IJAE
Vol. 124, n. 1: 5-15, 2019
ITALIAN JOURNAL OF ANATOMY AND EMBRYOLOGY

Review - Basic and Applied Anatomy

Aortic arch branching pattern variation: its incidence on a 20030 cases review

Caryn Recto, Maria Boddi, Jacopo Junio Valerio Branca, Gabriele Morucci, Alessandra Pacini, Massimo Gulisano, Ferdinando Paternostro*

Department of Experimental and Clinical Medicine, University of Florence, Florence, Italy

Abstract

Variations in the branching pattern of the aortic arch are clinically relevant because of the direct influence that their presence can have on the success of cardio-vascular procedures, neck or thorax surgery, trauma management or intensive care. In most cases these anatomical variations are asymptomatic and considered clinically benign, but some particular aortic branching patterns have been associated with surgical complications or with vascular diseases in non-surgical patients. The main objective of this work was to study the frequency of variation of the aortic arch branching pattern in a wide and varied population on the basis of literature reports. The aortic arch branching pattern of 20,030 cases reported by 40 anatomical or radiological studies were analyzed. 84,52% of the studied population had a three branches pattern and 14,65% had a two branches pattern. The four primary arteries were seen arising directly from the aortic arch in 0,81% of the cases and only 0,02% had them all arising from a common trunk.

Key words

Aortic arch, branching pattern, aortic variations, bovine arch.

Key to abbreviations

BCT: brachiocephalic trunk
LBT: left brachiocephalic trunk
LCCA: left common carotid artery
LECA: left external carotid artery
LICA: left internal carotid artery
LSA: left subclavian artery
LVA: left vertebral artery
RBT: right brachiocephalic trunk
RCCA: right common carotid artery
RSA: right subclavian artery
RVA: right vertebral artery
Tima: thyroid ima artery

* Corresponding author. E-mail: ferdinando.paternostro@unifi.it

http://www.fupress.com/ijae
DOI: 10.13128/IJAE-25245

Introduction

Several anatomical variations of the aortic arch related to the different origin of carotid, subclavian, vertebral and thyroid arteries are known. They have been variously described by autoptic studies or by second-level imaging exams. In most cases these anatomical variations are asymptomatic, but some patterns of aortic arch branching have been associated with a broad spectrum of pathologies, such as peripheral and/or central nervous system vascular diseases or aortic aneurysms dissection (Lu et al., 2015; Gudbrandsson et al., 2016; Maiti et al., 2016; Shang et al., 2016).

The embolic spread of atherosclerotic plaques is a possible complication during aortic arch interventions, leading to a higher impairment of brain perfusion if both common carotid arteries arise from an unique trunk (Herrera et al., 2013; Cordova et al., 2011).

An atypical origin of the left vertebral artery (LVA) can be wrongly described by radiologists, predisposing to surgical or endovascular complications (Huapaya et al., 2015; Hu et al., 2009) or to excessive/unnecessary treatments if erroneously considered obstructed (Goray et al., 2005).

When dysphagia cannot be explained by usual cause, dedicated exams should be performed to search for a right subclavian artery (RSA) arising from the left side of the aortic arch. This variation, usually asymptomatic, can sometimes cause dysphagia, especially when it develops an aneurismatic dilatation. Some authors also suggest that intensive care patients should be screened for an aberrant RSA before nasogastric tube long term placement due the extreme unfavorable prognosis in case of the development of an esophageal fistula (Fazan et al., 2003). Others suggest that if an aberrant RSA is diagnosed during aortic arch repair, corrective surgery should be considered to prevent complications and further disease (Fazan et al., 2003, Feugier et al., 2003; Inzunza and Burdiles, 2010). An aberrant RSA also determines a non-recurrent right laryngeal nerve, which translates into a higher risk of nerve's injury during otorhinolaryngeal and endocrinological surgery of the neck (Inzunza and Burdiles, 2010).

