostal space and entered the first costotransverse foramen, and then all of the transverse foramina from C VII to C I vertebra. Retroesophageal course of the right VA of aortic origin was also noted by some authors [26, 106, 121, 133, 135, 136, 139]. In addition, Fazan et al. [143] discovered that the right VA was crossed anterior to the ITA and upstream outside and anterior to the transverse foramina from C VII to C III, whereas Park et al. [107] reported about a location of the right VA in the retro-thyroid area and very close to the thyroid gland.

Segmentally duplicated right VA of SA origin were kinked at V1 part in one case [122], whereas simple VA stem was underdeveloped at intracranial part after fusion of its double segments in another case [113].

Hypoplastic right VA of supreme intercostal artery (SIA) origin anastomosed with the right persistent primitive hypoglossal artery (PPHA) at the internal opening of the hypoglossal canal in a 74-year-old Japanese male cadaver [146].

Collaterals

Only Higashi et al. [119] discovered the esophageal, prevertebral and second right posterior intercostal arteries as the right VA branches in V1 part.

Additional vascular variants

Left VA. It ended as the posterior inferior cerebellar artery in a case of aortic origin [36], or segmental duplication [122], or it made terminal trifurcation in a case of CCA origin [125]. Mild tortuosity and constricted portion of the left VA in a case of thyrocervical origin [147], or its hypoplasia in a case of external carotid origin of the right VA [129] were revealed.

There was a description of an anastomosis of the left VA and anterior inferior cerebellar artery in a case of SIA origin of the right VA [146].

Aorta. Multiple aortopulmonary collaterals supplying the left lung were found in a 2-year-old child [118].

BT. Aplasia of BT existed in 16/47 cases [23, 49, 98, 107, 116, 118, 120, 123, 125, 127, 131, 137, 138, 143, 145, 148]. A brachioarterotid trunk was found in two cases [106, 139].

CCA. This artery on the right side was noted usually as the first single or a common branch of the arch of the aorta in cases of BT aplasia and/or origin of the right VA from ipsilateral CCA [23, 49, 98, 107, 116, 120, 123, 125, 127, 131, 137, 138, 143, 145, 148], or aorta [118, 148]. Above mentioned brachioarterotid trunk was associated with CCA or aortic origin of the right VA, respectively [106, 139]. The right CCA in a case described by Morasch [140] was bifurcated into right VA and ECA, because the right ICA was aplastic.

SA. Lusoria right SA was associated with origin of the right VA from ipsilateral CCA [23, 49, 98, 107, 116, 120, 125, 137, 138, 140, 143, 145], or the arch of the aorta [148], or ascending [131], or descending aorta [118]. Right SA, as the third branch of the arch of the aorta, passed behind the two CCAs and in front of the right VA in a case of CCA origin of the right VA [123].
Aplasia of ITA was associated with the persistence of a common trunk of the right VA and thyroid ima artery at the arch of the aorta [148].

**Persistent primitive arteries.** Right PPTA was associated with CCA origin of the right VA [120], whereas the right PPHA was associated with SIA origin of the right VA [146].

**Associated disorders**

**Basic congenital anomaly**

1. Cardiac anomaly (atrioventriculoarterial discordance, double outlet right ventricle, multiple muscular ventricular septal defects, and right ventricular outflow tract obstruction with hypoplastic right ventricle) was a primary reason of discovery of aortic origin of the right VA in a 2-year-old child [118].

**Acquired pathological disorders**

1. Dissection of the right VA was associated with its segmental duplication in a 49-year-old woman [134].
2. Aneurysms of different arteries—some cerebral artery [49], ascending [106] and abdominal aorta [135], anterior communicating [129] and basilar arteries [134] were discovered in the presence of different origin of the right VA.
3. Infarction of the cerebrum [49], or cerebellum [36, 141], or the myocardium [23] was associated with segmental duplication, or aortic origin, or CCA origin of the right VA.
4. Partial stenosis of different arteries—right SA [98, 125] and right CCA [23, 125] was associated with CCA origin of the right VA.
5. Intracerebral hemorrhage was diagnosed simultaneously with aortic origin of the right VA after a cerebrovascular accident in a 40-year-old man [128].
6. Subarachnoid hemorrhage was diagnosed in a 32-year-old woman with CCA origin of the right VA [120].
7. Arteriovenous malformation in the right cerebellopontine angle was diagnosed simultaneously with CCA origin of the right VA in a 52-year-old woman [116].
8. Spinal neurinoma was a primary reason in a 57-year-old patient when the right VA of aortic origin was discovered [124].
9. Thyroglossal duct cyst was associated with CCA origin of the right VA in a 30-year-old man [107].
<table>
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<tr>
<th>Vascular source(s)</th>
<th>Schemes and description of primary models of variable right VA</th>
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<td>Subclavian stem (S*)</td>
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<td><img src="complementary.models.png" alt="Diagram" /></td>
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<td>M*1: Segmental duplication of the right VA of subclavian (SA) origin.</td>
<td>M<em>1: V</em>&lt;sub&gt;f&lt;/sub&gt;/V*&lt;sub&gt;m&lt;/sub&gt; / S*</td>
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<td>[30, 49, 122, 134, 141, 142]</td>
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<td>Subclavian stem + thyro-cervical trunk (S* + T*)</td>
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<td>M*2: Segmental duplication of the right VA of subclavian (SA) and thyro-cervical (TT) origin.</td>
<td>M<em>2: V</em>&lt;sub&gt;f&lt;/sub&gt;/ S*+ V*&lt;sub&gt;m&lt;/sub&gt;/T*</td>
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<td>Branch</td>
<td><img src="branch.png" alt="Diagram" /></td>
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<td>M*3: Single right VA of TT origin.</td>
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<td>Supreme intercostal a. (sia*)</td>
<td><img src="superior.intercostal.png" alt="Diagram" /></td>
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<td>M*4: Single right VA originates from the supreme intercostal a.</td>
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**M5:5a:** Additionally, aplasia of the brachiocephalic trunk (BT); right CCA is the first branch and Lat* is the last branch of the arch of the aorta [23, 98, 107, 115, 125, 137, 138, 143].

