



THE THEBESIAN SYSTEM: BETWEEN EMBRYONIC VASCULAR ORGANISATION AND FUNCTIONAL ADAPTATION IN THE ADULT MYOCARDIUM

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Summary

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The Thebesian system represents a unique component of cardiac microcirculation whose structural and functional significance extends beyond the classical concept of the smallest cardiac veins. Traditionally described as *Vv. cordis minimae*, these vessels have been regarded as part of the minor cardiac venous system, providing direct drainage of myocardial blood into the cardiac chambers. However, accumulated morphological, embryological, and experimental evidence demonstrates that the term “Thebesian vessels” encompasses a heterogeneous group of intramural vascular communications, including true venous channels, sinusoidal structures, and arterial or mixed-type vascular connections. The present review summarises current concepts regarding the organisation, development, and functional significance of the Thebesian system. Particular attention is given to its relationship with the primitive sinusoidal circulation of the embryonic heart, which precedes the formation of the mature coronary vascular system. The persistence of elements of this early organisation in the adult myocardium may explain the morphological diversity of these vessels and their dual association with venous drainage and potential nutritive pathways. Modern imaging approaches and vascular reconstruction techniques further support the concept that these structures are integrated into the overall microcirculatory network of the heart rather than representing isolated anatomical formations. These approaches expand the understanding of the Thebesian system as part of the complex interactions between the coronary vasculature, myocardium, and cardiac chambers. Current evidence suggests that the Thebesian system should be regarded as a morphofunctional link between embryonic and mature patterns of cardiac circulation. Although its exact physiological contribution remains incompletely understood, this system represents an important subject for future morphological, experimental, and clinical investigations aimed at clarifying its potential role in myocardial adaptation and coronary circulation.

Key words: cardiac embryology, coronary-cameral communications, myocardial perfusion, Thebesian system, Thebesian vessels, *Vv. cordis minimae*

INTRODUCTION

The cardiac vasculature represents a highly specialised and complex system that ensures continuous myocardial function under substantial metabolic and mechanical demands. The coronary arterial system is among the most extensively investigated components of cardiac circulation, whereas venous drainage of the heart has traditionally been described primarily through the coronary sinus and its major tributaries. Within this classical framework, the smallest cardiac vessels, known as *Vasa cordis minimae* or Thebesian vessels, have remained a relatively understudied component of cardiac circulation despite their potential morphological and physiological significance (von Lüdinghausen *et al.*, 1995; von Lüdinghausen, 2003).

The history of Thebesian vessels dates back to the beginning of the eighteenth century, with the observations of Raymond Vieussens (1641–1713) and Adam Christian Thebesius (1686–1732), whose different interpretations initiated a long-standing scientific debate regarding the origin and function of these structures (von Lüdinghausen, 2003). Thebesius recognised a relationship between these small cardiac vessels and the coronary circulation, whereas Vieussens described them as non-coronary veins (von Lüdinghausen *et al.*, 1995). Subsequently, Wearn (1928) and Wearn *et al.* (1933) confirmed the existence of direct communications between the myocardium and the cardiac chambers, contributing to the establishment of the concept of *Vv. cordis minimae*.

Classical anatomical studies have described Thebesian vessels as small intramural vascular structures that open through *foramina venarum minimarum* on

the internal surfaces of the cardiac chambers (Tandler, 1926; Wearn *et al.*, 1933; McAlpine, 1975). These structures have traditionally been regarded as components of the cardiac venous system. However, subsequent morphological investigations have demonstrated that the Thebesian system represents a heterogeneous group of vascular communications, including venous channels, intramural conduits, sinusoidal structures, and arterial-sinusoidal connections (von Lüdinghausen *et al.*, 1995; Cendrowska-Pinkosz, 2004).

Recent morphological and embryological studies have challenged the concept of Thebesian vessels as merely passive venous drainage pathways. The presence of direct communications between myocardial vessels and cardiac chambers suggests a more complex organisation, in which these structures may participate not only in venous drainage but also in maintaining additional pathways for myocardial perfusion (Rosinia *et al.*, 1986; Taylor & Taylor, 2000). Of particular interest is the concept that the Thebesian system represents a persistent component of the embryonic sinusoidal circulation that precedes the development of the mature coronary vascular network.

Embryological studies have demonstrated that during the early stages of cardiac development, the myocardium receives blood supply through direct sinusoidal communications between the cardiac chambers and the developing myocardial tissue. With the maturation of the coronary vascular system, these communications become reduced, although some persist as Thebesian vessels (Taylor & Taylor, 1999; 2000). Using vascular corrosion casting techniques, Ratajska *et al.*

(2003) demonstrated that complex interactions between coronary vessels, capillary networks, and intramural vascular communications are already present during early stages of cardiac development.

The potential functional significance of the Thebesian system extends beyond venous drainage and includes its possible contribution as an additional pathway for myocardial perfusion. Gates *et al.* (1993) demonstrated the importance of Thebesian vessels in retrograde blood delivery to the myocardium, while von Lüdinghausen *et al.* (1995) considered these structures as components of a specialised “small cardiac venous system” distinct from the classical coronary venous drainage. Findings by Taylor & Taylor (2000) further support the concept that Thebesian sinusoids may represent a preserved mechanism capable of contributing to compensatory myocardial perfusion under specific conditions.