The reduced number of fixation points found in some arch patterns determinates a concentration of energy in the arising point of the artery during blunt trauma, leading to arterial dissection or transversal section (Dumfarth et al., 2015). Patients with these anatomical variations might need particular attention in the immediate follow-up, mainly those in which both carotid arteries share a common trunk, where an hyperextension mechanisms of trauma could lead to a complete compromise in brain perfusion (Cordova et al., 2011).

Because of all these reasons, it is highly advisable to know and consider the possible anatomical variations of the aortic arch in clinical practice. The correct recognition of the main anatomical variations could have direct positive effects on endovascular treatments and in diagnostic or therapeutic procedures.

Materials and methods

The key words "aortic branching pattern", "aortic anatomical variations" and "aortic variations" were introduced in search engines such as PubMed, SciELO and EMBASE. They were also used directly in several anatomical and medical journals such as Scholar Science Journals (www.ssjournals.com), Romanian Journal Of Morphology and Embryology (www.rjme.ro), African Journals Online (www.ajol.info), Hindawi Publishing Corporation (www.hindawi.com), International Journals in Medical and Health Reseach (www.ijmhr.org), Asian Pacific Journal of Health Sciences (www.apjhs.com), Firenze University Press (www.fupress.net), International Journal of Experimental and Clinical Anatomy (www.anatomy.org.tr), American Journal of Roentgenology (www.ajronline.org), Via Medica Journals (www.journals.viamedica.pl), Impact Journals (www.impactjournals.us), Revista Argentina de Anatomía Clínica (www.anatclinar.com.ar).

The selected articles presented an accurate anatomical description of the branching pattern, obtained either by dissection or imaging studies performed in an adult healthy population. As some of these studies lacked a clear anatomical description, the authors were contacted to provide further anatomical details.

Exclusion criteria were case-report studies, studies with less than 20 cases descriptions, and studies for which the anatomical description was unavailable or incomplete.

We found 20,081 cases of aortic arch branching variations reported by 39 cohort studies and one case-control study.

Fifty-one cases out of 20.081 were excluded because they described either anatomical anomalies of the arch (i.e.: double or right sided aortic arch, aortic coarctation) or previously known congenital heart disease. Finally, 20.030 cases were included for the statistical analysis.

Results

If we just consider the four primary arteries - *i.e.* left common carotid artery (LCCA), right common carotid artery (RCCA), right subclavian artery (RSA) and left subclavian artery (LSA) - 84.52% of the population has a 3 branch pattern and 14.65% has a two branch pattern, independently of the order in which they arise, the combination of the primary arteries or the presence of secondary arteries (Table 1).

In a minority of the cases (0.81%) the four primary arteries could be seen originating independently from the arch, whereas in a 0.02% of the analyzed cases they will all arise from a common trunk.

The prevalence of the normal anatomical disposition in our review resulted to be 80.0%. In the literature the prevalence of this condition varies in a wide range, going from 63.5% (Budhiraja et al., 2013; Tapaia et al., 2015) to 97.4% (Sunitha and Narasinga Rao, 2012).

Table 1. Number of primary arteries arising directly from the aortic arch

Number of primary arteries	Number of cases	Percentage
1	3	0.02
2	2935	14.65
3	16929	84.52
4	163	0.81
Total	20030	100.00

Table 2. Totality of the described patterns and its prevalence.

