

MODERN INTERPRETATION OF THE ANATOMOMORPHOLOGICAL STATE OF THE AORTA

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INTRODUCTION

The aorta is the largest and most important artery in the human body, forming the foundation of the entire systemic circulatory system. It originates from the left ventricle and performs the function of delivering oxygen-rich blood to the entire organism. A deep understanding of the anatomical structure and physiological functions of the aorta is of fundamental importance for the fields of cardiovascular medicine, surgery, and diagnostics.

This literature review covers the embryology, anatomy, historical division, wall structure, physiological characteristics, and age-related changes of the aorta. The sources used were taken from modern scientific publications and medical manuals from 2019-2024.

EMBRYOLOGY OF THE AORTA

The embryonic development of the aorta begins in the third week of pregnancy and forms simultaneously with the endocardial tube. This complex process includes several stages.

INITIAL DEVELOPMENTAL STAGES

In the early stages of embryonic development, the primitive aorta consists of dorsal and ventral segments, connected by the first aortic arch. As a result of the fusion of the ventral segments, the aortic sac (aortic saccus) is formed, while the dorsal segments give rise to the descending aorta along the middle axis.

Between the ventral and dorsal aortae, six pairs of aortic arches develop - they are also called branchial arch arteries. In the final stage of development, as a result of the regression of the right dorsal aortic root and the right ductus arteriosus, a physiologically normal left aortic arch is formed. (*White HJ, Bordes SJ, Borger J. Anatomy, Abdomen and Pelvis: Aorta. StatPearls [Internet]. 2023 Jul.*)

MORPHOLOGICAL DEVELOPMENT OF THE AORTA BLOOD VESSEL

Modern studies have shown that different segments of the aorta originate from different embryonic sources. These differences determine the physiological characteristics and susceptibility of each segment to diseases:

- Aortic root smooth muscles - from the secondary heart field (lateral plate mesoderm)
- Smooth muscles of the ascending aorta and arch - neural crest cells (ectoderm)
- Smooth muscles of descending and abdominal aorta - from somites of paraxial mesoderm

(*Thoracic Aorta: Anatomy and Pathology. PMC, 2023. doi:10.3390/jcm12134336*)

ANATOMY OF THE AORTA BLOOD VESSEL

The aorta originates from the aortic valve of the left ventricle and terminates at the level of the L4 vertebra, dividing into the common iliac arteries (aa. iliacae communes). Clinically and anatomically, the aorta is divided into two main parts: thoracic aorta and abdominal aorta.

THORACIC AORTA (Aorta thoracica)

The thoracic aorta, in turn, consists of three segments:

1. The ascending aorta (Aorta ascendens) extends from the sinotubular junction (STJ) to the level of the fourth thoracic vertebra. The coronary arteries originate from it.
2. The aortic arch (Arcus aortae) gives off three major branches: the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery. Various branching patterns (Type I, Type II "Bovine arch," Type III "Isolated") are found among humans.
3. The descending thoracic aorta (Aorta descendens thoracica) passes through the aortic hiatus (hiatus aorticus) at the T12 level and transitions into the abdominal aorta.

(Murillo H, Lane MJ, Punn R, Fleischmann D, Restrepo CS. Imaging of the aorta: embryology and anatomy. Semin Ultrasound CT MR. 2012.)

AORTIC ROOT (Radix aortae)

The aortic root extends from the annulus to the sinotubular junction (STJ) and includes the following components: sinuses of Valsalva, aortic cusps, coronary artery ostia, and interleaflet triangles. The wall of the aortic root is relatively thinner (approximately 2 mm vs 4 mm) compared to the rest of the thoracic aorta. *(Loukas M, Bilinsky E, Bilinsky S et al. The anatomy of the aortic root. Clin Anat. 2014;27 (5):748-756.)*

Abdominal aorta (Aorta abdominalis)

The abdominal aorta originates from the aortic opening of the diaphragm and divides into two common iliac arteries at the L4 level. Along this segment, the following important arteries branch off: the inferior phrenic arteries (aa. phrenicae inferiores), the celiac trunk (truncus coeliacus), the superior and inferior mesenteric arteries, the renal arteries, and the gonadal arteries. (Table 1.) *(White HJ et al. Anatomy, Abdomen and Pelvis: Abdominal Aorta. StatPearls. 2023.)*

Table 1. Anatomical segments of the aorta and their main branches

Segment	Location	Main branches
Aortic root	From aortic valve to STJ	Coronary arteries
Ascending aorta	STJ - IV thoracic vertebra	Coronary arteries
Aortic arch	IV - III thoracic vertebrae	Brachiocephalic, left common carotid, left subclavian a.
Descending thoracic aorta	III thoracic vertebra - T12	Bronchial, intercostal arteries
Abdominal aorta	T12 - L4	Celiac trunk, renal, mesenteric, gonadal arteries

STRUCTURE (HISTOLOGY) OF THE AORTIC VESSEL WALL

The aortic wall consists of three layers, corresponding to the classical artery structure: intima, media, and adventitia. The ratio and composition of these layers differ in various segments of the aorta.

TUNICA INTIMA

The intima consists of a single layer of endothelial cells, beneath which is the subendothelial layer. This layer ensures laminar blood flow and prevents thrombotic processes. As an age-related change, the intima layer gradually thickens.

TUNICA MEDIA

The media layer is the thickest and functionally most important layer of the aorta. It contains elastin fibers, collagen, and smooth muscle cells (SMC). The elastic properties of the aorta, i.e., its ability to expand during systole and constrict during diastole to create pulsation, depend mainly on the media layer.

