# New visions upon the neurovascular apparatus of the thoracic aorta

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**Abstract**

**Background:** This research has revealed a number of structural features of the innervation and vascularization of human aorta which arouse great interest for clinicians, recently. The following items were highlighted: a) the variability of the intraparietal nervous and vascular elements of the thoracic aorta; b) regional regularities of their histotopography; c) age and individual peculiarities of the glomic structures of the aorta; d) location of the reflexogenic areas of the aorta.

**Material and methods:** The study was performed on subjects coming to autopsy not more than 24 hours after death. A total 354 human aortas, with mean age from 16 weeks of intrauteral development up to 96 age were examined. A number of research methods have been used: morphometry; histological examination, coloring with Schiff reagent, injectional investigation and anatomical dissection.

**Results:** Dependent and non-dependent gender, age and body type characteristics of the aorta were revealed. Special attention was paid to applied aspects of clinical importance related to the zones of the thoracic aorta.

**Conclusions:** The variability of the shape, size and location of the glomus structures of ascending aorta was described. Macroscopic, mesoscopic and microscopic structural specific features of the vasculonervous elements of the thoracic aorta were studied from the applied point view.

**Key words:** aorta, fat body, *vasa vasorum*, glomus, corpus adiposum Rindfleisch.

## Introduction

At the beginning of the 21st century, clinicians showed great interest to the cardiac morphology and adipose bodies of the aorta, especially to its ascending portion, which is involved in performing the coronary and cardiopulmonary bypass, as well as the aortotomy of aortic valve plasty (AVP) etc.

Currently, the most common complication of cardiac surgery is postoperative atrial fibrillation [1, 2, 3, 4, 5, 6]. Since 1970s of the previous century, several experimental researches were made [7, 8] to describe the neurogenic tissue within the adipose bodies' content of the heart and of the ascending aorta [9]. J. A. Armour et al. (1997) reported about numerous neurons, which were detected in the epicardic fat pads of human body [10].

Jennifer E. Cummings et al. (2004) reported lower occurence of postoperatory atrial fibrillation (POAF) cases in maintenance of anterior adipose body integrity (and of parasympathetic ganglia within its composition) [7, 10]. J. J. Morrison et al. (2004) conducted and described their own observations regarding the presence of adipose transverse ridge, located on the anterior side of ascendant aorta (AA), whether it is eradicated or impaired during the surgical interventions on the ascending aorta [11, 12]. They assumed that profuse postoperative hemorrhages are caused by some intraoperative actions. The authors detected a number of blood vessels and nerves in the composition of aortic crest, which are relative to the adjacent areas, but did not indicate any glomus structures in adults.

Nowadays, there are several clinical and experimental studies related to POAF, but the results are quite contradictory. A series of questions arise regarding the pathogenesis of aneurysms.

During the 80s of the last century, a series of valuable works on the biomechanical properties of the aortic wall were published [13, 14], whereas in 2001 this study was extended to fetuses [82] but still there is no data regarding the development of resistant and deformative properties in various aortic diseases.

The last decade of the 20th century and the first one of the 21st century were marked by a huge interest, among the clinicians, regarding the subepicardic adipose accumulation of the ascending aorta [16, 17, 18, 19, 20], but the morphologists did not state any appropriate response with respect to this request. The cardiosurgery guidelines, such as "Cardiovascular surgery" by V. I. Burakovski and L. A. Bokeria [21] and «Safeguards and Pitfalls in operative technique» of Siavosh Khonsary [22] do not report any information about preventing the most frequent and severe postoperative complications in this field.

This very investigation was initiated in conditions when there is an obvious lack of information, which has been obtained through generations of morphologists, referring to morphology of aorta, and does not longer meet the modern demands of cardiovascular surgery and of advanced angiology. The discussed topic is authentic and complements the lack of information from specialized literature and refers to the morphological interpretation underlying some clinical problems. Firstly, the purpose was defined as follows: to determine the possible impact of the vascular nervous apparatus, which may cause postoperative complications and possible aortic disorders.

This paper addresses an urgent current issue in morphology, since the occurrence of cardiovascular pathologies is continuously growing and has become the main cause of death both in developed countries and in developing ones. In Moldova, 66.7% of mortality rate is due to cardiovascular diseases. Difficulties, which may occur in modern diagnosis and curative studies, conservative and surgical treatment, as well as in the prophylaxis of the aortic disorders are somewhat related to the discrepancy and misinterpretation of the role of different components within the intramural neurovascular apparatus of the aorta in the etiology and pathogenesis of some vascular diseases.

The on-going growth in the number of patients requiring heart surgery, on the one hand, and aortic surgery, on the other hand, as well as the problem of postoperative complications are, unfortunately, quite common, nowdays. Immediate complication is hemorrhage, often abundant, which necessarily require re-sternotomy and the delayed ones – of atrial arrhythmias, which in 7-20% of cases lead to death.

Currently, surgical interventions on various segments of the aorta are widely practiced, therefore an urgent need for diverse data regarding the zone peculiarities of macro- and microscopic structure of the vascular system of the aorta is required, otherwise the desired clinical results will not be achieved. VV condition of the transplantation tissues play a crucial role in a successful treatment (A. H. Cragg and et al, 1983) [23].

The presented study was conducted according to specialists' requirements in the fields of cardiology, vascular surgery (coronary and cardiopulmonary bypass, alloplasty and hetero-plasty of aorta), from the field of mediastinum and spine surgery (spondylectomy) to minimize postoperative complications, primarily in cardiac surgery. The submitted data will contribute to the use of less traumatic treatment approaches.