	N	%
One branch patterns		
1: BCT + LCCA + LSA	2	0.010
1: BCT + LCCA + LSA 2: LVA	1	0.005
Two branches patterns	N	%
1: BCT + LCCA 2: LSA*	2025	10.100
1: BCT + LCCA 2: LVA 3: LSA	42	0.210
1: BCT + LCCA 2: LSA 3: LVA	5	0.030
1: BCT + LCCA 2: LVA + LSA	1	0.005
1: BCT + LCCA 2: LSA 3: RVA	1	0.005
1: BCT + LCCA 2: Suprascapular artery 3: LSA	1	0.005
1: oc BCT + LCCA 2: LSA	764	3.810
1: oc BCT + LCCA 2: LVA 3: LSA	28	0.140
1: BCT + LICA 2: LECA 3: LSA	1	0.005
1: BCT 2: LBCT	63	0.310
1: BCT 2: LBCT 3: left coronary artery	1	0.005
1: BCT 2: Tima 2: LBCT	1	0.005
1: RCCA + LCCA 2: RSA + LSA	2	0.010
Three branches patterns	N	%
1: BCT 2: LCCA 3: LSA**	16023	80.000
1: BCT 2: LCCA 3: LVA 4: LSA	752	3.750
1: BCT 2: LCCA 3: LSA 4: LVA	13	0.070
1: BCT 2: LCCA 3: oc LVA + LSA	3	0.020
1: BCT 2: LCCA 3: LSA 4: RVA	3	0.020
1: BCT 2: RVA 3: LCCA 4: LSA	2	0.010
1: BCT 2: Tima 3: LCCA 4: LSA	38	0.190
1 : BCT 2 : RCCA 3 : double LVA 4 : LSA	1	0.005
1: oc RSA + RCCA 2: LCCA 3: LSA	3	0.020
1: RSA 2: RCCA + LCCA 3: LSA	13	0.070
1: LCCA + RCCA 2: LSA 3: RSA	68	0.340
1: RCCA + LCCA 2: LVA 3: LSA 4: RSA	2	0.010
1: LSA 2: BCT 3: LCCA	3	0.020
1: BCT 2: LSA 3: LCCA	3	0.020
1: RCCA 2: LICA 3: LECA 4: LSA 5: RSA	1	0.005
1 : RSA 2 : RCCA 3 : LBT	1	0.005

The classically known "bovine arch" refers to a common origin of the right brachiocephalic trunk (RBT) and the LCCA. In our review, the bovine arch was described in

	N	%
Four branches patterns	N	%
1: RSA 2: RCCA 3: LCCA 4: LSA	43	0.210
1: RSA 2: RCCA 3: LCCA 4: LVA 5: LSA	8	0.040
1: RCCA 2: LCCA 3: LSA 4: RSA	108	0.540
1: RCCA 2: LCCA 3: LVA 4: LSA 5: RSA	3	0.020
1: RCCA 2: LCCA 3: LVA 4: Tima 5: LSA 6: RSA	1	0.005
Total	20030	100,000

* bovine arch, ** normal anatomy.
oc: ostium. RCCA: right common carotid artery. LCCA: left common carotid artery. LVA: left vertebral artery. RVA: right vertebral artery. LSA: left subclavian artery. RSA: right subclavian artery. LICA: left internal carotid artery. LECA: left external carotid artery. Tima: thyroid ima artery. BCT: brachiocephalic trunk. LBT: left brachiocephalic trunk (LCCA + LSA).

10.1% of the cases, being the variation most frequently found. Other studies reported its prevalence in a range from 0% (Davivongos and Sangiampong, 1986; Alsaif and Ramadan, 2010; Bhattarai and Poundel, 2010; Demertzis et al., 2010; Inzunza and Burdiles, 2010; Ogeng'o et al., 2010; da Silva, 2012; Fazal et al., 2012; Yuksekkaya et al., 2012; Budhiraja et al., 2013; Acar et al., 2013; Herrera et a., 2013; Rekha and Senthilkumar 2013; Durai Pandian et al., 2014; Karacan et al., 2014; Lale et al., 2014; Maheria et al., 2014; Makhanya et al., 2004; Bhatia et al., 2015; Ergun et al., 2015; Nurefşan et al., 2015; Tapaia et al., 2015) up to 33.3% (Ergun et al., 2015). Table 2 to show the patterns described and its prevalence.

The presence of a RSA as the last branch emerging from the arch, also known as arteria lusoria, was described in 0.91% of the reviewed cases. In 96.2% of these cases the aberrant RSA was the sole anatomical variation, while in 3.8% the lusoria artery was accompanied by secondary arteries arising directly from the arch.

