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Anomalies and anatomical variations in the coronary arteries and their possible implications

Anomalias e variações anatômicas incidentes nas artérias coronárias e suas possíveis implicações

Anomalías y variaciones anatómicas incidentes en las arterias coronarias y sus posibles implicaciones

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Abstract
With the increase in coronary procedures, understanding the anatomical patterns of the coronary arteries is becoming increasingly crucial, since they can result in implications for the patient. The aim of this study was to carry out a detailed analysis of the coronary arteries of hearts from the Human Anatomy and Pathology Laboratory at the University of Uberaba (UNIUBE). This topic was selected due to its relevance in understanding pathological changes resulting from alterations in blood flow. A cross-sectional analytical observational study was carried out over a period of 20 months: August 2022 to April 2024. The material for the study consisted of 40 preserved cadaveric hearts and data collection was based on a script with previously prepared questions, according to the cardiac anatomy described in the literature. In the study carried out, of the total number of hearts analyzed, four had an irregular coronary pathway, representing a total of 10%. Based on the universally accepted coronary branching pattern, 13 alterations were found, representing a total of 33%. Among them, the main and rarest was the double origin of the anterior descending artery, with one branch originating from the right coronary artery and one from the left coronary artery. Regarding the pattern of coronary dominance, right dominance was predominant in 87% of cases. In general, the research will contribute to a better understanding of the importance of cardiac anatomy for the understanding of clinical events, for the correct performance and interpretation of examinations and for the surgical approach to patients.
Keywords: Coronary arteries; Coronary vessel anomalies; Anatomy.

Resumo
Com o aumento de procedimentos coronarianos, a compreensão dos padrões anatômicos das artérias coronárias está se tornando cada vez mais crucial, visto que podem resultar em implicações ao paciente. Este estudo tem como objetivo a análise detalhada das artérias coronárias de corações do Laboratório de Anatomia Humana e Patologia da Universidade de Uberaba (UNIUBE), sendo este tema selecionado devido à sua relevância na compreensão de mudanças patológicas decorrentes de alterações no fluxo sanguíneo. Foi realizado um estudo do tipo observacional analítico transversal, com vigência de 20 meses: agosto de 2022 a abril de 2024. O material para o estudo foi composto por 40 corações cadavéricos conservados e a coleta de dados foi baseada em um roteiro com questões previamente elaboradas, de acordo com a anatomia cardíaca descrita na literatura. No estudo feito, do total de corações analisados, quatro continham trajeto coronariano irregular, representando um total de 10%. Baseado no padrão de ramificação coronariana universalmente aceito, foram encontradas 13 alterações, representando um total de 33%. Dentre elas, a principal e mais rara foi a dupla origem da artéria descendente anterior, apresentando um ramo originado da coronária direita e um ramo da coronária esquerda. Em relação ao padrão de dominância coronariana, a dominância direita foi predominante em 87% dos casos. A pesquisa, de maneira geral, contribuirá para o melhor entendimento da importância da anatomia cardíaca para a profissão médica, para a compreensão de eventos clínicos, para a realização e interpretação correta de exames e para a abordagem cirúrgica de pacientes.
Palavras-chave: Artérias coronárias; Anomalias dos vasos coronários; Anatomia.

Resumen

Con el aumento de los procedimientos coronarios, la comprensión de los patrones anatómicos de las arterias coronarias es cada vez más crucial, ya que pueden resultar en implicaciones para el paciente. El objetivo de este estudio fue analizar detalladamente las arterias coronarias de corazones del Laboratorio de Anatomía Patológica Humana de la Universidad de Uberaba (UNIUBE), tema seleccionado por su relevancia en la comprensión de los cambios patológicos resultantes de alteraciones en el flujo sanguíneo. Se realizó un estudio observacional analítico transversal durante un período de 20 meses: de agosto de 2022 a abril de 2024. El material para el estudio consistió en 40 corazones cadavéricos preservados y la recogida de datos se basó en un guión con preguntas previamente preparadas, según la anatomía cardiaca descrita en la literatura. En el estudio realizado, del total de corazones analizados, cuatro presentaban un trayecto coronario irregular, lo que representa un total del 10%. Basándose en el patrón de ramificación coronaria universalmente aceptado, se encontraron 13 alteraciones, lo que representa un total del 33%. Entre ellas, la principal y más rara fue el doble origen de la arteria descendente anterior, con una rama originada en la arteria coronaria derecha y otra en la arteria coronaria izquierda. En cuanto al patrón de dominancia coronaria, la dominancia derecha fue predominante en el 87% de los casos. En general, la investigación contribuirá a una mejor comprensión de la importancia de la anatomía cardiaca para la profesión médica, para la comprensión de los acontecimientos clínicos, para la correcta realización e interpretación de los exámenes y para el abordaje quirúrgico de los pacientes.

Palabras clave: Arterias coronarias; Anomalías de los vasos coronarios; Anatomía.

1. Introduction

The coronary arteries play an essential role in the blood perfusion of the heart, ensuring its proper functioning and indirectly participating in the cellular nutrition of the entire body (Batista et al., 2011). They give rise to several branches that are also essential for optimal cardiac perfusion. Thus, there are numerous anatomical variations in these arteries that may have implications for the patient and deserve scientific attention.