## Material and methods

The study was performed on subjects coming to autopsy not more than 24 hours after death. A total 354 human aortas were examined with mean age from 16-week fetuses up to 96 years. A number of research methods have been used: morphometry; histological examination, coloring with Schiff reagent, injectional investigation and anatomical dissection.

## Results and discussion

Through anatomical dissection, we established the connections which occur between vagus nerves and all three cervical ganglia. The sympathetic cervical ganglia branches off ramifications which are connected with vagus and then through vagosympathetic trunk reaches the aortic arch. The left vagus nerve is directed towards the convex and ventral side of the aortic arch, whereas a few small nerve trunks come off towards the anterior aortopulmonary groove and towards the front of the ascending aorta. The right vagus nerve branches are distributed to the back of the arch and ascending aorta.

Hence, the ascending aorta and aortic arch have steady bilateral sources, asymmetrical to the origin of nerve trunks, directed to the heart; each of these trunks is formed by the confluence of the vagus nerve branches and sympathetic chain. Branches of the intercostal, vagus and splanchnic nerves are oriented towards the descending segment of the thoracic aorta

The existence of aortic nerve connections with all adjacent organs was determined by staining via Schiff's reagent, data which contributes to a clearer understanding of the vaso-vasal and vaso-visceral reflexes, and is useful for medical practice as well.

Nerve elements are not equally distributed in the aortic wall. Thus, the density of nerve trunks per 1 $cm^2$ reaches its maximum in the following segments: between the ascending aorta and pulmonary trunk; between the aortic arch and trachea; the posterior wall of the descending aorta.

During our study, the nerve plexus of adventitial aorta was identified, which was well developed had all kinds of nerve elements: nerve trunks, nerve fibers and solitary fibers, free nerve endings, those with well pronounced glial content, Crause corpuscles as well as ganglia, nerve microganglia, solitary and intratrunkul neurons, aortic corpuscles, similar to the carotid ones. Solitary and free sensory nerve endings predominantly occur in the tunica media.

The largest nerve trunks are located in the anterior and posterior aortopulmonary grooves, and on the ventral side of the aortic arch. The spatial arrangement of the nervous structures of the aorta is similar to that existing in other areas of the body, where neurovascular bundles are formed and which commonly contain an arteriole, two venules and a nervous fiber. Haysman phenomenon (dilaceration of nerve bundle) is noted at the intersection of the nerve trunk with a blood vessel.

Another phenomenon is the presence of nerve cells in the above mentioned areas. They are more abundant and disseminated in the outer layer of adventitia, whereas essentially reduced in deeper layers, at the limit of the tunica media. The number and size of intraparietal nerve ganglia on the ventral side of AA are larger than on the dorsal side. The AA convex side contains fewer nerve structures compared to the concave side. In all cases, nerve connections between the nerve trunks of the ascending aorta and the pulmonary trunk are defined.

A specific interest is shown to the location of nerve structures in adventia, which occur predominantly along the *vasa vasorum* ramifications and vascular networks. Nerve trunks, solitary nerve fibers and receptors are located on their pathway. Nerve plexuses which are macroareolar in the outer layers of the vascular tunica, become microareolar in the deep layers. Micro-ganglia are revealed in places of origin of the aortic arch branches, along aortopulmonary grooves and on the convex side of the ascending aorta.

During its lifetime, aortic intramural nervous apparatus will undergo a series of changes depending on age, or response to pathological conditions. Studying aortic intramural nervous apparatus in various diseases, we found no specific changes. In all cases we defined reactive alterrations of the nervous apparatus: hyper-staining of myelinated fibers, varicosities, neuroplasmatic fusions, vacuolation of myelin membrane, brutalization of preterminal and terminal portions of the receptors, mainly of sensitive ones, or their fragmentation. Most people with atherosclerotic aorta, besides the degenerative processes, have also the compensatory terminal devices, characterized by abundant growth or thickening.

Ascending aorta and aortic arch are constant sources of bilateral nerve supply, being asymmetric to the origin of nerve trunks and directed to heart; each of these trunks are formed by the confluence of the vagus nerve branches and those with genesis of the sympathetic chain.

Anterior part of the ascending aorta, is generally innervated by branches of the left vagus nerve, while the posteriorly - by the right vagus nerve. It is necessary to highlight that anteriorly of the aortic arch, connections between these two vagus nerves occur. Nerve trunks of the ascending aorta usually pass anteriorly and posteriorly of AA near the anterior and posterior aortopulmonary grooves. Their branches form a adventitial nerve plexus, whereas ramifications come off into tunica media, where the secondary plexus is formed.

Vago-simpatic nerve trunks, are formed at the level of concave arch, then directed downwards its origin, along the aortopulmonary grooves, whereas the anterior ones are larger in size. They are followed by numerous nervous micro-ganglia. The trunks are smaller in size on the convex side of AA compared to the concave one. As a result of the morpho-functional peculiarities of the ascending aorta, the nerve trunks and nerve bundles present more or less sinuous pathway.

It is a well-known fact that if the function of the vascular segment is complex, then the nervous apparatus is more varied and intricate. According to our data, the most complex and diverse neurovascular structure was detected in the ascending aorta, particularly in the adipose body of the ascending aorta.

We also observed some regional differences in the placement of nerve elements. Nerve bundles are predominantly directed longitudinally, according to the AA major axis, except for corpus adiposum Rindfleisch' (CAR) where horizontal orientation is present. We identified nerve endings in the CAR structure, characterized by button appearance, in particularly, Krause corpuscles. At the level of adipose body, a larger number of nerve cells and solitary intratrunkal are detected, compared to adjacent areas.

