# Atypical aortic arch branching variants: A novel marker for thoracic aortic disease

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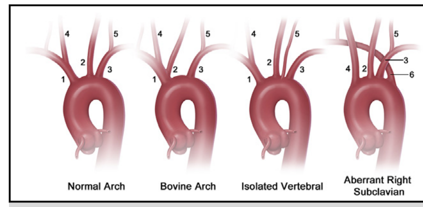
## ABSTRACT

**Objective:** To examine the potential of aortic arch variants, specifically bovine aortic arch, isolated left vertebral artery, and aberrant right subclavian artery, as markers for thoracic aortic disease (TAD).

**Methods:** We screened imaging data of 556 patients undergoing surgery due to TAD for presence of aortic arch variations. Demographic data were collected during chart review and compared with a historical control group of 4617 patients.

**Results:** Out of 556 patients with TAD, 33.5% (186 patients) demonstrated anomalies of the aortic arch, compared with 18.2% in the control group ($P < .001$). Three hundred seventy (66.5%) had no anomaly of the aortic arch. Bovine aortic arch emerged as the most common anomalous branch pattern with a prevalence of 24.6% (n = 137). Thirty-five patients (6.3%) had an isolated left vertebral artery, and 10 patients (1.8%) had an aberrant right subclavian artery. When compared with the control group, all 3 arch variations showed significant higher prevalence in patients with TAD ($P < .001$). Patients with aortic aneurysms and anomalous branch patterns had hypertension less frequently (73.5% vs 81.8%; $P = .048$), but had a higher rate of bicuspid aortic valve (40.8% vs 30.6%; $P = .042$) when compared with patients with aneurysms but normal aortic arch anatomy. Patients with aortic branch variations were significantly younger (58.6 ± 13.7 years vs 62.4 ± 12.9 years; $P = .002$) and needed intervention for the aortic arch more frequently than patients with normal arch anatomy (46% vs 34.6%; $P = .023$).

**Conclusions:** Aortic arch variations are significantly more common in patients with TAD than in the general population. Atypical branching variants may warrant consideration as potential anatomic markers for future development of TAD. (J Thorac Cardiovasc Surg 2015;149:1586-92)




Arch branching: normal, bovine arch, isolated left vertebral artery, aberrant right subclavian artery.

**Central Message**

Variations of the aortic arch are more common in patients with thoracic aortic disease. Therefore, atypical branching variants should no longer be considered clinically irrelevant. Instead they may warrant consideration as potential anatomic markers for future development of thoracic aortic disease.

**Perspective**

Prevalence of aortic arch variations is elevated in patients with thoracic aortic disease. Patients with aortic arch variations are younger and need more extensive surgical procedures than patients with normal aortic arch anatomy. Arch anomalies can considerably influence perfusion strategies as well as surgical treatment. Therefore, clinicians should pay special attention to imaging studies and carefully evaluate the anatomy of the aortic arch in all patients with thoracic aortic disease. Different branching patterns should no longer be considered benign variations but rather as potential anatomic markers or risk factors for future thoracic aortic disease.

See Editorial Commentary page 1593.



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According to the latest report of the Centers of Disease Control and Prevention, aortic aneurysms are the 18th leading cause of death in the United States.[1] Because thoracic aneurysms are usually asymptomatic, identification of thoracic aortic aneurysms and prevention of complications of the disease can be challenging for physicians. Timely detection is crucial. Identification of associated conditions and biomarkers of aortic disease would enhance diagnosis. A bicuspid aortic valve and a strong family history of aortic disease are well-known risk factors for thoracic aortic disease (TAD), as is the presence of intracranial aneurysm.[2-4] The significance of

**Abbreviations and Acronyms**
LSA = left subclavian artery
TAD = thoracic aortic disease

aortic arch anomalies as associates of aneurysm disease is largely unexplored.

Anatomic variations of the aortic arch and its vessels are common in the general population.[5-8] They are usually considered clinically insignificant or benign variants and are commonly asymptomatic. To date 5 large imaging studies have been published depicting the frequency of the 3 well-defined variations (Figure 1)[5-9]:

1) Bovine aortic arch: A common origin of the left common carotid artery and the brachiocephalic artery at the aortic arch, or less commonly a variation in which the left common carotid artery arises directly from the brachiocephalic artery;
2) Isolated left vertebral artery: A branching variant in which the left vertebral artery originates directly from the aortic arch; and
3) Aberrant right subclavian artery: Right subclavian artery originating directly from the aortic arch as a fourth branch, typically distal to the left subclavian artery (LSA).