In the literature, an aberrant RSA was described in a range that goes from 0% (Davivongos and Sangiampong, 1986; Zamir and Sinclair, 1990; Fazan et al., 2003; Natsis et al., 2009; Alsaif and Ramadan, 2010; Bhattarai and Poundel, 2010; Demertzis et al., 2010; Indumathi et al., 2010; Inzunza and Burdiles, 2010; Ogeng'o et al., 2010; Fazal et al., 2012; Mata-Escolano et al., 2012; Patil et al., 2012; Budhiraja et al., 2013; Herrera et a., 2013; Rekha and Senthilkumar 2013; Shakeri et al., 2013; Vučurević et al., 2013; Maheria et al., 2014; Rea et al., 2014; Ajit and Amarnath 2015; Bhatia et al., 2015; Ergun et al., 2015; Tapaia et al., 2015; Jalali et al., 2016) to 2.25% (Nurefşan et al., 2015). Table 3 shows the aberrant RSA prevalence.

The LVA was the secondary artery most frequently found arising directly from the aortic arch. While in the present review it was found in 4.3% of the cases, its prevalence in the literature varies from 0% (Makhanya et al., 2004; Fazal et al., 2012) to 15.4% (Budhiraja et al., 2013).

The thyroid ima artery (Tima) was the second most frequent secondary artery, representing 0.20% of the cases in the present work. In the literature its prevalence ranges from 0% (Davivongos and Sangiampong, 1986; Zamir and Sinclair, 1990; Fazan et al., 2003; Makhanya et al., 2004; Nayak et al., 2006; Il-Young et al., 2008;

Table 3. Aberrant RSA prevalence.

	Number of cases	Percentage
Aberrant RSA as the only variation	176	0.88
Aberrant RSA + secondary arteries	7	0.03
Total number of cases with an aberrant RSA	183	0.91

Table 4. Secondary arteries prevalence.

Secondary artery	Total number of cases	Percentage
LVA	860	4.300
TIma	40	0.200
RVA	6	0.030
LICA/LECA	2	0.010
Left coronary	1	0. 005
Suprascapular	1	0. 005
Total	910	4.500

* one patient presented more than one secondary artery arising directly from the AA (LVA+TIma) and was considered in each one of the single categories.

Berko et al., 2009; Alsaif and Ramadan, 2010; Bhattarai and Poundel, 2010; Demertzis et al., 2010; Indumathi et al., 2010; Inzunza and Burdiles, 2010; Ogeng'o et al., 2010; da Silva, 2012; Mata-Escolano et al., 2012; Patil et al., 2012; Sunitha and Narasinga Rao, 2012; Yuksekkaya et al., 2012; Acar et al., 2013; Budhiraja et al., 2013; Ergun et al., 2013; Herrera et a., 2013; Rekha and Senthilkumar 2013; Lale et al., 2014; Maheria et al., 2014; Rea et al., 2014; Ajit and Amarnath 2015; Bhatia et al., 2015; Shakeri et al., 2013; Ergun et al., 2015; Nurefşan et al., 2015; Tapaia et al., 2015) up to 2.2% (Vučurević et al., 2013).

The rest of the secondary arteries, when not isolated cases, were very infrequently found, as seen in Table 4.

Discussion

Over the last years growing evidence was collected that anatomical variations of aortic arch branching may be associated with a broad spectrum of pathologies, such as peripheral and/or central nervous system vascular diseases or aortic aneurysms dissection.

Even if variations of aortic arch branching are commonly asymptomatic and considered clinically benign, in recent years some patterns (like that classically known as "bovine arch" or variants in which the LVA or an aberrant RSA originate directly from the arch) have been linked to a higher rate of thoracic aortic disease when compared to general population. A role as potential anatomic biomarkers or as a risk factor for future development of thoracic aortic disease has been suggested by some authors (Dumfarth et al., 2015).

The knowledge of the exact morphology of anatomical organization of aortic arch branching in each subject should be an essential information to be acquired for the correct planning of surgical interventions (Ried et al., 2015; Spear et al., 2016;Yang et al., 2016), being relevant not only for vascular surgeons but also for general and thoracic ones (Thors et al., 2014; Ried et al., 2015; Jalali Kondori et al., 2016), clinical physicians (Fujita et al., 2015; Lu et al., 2015) and radiologists (Jalali Kondori et al., 2016; Maiti et al., 2016; Wilbring et al., 2016).