The aortic intraparietal nervous apparatus is well-developed. On segments collected from newborns, we observed an intricate nerve network, which includes nerve ganglia in its composition. Therefore, the aortic wall in infants, including CAR, contains the same nerve elements characteristic of adults.

The peculiarities of AA innervation consists, mainly in the presence of numerous constant nerve structures, of "glomus" type. These are characteristic for both prenatal and postnatal periods of ontogenesis. In other areas, they are commonly lacking or reduced during lifetime. We stress upon this structural peculiarity, since taken individually, it is characterized by a wide range, regardless of the age group of subjects undergoing study. Hence, this portion of the aorta requires extensive physiological research.

Unlike the glomus structures which are located elsewhere in the aorta, those from the CAR are more numerous and constant. Furthermore, depending on the shape and location of the Rindfleisch' fat body, its corpuscles also vary in location. They may be located on the anterior, on the right and/or posterior surfaces of AA.

According to own observations, these glomus cells undergo reshuffling, although some specifications are required. For example, in adults, the glomus cells are present in CAR, although J. J. Morrison and et al. (2003) stated that glomus structures are missing in adults, being substituted by adipocytes.

The examination of a large number of histological samples, which elucidate the *vasa vasorum internae* (on its pathway), enabled to perform some observations. No glomus structures were found on the incipient portions of VVI pathway, which is 2.0-2.5 cm long, until they penetrate CAR. There are contradictory opinions in the specialized literature, which refer to aortic chemoreceptor apparatus. Thus, the prior purpose of this study was to elucidate the situation, referring to aortic chemoreceptor apparatus.

There were made a series of transverse and longitudinal sections of the CAR. An arterial vessel is present on the cross-sections of the adipose body of AA, passing through the glomus center; on both sides of the arterial vessel, larger venous vessels are often located, compared to those of the artery. In most cases, glomus cells and various-sized supporting cells are contained in the mentioned above structures. Rarely, an arterial vessel of a greater diameter passes through its glomus pole or, in some cases; larger glomus cells may contain two sources of vascularization.

Our results prove a wide variation of glomus structures, located in the adipose body of the ascending aorta. They vary mostly in shape, size, depth, and blood and lymph vessels relationship. There were detected glomus ranging from 100 mcm up to 2 mm – diameter. Usually, smaller glomuses are located deeper, near the aortic media, the larger ones in the outer layers of adventitia, whereas the glomus cells are dispersed within the aortic media. The functional role of these structures presents an increasing interest among practioners.

A. M. Verity, T. Hughes and J. A. Bevan (1964), when underlining the continuity of glomic-aortic-pulmonary structures, considered it unreasonable to highlight their individual variations. We could not overlook the extremely wide variability of glomus formations enclosed within CAR. There should be noted some changes regarding their structure, in adults. It is not clear why they are found in absolutely healthy and younger people, whereas in pre-senile and senile- aged persons they often show no changes, although persons died of cardiovascular diseases. We can not confirm that glomus cells disappear along with aging: we have found them in all cases, at various ages. Obviously, the number of sections must correspond to the CAR dimensions. While making the analysis of numerous sections in the more pronounced developing zones of adipose tissue, including the adipose body fat, no cases of failure were recorded. There were recorded dispersed forms of the respective structures, when groups of cells are observed along the blood and lymph vessels pathway.

There was not observed any relationship between the presence or absence of glomus formations and person's gender.

The AA glomus characteristics are similar to the carotid ones: their location is closely allied to arterial, venous and lymphatic vessels; the presence of glomus cells located within the intercellular spaces describes their role as chemoreceptor, it was proved that the location of chemoreceptor structures of the ascending aorta is closely related to the shape, location of the fat body and the advanced development of adipose tissue. Therefore, when the Rindfleisch adipose body is less pronounced anteriorly of the ascending aorta, glomus structures are located in the most developed zone of adipose tissue: on the right or posteriorly of the ascending aorta.

Besides the glomus structures, which have the classic appearance of various- sized carotid corpuscles, there were found agglomerations of various-shaped glomus cells, including dispersed ones. Compact type corpuscles predominate in neonates, whereas in adults a more relevant organizational diversity.

As a rule, those similar to carotid glomus are placed in the outer layers of the adventitia, whilst the other forms within the deep layers. Disperssed cells are detected at the limit of media and adventitia along the lymphatics, in shape of extended cords or rows of glomus cells nests and those which are freely distributed within the intercellular spaces.

The glomus para-aortic structures, which have been well documented and argumented by other investigators (Addison and Comroe, 1930 Daly and co., 1970; Coleridge Hazel M. and co., 2016), were not included in the study.

Based on the obtained data, we can state that the number and distribution of corpuscles varies from case to case. However, there is some regularity: aortic corpuscles in the superficial layers are closely allied to the blood vessels, whereas the small glomus structures and their clusters within deep adventitia are placed near the lymphatic vessels. Most commonly, arterial vessels pass through the center of glomus which ramifies. The correlation between the lymphatic and venous vessels present different structural aspect: the glomus cells or corpuscles are paravasally anchored and closely bound to the vessels.

The size of glomus structures of the ascending aorta changes according to age: in the first 3-5 years of life, their sizes grow until the age of adolescence when a slight decrease occurs. In adults there is an increase of linear parameter values of the glomus structures. The connective tissue lies on the basis of their volume extension. The larger glomus structures are ovoid-shaped, their spatial orientation corresponds to the major axis of the Rindfleish fat body. Thus, it is perpendicular to the longitudinal axis of the ascending aorta. There can be observed multiple clusters of glomus cells along the lymphatic vessels.