**M5:5b:** Additionally, aplasia of the brachiocephalic trunk (BT); right CCA as the first aortic branch bifurcated into right VA and ECA, left CCA is the second; right SA is the third and left SA is the fourth branch of the arch [140].

**M5:5c:** Additionally, aplasia of the brachiocephalic trunk (BT); right CCA is the first, left CCA is the second, right SA is the third and left SA is the fourth branch [123].

**M5:5d:** Additionally, aplasia of BT; right CCA is the first branch of the arch; LuS* is the branch of the descending aorta [120].

**M5:5e:** Additionally, aplasia of BT; common stem of the right and left CCAs (bicaudal trunk) is the first branch of the arch; right SA is the second branch of the arch of the aorta [127].

**M5:5f:** Additionally, aplasia of BT; common stem of the right and left CCAs (bicaudal trunk) is the first branch of the arch; LuS* is the last branch of the arch of the aorta [49, 130, 145].

<table>
<thead>
<tr>
<th>Right common carotid a. (C* )</th>
<th>M5:5: Single right VA of common carotid (CCA) origin.</th>
<th>M5:5a:</th>
<th>M5:5b:</th>
<th>M5:5c:</th>
<th>M5:5d:</th>
<th>M5:5e:</th>
<th>M5:5f:</th>
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<tr>
<td>[49, 53, 144]</td>
<td>[23, 98, 107, 115, 125, 137, 138, 143]</td>
<td>[140]</td>
<td>[123]</td>
<td>[120]</td>
<td>[127]</td>
<td>[49, 130, 145]</td>
<td>[49, 130, 145]</td>
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<td>Variable Left and/or Right Vertebral Artery in Prevertebral Part: a Review of Features in the Postnatal Period</td>
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<td><em><em>Right external carotid a. (E</em>)</em>*</td>
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<td><img src="image1.png" alt="Diagram" /></td>
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<td><strong>M*6:</strong> Single right VA of the right ECA origin.</td>
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<td><strong>M*6:</strong> V*/E*</td>
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<td><strong>Brachiocephalic trunk (B)</strong></td>
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<td><strong>M*7:</strong> Single right VA of BT origin.</td>
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<td><strong>M*7:</strong> V*/B</td>
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<td><strong>Aorta</strong></td>
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<td><strong>Ascending aorta (AA)</strong></td>
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<td><strong>M*8a:</strong> Right VA originates from ascending aorta. Additionally, aplasia of BT; bicarotid trunk is the first branch of the arch; Lsu* is the last branch of the arch of the aorta</td>
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<tr>
<td><strong>M*8a:</strong> V*/AA</td>
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<td><strong>Arch of the aorta (A) and descending aorta (DA)</strong></td>
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<td><strong>M*8:</strong> Right VA, as the third branch of the arch of the aorta.</td>
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<td><strong>M*8:</strong> Additionally, common stem of so-called brachiocephalic aa [106].</td>
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<td><strong>M*8b:</strong> Additionally, brachiocephalic trunk is the first branch of the arch of the aorta. Right VA had retroesophageal course [121, 128, 139].</td>
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Lj. Vasović, G. Radenković, M. Trandafilović, G. Barđosić

Abbreviations of arteries in the text are explained during the description of each pattern; abbreviations of same arteries in schemas include only the first capital letter from corresponding previous because of practical reasons. The current relationship of VA and the main supra-aortic arteries is personally presented by “mathematical relation” in the row below corresponding pattern. 