The aortic arch branching pattern influences not only the technical procedure *per se* but also reconstruction, catheterization phases and brain perfusion strategies. Indeed, patients with anatomical variations are reported to have higher rates of direct interventions on aortic arch (Dumfarth et al., 2015) and increased neurological complications during simple procedures such as carotid stenting, due to additional technical difficulties (Faggioli et al., 2007).

An incidental injury of an unrecognized LVA arising from the aortic arch during surgery or endovascular procedures can lead to hemorrhagic or permanent neurologic complications (Hu et al., 2009; Huapaya et al., 2015).

Anatomical variations can also represent an obstacle in radio-diagnostics, especially when imaging techniques are applied in adverse situations such as emergencies and trauma (Wilbring et al., 2016). In other cases, an artery might be erroneously considered obstructed during radiological studies either because it eludes catheterization or because it is not found in the normally expected area, leading to diagnostic mistakes and eventually unnecessary or excessive treatments.

The aberrant RSA, independently of the number or type of the other branches, was present in 0,91% of the cases. These numbers should be evoked before long term nasogastric tube placement and during aortic arch repair surgery, otorhinolaryngological and endocrinological neck's surgery or study of dysphagic patients.

Emergency room physicians and trauma surgeons should consider the presence of two branches patterns in trauma patients who show unexpected neurological clinical signs and evolution due to a complete brain perfusion hampering (Feugier et al., 2003; Cordova et al., 2011).

Anatomical variations of aortic arch branching may also alter data interpretation during hemodynamic procedures because pattern of blood flow, pressure waves and velocity profiles are highly influenced by and correlated with the vascular morphology. If the anatomical disposition of vessels is not taken into account, measures can be misinterpreted and cause wrong diagnosis (Babu and Sharma, 2015; Flores et al., 2016).

Conclusions

This work includes, as far as we know, the highest number of cases and the widest ethnical representation on the addressed issue. Its results should be taken into account in the different situations described.

The normal anatomy still remains the most frequent pattern. The two branches patterns are less frequent, but they're found in almost 15% of the population. Four branches patterns were found in almost 1% of the evaluated cases, while patterns in which all the primary arteries arose from a common trunk are almost anecdotal.

Variants in which the LVA or an aberrant RSA originate directly from the aortic arch have low prevalence but must be known because of the clinical relevance of its potential complications (Shakeri et al., 2013; Rea et al., 2014).

References

Acar M., Ulusoy M., Zararsiz I., Efe D. (2013) Anatomical variations in the branching of human aortic arch. Biomed. Res. India 24: 531-535.

Ajit K., Amarnath M. (2015) Anatomical variations in the branching pattern of human aortic arch: a cadaveric study from Nepal. Eur. J. Anat. 19: 43-47.

Alsaif H.A., Ramadan W.S. (2010) An anatomical study of the aortic arch variations. JKAU: Med. Sci. 17: 37-54.

Babu C.S., Sharma V. (2015) Two common trunks arising from arch of aorta: Case report and literature review of a very rare variation. J. Clin. Diagn. Res. 9: AD05-AD07.

Berko N.S., Jain V.R., Godelman A., Stein E.G., Subha Ghosh S., Haramati L.B. (2009) Variants and anomalies of thoracic vasculature on computed tomographic angiography in adults. J. Comput. Assist. Tomogr 33: 523-528.

Bhatia K., Ghabriel M.N., Henneberg M. (2005) Anatomical variations in the branches of the human aortic arch: a recent study of a South Australian population. Folia Morphol. 64: 217-223.

Bhattarai C., Poudel P.P. (2010) Study on the variation of branching pattern of arch of aorta in Nepalese. Nepal Med. Coll. J. 12: 84-86.

Budhiraja V., Rastogi R., Jain V., Bankwar V., Raghuwanshi S. (2013) Anatomical variations in the branching pattern of human aortic arch: A cadaveric study from central India. ISRN Anatomy 2013: 828969 (5 pages).