Collagen, elastin, and smooth muscle cells are the main components of the arterial wall, and their quantity and distribution differ in each layer. In age-related changes, significant alterations are observed in the number and organization of these components. (*Morphology of the human aorta and age-related changes. Anat Cell Biol. 2019;52(2):109-114. PMC6624342.*)

TUNICA ADVENTITIA

The adventitia is the outer layer consisting mainly of collagen fibers. It contains small blood vessels (vasa vasorum) and nerve fibers. Vasa vasorum is a capillary network that supplies blood to the aortic wall.

PHYSIOLOGY OF THE AORTA

The main physiological function of the aorta is to deliver oxygen-rich blood from the left ventricle to the systemic circulation. However, the role of the aorta is not limited to this.

Windkessel effect (Elastic buffer function)

The ascending aorta and arch possess high compliance, which is important for maintaining diastolic pressure and stabilizing peripheral circulation. During systole, the aorta stretches and stores energy, which is then expended during diastole to ensure continuous blood flow. This is called the "Windkessel effect." The thoracic aorta has significantly higher compliance than the abdominal aorta. Therefore, the proximal segments play an active role in maintaining diastolic pressure and peripheral circulation.

(*Thoracic Aorta: Anatomy and Pathology. PMC. 2023. doi:10.3390/jcm12134336*)

Hemodynamic state.

Normally, the amount of blood ejected into the aorta from the left ventricle (stroke volume) is approximately 60-80 ml. Pressure in the aorta (average 120/80 mm Hg in the USA) is determined by vascular resistance, heart rate, and stroke volume.

In recent years, 4D-flow MRI technology has made it possible to obtain a three-dimensional image of blood flow in the aorta. This method allows for non-invasive assessment of hemodynamic parameters in various segments - flow velocity, pressure gradient, and turbulence. (Markl M, Frydrychowicz A, Kozerke S et al. 4D flow MRI. *J Magn Reson Imaging*. 2012;36:1015-1036.)

Morphometric parameters

The average dimensions of the aorta in healthy adults are reported in the literature as follows: the diameter of the ascending aorta is 28-38 mm, the aortic arch is 22-32 mm, the descending thoracic aorta is 20-28 mm, and the abdominal aorta is 15-25 mm. These measurements may vary depending on gender, age, and body weight. (*Frontiers in Cardiovascular Medicine. Development of idealized human aortic models*. 2024. doi:10.3389/fcvm.2024.1358601)

AGE-RELATED CHANGES

Age is considered the primary risk factor for degenerative changes in the aorta. During the aging process, significant changes occur in the diameter, length, wall thickness, and tissue composition of the aorta.

MORPHOLOGICAL CHANGES

Studies indicate that the diameter of the aortic lumen gradually expands with age. These changes are observed in both sexes. The thickness of the intima and media layers also increases with age. Additionally, the elastin fibers in the wall decrease, while collagen fibers increase, which enhances the stiffness of the aorta.

Changes in the composition and arrangement of collagen, elastin, and smooth muscle cells lead to increased arterial wall stiffness. The expansion and stretching of the arterial wall result in elevated arterial blood pressure.

(Mahakkanukrauh P et al. Morphology of the human aorta and age-related changes. Anat Cell Biol. 2019;52 (2):109-114.)

PATHOLOGICAL CONDITIONS OF THE AORTA IN CLINICAL SETTINGS

Understanding age-related morphological changes is crucial for clinical practice, as age is the primary factor determining susceptibility to various aortic diseases (aneurysm, atherosclerosis, dissection). Additionally, this information is also used for age determination in forensic medicine.

DIAGNOSTIC METHODS FOR THE AORTA

Various diagnostic methods are employed to assess the anatomical and functional state of the aorta. Their selection depends on the clinical condition and the patient's age:

- Magnetic Resonance Imaging (MRI) - the gold standard for imaging the aortic arch and its branches *(StatPearls 2023)*
- Computed Tomography (CT) and CT angiography - widely used for rapid assessment of aortic pathology
- Transthoracic Echocardiography (TTE) - useful in evaluating the ascending aorta
- Transesophageal Echocardiography (TOE) - allows for detailed visualization of the thoracic aorta
- 4D-flow MRI - a novel method for assessing blood hemodynamics in three dimensions *(Markl 2012)*
- Invasive catheter angiography - used in complex cases

The introduction of artificial intelligence and machine learning methods is further advancing the diagnosis of aortic diseases. Recently, digital modeling based

on MSCT has opened up significant opportunities for detecting aortic coarctation in children.

(Doroshenko OV et al. Investigation of Relationship between Hemodynamic and Morphometric Characteristics. J Clin Med. 2024;13 (17):5141.)

CONCLUSION

The anatomy and physiology of the aorta are of fundamental importance in numerous fields of medicine. A review of contemporary literature allows us to draw the following key conclusions:

- During embryonic development, the aorta forms a complex structure originating from various sources, which determines the distinct physiological characteristics of its segments.
- The thoracic aorta (particularly the proximal segments) possesses strong elastic properties, ensuring hemodynamic stability through the Windkessel effect.
- The aortic wall comprises three layers (intima, media, adventitia), whose functional properties are determined by their composition of elastin, collagen, and smooth muscle cells.
- With age, the aorta's diameter expands, its wall thickens and stiffens - this process increases susceptibility to diseases.
- MRI and 4D flow methods are widely employed in modern diagnostics; the utilization of artificial intelligence capabilities is emerging as a new direction of development.

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