The collected information allows us to complete the classification of glomus cells, which was proposed by A. Hove (1956). It provides four groups of these anatomical structures with the following locations: on the ventral part of right subclavian artery root; on the ventral part of the left subclavian artery root, on the ventral side of the aortic arch, within the connective tissue, located between the aortic arch and ductus arteriosus. Therefore the fifth will include corpuscles incorporated into the Rindfleisch fat body.

The location of the glomus structures closely allied to the blood and the lymphatic vessels, the appearance of dispersed forms, confirm the functional diversity of these structures, mainly the monitoring of the biochemical composition of the blood, lymph and tissue fluids, i.e. of the aquatic medium which surrounds them.

The detailed study of the nervous and vascular apparatus of different portions of the thoracic aorta, showed specific neurovascular complexes only within the fat body structure of the ascending aorta. On minimum amplification their shape resembles "button" nerve endings, whereas on maximum, they become spindle-shaped and contain a nerve bundle surrounded by a vascular network.

Their sizes vary from 0.3 cm to 1.0 cm in length, and between 0.15 - 0.5 cm in width. I met no descriptions of these formations in the specialized literature, which was accessed. In our opinion, such a structural organization is suitable for perception of blood pressure, viz. these are baro- or presoreceptor structures.

In adults, the nerve endings are located in the adventia and the third external part of tunica media, whereas in fetuses and newborns they often reach the limit of intima. This peculiarity is due to the fact that depressor nerve fibers penetrate the walls of the branchial arches when the medial tunica is still undeveloped. As the vascular wall thickens, the nerve structures move passively from the intima to the external tunica, and, finally, are located in the outer layers of media.

The presence of fat body in the subepicardic layers of ascending aorta formations being similar in structure to that of the endocrine glands may be an argument for performing endocrine functions.

The aortic arch is innervated by branches of the left vagus nerve, except for the posterior part of the right extremity of the aortic arch, which is innervated via right vagus nerve. There were identified sources of innervation of spinal origin, which are directed from the sympathetic chains and intercostal nerves to the arch.

The nerve apparatus of baroreceptor area within the

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aortic arch is represented by extended tree-shaped ramifications with free endings, anchored into the deep adventitial layer; by free bush-like nerve endings and lots of compact bushes with glial elements, located in the middle layer of the adventitia. We found no encapsulated endings in the aortic arch. There were detected nerve micro-ganglia in adventitia of aortic arch, accumulations of neurons in the aortic wall; especially in places were ramifications emerge.

The concept approaches on aortic glomus differ greatly. According to data from «Wikipedia, the free encyclopedia, 2015,» there are several small groups of chemoreceptors, baroreceptors and supporting cells along the aortic arch. At the same time, E. V. Trifonov (2015) writes that aortic corpuscles are a single chemoreceptor structure, located in the aortic arch. It is stated that this structure is oval, red-brown, about 5 mm diameter, surrounded by a fibrous capsule. While examining various portions of the aortic arch there was determined the presence of the aortic corpuscles only in the lower wall of the aortic arch, near the arterial ligament in the neonate.

At the origin of aortic arch branches there is a reduced number of nerve endings compared to the adjacent area of the arterial ligament, but they are more crowded than on the anterior and posterior parts of the aortic arch. The maximum concentration of nerve regards to the middle layer of adventitia. The external tunica of the aortic arch reveals numerous nervous micro-ganglia, whereas the characteristics of nervous structures are similar to the area of the anterior aortopulmonary groove.

The descending thoracic aorta is innervated by branches of the vagus nerves, major splanchnic nerves, ganglia of sympathetic chain and intercostal nerves, respectively. The superior cardiac branch top of vagus nerve, depressor nerve, initially it goes isolated, and then it connects with superior cardiac nerve that originates in the superior cervical ganglia.

As regarding intraparietal nerve units of the descending thoracic aorta, they are similar to other portions of this major vessel, except for glomic structures. The latter were not detected.

During lifetime, the constituent elements of intramural nervous apparatus adapt to the conditions of the substrate. In response to the pulsating character of the functioning aorta, the pathway of the nerve bundles appears wavy or spiral. At the level of the ascending aorta, this phenomenon is observed earlier than in the other portions of the aorta.

There were observed some regularities regarding the vascularization of thoracic aorta: along the aortic pathway some characteristics of the vascular bed area were found; *vasa vasorum* density per area unit of the macroareolar network of anterior aortic wall above is more intricate than the posterior one. Vascular loops are elongated, according to the major axis of the aorta.

The obtained results allow us to conclude that two groups of irrigation sources participate in the vascularization of the ascending aorta viz. ascending and descending. Mainly, Schiff's reagent staining makes it possible to determine a series of new data.

The lower portion of the anterior side is irrigated by branches of the right coronary artery, whilst the posterior by the ramifications of both coronary arteries. The vasculature of AAs anterior part, is carried out by branches of both coronary arteries in 97% of cases, and only in 3% of cases by branches originating only in the right coronary artery. This is determined by the morpho-topographical characteristics of the CAR.

In 45% of cases, at the basis of aortic semilunar valve, there were detected arcuate arteries, which originate in both right and left coronary arteries. There is a high probability that these are present more frequently, or perhaps, permanently. During the study, it was technically difficult to separate, by means of existing methods for determination of these vessels, the base of aortic bulb from the cardiac walls, without damaging the above mentioned arteries.

Their ramifications branch off, predominantly, in basal portions of the aortic valve cusps. In the middle of cusp, the number is reduced whereas they are lacking in the free portions.

