

## Human coronary sinus — from Galen to modern times

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**Abstract:** Based on the review of the current literature and our own experiences we reviewed the literature paying most attention to human venous coronary system with special respect to coronary sinus — the largest vein of the heart. Many details still remain obscure, although most of modern procedures require deep anatomical knowledge on cardiac veins. Many of developmental remarks are still not clear, regarded to development of the vessels of the heart in association with origin of heart conductive system.

**Key words:** coronary sinus, anatomy, triangle of Koch.

### Introduction

Composition of human heart and its vasculature were subjects of numerous anatomical studies, almost from the very beginning of the history of natural sciences. It was Galen who based mostly on observation of monkeys, remained descriptions of the heart and its vessels, which for long time have been treated as a canonic. However Galen did not know the basics of the physiology of circulation. Many of Galen's mistakes were corrected by Vesalius (1515–1564). His work “De humani corporis fabrica” (1543) was a milestone in modern anatomy, based on dissection of human cadavers. His work was continued by his students and adopters. More important structures of the heart and the circulatory system were described in turn of XVII century. Bartolomeo Eustachii (1510–1574) described the

valve of inferior vena cava; Giulio Aranzio (1530–1589) described fetal vessels; Fabricius ab Aquapendente (1537–1617) described the valves of peripheral veins, although he did not recognize their function; Leonardo Botallo (1530–1600) discovered and described ductus arteriosus. Role of venous valves and systemic circulation were described only in 1628 by Wiliam Harvey (1578–1657). Pmonary circulation was discovered and described by Miguel Seveto (1511–1553) who in the chapter of the treaty “Christianismi restitutio” placed its estimated description. It must be considered however that still in 13<sup>th</sup> century Ibn an-Nafis postulated that if there is no direct connection between the ventricles then must be a “venous artery” which conveys the blood to the lungs and “arterial vein” which carries the blood to the left half of the heart. His theory was not however promulgated.

Studies on the heart were carried out also by Raymond Vieussens (1641–1715) who described a valve located in the vicinity of the termination of great cardiac vein; Richard Lower (1631–1691), Nicolas Stenon (1638–1686) and Anton Valsalva (1656–1723). Work of Christian Thebesius published in 1708, “De circulo sanguinis in corde” brought many innovative observations, among other also characterization of the valve of coronary sinus, known from these times as Thebesian valve. Description of the coronary sinus and other cardiac veins was completed by Marshall, who in 1850 discovered oblique vein of the left atrium, Cruviliher — who described right marginal vein and Zuckerkandl who worked on smallest cardiac veins.

Just in the turn of 20<sup>th</sup> century structures of heart conductive system were discovered. In 1829 physiologist from Wrocław, Johannes Purkinje described a network of special muscular cells located within the myocardium, which were important for transmission of stimuli within the heart. Despite this discovery it was questionable if the impulse in the heart is transported by nerves or by muscular cells.

Only in 1852 Stanius carried out an experiment on reptile’s hearts thank to which he proved that stimuli are conducted by muscular cells. A milestone in investigations on heart conduction system was detection of atrioventricular bundle in 1893. It was Wilhelm His who did it, and currently used name of this bundle (bundle of His) commemorates this event. Anatomists who wanted to localize elements of heart conduction system were not able to distinguish cardiac muscle from conduction structures by simple dissection. Application of histologic methods enabled to distinguish these specific elements. German pathologist Ludwig Aschoff and his Japanese assistant Sunao Tawara described in 1906 location and composition of atrioventricular node. The eponym Keith–Flack’s node originates from names of Scottish (Keith) and English (Flack) anatomists who discovered and described the sinoatrial node in 1907 [1].

Big effort in recognition of coronary sinus was put by Buntaro Adachi who in his work “Das Venesystem der Japaner” (1933) based on observation of unimaginable number of autopsies, thank to application of Teichmann’s mass to injection of blood vessels, described a huge number of venous variations. Although currently his work is over 80 years old, it is difficult to find equally wide and precise description of venous system, among others of coronary sinus and its tributaries, illustrated with unique pictures showing various anomalies of coronary venous system [2].