Significant interspecies differences in the distribution and morphological characteristics of Thebesian vessels have been reported in various animal models. Esperança-Pina *et al.* (1975) described morphologically diverse Thebesian structures in the canine heart, with a predominance in the right cardiac chambers. Similar observations were reported in sheep, where small cardiac veins were found to be most frequently represented in the right ventricular myocardium (Ansari, 2001). Habermehl (1966) described variations in the course and organisation of cardiac veins in the cat, including specific characteristics of vessels penetrating the right atrium, emphasising the considerable variability of the cardiac venous system. The morphofunctional characteristics of the feline coronary vasculature were investigated by Vladova (2005, 2007), who described coronary branching patterns, ventricular vascularisation, and the organisa-

tion of the myocardial vascular bed. Furthermore, the microcirculatory architecture of the feline myocardium has been analysed using vascular corrosion casting combined with scanning electron microscopy, allowing three-dimensional evaluation of vascular organisation (Vladova *et al.*, 2017).

The development of advanced three-dimensional approaches for studying vascular architecture, particularly vascular corrosion casting combined with scanning electron microscopy, has significantly expanded the understanding of cardiac microvasculature. These techniques enable detailed visualisation of vascular branching patterns, terminal structures, anastomotic connections, and spatial relationships between different components of the coronary vascular system (Hossler *et al.*, 1986; Aharinejad *et al.*, 1992; Motta *et al.*, 1992).

Despite extensive investigation of Thebesian vessels, several aspects regarding their morphological classification, embryological origin, and functional role remain unresolved. Evidence from classical anatomy, experimental morphology, and contemporary clinical studies indicates that the Thebesian system represents a complex and functionally diverse component of cardiac circulation that cannot be interpreted solely as a venous drainage mechanism (Habermehl, 1966; Aharinejad *et al.*, 1992; Mettenleiter, 2001; Vladova, 2007).

The aim of the present review is to present the historical development of the concept of Thebesian vessels, to analyse current morphological and embryological perspectives regarding their organisation and discuss their potential functional significance as a component of myocardial circulation.

HISTORICAL DEVELOPMENT OF THE CONCEPT OF THE THEBESIAN SYSTEM

The first descriptions of small intramural vascular communications of the heart marked the beginning of one of the longest-lasting morphological and physiological debates in cardiac anatomy. Since the early eighteenth century, these structures have attracted the attention of anatomists due to their unusual localisation and the direct communication between the myocardium and the cardiac chambers. The observations of Raymond Vieussens and Adam Christian Thebesius led to two different interpretations of the nature of these vessels: either as components of the cardiac venous system or as remnants of a primitive mechanism for myocardial perfusion (von Lüdinghausen *et al.*, 1995; von Lüdinghausen, 2003). This duality in the interpretation of the Thebesian system has persisted into modern concepts, according to which these structures represent a heterogeneous network of venous, sinusoidal, and potentially arterial components (Mazurak *et al.*, 2019; Ghosh *et al.*, 2021; Nordick *et al.*, 2023).

Raymond de Vieussens (1641–1715) was among the first investigators to systematically study the anatomy of the heart and coronary vascular bed. In his morphological observations, he described small vascular structures distinct from the major coronary vessels and interpreted them primarily as non-coronary venous communications. This early concept was significant because it demonstrated that from the very beginning of investigations into cardiac vasculature, anatomists recognised the existence of additional vascular pathways beyond the classical coronary system (Ghosh *et al.*, 2021; Kaçur *et al.*, 2024).

Several decades later, Adam Christian Thebesius (1686–1732) provided one of the first detailed descriptions of the small cardiac vessels that subsequently were named after him. He described small openings on the internal surface of the cardiac chambers and suggested the existence of direct connections between myocardial vessels and the ventricular cavities. In contrast to Vieussens, Thebesius emphasised the possible relationship between these structures and the coronary circulation, an idea that later contributed to the concept of Thebesian vessels as potential conduits between the coronary vascular system and the cardiac chambers (Mazurak *et al.*, 2019).

The difference between these two early interpretations – a venous drainage structure versus a direct communication between the coronary vascular bed and the cardiac chambers – shaped the direction of subsequent anatomical and physiological investigations. Gradually, the term *Vv. cordis minimae* became established to describe the small vessels opening directly into the cardiac chambers (von Lüdinghausen, 2003; Loukas *et al.*, 2008). However, even in classical anatomical studies, discrepancies remained between their morphological appearance and their functional classification, maintaining an ongoing scientific discussion regarding their true nature and role (Taylor & Taylor, 2000; von Lüdinghausen, 2003).

During the nineteenth century, the development of injection techniques and refinement of anatomical methods enabled more precise investigation of the small vascular structures of the heart. During this period, Odilon Marc Lannelongue (1840–1911) described endocardial crypt-like formations, which later became known as “Lannelongue’s crypts” (Mettenleiter *et al.*, 2001). Although these

structures are not considered part of the Thebesian system in the strict anatomical sense, their description expanded the understanding of the complex organisation of relationships between the endocardium, myocardium, and intramural vascular network, stimulating further investigations of small coronary-cameral communications (Mettenleiter *et al.*, 2001).

A major milestone in the development of the concept of Thebesian vessels was achieved through the studies of Wearn (1928) and Wearn *et al.* (1933). Using injection techniques, histological analysis and morphological investigations, these authors demonstrated the widespread distribution of small vascular communications in different regions of the heart. They showed that these structures were not merely incidental anatomical variations but consistent components of cardiac microcirculation. The studies of Wearn (1928) and Wearn *et al.* (1933) established the basis for considering *Vv. cordis minimae* as a functionally significant component of cardiac vascular organisation.

