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Anatomy of the septal perforating arteries of the heart

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Abstract: The septal perforating arteries of the heart usually branch off from the anterior and inferior interventricular arteries and supply the interventricular septum and the conduction system therein. Since the septal perforating arteries are not directly visible from the outside of the heart, their anatomy and variations might be overlooked. However, the septal perforating arteries have their unique anatomy that needs to be recognized to avoid the damage of the vessels especially during common cardiac procedures such as the coronary artery bypass graft, percutaneous coronary intervention, and aortic valve replacement. A better understanding of these important arteries will help physicians to enhance the overall cardiac care for their patients. Therefore, this article discusses the anatomy, the relationship to the conduction system of the heart and the clinical significance of the septal perforating arteries.

Key words: Main septal perforating artery, Anterior interventricular artery, Inferior interventricular artery, Septal perforating artery, Interventricular septum

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Introduction

The normal anatomical arrangement of the coronary arteries of the heart is well described [1]. The value of the anatomical knowledge of the coronary arteries has been demonstrated through treating patients with heart diseases such as atherosclerosis, ischemic heart diseases and congenital cardiac malformations [1]. Coronary artery disease is significant not only for the aged population but also for the young population [2], and common cardiac procedures such as the coronary artery bypass graft (CABG) and percutaneous coronary intervention (PCI), and aortic valve replacement heavily depend on the good understanding of the anatomy and physiology of the cardiovascular system. Much attention is paid on the major coronary arteries such as the right coronary artery, the left coronary artery, the circumflex artery, and the anterior interventricular artery. To the author's knowledge, the septal perforating arteries are not as extensively studied as the other coronary arteries although the septal perforating arteries have their unique anatomy and the critical function. Understanding the anatomy of the septal perforating arteries is very important since the septal perforating arteries supply the interventricular septum and the conduction system therein.

This review aims to discuss the anatomy, the relationship to the conduction system, and the clinical significance of the septal perforating arteries.

Nomenclature

The basic rule of describing human anatomy is to describe it relative to the bodily coordinates [1]. However, the most popular nomenclature of the heart is based on the Valentine orientation, which describes the heart as if it sits on its apex [1]. In reality, the heart sits diagonally in the mediastinum so that the apex points to the left. Therefore, it is more appro-

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priate to describe the cardiac anatomy with the attitudinally appropriate nomenclature [3]. The "left anterior descending artery" should, therefore, be called the anterior interventricular artery. This is also the currently accepted term according to Terminologia Anatomica. In the same matter, the more appropriate term for the posterior interventricular artery or the posterior descending artery is the inferior interventricular artery. In this article, the author uses the attitudinally appropriate nomenclature.

The term "septal perforating artery" is specifically used instead of "septal branch" or "septal artery" since "septal perforating artery" specifies that it is a deep artery that enters the interventricular septum. The atrioventricular (AV) nodal artery is usually considered as the first septal perforating artery of the inferior interventricular artery, and its detailed study is reserved for a separate article.

Anatomy

The septal perforating arteries are vessels that typically branch off the anterior and inferior interventricular arteries. They arise approximately at right angles, penetrate and supply the interventricular septum. While both the anterior and inferior interventricular arteries supply the interventricular septum, the contributions of arterial supply made by each interventricular artery are not the same. James [4] stated that the interventricular septum is supplied predominantly by the anterior interventricular artery. Also, it should be pointed out that the anterior and inferior interventricular arteries are not the only arteries that give off the septal perforating arteries. The diagonal arteries, the circumflex artery or even the trunk of the left coronary artery can give off the septal perforating arteries [5]. There is also a case report that the first and second septal perforating arteries branch off the long trunk of the left coronary artery [6]. The lengths of the anterior septal perforating arteries range from 40 to 80 mm, and the length of the inferior septal perforating arteries is about or shorter than 15 mm [7]. Also, in the cadaveric study of 100 hearts, Muresian [5] observed that the average number of the anterior septal perforating arteries is 9 (between 6 and 14). The inferior interventricular artery gives off 5 to 20 inferior septal perforating arteries. The variations in number and size did not seem to have relation to the left ventricle dimensions, the coronary artery dominance or the septal thickness.