Injection of blood vessels and other natural body channels developed dynamically during the first half of 17<sup>th</sup> century. It was Wiliam Harvey who injected color liquid into arteries and

searched distribution of substances thus discovering systemic circulation. His methods were next improved by Svammerdam and Ragnier de Graaf. At that time anatomic specimens were composed by application of various filling media such as air, water or liquid pigments. During preparation injected vessels were commonly damaged by the pressure. Thus obtained specimens were not lasting. That is why numerous authors were looking for another materials which could fill the vascular beds, in example a molten bee-wax, glue or resin mixed with dyes. After hardening of injected mass corrosion was performed — using hydrochloric acid, potassium lye or using larvae of insects (i.e. *Musca vomitoria*), which destroyed soft tissues. Occasionally during preparation of injection masses anatomists did lots of precious inventions, i.e. Svammerdam constructed a ball-pen-needle, which for anatomical injection is used until nowadays. Acting in 17<sup>th</sup> century Frederick Ruysch was famous for injection of capillaries and his macroscopic specimens — one of its collections was bought by king Stanislas Leszczyński [Stanisław Leszczyński] who offered it to university in Württemberg. In 18<sup>th</sup> century Lieberkühn injected mass consisted of bee-wax, turpentine and resin mixed with dyes. Thus obtained specimens were however very fragile. To improve their lasting he soaked them in a water mixture of powder plaster and brick meal. After hardening of the external cover he used to dissolve the primary injection mass obtaining tubular form of investigated vessels. He poured into such tubes molten silver and next he removed the ceramic form by immersion in acetic acid. Thus obtained specimens were quite lasting, although the method was laborious, difficult and expensive. This is why, his successors were looking for injection substances which could be used for injections. Such a mass turned out glass putty. The components of injection mass and the way of its application was given by Ludwik Karol Teichmann (1823–1895), head of Anatomy Dept. of Jagiellonian University in Krakow. Thank to technical education he managed to construct a syringe for injections of masses. In 20<sup>th</sup> century plastic masses were applied for injection and preparation of corrosion specimens. Their basal component was vinyl polychloride, polyester resins, methyl metacrylate. In 1860 Hyrtl used celoidine for injections. It was prof. Jan Kuś who injected the vessels with vinyl polychloride — his specimens are adornment of the exposition of the museum in Dept. of Anatomy of Jagiellonian University. There were several innovations made in the second half of 20<sup>th</sup> century in the microcorrosion technique — first was application of resins characterized by low viscosity, which could penetrate capillary bed, so during injection of the arteries they filled also the capillaries and the veins. They have been used to obtain the casts of lymphatic system. Next milestone was application of scanning electronic microscope. Based on it in 1976 Miodoński *et al.* distinguished veins from arteries [2–5].

### General characteristics of the coronary sinus

Coronary sinus, the largest cardiac vein courses along the diaphragmatic surface of the heart, within the coronary sinus, between the left atrium and the left ventricle. It a direct continuation of the great cardiac vein. The beginning of the coronary sinus is supposed to be localized at the orifice of the oblique vein of the left atrium. The length of the coronary sinus varies from 3 to 5 cm, and a caliber is around 1 cm. It is usually 2 or 3 times wider than

great cardiac vein. To the main tributaries of the coronary sinus we include: great cardiac vein, middle cardiac vein, small cardiac vein, posterior vein of the left ventricle and the oblique vein of the left atrium. All tributaries except for oblique vein of the left atrium have usually the valves in their orifices into coronary sinus. Also in the orifice of the coronary sinus one can see the valve. Coronary sinus is the main outflow of venous blood from the heart. Around 60% of venous blood drops into the right atrium through the coronary sinus and its tributaries. The remaining 40% of blood is collected by anterior and smallest cardiac veins [2].

### Histology of the coronary sinus

The wall of the coronary sinus similar to the wall of other veins is composed of three concentric layers: external, middle and internal. Because of the type of its structure the coronary sinus is included into the elastic-fibrous type, in which the media contains also the muscular fibers. The internal coat, usually thin, is composed mostly of endothelium, which forms single layer of flattened cells. The media is usually weakly developed, contains layers of smooth muscles, arranged spirally or circularly. The external coat — the adventitia, consists peripherally of collagen fibers, while internally of elastic fibers which course longitudinally. Large veins which empty into the heart are predominantly coated on a small distance with heart musculature. Posterior wall of the coronary sinus all along its length is coated by the thin delicate layer of muscle descending to it from the left atrium of the heart. This muscle does not play a role of a sphincter since it does not run circularly. Histological structure of the valve which is located in the orifice of the coronary sinus differs from the wall composition. Lauenstein (1867) discovered that it is consisted of thin layer of endocardium which coats connective tissue containing numerous fibers of muscular tissue [6]. This description was supplemented by Szuszkiewicz who confirmed the presence of smooth muscles in the valve of coronary sinus. In the middle layer these fibers paralleled the free margin of a valve, just beneath the endocardium they run also parallel, while in the intermediate zone they are very few and inconstant. They commonly run at right angle to the remaining. Apart from the muscular tissue the valve contains connective tissue and elastic fibers [7]. Some authors postulate that in the certain morphological type of the valve of the coronary sinus one can find the elements of the heart conduction system [2, 8].