During the second half of the twentieth century, advances in microangiography, vascular corrosion casting, and scanning electron microscopy provided new opportunities for three-dimensional investigation of the Thebesian system. The studies of Habermehl (1966) contributed to the morphological characterisation of small cardiac vessels and emphasised the complexity of their structural organisation.

Subsequent investigations in humans and experimental animals demonstrated that these vessels are not a homogeneous group but rather include vascular communications with diverse structural and functional characteristics. Von Lüdinghausen *et al.* (1995; 2003) developed the concept of dividing the cardiac venous system into

a major and a minor venous system. The major venous system includes vessels that drain the myocardium into the coronary sinus, whereas *Vv. cordis minimae* are considered a specialised component of the minor cardiac venous system. This concept contributed to a better understanding of the drainage function of Thebesian vessels, while simultaneously raising the question of whether all structures traditionally classified as “Thebesian veins” truly possess an exclusively venous nature.

Morphological studies using corrosion casting techniques and scanning electron microscopy have demonstrated the presence of different types of vascular communications between the myocardium and cardiac chambers. Some of these structures display characteristics of venous vessels, whereas others are associated with sinusoidal and arterial-sinusoidal communications (Rosinia *et al.*, 1986; Cendrowska-Pinkosz, 2004). These findings have challenged the traditional use of the term “Thebesian veins” as a universal designation for all small intramural vascular structures.

The embryological studies of Taylor & Taylor (1999, 2000) have been of particular importance for the modern interpretation of the Thebesian system. According to the authors, Thebesian sinusoids are persistent elements of the early stages of cardiac development, when the myocardium receives blood supply through direct connections between blood within the cardiac chambers and the primitive vascular network. Following the formation of the mature coronary vessels, these communications do not disappear completely but may retain a complementary role as potential nutritive or compensatory pathways.

The contemporary concept of Thebesian vessels has gradually moved away from

their narrow classification as small venous structures. Accumulating anatomical, embryological, and experimental evidence indicates that the Thebesian system represents a heterogeneous complex comprising venous drainage components, sinusoidal and arterial-sinusoidal communications, as well as potential direct connections between the coronary circulation and cardiac chambers (von Lüdinghausen *et al.*, 1995; von Lüdinghausen, 2003; Rosinia *et al.*, 1986; Cendrowska-Pinkosz, 2000; Taylor & Taylor, 1999, 2000; Mazurak *et al.*, 2019). This morphological and functional diversity emphasises the need for an integrated approach to the study of the Thebesian system, incorporating comparative anatomical, embryological, and functional investigations.

FROM ANATOMICAL DESCRIPTION TO THE CONTEMPORARY MORPHO-FUNCTIONAL CONCEPT

The interpretation of the Thebesian system has gradually evolved from a purely anatomical description of the smallest cardiac veins toward a broader morpho-functional concept. Traditionally, *Vv. cordis minimae* have been defined as the smallest cardiac veins, consisting of intramyocardial vascular channels that open directly into the atrial and ventricular cavities through small endocardial openings known as *foramina venarum minimarum* (Tandler, 1926; Wearn *et al.*, 1933). Within this classical anatomical framework, Thebesian vessels were considered a component of the minor cardiac venous system, distinct from the major venous drainage pathway through the coronary sinus and the large cardiac veins.

However, accumulating morphological evidence has demonstrated that the organisation of these structures is considerably

more complex and cannot be limited exclusively to small venous vessels. Contemporary studies have revealed the presence of various types of intramural communications, including vessels with distinct venous characteristics, intramyocardial channels, sinusoidal spaces, and structures exhibiting mixed or arterial-sinusoidal features (Rosinia *et al.*, 1986; Aharinejad *et al.*, 1992; von Lüdinghausen *et al.*, 1995; Cendrowska-Pinkosz, 2004). Due to this morphological heterogeneity, the term “Thebesian vessels” is currently used as a broader concept encompassing different types of myocardial-cameral communications, whereas *Vv. cordis minimae* should preferably refer to structures with demonstrated venous origin.

Classical anatomical studies have shown that *foramina venarum minimarum* can be identified in all cardiac chambers; however, their distribution is not uniform. The highest density is generally observed in the right atrium and right ventricle, whereas these structures are less frequently encountered in the left-sided cardiac chambers. This distribution pattern has been described in classical anatomical investigations as well as in modern comparative anatomical studies and is likely related to differences in venous organisation, regional cardiac development, and local haemodynamic conditions (Tandler, 1926; Wearn *et al.*, 1933; Nickel *et al.*, 1996; Gadjev, 1999; König *et al.*, 2004).

An important contribution to understanding the position of these vessels within the overall organisation of cardiac circulation was provided by von Lüdinghausen *et al.* (1995), who distinguished different components of the cardiac venous system and defined *Vv. cordis minimae* as part of the “minor cardiac venous system”. According to these authors, small

cardiac veins differ from larger venous vessels not only in size but also in their terminal pattern of communication, as a part of them does not drain into the coronary sinus system but instead establishes direct connections with the cardiac chambers (Adyshirin-Zade & Gabain, 1984; von Lüdinghausen *et al.*, 1995; von Lüdinghausen, 2003). This unique anatomical feature defines *Vv. cordis minimae* as a specialised component of cardiac venous organisation, distinct from the classical model of venous return through the major coronary veins.

Contemporary imaging methods have expanded the classical anatomical concepts regarding the organisation of the cardiac venous system. Saremi *et al.* (2012), through computed tomography-based classification of coronary veins, demonstrated the considerable anatomical variability of the venous network and emphasised the importance of individual anatomical characteristics in the assessment of cardiac venous architecture. These observations are also relevant for the interpretation of small intramural vascular communications, as they place the Thebesian system within the context of a broader and highly variable organisation of the cardiac venous network (Saremi *et al.*, 2012).