The presence of microvascular networks into the aortic cusps proves that the amount of oxygen within valve's tissue exceeds the possibility of its diffusion. Tissue engineering should consider this information while designing the heart valves transplants. Thus, a valve consisting of avascular tissue should not exceed 0.4 mm - thick (approximately). The presence of vascular bed shows that the metabolic activity of the valve is greater than the diffusion might bear it.

The anterior part of AA is irrigated, mostly by the primary branches of the right coronary artery; in other cases, by the auxiliary branches of right auricular artery; and the posterior part- by the auricular branches of both coronary arteries.

There are numerous small branches, which emerge from the bronchial arteries viz. the mediastinal and artery branches associated with the vagus nerve. We detected that in all cases the descending branches go off from the concave part of AA and above the bulb-tubular junction. We did not find any description of them in the consulted bibliography. They present a peculiarity viz. they start from the aortic lumen and do not exceed its wall margins, being located intraparietally, thus represent *vasa vasorum internae*. Their number varies from one to seven, the lumen is larger than that of other sources (in some cases, their diameter reaches 1.5 mm). Normally, they are directed towards the Rindfleisch fat body, whereas larger branches penetrate within it, and branch off depending on the shape and size of this anatomical structure, where it branches to the capillaries, forming anastomoses with all irrigation sources of the AA. This vascular network is richer in the area of pronounced development of fat body, which varies in size and shape from case to case.

It should be mentioned that in fetuses, *vasa vasorum* *interna* is the first source of blood supply of AA, which is seen with the naked eye. In 16-weeks fetuses, they form a red stripe, which extends from the concave part of the ascending aorta, and is oriented downwards and to the right, up to the level of connection between the aorta and right atrium auricle. The fat tissue which surrounds these vessels occurs later. In the postnatal period, the most pronounced and larger in diameter AA irrigation sources, are also the mentioned above VVI. In adults, these vessels are often seen under the epicardium, when special techniques are required to detect other types of vessels. It is obvious that these VVI are specifically important to be known, since AA serves as a gateway to heart surgery. In order to facilitate the access, body fat is removed before these procedures are applied.

The blood pressure within vasa vasorum interna with the AA genesis is high. Their impairment may result in profuse postoperative bleeding (in cardiac surgery), which requires re-sternotomy. The recorded cases answer somewhat the questions of the clinicians in recent years, thus showing the importance of body fat study before choosing a place for access. Therefore, special efforts are required to maintain the integrity of CAR.

Based on the information we have about *vasa vasorum intenae* (VVI), we may claim the following: the blood pressure within these VVI is higher than in the other sources of AA vasculature. This fact somewhat reduces the effect of intralumenal pressure on the AA walls. Thus, namely these sources are essential for irrigation of reflexogenic area. The premature development of VVI, unlike other descending irrigation sources of this aortic portion (bronchial and mediastinal arteries, artery associated with right vagus nerve) confirms this idea.

The appearance of CAR vascular bed depends on the shape and movement of this fat structure. The VVI pathway of AA differs in different locations and shapes of adipose body. In cases if CAR gets into contact with anterior adipose body above (from the anterior aortopulmonary groove), usually these vessels are not seen with the naked eye. They are rooted initially in the fat tissue of the latter, and then occur under the epicardium and above the AA adipose body.

They can be fully revealed only by means of special investigation techniques. In cases when CAR has different configurations, except for the adipose pad, it starts anteriorly of the ascending aorta and does not contact with CAA, *vasa vasorum internae* is directed downwards, a bit to the right from its origin, on the concave side of the ascending aorta and parallel to the anterior aortopulmonary groove. They neither do nor branch off until they enter into CAR, and are major-type inside. They branch off, thus forming anastomoses with other AA irrigation sources.

In cases of fat pads, the VVI pathway is quite different. It is worth reminding, that this form of CAR is found only on the right and posterior parts of the ascending aorta. We have not found any case of its location anteriorly of human ascending aorta. *Vasa vasorum* is oriented obliquely (down to the right) from its origin, forming a reclining angle against the major axis of AA the angle is sharp when CAR is placed on the right side and obtuse if it locates posteriorly.

In such situations, VVI does not branch off until it enters into adipose body, but once inside it breaks down into fan-shaped branches. These branches form anastomoses among themselves and with other sources of irrigation, forming a dense vascular network, similar to a ball. These peculiarities of vascularization among the adipose pads should be considered when determining the place of surgical incision in the ascending aorta.

The statistical analysis of the obtained information has indisputably demonstrated that the oblique pathway of the VVI is typical for the CAR localizations on the right and left sides of AA, when the fat body is placed differently; whereas when the anterior surface of the ascending aorta is involved, we can observe that VVI pass from their origin downward along the AA concave surface till the fat body, and then they are enclosed within this structure.

Currently, the underestimation or ignoring the existence of VVI during the cardiac surgeries leads to many casualties in the postoperative period. Recently, due to the lack of information about these blood vessels, discussion arose about, “enigmas” which occur in zone of ascending aorta (Jokz C. Lindsay H., 2004; J. J. Morrison, Codispoti M., Campanella C., 2003, 2004) [11, 12, 24].

We noticed that the presence of multiple VVI is typical in cases where AA is sharply curved. Under these conditions, one or two larger vascular trunks are directed to the fat body in typical manner for each type of it. Other branches move to the convex part of this aortal segment, where the radial compression is at highest. No glomus structures were detected throughout these branches.