Cordova A.C., Bowen F.W., Price L.A., Dudrick S.J., Sumpio B.E. (2011) Traumatic innominate artery pseudo aneurysm in the setting of a bovine arch. Ann. Vasc. Dis. 4: 252-255.

da Silva R. (2012) Anatomical study of the variation in the branching patterns and histology of the aorta in a South African population. A thesis submitted in fulfillment of the requirements for the degree Master of Science (Medicine) in Anatomy, Department of Human Biology. Faculty of Health Sciences, University of Cape Town.

Davivongs V., Sangiampong A. (1986) Patterns of the aortic arch in Thais. Siriraj Med. J. 38: 789-793.

Demertzis S., Hurni S., Stalder M., Gahl B., Herrmann G., Van den Berg J. (2010) Aortic arch morphometry in living humans. J. Anat. 217: 588-596.

Dumfarth J., Chou A.S., Ziganshin B.A., Bhandari R., Peterss S., Tranquilli M., Mojibian H., Fang H., Rizzo J.A., Elefteriades J.A. (2015) Atypical aortic arch branching variants: A novel marker for thoracic aortic disease. J. Thorac. Cardiovasc. Surg. 149: 1586-1592.

Durai Pandian K., Radha K., Sundaravadhanam K.V.K. (2014) Study on branching pattern of arch of aorta in south Indian population. Int. J. Anat. Res. 2: 673-676.

Ergun E., Simsek B., Kosar P.N., Yılmaz B.K., Turgut A.T. (2013) Anatomical variations in branching pattern of arcus aorta: 64-slice CTA appearance. Surg. Radiol. Anat. 35: 503-509.

Ergun O., Tatar İ.G., Birgi E., Durmaz H.A., Akçalar S., Kurt A., Hekimoğlu B. (2015) Angiographic evaluation of branching pattern and anatomy of the aortic arch. Türk. Kardiyol. Dern. Arş. Arch. Turk. Soc. Cardiol. 43: 219-226.

Faggioli G.L., Ferri M., Freyrie A., Gargiulo M., Fratesi F., Rossi C., Manzoli L., Stella A. (2007) Aortic arch anomalies are associated with increased risk of neurological events in carotid stent procedures. Eur. J. Vasc. Endovasc. Surg. 33: 436-441.

Fazal M.D., Sherke A., Suseelamma D. (2012) The variations in the branching pattern of arch of aorta and its embryological correlation. Panacea J. Med. Sci. 2: 29-31.

Fazan V.P.S., Ribeiro R.A., Ribeiro J.A.S., Rodrigues Filho O.A. (2003) Right retroesophageal subclavian artery. Acta Cir. Bras. 18: 54-56.

Feugier P., Lemoine L., Gruner L., Bertin-Maghit M., Rousselet B., Chevalier J.M. (2003) Arterio esophageal fistula: a rare complication of retro esophageal subclavian arteries. Ann. Vasc. Surg. 17: 302-305.

Flores J., Alastruey J., Corvera Poiré E. (2016) A novel analytical approach to pulsatile blood flow in the arterial network. J. Thorac. Cardiovasc. Surg. 151:1203-1212.

Fujita M., Sakabe M., Ioka T., Watanabe Y., Kinugasa-Katayama Y., Tsuchihashi T., Utset M.F., Yamagishi H., Nakagawa O. (2015) Pharyngeal arch artery defects and lethal malformations of the aortic arch and its branches in mice deficient for the Hrt1/Hey1 transcription factor. Mech. Dev. 139: 65-73.

Goray V.B., Joshi A.R., Garg A., Merchant S., Yadav B., Maheshwari P. (2005) Aortic arch variation: a unique case with anomalous origin of both vertebral arteries as additional branches of the aortic arch distal to left subclavian artery. Am. J. Neuroradiol. 26: 93-95.

Gudbrandsson B., Molberg Ø., Garen T., Palm Ø (2016) Prevalence, incidence and disease characteristics of Takayasu arteritis differ by ethnic background; data from a large, population based cohort resident in southern Norway. Arthritis Care Res. 69: 278-285.