The morphological structure of Thebesian vessels demonstrates considerable variability. The application of injection techniques, microangiography, and vascular corrosion casting has enabled the identification of different structural patterns, including single tubular vessels, short and long intramural channels, branching vascular networks, and sinusoidal communications (Aharinejad *et al.*, 1992; Cendrowska-Pinkosz, 2004). These differences indicate that the Thebesian system does not follow a uniform morphological pattern but represents a structurally adaptable

organisation in which individual components may differ in their origin, architecture, and relationship with other elements of cardiac microcirculation.

Various morphological types of small cardiac vessels have been described in experimental animal models. Esperança-Pina *et al.* (1975) identified several major forms of Thebesian vessels in the canine heart, including tree-like, serpentine, brush-like, tubular, and star-shaped structures. The authors demonstrated that these vessels are distributed throughout different regions of the heart, although their concentration is higher in the right cardiac chambers. These observations support the concept that the organisation of the Thebesian system depends on myocardial architecture and local circulatory conditions.

Similar species-specific characteristics have been identified in other mammals. Ansari (2001) reported a predominance of small cardiac veins in the right ventricle of sheep, confirming differences in the number and distribution of these vascular communications among species. Such variations are likely associated with differences in myocardial thickness, coronary vascular development, and functional requirements of regional circulation.

Studies in the cat as an experimental model are of particular importance for comparative morphological interpretation of the Thebesian system. Vladova (2005, 2007) described specific characteristics of coronary vascular organisation and intramyocardial vascular networks in this species. Further investigations using vascular corrosion casting and scanning electron microscopy demonstrated the complex three-dimensional organisation of the feline myocardium and its microcirculation (Vladova *et al.*, 2017). These findings are particularly relevant because they indicate

that small vascular communications in the cat exhibit specific distribution patterns among different cardiac regions and should not be regarded as a completely uniform system.

Recent comparative anatomical studies further support the concept that coronary vascular organisation in mammals demonstrates considerable species-specific variation. Albuquerque *et al.* (2024) described characteristics of coronary artery distribution and histological cardiac organisation in the three-toed sloth (*Bradypus variegatus*), emphasising the importance of comparative anatomy for understanding diversity in cardiac vascularisation. These findings support the idea that myocardial microvascular organisation, including small intramural vascular communications, does not present a universal pattern but is associated with species-specific features of myocardial architecture, cardiac wall thickness, and coronary vascular organisation (Albuquerque *et al.*, 2024).

Contemporary experimental models have further expanded the possibilities for investigating evolutionarily conserved mechanisms of cardiac development. Angom *et al.* (2025) emphasised the importance of zebrafish (*Danio rerio*) as a model for studying cardiogenesis, vascular development, and genetic regulation of the cardiovascular system. Although the organisation of the fish heart differs from that of mammals, the conservation of fundamental molecular and cellular mechanisms provides valuable comparative insight into the early stages of cardiac vascular development (Angom *et al.*, 2025).

Particular interest has been directed toward the distribution of Thebesian vessels within the ventricular myocardium and interventricular septum. Studies by Rosinia *et al.* (1986) and Aharinejad *et al.* (1992) demonstrated the presence of di-

rect myocardial-cameral communications in different regions of the heart, with their frequency and morphological characteristics varying according to anatomical location. These observations suggest that the Thebesian system does not represent a uniformly distributed network but rather a structurally differentiated component of myocardial microcirculation.

Contemporary discussions regarding the terminology of small coronary-cameral communications further accentuate on the need for structural and functional distinction among these vascular structures. Snodgrass (2025) highlighted that terms such as “microfistulae”, “Wearn vessels”, and “Thebesian vessels” have sometimes been used interchangeably in the literature, despite potentially referring to communications with different morphological and possibly embryological origins. The author proposed the use of more descriptive terminology, such as “coronary artery-cameral vessels”, which reflects the established anatomical relationship between the coronary circulation and cardiac chambers without prematurely defining their physiological or pathological significance (Snodgrass, 2025). This terminological approach supports the modern concept that the Thebesian system should be considered a morphologically and functionally heterogeneous complex rather than a group of small venous vessels.

Modern approaches for three-dimensional visualisation, including microangiography, vascular corrosion casting, and scanning electron microscopy, demonstrate that these vascular communications are integrated into the overall architecture of the coronary microcirculatory network. They are not isolated anatomical structures but rather components of a complex system of interactions between coronary

vessels, myocardium, and cardiac chambers (Hossler *et al.*, 1986; Aharinejad *et al.*, 1992; Motta *et al.*, 1992; Vladova *et al.*, 2005a,b; 2017).

The development of advanced imaging techniques, particularly cardiac computed tomography and high-resolution visualisation methods, has contributed to more frequent identification and more accurate characterisation of small coronary-cameral communications. Xu *et al.* (2021) affirmed that cardiac computed tomography enables simultaneous visualisation and differentiation of coronary-cameral fistulas, Thebesian veins, and abnormal coronary venous structures, highlighting the importance of imaging techniques for understanding the morphological diversity of these vascular communications. These observations support the concept that some structures traditionally considered rare or difficult to demonstrate anatomically may actually be more common than previously assumed, but remain under-recognised due to limitations of classical investigative methods (Xu *et al.*, 2021).

Thus, contemporary morphological and imaging studies have transformed the classical understanding of the Thebesian system by placing it within the context of a dynamic and heterogeneous microcirculatory organisation, where features of embryonic vascular development and the mature pattern of coronary circulation converge.