The largest inferior septal perforating artery (usually the first inferior septal perforating artery) of the inferior interventricular artery branches off from the right coronary artery, and it supplies the AV node in about 80% of cases. The largest inferior septal perforating artery of the inferior interventricular artery branching off from the circumflex artery supplies the AV node in about 20% of cases [8]. This prominent inferior septal perforating artery is appropriately called the AV nodal artery.

Levin [9] described anastomoses between the septal perforating arteries of the anterior and inferior interventricular arteries when there was a significant occlusion either in the right coronary artery or the left coronary artery [10]. Levin [9] also demonstrated that there were anastomoses between the proximal and distal anterior septal perforating arteries of the anterior interventricular artery [10]. These anastomoses help the entire septum to be supplied even if there is an occlusion in the epicardial coronary circulation. James [4] also stated that the septal perforating arteries of the inferior interventricular artery provide a collateral circulation if the anterior interventricular artery is occluded. Therefore, for the AV node and the bundle of His to have irreversible ischemia, both the right coronary artery and the anterior interventricular artery need to be occluded [11]. Although the sufficiency of the anastomosed arterial supply might be questionable [9], it is true that there are many anastomoses in the interventricular septum that help to provide arterial supply in case of ischemia.

Usually, the first or second anterior septal perforating artery is long and strong, runs along the right side of the interventricular septum, courses through the moderator band, reaches the anterior papillary muscle in the right ventricle and begins its terminal arborization from there [12]. Although the majority terminate in the right ventricle, it might terminate before reaching the right ventricle [13]. The occlusion of this artery can cause right bundle branch block, the anterior septal infarction or even the complete heart block [14, 15]. This prominent septal perforating artery is designated as "the main septal branch" by McAlpine [16] and Muresian [5] and "the left descending septal artery" by Lüdinghausen [12]. Reig et al. [17] named it "the moderator band artery." In this article, it is called as the main septal perforating artery to highlight it is the main one among many septal perforating arteries.

It is suggested that the anterior papillary muscle in the right ventricle should be used as a landmark to locate the main septal perforating artery [18]. It is also important to remember that the main septal perforating artery courses through the moderator band before it reaches the anterior papillary muscle in the right ventricle. The moderator band is

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a fibromuscular structure crossing the ventricular cavity usually in the right ventricle without being attached to the cusps [19], and it contains the right bundle branch [20].

Table 1 summarizes the findings on the septal perforating arteries of the cadaveric hearts studied by Von Lüdinghausen et al. [21] and Muresian [5].

Relationship to the Conduction System of the Heart

The atrioventricular node (AV node) is located at the triangle of Koch in the right atrium, and the bundle of His (approximately 1 to 3 mm long) passes leftward and runs along the membranous septum and the interventricular septum [22]. The triangle of Koch is a triangular area of the right atrial wall demarcated by the continuation of the Eustachian valve of the inferior vena cava into the atrial myocardium, the tendon of Todaro and the hinge of the septal leaflet of the tricuspid valve [23]. However, the tendon of Todaro is not necessarily always present [24]. After the bundle of His enters the interventricular septum, it bifurcates into the left and right bundle branches. The left bundle branch descends through the interventricular septum and divides into three fascicles of the Purkinje fibers in the left ventricle near at the apex (i.e., left anterior fascicle, left posterior fascicle and left septal fascicle). The right bundle branch descends through the interventricular septum, and a prominent portion of it runs through the moderator band (i.e., the septomarginal trabecula) and innervates the anterior papillary muscle of the right ventricle [22].

In a histologic study, Frink and James [25] observed that the bundle of His was supplied by both the AV nodal and the anterior septal perforating arteries in nine of 10 hearts. In contrast, the dual supply of the AV node was only observed in 2% of subjects studied using Multidetector computed tomography [26]. Essentially, the septal perforating arteries are responsible for supplying the bundle of His and the right and left bundle branches in the interventricular septum.

Clinical Significance

Due to its critical function and location of the septal perforating arteries, great care should be sought during any procedure or surgery that deals with the coronary vessels. The common cardiac procedures such as the coronary artery bypass graft, PCI, and aortic valve replacement are good examples in which the septal perforating arteries need to be well protected. In fact, any cardiac procedure or surgery can put the septal perforating arteries in danger. Serious complications such as incidences of iatrogenic coronary artery dissection were resulted from catheters during percutaneous coronary intervention, cardioplegia administration, or performing surgeries [27]. The conduction disturbances due to the injury on the main septal perforating branch during the CABG were reported as well [28]. Also, it must be kept in mind that there are variations of the coronary vasculature, and such variations should be recognized to avoid misinterpretation of the vasculature and further complications following clinical procedures [29].

