Original Article

Propensity of Stroke in Standard versus Various Aortic Arch Variants: A 200 Patients Study

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Abstract

Background: Abnormal origin of arteries from the aortic arch could alter the hemodynamics. Therefore, aortic arch variations might predispose patients to atherosclerosis, which would increase the stroke risk by impending thrombus formation. **Objectives:** To investigate the prevalence of various types of the anatomy of the aortic arch in ischemic stroke patients and determine if aortic morphology has any effect on early-onset strokes. **Materials and Methods:** Observational study including 200 imaging-confirmed (Non Contrast Computed Tomography(NCCT)/magnetic resonance imaging [MRI] of the brain) acute ischemic stroke patients. This was followed by computed tomography [CT]/MRI angiography of the arch of the aorta, neck vessels, and intracranial arteries. The occurrence of various types of standard and other aortic arch variants was studied. The prevalence of stroke and its characteristics were analyzed for demographics, types, location, and the predominant side of involvement among standard arch variants and standard versus various aortic arch variants. A P value < 0.05 was considered significant. **Results:** Standard arch Type I was the most common ($P < 0.0001$). Age at stroke onset in Type 1 was 61.83 years ± 2.78 years, in Type 2 was 59.8 years ± 3.55 years, and in Type 3 was 60.96 years ± 3.56 years ($P = 0.0012$). Among the bovine aortic arch, age at stroke presentation in Type A was 53.33 years ± 8.35 years, in Type B was 53.36 years ± 7.4 years, and in Type C was 63.25 years ± 9.25 years ($P < 0.0001$). **Conclusions:** Standard aortic arch Type 2, bovine aortic arch Type A, and Type B are associated with an early age at stroke presentation. During routine carotid evaluation by CT or MR angiography in stroke patients, it would be better to evaluate the aortic arch as well, especially in young patients.

Keywords: Bovine aortic arch, ischemic stroke, standard aortic arch

Context: Stroke and Aortic arch

Introduction

The aortic arch generally gives rise to three arteries that supply blood to the head, neck, and upper part of the thorax. The most frequent branching pattern known as the standard arch consists of the right brachiocephalic, left common carotid, and left subclavian arteries from right to left. According to Lippert and Pabst (1985),[1] in a normal population, the prevalence is around 65%; however, an Indian study by Soubhagya *et al*.[2] (2006) reported that a standard arch is seen in 91.4% of individuals. In a systematic review and meta-analysis of 51 articles (n = 23,882) by Popielusczko *et al*.[3] (2017), the prevalence of standard arches was 80.9%. Inanc *et al*.[4] (2018) conducted a retrospective analysis of data from 288 patients in whom cerebrovascular disease had been diagnosed. They identified three variations in the standard arch. The most common type, Type 1, was found in 60.7% of patients, Type 2 was seen in 34.3% of patients, and Type 3 was seen in 4.8% of patients. Many variations of the aortic arch existed, with the bovine aortic arch being the most common [Figure 1]. Popielusczko *et al.* (2017) found the prevalence of bovine aortic arch to be 13.6%, left vertebral variant to be 2.88%, and aberrant right subclavian artery variant to be 0.7% in the normal population [Figure 2]. In patients with ischemic stroke, the bovine arch was found in 25.7% of patients, according to Syperek *et al*.[5] (2019). Gold *et al*.[6] (2018) reported that it was present in 33% of stroke patients. Satti *et al*.[7] hypothesized that the abnormal origin of the arteries from the aortic arch could alter the hemodynamics. Therefore, aortic arch variations might predispose patients to atherosclerosis, which would increase stroke risk by impending thrombus formation. According to a study by Ribo *et al*.[8] in 2013, aortic arch variants prolong the endovascular stroke treatment procedure time. Endovascular procedures such as cannulation and carotid artery stent insertion are difficult in these patients.[9,10] In light of the widening spectrum of interventional neurology procedures, it is of paramount importance that an interventionist should have a thorough understanding of anatomic variations of the aortic arch[11,12] to help overcome technical difficulties encountered during procedures. An increased shear rate plays a role in thrombus