EMBRYOLOGICAL ORIGIN AND RELATIONSHIP WITH PRIMITIVE SINUSOIDAL CIRCULATION

Understanding the morphological and functional nature of the Thebesian vessels requires their consideration within the context of early cardiac vascular development. The formation of the myocardium

is a complex process of cellular organisation and remodelling, during which the early cardiac muscle structure is established through interactions between different cellular populations and local morphogenetic signals. Eisenberg & Markwald (2004) discussed the importance of cellular interactions and spatial organisation of the developing myocardium in the formation of the mature cardiac muscle. These processes are particularly relevant for understanding the early trabecular architecture of the embryonic heart, in which the myocardium maintains direct relationships with the cardiac chambers before the definitive coronary circulation is established.

During the initial stages of cardiogenesis, the developing myocardium lacks an organised coronary vascular system, and its metabolic requirements are supported through direct interaction between blood within the cardiac chambers and myocardial tissue. This exchange occurs through a primitive sinusoidal network formed between the endocardium and trabecular myocardium, representing an early mechanism for nutritional support of the developing heart (Viragh & Challice, 1981; Ratajska *et al.*, 2003). During early embryonic development, the trabecular organisation of the myocardium allows direct penetration of blood from the ventricular cavity into the deeper cardiac wall layers.

With increasing myocardial thickness and growing oxygen demands, this primitive organisation is gradually supplemented and replaced by the specialised coronary vascular system. The development of coronary arteries and veins is not an abrupt substitution of the primitive circulation, but rather a complex remodelling process in which some early sinusoidal communications regress, whereas others

may persist as intramural vascular connections between the myocardium and cardiac chambers (Taylor & Taylor, 1999; Ratajska *et al.*, 2003).

The concept of the embryological origin of the Thebesian system has been extensively developed by Taylor & Taylor (1999, 2000). According to the researchers, Thebesian sinusoids are persistent elements of an early phase of cardiac circulation that precedes the formation of the mature coronary vascular system. In the embryonic heart, these structures provide a direct pathway between blood within the cardiac chambers and the developing myocardium. Following the establishment of the coronary circulation, some of these communications may persist and retain a complementary function as a potential nutritive or compensatory mechanism.

This concept is supported by studies on coronary vascular development, which demonstrate that the formation of the coronary system results from complex interactions between the epicardium, subepicardial mesenchyme, and myocardium. Coronary vascularisation develops progressively through processes of vasculogenesis, angiogenesis, and subsequent vascular remodelling, leading to the formation of the mature vascular organisation of the heart (Ratajska *et al.*, 2003; Tomanek, 2005). Tomanek (2016) showed that in the human embryo, coronary vessel development proceeds through the sequential formation and differentiation of vascular plexuses associated with the proepicardial region, followed by the development of arterial, venous, and capillary components. These observations emphasise that the mature coronary vascular pattern does not arise as an entirely new structure but is rather the result of gradual transformation of early vascular networks

and cellular interactions within the developing myocardium (Tomanek, 2016).

The persistence of such structures in the adult heart raises the question of whether Thebesian vessels represent merely remnants of embryonic organisation or whether they retain functional significance. From a morphological perspective, their direct communication with the cardiac chambers, intramural localisation, and absence of typical venous valve organisation distinguish them from classical venous vessels. These characteristics support the possibility that some of these communications may function as a dynamic interface between the coronary circulation, myocardium, and cardiac chambers (Bohning *et al.*, 1933; Rosinia *et al.*, 1986).

The embryological origin of Thebesian vessels also provides an explanation for their functional duality. If these structures originate from the primitive sinusoidal circulation, their organisation should not be interpreted strictly within the framework of either arterial or venous anatomy. Some components may contribute to myocardial venous drainage, whereas others may retain characteristics of arteriosinusoidal or arterioluminal communications, potentially providing an alternative pathway for myocardial perfusion (Bohning *et al.*, 1933; Gates *et al.*, 1993; Taylor & Taylor, 2000).

Therefore, the embryological perspective places the Thebesian system as a persistent component of an evolutionarily older pattern of cardiac circulation. This model provides an explanation for both the observed morphological variability and the contemporary concept of these structures as an integral part of myocardial circulation, combining drainage, communication, and potentially nutritive functions.

FUNCTIONAL SIGNIFICANCE OF THE THEBESIAN SYSTEM: FROM VENOUS DRAINAGE TO A POTENTIAL ROLE IN MYOCARDIAL MICROCIRCULATION

The initial functional interpretations of Thebesian vessels were primarily associated with their role as an additional pathway for myocardial venous drainage. Using injection techniques and morphological analysis, Wearn *et al.* (1933) demonstrated the widespread distribution of these vessels within the myocardium and identified their direct opening into the cardiac chambers as a consistent feature of cardiac vascular organisation. Subsequently, McAlpine (1975) incorporated the small cardiac veins into the overall organisation of the coronary venous system, while the studies of Lendrum *et al.* (1945) further contributed to the understanding of their significance as an additional route for venous blood outflow, distinct from the major venous drainage pathway through the coronary sinus.

The studies of von Lüdinghausen *et al.* (1995) contributed to the functional differentiation of *Vv. cordis minimae* as a component of the small cardiac venous system, distinct from the major coronary veins. According to the authors, the small cardiac veins differ not only in size but also in their mode of terminal communication, as some of them do not drain into the coronary sinus system but instead establish direct drainage pathways into the atria and ventricles (von Lüdinghausen *et al.*, 1995; von Lüdinghausen, 2003). This concept extends the classical observations of Wearn *et al.* (1933) and emphasises the specific role of these vessels within the organisation of cardiac venous outflow.