### Anatomy of the coronary sinus

The coronary sinus and its tributaries are quite various. Between all branches of the venous coronary tree, the great cardiac and the middle cardiac veins are relatively permanent vessels (90%), contrary to the lateral and posterior branches which can be found in about 50% of human hearts [2, 8, 9–11].

The great cardiac vein arises in the vicinity of the heart apex on the sternocostal surface. Initially it runs through the anterior interventricular sulcus, going in company with the anterior interventricular branch of the left coronary artery (LAD — left anterior descending

artery) — this is why clinically it is named the anterior interventricular vein. Next it runs through the coronary sulcus together with the circumflex branch of the left coronary artery and on the diaphragmatic surface of the heart it empties into the coronary sinus. At its orifice into coronary sinus one can find (in about 75%) a rudimentary valve [12]. The dimension of the orifice of great cardiac vein into the coronary sinus is around  $3.55 \pm 1.34$  mm. Its maximal length is 25.3 cm, minimal — 12.4 cm — medium value is 17.7 cm. Usually it enters the coronary sinus at the angle  $180^\circ$  [13].

Apart from numerous and small tributaries from the left atrium and the left ventricle, the great cardiac vein receives two main tributaries — left marginal vein (known as postero-lateral branch), which is its tributary in about 20%. The great cardiac vein drains the blood mainly from the left half of the heart, partially from the interventricular septum and right ventricle. It must be taken into consideration that left marginal vein may change its course with respect to the lateral wall and empty both into the great cardiac vein as well as directly into the coronary sinus [2, 9, 11, 14, 15].

The middle cardiac vein runs across the posterior interventricular groove from the cardiac apical notch toward the cardiac base, running in company with the posterior interventricular branch of the right coronary artery. Because of its course it is named the posterior interventricular vein. It empties into the coronary sinus from the right and from below. The circumference of its orifice is around  $2.62 \pm 1.26$  mm. It drains the venous blood from both ventricles and interventricular septum [2, 9, 10, 11, 14].

The small cardiac vein runs across the right fragment of the coronary sulcus and accompanies the right coronary artery. It empties into the right aspect of the coronary sinus. It mediates the drainage of the blood from diaphragmatic surface of the right half of the heart. It has one greater tributary — right marginal vein. It sometimes enters the coronary sinus directly [2, 9, 11, 15].

The posterior vein of the left ventricle runs across the posterior aspect of the left ventricle, from below upward and empties into the coronary sinus from the left and the bottom, usually in the middle of it. Sometimes it is a direct tributary of the great cardiac vein. Its orifice measures around 2.25 mm. It is quite variable, both according to the size and angle at which it empties into the coronary sinus [2, 10, 11, 14].

The oblique vein of the left atrium runs obliquely downward and to the right on the posterior aspect of the left atrium, and empties into the coronary sinus from the left and from the above. It is usually a small vessel, difficult to see vessel, although it has a great importance in topography. Its orifice marks the border between the great cardiac vein and the coronary sinus. Besides it may be a source of developmental anomaly — left inferior vena cava [2, 9–11].

The left marginal vein begins on the posterior surface of the heart next to the heart apex and runs along the left aspect of the left ventricle, little bit more posterior to it. It can open into the great cardiac vein as well as into the coronary sinus [9, 15].

The right marginal vein runs along the right border of the heart. Usually it is distinguished as the strongest vessels among the anterior cardiac veins. It may open into the small cardiac vein or coronary sinus. Both marginal veins exist in about 20–25% of human hearts [2, 9, 11] (Fig. 1).

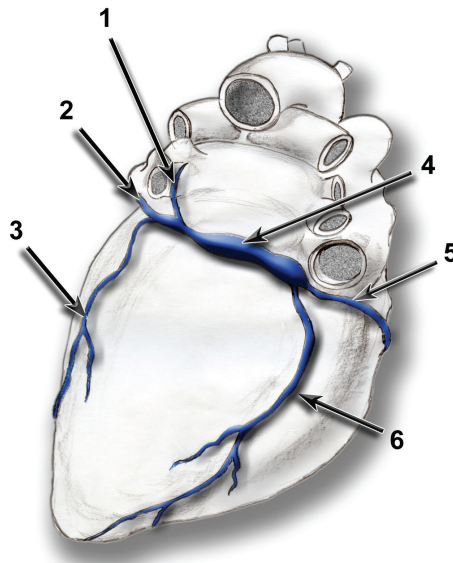


Fig. 1. Coronary sinus and its tributaries. 1 — oblique vein of the left atrium; 2 — great cardiac vein; 3 — posterior vein of the left ventricle; 4 — coronary sinus; 5 — small cardiac vein; 6 — middle cardiac vein.