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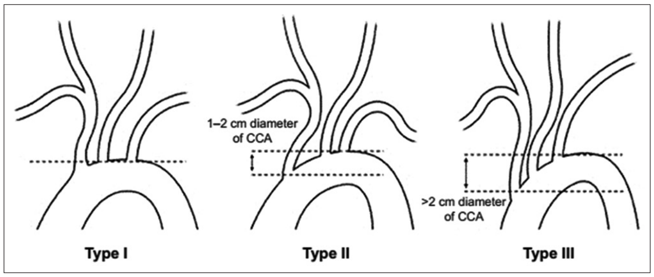

Figure 1: Types of the standard aortic arch. Upper line: level of the top of the aortic arch; lower line: level of the origin of the brachiocephalic branch (Inanç *et al*. 2018)

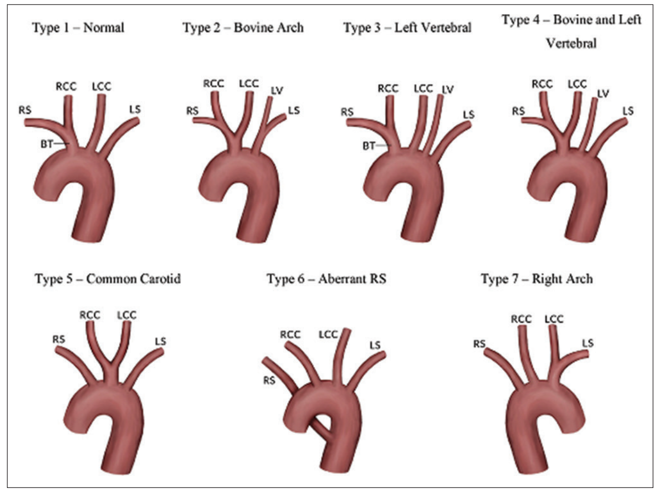

Figure 2: BT (brachiocephalic trunk); LCC (left common carotid artery); LS (left subclavian artery); LV (left vertebral artery); RCC (right common carotid artery); RS (right subclavian artery) Popileusczko *et al*.[3] 2017

formation[13] and has been shown to depend on the curvature of the aortic arch[14] Therefore, we planned to study various types of aortic arch anatomy, their prevalence, and various characteristics of lesions in ischemic stroke patients and their implications in ischemic stroke.

Subjects and Methods

This study was conducted in the Department of Neurology, Government Medical College, Kota. Acute ischemic stroke patients attending the Neurology outpatient department (OPD) and in-patient department (IPD) were included in the study after taking the written informed consent. **Study design:** Observational study. **Sample size:** The sample size consisted of **200** acute ischemic stroke patients confirmed by imaging. **Inclusion criteria: For cases:** 1) Patients of age >18 years. 2) Neuroimaging-confirmed stroke with imaging of the arch of aorta, neck vessels, and intracranial vessels. 3) Informed written consent from all subjects. **Exclusion criteria:** 1) Patients who were having a primary hemorrhagic stroke, subarachnoid hemorrhage, or CVT; 2) spinal infarction, and 3) retinal infarction.

Methods: A: Clinical: 1) All patients were subjected to a comprehensive proforma that included the type, location, and side of stroke. 2) In addition, evaluation of hematological, cardiac, and other causes including artery-to-artery embolism were also done. **B: Investigations:** 1) Blood samples were collected from selected subjects after informed consent. 2) Routine investigations including Complete Blood Count (CBC), Renal Function Test (RFT), Liver Function Test (LFT), serum electrolytes, lipid profile, blood sugar, electrocardiogram (ECG), two-dimensional (2D) Echocardiography (ECHO) were done in all patients to identify risk factors. 3) NCCT/MRI brain followed by CT/MRI angiography of the arch of aorta, neck vessels, and intracranial arteries. **C: Data analysis:** The prevalence of various types of the standard arch [Figure 1] and other aortic arch variants [Figure 2] were studied. The prevalence of stroke was analyzed for its type, location, predominant side of involvement in standard arch versus various aortic arch types. Statistical analysis was performed using the SPSS package (version 11.5, SPSS Inc, Chicago, IL). Categorical variables are reported as numbers and percentages of patients and continuous variables as means ± standard deviations. For categorical data (patient sex, aortic arch branching patterns), Pearson's χ^2 test with a Yates correction was used to evaluate statistical independence and the *P* value calculated. Continuous variables (patient age) were tested for normal distribution using the Shapiro–Wilk test. A *P* value <0.05 was considered significant. One-way analysis of variance (ANOVA) was used to estimate the differences between the study groups.