The Ross procedure involves the replacement of the aortic valve with an autograft taken from the patient's pulmonary valve [30], and the surgeons need to be careful not to ligate the septal perforating arteries accidentally during the Ross procedure [15].

For the patients with hypertrophic obstructive cardiomyopathy, the nonsurgical septal reduction therapy can be done to induce the infarct of a portion of the interventricular septum through injecting ethanol into the selected septal perforating arteries [31]. Thus, the selected septal perforating arteries are intentionally destroyed instead of being protected during the nonsurgical septal reduction therapy. However,

Table 1. The summary of the findings on the septal perforating arteries of the cadaveric hearts studied by Von Lüdinghausen et al. [21] and Muresian [5]

	Von Lüdinghausen et al. [21]	Muresian [5]
No. of the cadaveric hearts studied	100	100
No. of the hearts in which the first anterior septal perforating artery branches off from the anterior interventricular artery rather than from the first diagonal artery or the circumflex artery (%)	54 (54)	88 (88)
Septal perforating artery designated as the main septal perforating artery	The second or third anterior septal artery in 72%	The second anterior septal perforating artery in 57%; the first anterior septal perforating artery in 21%
Diameter of the main septal perforating artery (mm)	1.5 to 2.0	About 2.5
Origin vessel of the inferior septal perforating arteries	The right coronary artery in 90%; the left coronary artery in 10%	The right coronary artery in 72%; the left coronary artery in 14%; both the right and left coronary arteries in 8%

the care should be taken when targeting a septal perforating artery. For instance, the large main septal perforating artery might supply more than the proximal interventricular segment [32], and the alcohol septal ablation might diminish the blood supply to the interventricular septum more than intended [6]. Visualization of the septal perforating arteries for the nonsurgical septal reduction therapy can be improved with the contrast echocardiogram [33]. Also, the lesions on the main septal perforating artery and the right coronary artery might indicate the necessity of the placement of the permanent pacemaker [34].

PCI is a procedure in which a stent is placed in a narrowed coronary artery to restore the coronary arterial supply to the heart. PCI has a considerable evidence base and is firmly established as the most common procedure used in the invasive treatment of patients with chronic heart disease, and when patients present with lesion in the left coronary artery, reduced antegrade coronary flow and clinical instability, PCI should be considered first [35]. Although the main septal perforating artery branches off from the anterior interventricular artery at an acute angle of 45° to 90° [21, 36], accessing into the occluded main septal perforating artery is technically feasible with a steerable guidewire [37, 38]. There are many cases of the successful PCI of the main septal perforating artery in the literature [36-41]. The percutaneous coronary intervention of the main septal perforating artery gives a great value since it can be an excellent alternative to the CABG [37]. In addition, PCI is a safe and effective treatment for pediatric patients with premature atherosclerotic coronary artery disease caused by familial hypercholesterolemia, etc. [42].

CABG is a revascularization procedure for which the left and right internal mammary arteries, radial arteries and the saphenous veins are commonly used [43]. Most patients with coronary artery disease have disease in multiple coronary arteries and require revascularization of more than two of them [44]. In fact, CABG is one of the most commonly performed surgeries in the world [43]. As the procedure names suggest, it restores the coronary arterial supply by inserting a graft distal to the blockage so that the blockage is bypassed, thereby restoring the blood supply in the septal perforating arteries.

Conclusion

There are numerous septal perforating arteries branching off from the anterior and inferior interventricular arteries that supply the interventricular septum and the conduction system therein. Also, the first or second anterior septal perforating artery is usually the main septal perforating artery, which is the largest and longest septal perforating artery that courses through the moderator band and supplies the anterior papillary muscle of the right ventricle. The septal perforating arteries should be protected with great care during cardiac surgeries, and the percutaneous coronary intervention of the main septal perforating artery is technically feasible. Understanding the clinical anatomy of the septal perforating arteries of the heart will help physicians to enhance the cardiac care for their patients.

In the future, the detailed study on how the atherosclerotic disease of the septal perforating arteries affects the conduction system of the heart would give us a better insight into the progression of coronary heart disease.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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