Abbreviations of arteries in inserts: 
- $V^*$: right vertebral a.; ($V^*$: $V^*$a): lateral and medial segments of duplicated right vertebral artery at prevertebral part. 
- $S^*$ ($S$): right (left) subclavian a. 
- $C^*$ ($C$): right (left) common carotid a.; 
- $B$: brachiocephalic trunk; 
- $A$: arch of the aorta; 
- $T^*$: right thyrocervical trunk; 
- $ct^*$: right costocervical trunk; 
- $sta^*$: right supreme intercostal a.; 
- $Aa$: ascending aorta; 
- $LuS^*$: so-called lusoria right subclavian a.; 
- $Da$: descending aorta; 
- $BC^*$ (C): brachiocephalic trunk; 
- $Ima$: thyroid ima a.
Concluding Remarks

Common morphological features

Vascular sources. There were one or two or three vascular sources in the presence of variable left and/or right VA. The arch of the aorta was the most frequent source of single left VA and bilateral VA variabilities. Segmentally duplication of the VA was more frequent on the left side, while the vascular sources were the arch of aorta and left SA.

Although the right CCA was the vascular source of the single right VA in one third of cases, it was a vascular source of the right VA in almost half of cases with bilateral VA variability.

A specificity of the VA represented a pyramidal widening or so-called Kommerell’ diverticulum of its beginning.

The origin of variable VA from the CCA (33 cases on the right and one on the left side) or right ECA in one case opens a problem of its denotation and differentiation from some of the persistent primitive CIA or PPIA.

Frequency of variable single VA origin. It was selected 94/171 cases of variable left VA, 30/171 cases of variable left and right VA and 47/171 cases of variable right VA. Our hypothesis is that the variability of the single left VA was two times higher than the variability of the right VA.

Unilateral vs. bilateral VA variability. Our hypothesis is that the variability of the single left or right VA was more frequent than bilateral variability of VA — three times for the left and 50% for the right side. In that manner, one cannot confirm the claim where one VA has an anomalous origin and the incidence of contralateral VA anomaly increases.

Sex difference. A variability of the left VA was more frequent in male specimens, whereas a variability of both VA was more frequent in female specimens, although there was no marking of gender for 25/171 cases.

Patterns of VA vs. total number of VA variability. The finding of 62 (30 of primary and 32 of complementary) patterns from 171 cases of unilateral or bilateral VA variability could suggest that in every third case can expect a special relationship of the VA and main supraaortic arteries.

Primary models vs. complementary models. Two thirds of total number of primary patterns or models of variable VA on one or both sides could indicate that it is the only vascular variation. However, most primary models were presented as single cases on the left and/or the right side, whereas 7/30 — four primary models on the left and three primary models on the right side were showed by three and more authors; this may mean that presented arrangements of VA(s) could be expected as isolated variation. Five complementary models (5/32) — one on the left, two on the right and two on both sides presented by three and more authors could indicate that only these VA variabilities are not isolated.

Course of VA. Retroesophageal course of the right VA of aortic origin could be expected in cases of aortic origin of both VAs, or aortic origin of single right VA distally from the left SA. From a morphofunctional view of point, the VA could be compressed at the higher level of entry at the foramen transversarium of cervical vertebra.

Although variable single VAs or their lateral or medial segments penetrated foramen transversarium from C IV to C VI vertebra in about one third of cases for each level, there was not a rule in relation to the VA beginning.

Caliber. It is well known that the posterior circulation is more vulnerable to ischemia in patients with VA severe hypoplasia, although most of these individuals remain asymptomatic if additional atherosclerotic factors are not associated. Having in mind only a few reports about the hypoplasia of VA, we can conclude that a way of the VA origin does not affect its caliber.

Side branches. The finding of unusual collaterals—the suprascapular artery, or ITA, or InTA, or bronchial artery, which branched from the left VA, as well as the esophageal, prevertebral and second right posterior intercostal arteries from the right VA, can point out on the VA variability.

Status of the arch of the aorta. Different patterns of branching of the arch of the aorta with respect to the number (from one to six), and/or position of these branches at the arch were main associated vascular variants with variable VA origin.

Associated supra-aortic arterial variants. A finding of lusoria right SA in almost half of the bilateral VA variability cases and in one third of variable right VA cases could be accepted as an indirect sign that variable right VA can be found, and vice versa.

Persistent primitive carotidbasilar anastomoses. According to the finding of only 5/171 cases—three PPTA, one PPHA and one lateral spinal artery, one can conclude that association of carotid-basilar anastomoses (CBAs) and a variable left VA origin was a coincidence, especially because of different embryologic base of VA and CBAs.

Common pathoanatomical conditions

Basic diseases. Nine different pathological processes — arterial disseotions, aneurysms, cerebral infarction, partial thrombotic occlusion, stenosis, intracerebral hemorrhage, subarachnoid hemorrhage, (pseudo)coarctation of the aorta and different tumors, although rare, were common independently from unilateral or bilateral variability of the VA.

Pathologic changes of variable VA. On one side, some authors claimed that anomalous VA origin does not result in clinical symptoms, what was proved on the example of variable left VA where the right VA of normal (SA) origin was stenosed approximately of 60%. On the other hand, some authors described that higher incidence of spontaneous dissection was presented in cases of variable VA. However we revealed only eight patients with some
pathological changes — a dissection, or aneurysm, or stenosis of the left VA, and a dissection or thrombotic occlusion of the right VA.

References

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Acknowledgments: The authors would like to thank the contract grant sponsor Ministry of Science and Technological Development of Republic of Serbia (nos. 43012, 41018 and 175092).


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