Studies employing microangiography, vascular corrosion casting, and scanning electron microscopy have demonstrated

the presence of various types of vascular structures, including sinusoidal, arteriosinusoidal, and arterioluminal communications (Hossler *et al.*, 1986; Rosinia *et al.*, 1986; Aharinejad *et al.*, 1992; Motta *et al.*, 1992). These observations indicate that some structures traditionally included within the Thebesian system possess characteristics that cannot be explained solely by their role as terminal venous vessels.

Of particular interest are the communications between the coronary vascular network and the cardiac chambers, which may participate in the exchange between circulating blood and myocardial tissue. Bohning *et al.* (1933) and Gates *et al.* (1993) discussed the functional significance of these connections and their potential role as additional pathways under conditions of altered coronary perfusion. Although the quantitative contribution of this mechanism to normal myocardial circulation remains insufficiently understood, experimental data support the possibility that certain components of the Thebesian system possess compensatory potential under specific haemodynamic conditions.

The embryological interpretation of these structures further expands the understanding of their potential functional significance. Taylor & Taylor (1999, 2000) considered a proportion of Thebesian sinusoids as persistent elements of the early organisation of cardiac circulation, when the developing myocardium was supplied through direct sinusoidal connections between blood within the cardiac chambers and the primitive vascular network. The findings of Ratajska *et al.* (2003) regarding coronary system development support the concept that some Thebesian system's components may represent preserved characteristics of earlier stages in the organisation of myocardial blood supply.

From this perspective, the functional role of Thebesian vessels should be interpreted as dual in nature. On one hand, some of these structures represent a well-established component of the small cardiac venous system and participate in the direct drainage of myocardial blood into the cardiac chambers (Wearn *et al.*, 1933; von Lüdinghausen *et al.*, 1995; von Lüdinghausen, 2003). On the other hand, certain intramural communications exhibit characteristics of primitive sinusoidal structures and may potentially contribute to myocardial perfusion maintenance under specific physiological or pathological conditions (Bohning *et al.*, 1933; Gates *et al.*, 1993; Taylor & Taylor, 2000).

Therefore, the contemporary concept considers the Thebesian system not as an isolated group of small veins, but as a functionally heterogeneous component of cardiac microcirculation. Its significance is likely determined by the combination of its established drainage function, preserved embryological characteristics, and potential role as an additional pathway for myocardial perfusion. This view corresponds with the modern concept of coronary microcirculation as a dynamic morphofunctional system in which vascular architecture, endothelial regulation, and adaptive mechanisms collectively determine the efficiency of myocardial blood flow (Del Buono *et al.*, 2021; Neffeová *et al.*, 2022; Crea & Montone, 2023; Rehan *et al.*, 2023; Alam & Pepine, 2024; Ji & Liu, 2024; Elamin *et al.*, 2025).

Within this context, the Thebesian system may be regarded as a specific structural component of the cardiac microcirculatory organisation, whose functional significance depends on the interaction between local vascular architecture, haemodynamic conditions, and the adaptive capacity of the myocardium.

CLINICAL SIGNIFICANCE AND PATHOLOGICAL ASPECTS OF THE THEBESIAN SYSTEM

One of the major areas of ongoing discussion concerns the potential involvement of the Thebesian system in the maintenance of myocardial perfusion. Experimental studies have demonstrated that some intramural communications may establish connections between the coronary vascular network and the cardiac chambers (Bohning *et al.*, 1933; Gates *et al.*, 1993). However, the significance of this mechanism under normal and pathological cardiac conditions remains controversial, as the quantitative contribution of these vascular communications to overall myocardial perfusion is difficult to evaluate.

Of particular clinical interest is the differentiation between physiological Thebesian communications and pathological coronary artery fistulas. Although both conditions involve direct communication between the coronary circulation and the cardiac chambers, they differ in terms of size, morphological organisation, haemodynamic significance, and clinical manifestations. Knowledge of the normal anatomy of *vasa cordis minimae* is essential for the correct interpretation of coronary angiographic and imaging findings and for avoiding misclassification of normal anatomical variants as pathological vascular communications (Farandzha *et al.*, 2024).

The application of modern imaging techniques, three-dimensional reconstruction methods, and morphological approaches based on serial sectioning and volumetric reconstruction enables more accurate differentiation between physiological Thebesian communications and pathological coronary fistulas (Angelini *et al.*, 2005; Manghat *et al.*, 2006; Farandzha *et al.*, 2024). The possibility of direct visualisation of Thebesian veins du-

ring coronary angiography further supports these observations and demonstrates that some of these structures can be identified during invasive diagnostic procedures. Scoglio & Cook (2020) described angiographic visualisation of Thebesian veins in a patient and emphasised the importance of recognising these structures as normal anatomical components that should be distinguished from pathological coronary fistulas. Similarly, Boeder *et al.* (2017) reported angiographically detectable direct drainage of coronary vessels into the cardiac chambers in a patient with recurrent angina pectoris despite the absence of significant coronary artery disease. The authors characterised most Thebesian veins as venoluminal structures and concluded that their clinical significance becomes relevant only in selected cases. More recent clinical evidence suggests that prominent Thebesian veins may also represent a clinically relevant finding in selected patients. Tannous *et al.* (2017) demonstrated that angiographically detectable Thebesian veins may be dynamic and reversible in patients with congenital heart disease, suggesting that their appearance may be influenced by haemodynamic conditions rather than representing a fixed anatomical characteristic. Despite the advances provided by modern imaging methods, the functional significance of these communications under normal and pathological conditions of myocardial microcirculation remains insufficiently understood. The main unresolved issues concern their actual contribution to myocardial blood flow and their possible involvement in adaptive mechanisms under different haemodynamic conditions (Aharinejad *et al.*, 1992; Taylor & Taylor, 1999; 2000; Ashokprabhu *et al.*, 2024).