Results

A total of 200 ischemic stroke patients were included in this observational study. The standard branching pattern was seen in 85.5% (*n* = 171) of patients, with Type I in 52.04% (*n* = 89), Type 2 in 32.16% (*n* = 55), and Type 3 in 15.78% (*n* = 27) [Figure 1]. In Type 1, age at stroke onset was 61.83 years ± 2.78 years, in Type 2 it was 59.8 years ± 3.55 years, and in Type 3 it was 60.96 years ± 3.56 years (*P* = 0.0012). Male-to-female distribution for Type 1, Type 2, and Type 3 was (60.67% vs. 39.33%), (67.27% vs. 32.73%), and (70.37% vs. 29.63%), respectively (*P* = 0.56). The other characteristics of types 1, 2, and 3 arches did not differ significantly [Table 1]. Among the other variants of the aortic arch, the bovine arch was the most common finding seen in 13.5% (*n* = 27) of patients. The bovine arch has three types [Figure 2], Type A was seen in 6% (*n* = 12;Table 2), Type B was seen in 5.5% (*n* = 11; Table 3), and Type C was seen in 2% (*n* = 4; Table 4). The age at stroke presentation in Type A was 53.33 years ± 8.35 years, Type B was 53.36 years ± 7.4 years, and Type C was 63.25 years ± 9.25 years. Type A and Type B bovine aortic arch patients had a relatively early age of stroke presentation (*P* < 0.0001). Type A bovine aortic arch patients had predisposition for anterior circulation stroke (*P* = 0.02; Table 2) and Type B had a predisposition for bilateral anterior circulation stroke (*P* = 0.0002; Table 3). Other demographic parameters and characteristics did not show any statistically significant findings. The least common variant out of all

Table 1: Stroke characteristics among various types of the standard arch

Characteristic	Type I	Type II	Type III	P
n=171	89	55	27	<0.0001
Percentage	52.04	32.16	15.78	
Average age of Presentation	61.83±2.78	59.8±3.55	60.96±3.56	0.0012
Male	54	37	19	0.56
Female	35	18	8	
Type of stroke				
Anterior	61	39	19	0.96
Posterior	22	13	6	
Both	6	3	2	0.93
Side of stroke				
Right	28	22	4	0.55
ACA	10	10	0	
MCA	18	12	4	
Left	30	14	14	0.59
ACA	9	3	7	
MCA	21	11	7	
Bilateral (anterior)	3	3	1	0.84
Right PCA	7	6	3	0.37
Left PCA	14	5	2	
Bilateral (posterior)	1	2	1	0.47

Table 2: Stroke characteristics: standard arch vs. bovine aortic arch type A

Characteristic	Standard arch	BAA	P
n=200	171	12	<0.0001
Percentage	85.5	6	
Average age of presentation	61.04±1.93	53.33±8.35	<0.0001
Male	110	9	0.54
Female	61	3	0.54
Type of stroke			
Anterior	119	12	0.02
Posterior	41	0	0.07
Both	11	0	0.78
Side of stroke			
Right	54	6	0.31
ACA	20	2	0.50
MCA	34	4	0.40
Left	58	5	0.79
ACA	19	1	0.44
MCA	39	4	0.76
Bilateral (anterior)	7	1	0.45
Right PCA	16	0	0.60
Left PCA	21	0	0.36
Bilateral (posterior)	4	0	0.59

variants was a standard arch with the left vertebral artery directly emerging from the arch of the aorta, present in 1% (n = 2) of stroke patients [Table 5]. The average age at presentation was 61 years ± 8.31 years. There were equal numbers of males and females (1 each). The difference in other stroke characteristics was not statistically significant.