The prominent density of *vasa vasorum* in AA and the presence of blood supply sources, originating directly into the aortic lumen (*vasa vasorum internae*) is a necessity to ensure adequate nourishment of the aortic area with the largest diameter, wall thickness and the highest radial compression. We conclude that, functionally, VVI which is embedded into fat body differs from those that supply the convex part of the ascending aorta. The first provide continuous irrigation of the chemoreceptor structures, whereas others – continuous irrigation of the aortic area, which undergoes the largest compressive forces and warrants its strength throughout lifetime. The findings regarding the pathway of *vasa vasorum internae* in different types of adipose bodies, prove the importance of their intraoperative visualization before making the incision of aorta, in order to prevent bleeding that turns to be life threatening.

It should be noted that the densest vascular network that contains the greatest number of anastomoses in human aortic wall, is localized at the level of the fat body in the ascending aorta. The list of irrigation sources of ascending aorta, according to the decrease of the lumen diameter up to Rindfleisch body fat is as follows: *vasa vasorum internae*, right and left coronary arteries, the artery associated with right vagus nerve, bronchial arteries and mediastinal arteries. How can we explain the existence of numerous irrigation sources of ascending aorta?

The results of experimental research of several scientists showed that radial compression force of the AA wall is four times larger than in the abdominal aorta. Such extreme operating conditions of this aortic portion require particular vascularization. The presence of VVI provides blood flow both during heart systole (via descending sources) and diastole (via descending – branches of the coronary arteries).

Previously I have described that the formation of this network is performed by branches of lots of sources, including *vasa vasorum internae*. The latter provides the necessary blood pressure level to properly irrigate the reflexogenic area, despite the high lumenal pressure in this portion of the aorta. The data available on the VVI of AA makes it clear the necessity to modify and improve cardiac surgery techniques.

As about the causes of profuse postoperative bleeding, after the patient has undergone surgical interventions on AA: irrigation sources form anastomoses not only between them, but with branches of intercostal and phrenic arteries (branches of descending aorta), as well as, at the transitional place of the parietal pericardium into the visceral.

We can not doubt the experimentally obtained results, such as heart rate and blood pressure alterations as a result of excitation of the aortic arch with venous blood [25]. This experiment also demonstrates that there is a zone or hemoreceptor zones within the aortic arch, but we can not actually prove their specific localization. The fact that we found no glomus structures in the descending thoracic aorta and arch level does not confirm their absence, in adults. The aorta is a large sized vessel and requires the study of any micro unit per mm2 of the thoracic wall in order to detect microscopic configurations incorporated into the walls of the vessel, the fact which, unfortunately, was not possible to perform during the current study.

We have also complemented the theoretical and practical importance of VVI information, confronting our obtained data (*vasa vasorum internae* in ascending aorta area) with Comroe's reports. We noticed that their origin corresponds to the indicated level and they have positive response to the introduction of Lobeline cannula within experimental investigations conducted by this remarcable scientist. The localizations of numerous structures similar to carotid corpuscle along the VVI of AAs is a valuable argument to conclude that reflexogenic chemoreceptor area of the aorta is localized in Rindfleisch fat body.

The branches of the intercostal and bronchial arteries to the aortic arch are various in number, and branching manner. There is also a third group of branches - from the brachiocephalic trunk. The latter branch off in adventitia of aortic sac derivatives: on convex surface of the central portion of the aortic arch and the incipient portion of arch, then extend anteriorly of the distal AA portion. The pathway of TBC branches changes in here, some of them turn to the convex side, the others - to the concave ascending aorta, and form mutual anastomoses posteriorly of AA. They do not form anastomoses with vascular sources of proximal or distal portions of the AA. Often, the branches of the bronchial arteries assist in the formation of anastomoses on the posterior part of the arch. Most commonly, several branches go upwards starting from the third left intercostal artery and move towards the anterior side of the distal portion of the arch. The branches of left bronchial artery supply blood to the concave side of the arch and lower portion of its posterior side.

Summarizing, we can state the following: the convex portion of the aortic arch is irrigated by an artery originating from the base of brachiocephalic trunk, whereas the concave (initial and terminal portions of the arch) – from the bronchial arteries, which vary greatly in number in the left third intercostal artery. Bronchial arteries form anastomoses with the branches of the brachiocephalic trunk both on the anterior and posterior parts of the aortic arch.

In some cases, there were found branches at the base of the left common carotid artery, which start from the lumen of this artery, pass through its adventitia and branch off in the adjacent area of the aortic arch. There was detected a clinically significant peculiarity of the vascular bed and the intramural aortic arch. The irrigation sources of aortic arch extend about 1 cm proximally to the origin of the brachiocephalic trunk and distally of the isthmus.

The morphological characteristics of the areas of the aortic vascularization are determined both by its ontogenesis (the presence of multiple sources of development) and arious hemodynamic conditions, which occur along them. Thus, the bulbar portion of ascending aorta, which is a derivative of arterial trunk is vascularized by coronary arteries; its tubular portion, mostly the aortic arch, derivatives of aortic sac are vascularized by branches of brachiocefalic trunk and *vasa vasorum internae*; the concave side of the arch, which develops from the IVth aortic arch is nouriched through the aortic bronchial and mediastinal branches; the distal portion of the arch, as well as the descending thoracic aorta, derivatives of dorsal aorta, are vascularized from intercostal arteries. In all cases, there is a poorer irrigation of the adjacent areas of the arch, both from the ascending aorta and descending thoracic aorta. Anastomoses rarely occur between sources of the arch with those of AA and the descending portion. This fact has been noticed both in adults and in children.

While comparing this situation with clinicians's data in the field of cardiovascular surgery, regarding the occurrence of dissecting aneurysms, we may conclude that this is not an accidental coincidence. Namely, these aortic walls are poorly vascularized, thus more commonly affected by the aneurysms. Hopefully, the stem cells usage created by modern technologies will enable the strengthening of the aortic wall with *vasa vasorum*.