Clinical observations complement morphological and imaging data by

demonstrating that prominent Thebesian communications may be present in patients with various cardiac conditions. Dixit *et al.* (2021) reported a case of markedly developed Thebesian veins in a patient with Takotsubo cardiomyopathy and discussed the possible relationship between these vascular structures and alterations in myocardial perfusion. Similarly, Snipelisky *et al.* (2016) reported an association between prominent Thebesian veins and structural cardiac changes, highlighting the potential clinical relevance of marked development of these vessels and the need for further investigation of their relationship with cardiac morphology and long-term outcomes. More recently, Mohammed *et al.* (2024) described a patient with typical cardiac chest pain associated with Thebesian veins draining into the left ventricular chamber. Their case report and review of the literature suggest that prominent Thebesian venous communications may, in selected cases, be associated with myocardial ischaemia and angina-like symptoms, although the underlying mechanisms and long-term clinical implications remain to be established. Although isolated clinical observations do not allow definitive conclusions regarding their functional role, they highlight the need for further investigation of the significance of the Thebesian system in conditions associated with changes in coronary microcirculation (Snipelisky *et al.*, 2016; Tannous *et al.*, 2017; Del Buono *et al.*, 2021; Dixit *et al.* 2021; Crea & Montone, 2023; Marano *et al.*, 2023; Mohammed *et al.*, 2024; Smati *et al.*, 2024; Tsuda & Patel, 2024).

From a broader clinical perspective, knowledge of the coronary venous anatomy and its anatomical variants is also important for interventional and surgical procedures involving the coronary sinus. Kesieme & Buchan (2025) emphasised

that variations of the coronary venous system, including abnormalities involving the coronary sinus and the Thebesian valve, may complicate coronary sinus cannulation for retrograde cardioplegia and procedures such as cardiac resynchronisation therapy, electrophysiological interventions, and percutaneous mitral valve annuloplasty. Recent clinical perspectives further emphasize the importance of detailed knowledge of coronary sinus and cardiac venous anatomy for cardiac resynchronisation therapy and other interventions involving the coronary venous system (Didenko *et al.*, 2026). Similarly, recent imaging-based studies of coronary venous anatomy highlight the diagnostic value of recognising anatomical variants and their spatial relationships when planning cardiovascular interventions (Protsak & Zabrodskyi, 2026). Although these considerations concern the broader coronary venous system rather than the Thebesian veins alone, they further demonstrate the clinical importance of detailed knowledge of coronary venous anatomy and its anatomical variability.

Therefore, current literature considers the Thebesian system as a structure with potential significance both for the normal organisation of cardiac microcirculation and for understanding certain pathological coronary communications. The recent clinical literature further suggests that prominent Thebesian veins may be dynamic, may occur in association with structural and congenital cardiac abnormalities, and, in selected cases, may be associated with symptoms suggestive of myocardial ischaemia. Nevertheless, the available evidence remains largely based on angiographic observations, case reports, and observational studies, and therefore does not establish a direct causal relationship between prominent Thebesian

veins and myocardial ischaemia. Further clarification of their role requires integration of morphological, imaging, and functional approaches to enable a more precise assessment of their contribution to myocardial microcirculation and the adaptation of cardiac blood flow under different physiological and pathological conditions.

EVOLUTIONARY-ONTOGENETIC PERSPECTIVE OF THE THEBESIAN SYSTEM

An intriguing aspect of cardiac development is that the early stages of heart formation include a number of morphological features characteristic of more primitive patterns of cardiac circulatory organisation in vertebrates. During this period, the developing myocardium is characterised by prominent trabeculation and the presence of direct connections between blood within the cardiac chambers and myocardial tissue through a primitive sinusoidal network (Virágh & Challice, 1981; Ratajska *et al.*, 2003). Such an organisation resembles early evolutionary patterns of cardiac structure among vertebrates, in which direct exchange between intracardiac blood and myocardial tissue plays a fundamental role in maintaining cardiac function. Contemporary studies on coronary vascular development demonstrate that the mature coronary pattern is established through gradual remodelling of the early myocardial organisation, involving complex interactions between the myocardium, endocardium, and developing vascular structures (Tomanek, 2016; Kapuria *et al.*, 2018; Lupu *et al.*, 2020; Ruiz-Villalba *et al.*, 2024).

With the development of the coronary circulation in higher vertebrates, this primitive pattern is progressively transformed into a more specialised system of

myocardial perfusion, adapted to the increasing thickness of the cardiac wall and the growing metabolic requirements of the myocardium. However, this process does not result in the complete elimination of all early myocardial-chamber communications. Some of these structures may persist as intramural vascular connections between the myocardium, the coronary vascular network, and the cardiac chambers (Ratajska *et al.*, 2003; Tomanek, 2016).

Within this context, the Thebesian system is an interesting example of the preservation of elements of an early cardiac circulatory organisation within an already specialised coronary system. Studies by Taylor & Taylor (1999, 2000) support the concept that a proportion of Thebesian communications may be considered persistent structures associated with the early sinusoidal organisation of the developing myocardium. The combination of characteristics derived from embryonic vascular organisation and the mature microcirculatory pattern may explain the observed morphological heterogeneity of these vascular communications.