The orifice of the coronary sinus into the right atrium of the heart is located in the corner between its inferior and medial walls, below the ostium of inferior vena cava and above the septal cusp of the tricuspid valve (Fig. 2).

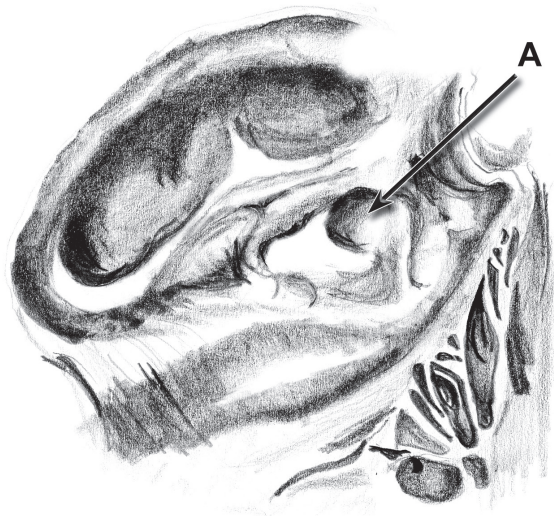


Fig. 2. Location of the ostium of the coronary sinus into the right atrium. A — ostium of the sinus.

The ostium of the coronary sinus demarcates the base of so called Koch's triangle, described for the first time in 1909. This triangular area is located between the ostium of the inferior vena cava, septal cusp of the tricuspid valve and the coronary sinus. Its base shows the ostium of the coronary sinus. From above it is bounded by so called tendon of Todaro (a tendinous structure which extends between the ostium of the coronary sinus and fossa ovalis), and from below by insertion of the septal cusp of the tricuspid valve. The apex of the triangle is directed toward the posterior fragment of the membranous interventricular septum (Fig. 3).

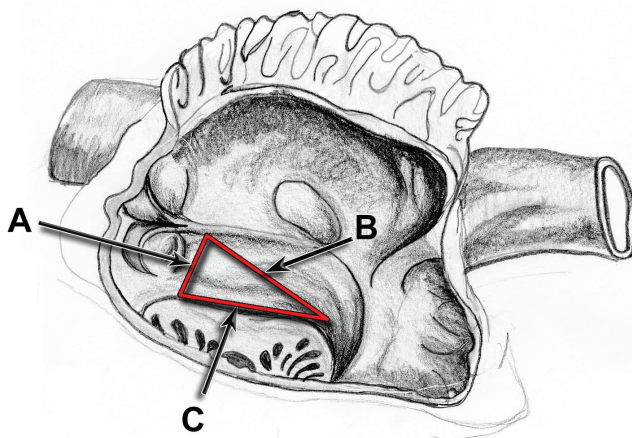


Fig. 3. Triangle of Koch. A — orifice of coronary sinus; B — tendon of Todaro; C — insertion of the septal cusp of the tricuspid valve.

Triangle of Koch is a significant topographic landmark during ablation procedures. It contains usually accessory conduction paths, described as postero-septal. Practically in individuals with relapsing paroxysmal nodal tachycardia the path of slow conduction occurs in the infero-posterior part of the triangle, in the vicinity of the ostium of the coronary sinus [16, 17]. In patients with atrial flutter the source of reentry loop can be located between the orifice of the coronary sinus and the septal cusp of the tricuspid valve. The reentry loop indicates numerous additional atrioventricular conduction paths and is a base of cardiac arrhythmias. Sometimes during atrial flutter, the path of accessory conduction localizes in the recess of coronary sinus. It is a depression located in the posterior wall of right atrium, slightly to the right from the ostium of coronary sinus [1, 18–21].

The ostium of the coronary sinus is usually guarded by Thebesian valve. It is a rudimentary structure and similarly to the valve of inferior vena cava it is a remnant of the valve of venous sinus [2]. The valve is usually located in the right edge of the ostium of coronary sinus. It is quite variable. Sometimes it can take shape of a narrow string-resembling band. It may be also semilunar or semilunar perforated. Sometimes perforated valve was inappropriately named the Chiara's network — which in fact is an anatomical variation which may exist in different location within the right atrium of the heart.