Herrera N.E., Ballestero L.E., Forero P.L. (2013) Caracterizacion de las ramas del arco aórtico en una muestra de población colombiana. Un estudio con material de autopsia. Int. J. Morphol. 30: 49-55.

Hu N., Christensen D.A., Agrawal A.K., Beaumont C., Clark E.B., Hawkins J.A. (2009) Dependence of aortic arch morphogenesis on intracardiac blood flow in the left atrial ligated chick embryo. Anat. Rec. 292: 652-660.

Huapaya J.A., Chávez-Trujillo K., Trelles M., Dueñas Carbajal R., Ferrandiz Espadin R. (2015) Variantes anatómicas de las ramas del arco aórtico en una población peruana. Medwave 15: e6194.

Il-Young S., Yong-Gu C., Won-Han S., Soo-Bin I., Sun-Chul H., Bum-Tae K. (2008) A morphometric study on cadaveric aortic arch and its major branches in 25 koreanadults: the perspective of endovascular surgery. J. Korean Neurosurg. Soc. 44: 78-83.

Indumathi S., Sudha S., Hannah Sugirthabai Rajila R. (2010) Aortic arch and variations in its branching pattern. J. Clin. Diagnostic Res. 4: 3134-3143.

Inzunza O., Burdiles Á. (2010) Arteria subclavia aberrante Int. J. Morphol. 28: 1215-1219.

Jalali Kondori B., Asadi MH., Rahimian E., Tahsini M.R. (2016) Anatomical variations in aortic arch branching pattern. Arch. Iran. Med. 19: 72-74.

Karacan A., Türkvatan A., Karacan K. (2014) Anatomical variations of aortic arch branching: evaluation with computed tomographic angiography. Cardiol. Young 24: 485-493.

Lale P., Toprak U., Yagiz G., Kaya T, Uyanik S.A. (2014) Variations in the branching pattern of the aortic arch detected with computerized tomography angiography. Adv. Radiol. 2014: 969728 (6 pages).

Lu Q., Feng J., Zhou J., Zhao Z., Li H., Teng Z., Jing Z. (2015) Endovascular repair by customized branched stent-graft: A promising treatment for chronic aortic dissection involving the arch branches. J. Thorac. Cardiovasc. Surg. 150: 1631-1638.e5.

Maheria P.B., Chaudhari M.L., Guntha Chinna N.S., Parchwani D.N., Rathod H.K. (2014) A study of the branching pattern of aortic arch. Natl J. Integr. Res. Med. 5: 27-30.

Maiti T.K., Konar S.K., Bir S., Nanda A., Cuellar H. (2016) Anomalous origin of the right vertebral artery: Incidence and significance. Eur. J. Vasc. Endovasc. Surg. 51: 380-385.

Makhanya N.Z., Mamogale R.T., Khan N. (2004) Variants of the left aortic arch branches. S. Afr. J. Radiol. 8: 10-12.

Mata-Escolano F., Aparicio-Bellver L., Martinez-Sanjuan V., Sanchis-Gimeno J.A. (2012) Aortic branch variations: An anatomical study in 900 subjects. Sci. Res. Essays 7: 2213-2217.

Natsis K.I., Tsitouridis I.A., Didagelos M.V., Fillipidis A.A., Vlasis K.G., Tsikaras P.D. (2009) Anatomical variations in the branches of the human aortic arch in 633 angiographies: Clinical significance and literature review. Surg. Radiol. Anat. 31: 319-323.

Nayak S.R., Pai M.M., Prabhu L.V., D'Costa S., Shetty P. (2006) Anatomical organization of aortic arch variations in the India: embryological basis and review. J. Vasc. Bras. 5: 95-100.

Nurefşan B, DilekŞen D, Ekrem K, Sema Y, Hasan C, Aydemir K, MehmetSalih A. (2015) Multidetector or computed tomography evaluation of aortic arch and branching variants. Turk Gogus Kalp Dama. (Turk. J. Thorac. Cardiovasc. Surg.) 23: 51-57.