Discussion

According to the literature, the prevalence of the standard arch varies between different populations across the globe. It ranges between 65% and 91.4% of the normal population.[1,2] The distribution of these percentages varies among patients with ischemic strokes. It has been rarely studied in stroke patients. In a study of 119 stroke patients done by Gold *et al*.[6] the standard arch was found in approximately 67% of the patients. In a study of 152 stroke patients by Syperek *et al*.,[5] the standard arch was found in approximately 74% of patients. There is a lack of such data from India. In a study of 200 patients with ischemic stroke, we found that 85.5% (n = 171) had the standard arch.

Inanc *et al.* in 2018 performed a retrospective study on 288 patients with cerebrovascular disease and estimated the prevalence of various types of the standard arch. They evaluated the risk of cerebrovascular disease associated with different types of the standard aortic arch. On the basis of the vertical distance between the level of the top of the aortic arch and the level of the origin of the brachiocephalic branch, the standard aortic arch was classified into Type 1, Type 2, and Type 3.[4] Type 1 arch was found in 60.3% of patients, Type 2 arch in 34.3% of patients, and Type 3 arch in 4.8% of patients. There were no statistically significant differences in demographic characteristics or stroke characteristics among the three standard arch types. In our study, we also found a similar pattern of prevalence as Type 1 in 52.04% of patients, which was the most common type, followed by Type 2 in 32.16% and Type 3 in 15.87%. Stroke patients with Type 2 arch were relatively younger compared to patients with Type 1 and Type 3 arch (P = 0.0012) [Table 2]. Although statistically significant, this appears to be misleading. Hence, a larger study population will be required for a better conclusion. Among the variants other than the standard aortic arch, the bovine aortic arch is the most prevalent. Its prevalence ranges from 6 to 31%.[15-27] Syperek *et al*.[5]'s study found that out of 474 patients, 152 had ischemic strokes, and of these, 25.7% had a bovine arch. A study of 119 ischemic stroke patients by Gold *et al*.[6] found that bovine arch was present in 33% of the cases. In our study of 200 ischemic stroke patients, we found bovine arch in 13.5% of patients (n = 27). These included bovine arch type A in 6% of patients (n = 12), type B in 5.5% of patients (n = 11), and type C in 2% of patients (n = 4). It has been proposed by Syperek *et al.* that bovine arch is a biomarker and a risk factor for embolic stroke, and this is evident in our study as well. The age at stroke presentation in patients having standard arch was 61.04 ± 1.93 years [Table 2], in bovine arch type A it was 53.33 ± 8.35 years [Table 2], in bovine arch type B it was 53.36 ± 7.40 years [Table 3], in bovine aortic arch type C it was 63.25 ± 9.25 years [Table 4], and in those having standard arch with left vertebral variant it was 61 ± 8.31 years [Table 5]. This shows an early age of stroke presentation in patients having bovine arch types A and B (P < 0.0001). Additionally, we found that Type A bovine arch had a statistically significant (P = 0.02) association with anterior circulation stroke due to altered

Table 3: Stroke characteristics: standard arch vs. bovine aortic arch type B

Characteristic	Standard arch	BAB	*P*
N=200	171	11	<0.0001
Percentage	85.5	5.5	
Average age of presentation	61.04±1.93	53.36±7.40	<0.0001
Male	110	7	0.96
Female	61	4	0.96
Type of stroke			
Anterior	119	11	0.24
Posterior	41	0	0.14
Both	11	0	0.82
Side of stroke			
Right	54	3	0.76
ACA	20	1	0.79
MCA	34	2	0.89
Left	58	4	0.86
ACA	19	1	0.83
MCA	39	3	0.73
Bilateral (anterior)	7	4	0.002
Right PCA	16	0	0.60
Left PCA	21	0	0.36
Bilateral (posterior)	4	0	0.60