There was detected, within the aortic arch, an autonomous network of vascularization from *vasa vasorum internae* system in the adjacent zone of the aortal ending of arterial ligament. The baroreceptor area is irrigated by 2-3 vessels which originate closely the target area. We have not recorded any anastomoses of these vessels with other irrigation sources of aortic arch.

At the level of the aortic arch, particularly in its convex portion, the blood vessels form multiple loops and rings oriented predominantly transversely. On the convex side, the loops are macroareolar and on the concave – of smaller size and more round-shaped.

VV of the descending thoracic aorta originate from the posterior intercostal arteries. Being placed posteriorly to the aorta, they form a denser network on the dorsal side of aorta. Thus, the descending thoracic aorta is vascularized by the branches of the major intercostal arteries of 150-200 mcm in diameter. Frequently, their segmental character was observed on the ventral side of the descending aorta, which was not found in the arteries on the posterior part of the descending portion of the thoracic aorta. The segmental contralateral anastomoses are well pronounced on the anterior side of the descending thoracic aorta, which are missing or have a very small diameter on the posterior area of the same aortic portion.

It was noticed that arterial *vasa vasorum* are easily distinguished from veins by a relatively rectilineal pathway, whilst in the veins it is more sinuous type. Furthermore, the arterial vessels are less numerous, with a smaller lumen compared to veins.

The data regarding the depth of *vasa vasorum aortae* localization are as follows: the adventitia is completely vascularized, the tunica media – only 2/3 externally, intima is normally not vascularized. The depth of the *vasa vasorum* localization is reduced as the distance from the cord decreases.

As referring to arterial bed of the descending thoracic aorta, it should be mentioned about the postnatal changes of primary *vasa vasorum*, which have a diameter of 150-200 mcm in newborns and are segmental ones; in adults they are relatively narrow, fewer in number because of the partial loss of their segmental character. In the latter cases, bilateral longitudinal arterial trunks are detected, which are anastomosed through cross arteries and form contralateral anastomoses.

The distribution of *vasa vasorum* of the descending thoracic aorta is not uniform. The aortic vascular network is richer on the posterior side, while the larger vessels occur mostly on the anterior side. *Vasa vasorum* form two similar networks to those in AA and arch, whereas the veins drain into the intercostal ones.

Numerous observations during the study reveal the presence of special sources of blood irrigation of the glomus structures of the ascending aorta, with specific histotopography. The glomus cells of adipose body of the ascending aorta are vascularized from *vasa vasorum internae*, which start on concave side of AA and above the bulbotubular junction and then go through their center, having numerous branches that enter the glomus. The stained samples via Schiff's reagent, display multiple arterial sources which approach glomus from different directions.

The structure of the vascular bed of the baroreceptors zone of aortic arch, placed near the site of insertion of the arterial ligament, differs from the fat body of the ascending aorta. A dense vascular network is detected in this area, consisting of vessel branches of specifically *vasa vasorum internae* category that starts from the adjacent portion of the concave part of aortic arch. No anastomoses with other sources have been revealed. Hence, both reflexogenic areas of the aorta are irrigated by *vasa vasorum internae*.

It is a well known fact that the structure of the aortic walls is constantly reshuffling. The aging changes of substrate, definitely lead to modifications in the vascular bed [14].

It is to be noted, that the number of capillaries in the tunica media of aorta decreases several times since the first age of maturity compared to the first age of infancy. Along the aging process, the number of blood vessels per area unit decreases, whereas their diameter essentially increases. As a result of these changes, the quality of aortic wall vascularization decreases, a fact which may explain the restructuring of vascular wall and its self-destructive processes due to aging.

In elderly, the arterial blood vessels are convoluted, larger in size and occur in deeper layers of adventitia. The capillaries show a sinuous pathway, as well. Depending on the age, *vasa vasorum* density gradually decreases (six or more times). The vessels become deformed, and are missing in the region of massive mineral deposits, whereas occur in a higher number in the areas of early calcium deposits.

Hence, the blood vessels can be detected only in the external tunica of the aorta in the first three years of postnatal development. Around the age of four, they penetrate the tunica media, then at 10-11 years old they reach its middle layers and finally in adolescence (16-17 years old) into the deep layers.

In the first period of maturity (22-35 years), a decrease in number of capillaries in tunica media of the aorta was detected; the change of this indicator is essential, for example, in comparison with the first period of childhood. Hence along with aging, the number of blood vessels per unit area decreases in the wall of thoracic aorta, while their diameter increases essentially.

The diameter of vascular sources and density of vascular plexus of the aorta are reduced proximodistally. In cross section, there is a dense vascular network seen on the background of multilayered aortic vascular plexus, which is located between the adventitia and aorta media.

Because of this aging reshuffle, the quality of human aortic vascular wall is lowered and the incidence of various pathologies increases. Thus, the formation and differentiation of the structural units of intramural vascular bed of the thoracic aorta continues in postnatal ontogenesis. Simultaneously, certain functional mechanisms are established which adapt to hemodynamic conditions and are constantly changing during lifetime.

It was identified that each portion of the aorta is characterized by specific histotopographical features of circulatory bed elements; by vascular network density and the presence or absence of *vasa vasorum internae*. Generally, there is a clear regularity: the total thickness of the wall of the aorta determines the penetration depth of the blood vessels into it.