From this perspective, an important question arises as to whether Thebesian vessels represent merely residual structures from early stages of cardiac devel-

opment or whether they retain a certain functional significance in the adult organism. The persistence of connections between the myocardium, the coronary vascular system, and the cardiac chambers suggests a potential role of the Thebesian system in regulating local conditions of myocardial blood flow, particularly under changes in haemodynamic load or coronary perfusion (Bohning *et al.*, 1933; Gates *et al.*, 1993; Taylor & Taylor, 2000; Vladova, 2007).

Therefore, the Thebesian system may be regarded as a structure in which different stages of cardiac circulatory organisation converge – from the embryonic sinusoidal network to the mature coronary vascular pattern. This characteristic emphasises the need to consider the Thebesian system not merely as an anatomical remnant of early development, but rather as a potentially adaptive component of cardiac microcirculation (Fig. 1).

The historical development of scientific concepts concerning the Thebesian system reflects a gradual transition from a primarily descriptive anatomical model toward a contemporary morphofunctional concept that integrates embryological, morphological, microcirculatory, and clinical perspectives (Table 1).

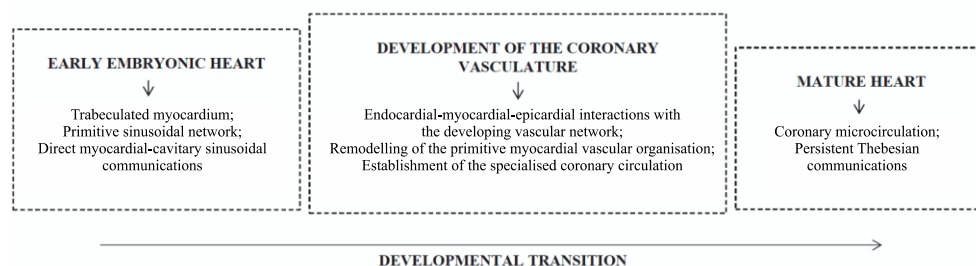


Fig. 1. Developmental transformation of myocardial blood supply organisation. Schematic representation of the transition from the early embryonic sinusoidal organisation of myocardial blood supply to the mature coronary pattern. During development, primitive myocardial-cavitary sinusoidal communications undergo remodelling parallel to the establishment of the coronary vasculature, while a subset of these communications may persist in the adult myocardium as components of the Thebesian system.

Table 1. Evolution of scientific concepts regarding the Thebesian system: from anatomical description to a contemporary morphofunctional concept

Historical stage	Key publications/authors	Research approach	Main contribution to the understanding of the Thebesian system
Classical anatomical period (1920–1940)	Tandler (1926); Wearn (1928); Bohning <i>et al.</i> (1933); Lendrum <i>et al.</i> (1945)	Anatomical dissection, histological studies, physiological observations	Initial description of Thebesian vessels and formulation of the concept of their role in venous drainage and their possible involvement in myocardial perfusion
Morphological and microanatomical period (1960–1995)	Habermehl (1966); Hossler <i>et al.</i> (1986); Rosina <i>et al.</i> (1986); Aharinejad <i>et al.</i> (1992); von Lüdinghausen <i>et al.</i> (1995)	Corrosion casting, scanning electron microscopy, microangiographic techniques	Detailed characterisation of small cardiac vessels, openings of Thebesian communications, and their relationship with myocardial microcirculation
Period of comparative anatomical and embryological interpretations (1990–2005)	Ratajska <i>et al.</i> (2003); Taylor <i>et al.</i> (1999, 2000); Tomanek (2005)	Embryological models, experimental studies, comparative anatomy	Development of the concept of the Thebesian system as a persistent component of the early sinusoidal organisation of the developing myocardium
Period of integration with clinical anatomy and imaging diagnostics (2000–2020)	Angelini <i>et al.</i> (2005); von Lüdinghausen (2003); Loukas <i>et al.</i> (2009); Manghat <i>et al.</i> (2006); Saremi <i>et al.</i> (2012)	Computed tomography, coronary angiography, three-dimensional reconstruction, clinical anatomy	Expansion of knowledge regarding anatomical variability and differentiation between physiological Thebesian communications and pathological coronary fistulas
Contemporary morphofunctional period (2020–2025)	Dixit <i>et al.</i> (2021); Del Buono <i>et al.</i> (2021); Crea & Montone (2023); Farandzha <i>et al.</i> (2024); Smati <i>et al.</i> (2024); Tsuda & Patel (2024); Elamin <i>et al.</i> (2025)	Modern imaging techniques, studies of microcirculation, functional assessment	Recognition of the Thebesian system as a functionally heterogeneous component of cardiac microcirculation with potential significance for myocardial blood flow adaptation

CONCLUSIONS

The Thebesian system represents a complex morphofunctional component of cardiac microcirculation, whose organisation extends beyond the classical definition of the smallest cardiac veins. Accumulated anatomical, embryological, and functional evidence indicates that these structures comprise various types of intramural vascular communications with distinct origins, organisation, and potential functional significance, combining features of venous drainage with persistent elements of the early organisation of cardiac circulation.

Despite the significant advances in understanding its morphology and development, the functional role of the Thebesian system in the adult myocardium remains insufficiently elucidated. Future studies integrating comparative anatomy, embryology, advanced imaging techniques, and functional approaches are required to further clarify the significance of these vascular communications in the normal and pathological organisation of cardiac microcirculation.

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