## Embryogenesis of the coronary sinus

The coronary sinus is a remnant of the left horn of sinus venosus (venous sinus). During organogenesis in the 8<sup>th</sup> fetal week, the venous sinus has a form of the cavity which receives the blood from umbilical veins. The venous sinus receives blood from venous part of fetal circulation. Venous sinus receives: vitelline veins, common cardinal veins and umbilical veins. One can distinguish in the venous sinus two horns: right and left, as well as median part (transverse). Right horn joins with the right common cardinal vein, which turns into terminal portions of the superior and inferior venae cavae. Left horn unifies with the left common cardinal vein, which partially turns into the coronary sinus. Ostium of the venous sinus is limited by two valves: left and right, localized within appropriate horns, which join between themselves in the upper portion of the atrium forming the septum spurium (alleged septum). Finally the left valve joins with the atrial septum and regresses, while the right remains. Rapid growth of right atrium causes incorporation of the ostium of the venous sinus into its posterior wall and this is how the superior and inferior venae cavae obtain the common orifice into this atrium. Right valve of the coronary sinus divides into three portions. First of them gives rise to the terminal crest, second turns into the valve of the inferior vena cava, and the third into valve of the coronary sinus. Occasionally (in 2% of population) Chiara's network develops because of incomplete re-sorption of the right valve of the venous sinus. According to Loukas [22] it is caused by dislocation of the fibers due to irregular growth of endocardium, and developmentally it is associated with the right and left valves of the venous sinus. This anatomical variant is accompanied by other developmental anomalies, i.e. persistent foramen ovale, aneurysm of the atrial septum [22]. In a developing heart the venous sinus is not only a venous blood container but it serves as heart pacemaker. Sinoatrial node develops in the fifth week of gestation. Originally it is located in the right horn of the venous sinus, and next together with it is incorporated into the right atrial wall. Besides, its cells can be located at the base of atrial septum, forward to the orifice of coronary sinus. These cells together with the cells of atrioventricular region create atrioventricular node. Fibers which arise from AV node enter the ventricle, forming subsequently right and left crus of the atrioventricular bundle. Part of the heart conduction system are richly innervated, although they develop almost fully before the elements of the nervous system penetrate the developing heart. In a four chambered heart connective tissue which begins to develop isolates the conduction system from the heart muscle. Myocardium of the auricular canal proves also quite slow conduction. It plays a role in slowing down the stimuli for contraction similar to AV node in adult heart. Comparing to the ventricles, development of the atria was not a subject of many interests. The conduction path in a developing atrium goes along its superior wall, transmitting the impulse from SA node to the left atrium. A morphologic base for this is a Bachman's bundle — elevated margin of the pectinate muscle which becomes the terminal crest [23].

Congenital malformations of the coronary sinus are rather rare and are usually of no clinical importance, because they do not disturb heart action. The most frequent malformation is an absence of the coronary sinus. Then venous flow goes through the smallest



cardiac veins, significantly enlarged directly to the right atrium, or less frequently to other heart chambers. Usually this malformation is not a single. It is accompanied by the left superior vena cava which empties into the left atrium. Absence of the coronary sinus was probably described for the first time by Marshall, and next by Gruber and Siding [24]. Among rare anomalies which deal with the coronary sinus the most frequent is the persistent left superior vena cava, which empties into coronary sinus. Other malformations of the coronary sinus consists of: obliteration, underdevelopment or dilatation of the coronary sinus, recess of the coronary sinus, connection between the coronary sinus and the left atrium or a direct communication between the pulmonary veins and the coronary sinus [25–27].

### Remaining cardiac veins

Anterior cardiac veins, usually 2–3 or even 5 run to the right and upward along the sternocostal surface of the right ventricle and empty into the right atrium directly. Part of the can be tributaries of the small cardiac vein [2, 9, 11].

Smallest cardiac veins, numerous and minute, direct tributaries of both ventricles and atria, empty by the orifices of the smallest cardiac veins [2, 11, 24].

Veins of the heart show numerous anastomoses. Not only neighboring veins join each other but one can find anastomoses between the tributaries of the coronary sinus and anterior cardiac veins. The most frequent anastomoses can be seen between the great and middle cardiac veins — they exist mostly in the vicinity of heart apex.

Electrophysiologists which catheterize the heart have problems caused by variability of venous coronary tree, course of the coronary sinus, its tributaries. Most of the problems deal with location of its orifice in the right atrium. Definition of this orifice, analysis of the tributaries, specially located on the posterior surface of the left ventricle, analysis of the structure of the valve of coronary sinus are not important anatomically only but can significantly decrease the number of complications during catheterization procedures [28–32].

### Conflict of interest

None declared.

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