The aortic function is not limited only to the distribution of blood to various organs. The aorta is an essential component in the biomechanics of the blood circulatory system. Thus, its resistant-deformative qualities, actually, deserve particular attention. Investigations of physical and mechanical characteristics of blood vessels (tearing strength, resistance limit, maximum relative extension, Young's modulus) have both theoretical and clinically applicative value. For example, the data about the resistance of blood vessels may arise interest to planning of high-speed flight. The sudden changes in biomechanical properties of vessels may occur during pathological processes: atherosclerosis, hypertension and others. Therefore, information about the condition of the vessel wall is necessary, for example, in checking up new drugs, in reconstructive surgery of vessels, including their prosthesis (viz. prosthesis manufacturing).

We started to examine this aspect, while facing a clinical unexplained problem: the incidences of sudden rupture of the ascending thoracic aorta without a history of aneurysms, injuries, infections, dissections or any previous surgery; it is a very rare event, but potentially fatal .

We studied the AA portion, which corresponds to the area of Rindfleisch fat body in atherosclerotic coronary damage. The segment which was selected, presented clinical value and the vascular sources were easily visible and documented. But, since Rindfleisch fat body and aortocardiac fat bodies were not given proper attention, so far, we used the tensometric study AA fat body zone. Since, we focused mainly on *vasa vasorum* of AA, especially in the CAR zone, we admit that they somewhat depend on the tensometry parameter values of the target body area.

In order to determine a certain link between the normal and abnormal states of *vasa vasorum* in this area, and in order to compare the two states, we established the same tensometry values in people who underwent ischemic cardiosclerosis, after which *vasa vasorum* was affected. We determined some differences in the given conditions (intact and affected *vasa vasorum*), then included this information into the study, which confirms the practical value of the present research.

The information obtained by means of determining the resistant-deformation characteristics of the aortic wall in the group of people with affected coronary vessels and in the control group, demonstrates, that both the resistance limit and maximum relative extension of the samples taken from the Rindfleisch fat body in people with heart disorders, caused by atherosclerosis of the coronary arteries, presented lower values, compared to the control group. These individuals had a lower stiffness coefficient – 1.095 gf/mm2 compared to 1,271 gf/mm$^2$. Obviously, one of the causes of aortic aneurysms, besides the hereditary diseases, characterized by connective tissue disorders (Marfan syndrome, Ehlers-Danlos vascular syndrome, Loyes-Dietz syndrome) may be the real state of *vasa vasorum*.

The results of the statistical analysis of biomechanical properties of AA have proved the following: during the process of impairment of aortic *vasa vasorum*, a decrease of biomechanical basic indexes occurs (tearing strengh, resistance limit, maximum extension and stiffness coefficient), both in men and women (p <0.001). Statistically, the changes of resistance-deformation characteristics of the aortic wall occur during the atherosclerotic impairment of vascular sources, mainly of the coronary arteries.

**Table 1**

**The basic resistance –deformation properties of the ascending aortic wall in the CAR zone, independent of gende**

| Indices | Group | N | Index value | Dev/ std. | m | p |
|---|---|---|---|---|---|---|
| **Mean age (years)** | control | 10 | 54.5 | 12.232 | 3.868 | >0,05 |
| | experimental | 10 | 58.8 | 10.963 | 3.467 | |
| **Tearing strengh, kg/mm** | control | 10 | 1.8767 | 0.10059 | 0.03181 | <0,001 |
| | experimental | 10 | 1.5146 | 0.06865 | 0.02171 | |
| **Resistance limit, kg/mm$^2$** | control | 10 | 0.092 | 0.00281 | 0.00089 | <0,001 |
| | experimental | 10 | 0.075 | 0.00182 | 0.00058 | |
| **Maximum relative extesion, %** | control | 10 | 84.02 | 1.265 | 0.4 | <0,001 |
| | experimental | 10 | 59.03 | 1.812 | 0.573 | |
| **Stiffness coefficient (gf/ mm$^2$)** | control | 10 | 1.0955 | 0.03263 | 0.01032 | <0,001 |
| | experimental | 10 | 1.2721 | 0.05329 | 0.01685 | |

Although this fact is not significant, it has several explanations: rich anastomosis of the coronary vessels to other sources of irrigation; presence of VVI with larger lumen and higher blood pressure.

## Conclusions

1. The nervous apparatus of thoracic aorta forms connections with all adjacent organs.
2. The intramural nervous apparatus of the aorta includes trunks and nerve fibers, nerve ganglia and microganglia, clusters of nerve cells, solitary nerve cells, glomus structures and nerve endings: encapsulated (presented by the Krause corpuscles) and unencapsulated.
3. The density and variability of nerve and vascular elements are the most obvious in the fat body composition of AA. Only in its composition there were detected specific neurovascular complexes, formations and structures specific for endocrine glands and glomus structures different in shape, size and location.
4. The proximodistal gradient of innervation and aortic vasculature is obvious.
5. Sources of vascularization of various portions of AA, arch and descending aorta, being ontogenetic derivatives of different structures, do not practically form mutual anastomoses in postnatal period.
6. Late onset of atrial fibrillation after a surgical intervention can not be justified by impairment of nerve and vascular structures embedded in it, whereas the profuse bleeding results from *vasa vasorum internae* injury with high blood pressure and rich network of anastomoses.
7. Impairment of certain atherosclerotic vascular sources leads to the decrease of main tensometric values of the aortic wall.
8. VVI is a mandatory source of vasculararization of reflexogenic zones, whilst histotopographic organization of the vascular bed within the chemoreceptor and baroreceptor zones is different.
9. The comparison of the unprecedented obtained results with the experimental data of Iu. Comroe indicates the presence of reflexogenic zone at the level of AA fat body [27].

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