In recent years the presence of a bovine aortic arch—the most common anatomic variation—was studied extensively in terms of clinical implications in patients with TAD. Based on the association of a bovine aortic arch with higher growth rates of the thoracic aorta and a higher prevalence in patients with TAD compared with the general population, this arch anomaly is currently viewed as a marker or risk factor for thoracic aortic aneurysms and their life-threatening complications.[10,11]

We aimed to describe the prevalence of aortic arch variations in patients with known TAD and their influence on the natural history of the disease or their potential role as an independent risk factor.

## PATIENTS AND METHODS

### Patient Population

TAD was defined as either aneurysmal dilation of the thoracic aorta (diameter $\geq$ 4.0 cm) or presence of aortic dissection, intramural hematoma, or rupture. Our usual criterion for surgery is 5 cm for the ascending aorta; however, selected patients may undergo operation if the aorta is smaller; for example, in case of symptoms, rapid growth, high aortic size index, or positive genetic test for early dissection syndrome.[12]

Our study was approved by the Institutional Review Board of Yale University. We turned a special eye toward isolated left vertebral artery and aberrant subclavian artery. We examined the records of 590 consecutive patients undergoing surgery TAD identified through the database of the Aortic Institute at Yale-New Haven Hospital. We chose the years 2008 to 2013 for our review. In evaluating the computed tomography scans, we took this opportunity to add to our prior published information on bovine aortic arch.[10] The time period of this review overlaps by 1.5 years with our prior report on bovine arch, but it includes 321 unique new cases studied and 83 unique new bovine aortic arch patients above and beyond our prior report, as well as our first-ever analysis of isolated left vertebral and aberrant subclavian artery.

Due to lack of appropriate imaging data, 34 patients were excluded. In total 556 patients were included for further analysis (mean age at presentation, 58.9 ± 13.8 years; range, 6-85 years; 69.2% male). Patients were divided into 2 groups based on the underlying disease: aortic aneurysms (n = 432; 77.7%) and acute aortic syndromes (n = 124; 22.9%) – aortic dissections (type A, n = 96 [17.3%] and type B, n = 23 [4.1%]), intramural hematoma [n = 2], and aortic rupture [n = 3].

We used all large-scale aortic imaging studies depicting different branch patterns in the general population to create a historical control population of 4617 patients.[5-8]

A study by Berko and colleagues[9] examined images of patients with suspected pulmonary embolism or aortic dissection. We believed this might not reflect a healthy general patient population and might carry confounding factors if used as a control cohort. For this reason data from this imaging study were excluded from our control group.

In addition to imaging data, patient demographic characteristics as well as risk factors, surgical procedures, and details on the underlying aortic disease as well as morphology of the aortic valve were collected during the chart review. Furthermore, we calculated age at the time of surgery and age at presentation—defined as the time when patients were first seen by a cardiologist or cardiac surgeon due to aortic disease.

### Definition of Aortic Branching Variants

Prevalence of aortic branching variants was determined by evaluating radiographic images (computed tomography or magnetic resonance imaging scans). Axial images were available for all patients with TAD; coronal, sagittal, and 3-dimensional reconstruction images were used for additional confirmation when available.

The following radiologic criteria were used for 3 different aortic arch patterns:

1. The presence of bovine aortic arch was determined if the brachiocephalic artery and left common carotid artery had their separation point cranial to the plane of the greater curvature of the aortic arch.
2. An isolated left vertebral artery was noted as a left vertebral artery arising directly from the aortic arch, either proximal or distal to the LSA.
3. An aberrant right subclavian artery was defined as a fourth vessel arising distal to the LSA and crossing to the posterior of the mediastinum toward the upper right extremity.

These 3 most common anatomic variations are illustrated in Figure 1.

### Statistical Analysis

Statistical analysis was performed using SPSS version 21.0 (IBM-SPSS Inc, Armonk, NY). Categorical variables are expressed as frequency distributions and percentages; continuous variables are expressed as mean ± standard deviation. The $\chi^2$ test or Fischer exact test was used for categorical variables and the Student *t* test or Mann-Whitney *U* test was used for continuous variables.[13]

To highlight the influence of single-branch patterns, all tests were performed comparing patients with specific anatomic variations to normal aortic arch patterns. For comparison of the TAD patient cohort to the healthy general population, data from 4 large imaging studies were summated and used as a historical control group throughout our analysis. Details on the control group are given in Table 1.

For comparison of comorbidities in different patient cohorts the $\chi^2$ test was performed. Based on the significant association in patients with aortic aneurysms, data were taken into a multivariate analysis. Due to the small sample size in the subgroups (especially patients with an aberrant

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