Ogeng'o J.A., Olabu B.O., Gatonga P.M., Munguti J.K. (2010) Branching pattern of aortic arch in a Kenyan population. J. Morphol. Sci. 27: 51–55.

Patil S.T., Meshram M.M., Kamdi N.Y., Kasote A.P., Parchand M.P. (2012) Study on branching pattern of aortic arch in Indian. Anat. Cell. Biol. 45: 203-206.

Rea G., Valente T., Iaselli F., Urraro F., Izzo A., Sica G., Muto M., Scaglione M., Muto M., Cappabianca S., Rotondo A. (2014) Multi-detector computed tomography in the evaluation of variants and anomalies of aortic arch and its branching pattern. Ital. J. Anat. Embryol. 119: 180-192.

Rekha P., Senthilkumar S. (2013) A study on branching pattern of human aortic arch and its variations in south indian population. J. Morphol. Sci. 30: 11-15.

Ried M., Neu R., Schalke B., von Süßkind-Schwendi M., Sziklavari Z., Hofmann H.S. (2015) Radical surgical resection of advanced thymoma and thymic carcinoma infiltrating the heart or great vessels with cardiopulmonary bypass support. J. Cardiothorac. Surg. 10: 137 (7 pages).

Shakeri A., Pourisa M., Deldar A., Goldust M. (2013) Anatomic variations of aortic arch branches and relationship with diameter of aortic arch by 64-row CT angiography. Pak. J. Biol. Sci. 16: 496-500.
Shang J.F., Chen D., Fang W., Wu Y., Cui Y.Y., Teng F., Fu W., Wang W., Lian G.L., Mei S.S. (2016) Autopsy findings of 19 cases of pulmonary vein abnormalities associated with fetal cardiac anomalies. Zhonghua Bing Li Xue Za Zhi 45: 186-190.
Spear R., Haulon S, Ohki T., Tsilimparis N., Kanaoka Y., Milne C.P., Debus S., Takizawa R., Kölbel T. (2016) Subsequent results for arch aneurysm repair with inner branched endografts. Eur. J. Vasc. Endovasc. Surg. 51: 380-385.
Sunitha V., Narasinga Rao B. (2012) Study on the anatomical organization of the aortic arch anomalies. J. Clin. Diagn. Res. 6: 1127-1131.
Tapia G.P., Zhu X., Xu J., Liang P., Su G., Liu H., Liu Y., Shu L., Liu S., Huang C. (2015) Incidence of branching patterns variations of the arch in aortic dissection in chinese patients. Medicine (Baltimore) 94: e795 (8 pages).
Thors A., Haurani M.J., Nelson K.C., Crestanello J.A. (2014) Aortic arch replacement through a left thoracotomy for right-sided aortic arch aneurysm with complete vascular ring. Ann. Thorac. Surg. 97: 317-319.
Vučurević G., Marinković S., Puškaš L., Kovačević I., Tanasković S., Radak D., Ilić A. (2013) Anatomy and radiology of the variations of aortic arch branches in 1.266 patients. Folia Morphol. 72: 113-122.
Wilbring M., Rehm M., Ghazy T., Amler M., Matschke K., Kappert U. (2016) Aortic arch mapping by computed tomography for actual anatomic studies in times of emerging endovascular therapies. Ann. Vasc. Surg. 30: 181-191.
Yang J., Liu Y., Duan W., Yi D., Yu S., Ma R., Ren J. (2016) A feasibility study of total endovascular aortic arch replacement: From stent-graft design to preclinical testing. Zhonghua Bing Li Xue ZaZhi 45: 186-190.
Yuksekkaya Celikyay Z.R., Koner A.E., Celikyay F., Deniz B., Acu B., Firat M.M. (2012) Frequency and imaging findings of variations in human aortic arch anatomy based on multidetector computed tomography data. Clin. Imaging 37: 1011-1019.
Zamir M., Sinclair P. (1990) Continuum analysis of common branching patterns in the human arch of the aorta. Anat. Embryol 181: 31-36.