Table 4: Stroke characteristics: standard arch vs. bovine aortic arch type C

Characteristic	Standard arch	BAC	*P*
N=200	171	4	<0.0001
Percentage	85.5	2	
Average age of presentation	61.04±1.93	63.25±9.25	0.055
Male	110	2	0.61
Female	61	2	0.61
Type of stroke			
Anterior	119	3	0.81
Posterior	41	1	0.96
Both	11	0	0.60
Side of stroke			
Right	54	2	0.81
ACA	20	0	0.46
MCA	34	2	0.39
Left	58	1	0.61
ACA	19	0	0.48
MCA	39	1	0.48
Bilateral (anterior)	7	0	0.67
Right PCA	16	0	0.52
Left PCA	21	1	0.41
Bilateral (posterior)	4	0	0.75

hemodynamics. Apart from this, type B bovine arch had a statistically significant association with bilateral anterior circulation stroke ($P = 0.002$) due to the common origin of right and left common carotid arteries. According to Hedna *et al*.,[28] left-sided anterior circulation strokes are more prevalent in THE standard arch. However, in the bovine aortic arch, there is a common origin of both right and left common carotid arteries; therefore, there are equal chances of emboli reaching either side of the anterior circulation (Gold *et al.*[6]). This is also evident in our study, especially in type B bovine arch [Tables 2 and 3].

Other less common variants, such as Type C bovine aortic arch and standard arch with left vertebral artery originating from the arch of the aorta, have not been studied in relation to stroke prevalence. We found the prevalence of bovine aortic arch type C to be 2% ($n = 4$) and that of the standard with left vertebral artery to be 1% ($n = 2$), which is very low. Because a very small number of cases were observed, no significant conclusions can be drawn regarding an association with stroke.

It was hypothesized by Bernardi *et al.*[29] that abnormalities in the aorta can alter hemodynamics and lead to stroke. Shalhub *et al.*[30] compared the flow pattern in the standard aortic arch and other variants such as the bovine arch and aberrant right subclavian artery. On hemodynamic evaluation, they found that in the bovine aortic arch as well as other abnormal arch variants, there were an endothelial injury and vascular stiffness due to the higher regional shear stress. This plays a role in thrombus formation. In previous studies that evaluated patients who had undetermined causes of strokes, atherosclerosis was observed in aortic arch variants.[31,32] Lesions that are >4 mm were found to be related to recurrent strokes. In our study also, we found 11 patients with atheroma >4 mm. Malone *et al.*[33] also suggested a pathophysiologic mechanism, which states that there is an increased velocity of blood flow in the aorta due to the reduced number of direct branches that are coming out of the aortic arch. This results in additional shear force and leads to aneurysm formation or vessel dissection.

The anatomical and morphological variations in the aortic arch and its branches have significant diagnostic and therapeutic implications in interventional neurology. Detailed knowledge of these aortic arch variations is helpful in reducing complications while performing four-vessel angiograms and stenting procedures in the anterior or posterior circulation. In abnormal aortic arch variants due to the presence of tight turns in the brachiocephalic trunk and left common carotid artery, carotid stenting becomes complicated and a difficult procedure. In our institution, performing a four-vessel angiogram on patients with an abnormal aortic arch requires approximately double the time (30–40 min). Anomalous arches were associated with adverse neurological outcomes after carotid artery stenting[19,31,34] and thrombectomies.[35] Therefore, it is recommended prior to any endovascular interventions in the neck that the aortic arch should be evaluated for branching patterns with contrast-enhanced CT.[36]

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Table 5: Stroke characteristics: standard arch vs. standard arch with left vertebral

Characteristic	Standard arch	SA + LV	*P*
N=200	171	2	<0.0001
Percentage	85.5	1	
Average age of presentation	61.04±1.93	61±8.31	0.97
Male	110	1	0.67
Female	61	1	0.67
Type of stroke			
Anterior	119	1	0.52
Posterior	41	1	0.42
Both	11	0	0.71
Side of stroke			
Right	54	1	0.10
ACA	20	0	0.60
MCA	34	1	0.44
Left	58	0	0.55
ACA	19	0	0.61
MCA	39	0	0.44
Bilateral (anterior)	7	0	0.77
Right PCA	16	0	0.64
Left PCA	21	1	0.23
Bilateral (posterior)	4	0	0.82

Key message

Aortic arch variants are predisposing factors for early-onset strokes.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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