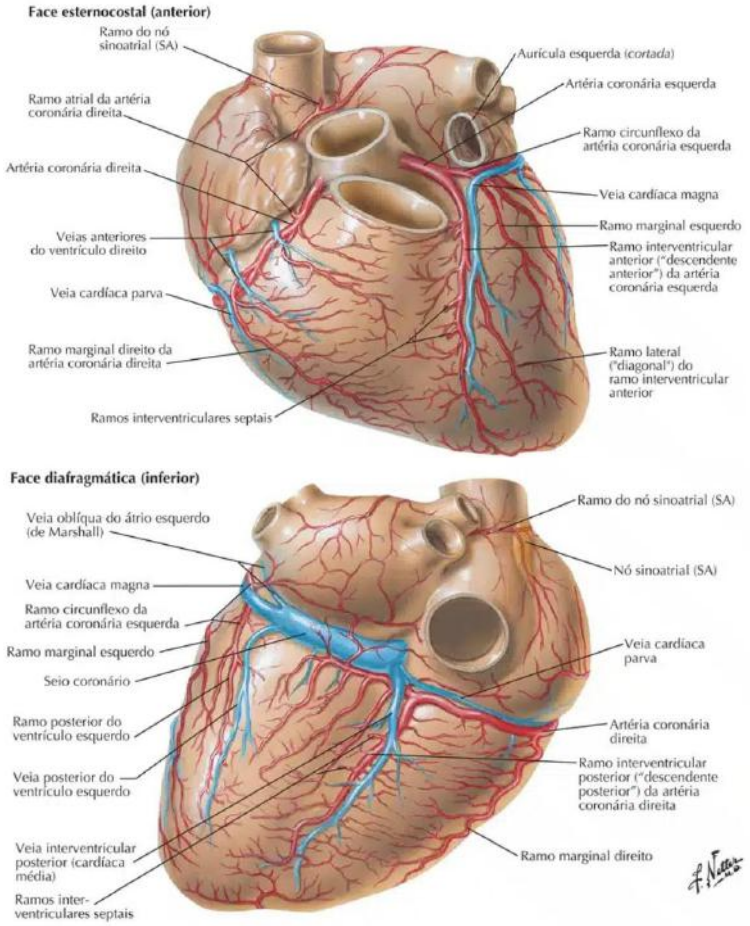
The anatomy of the coronary arteries has been studied to understand their anatomy and physiology because of its clinical relevance. Although many individuals have normal coronary anatomy, variations and anomalies that may lead to complications during a procedure are not uncommon (Di Guglielmo et al., 1975). These variations may be related to the origin, course, and termination of these arteries or to changes in their intrinsic anatomy. Some coronary artery anomalies cause occasional ischemia, while others predispose to complications such as spasm or the development of atheromatous plaques (Farias et al., 2013).

Schlesinger (1940) created the concept of coronary dominance, determining that it is right or left depending on which of the coronary arteries supplies the posterior descending artery. Variations in the branching pattern and distribution of the coronary arteries are common (Schlessinger et al., 1940).

According to the widely accepted standard coronary anatomy, the trunks of the coronary arteries originate in the right and left anterior aortic sinuses, respectively, and pass through the coronary sulcus, as described in Figure 1. In approximately 67% of cases, the right coronary artery through the corresponding sulcus and branches off to supply the right atrium and ventricle until it reaches the origin of the posterior interventricular artery, characterizing the right dominance pattern.

In contrast, the left coronary artery takes the form of a small trunk that passes through the space defined by the pulmonary trunk and the left atrium to reach the coronary sulcus, where it divides into the anterior descending and circumflex arteries. In 15% of cases, the circumflex branch originates from the posterior interventricular artery, which is responsible for perfusing the left ventricle, ventricular septum, and part of the right ventricular wall, characterizing the left dominance pattern. In approximately 15% of cases, both coronary arteries share responsibility for perfusing the posterior interventricular sulcus, the so-called codominance pattern (Williams et al., 1995).

Figure 1 - Coronary branching.



Source: Netter: Frank H. Netter, Atlas of Human Anatomy. (7 ed.). Elsevier (2018).

By dividing the coronary artery tree into segments, it is possible to analyze these vessels and their branches individually and separately, which provides greater accuracy in identifying abnormalities (congenital or acquired), understanding the resulting clinical implications and planning therapeutic approaches when necessary.

With the growing increase in coronary angiographies and invasive coronary procedures, understanding the variations, anomalies and anatomical patterns of the coronary arteries is becoming increasingly crucial, as they can result in complications during procedures.

Therefore, this study aims to analyze the coronary arteries and their anatomical variations in hearts from the Human Anatomy Laboratory at the University of Uberaba (UNIUBE). This topic was selected due to its relevance in understanding pathological changes resulting from alterations in blood flow, as well as in carrying out examinations and surgical procedures related to the cardiac irrigation system.

2. Methodology

A cross-sectional analytical observational study was carried out, with a quantitative approach and of a basic nature, in the Human Anatomy Laboratory and the Pathology Laboratory, for a period of 20 months: August 2022 to April 2024. Data was only collected after the project had been approved by the Ethics Committee, whose Certificate of Presentation of Ethical

Appreciation (CAAE) has the number 40075020.3.0000.5145. The methodological support was provided by supervisor and co-author Ana Cristina Romano, lecturer of anatomy at the University of Uberaba, where the study was carried out.

The material for the study consisted of 40 cadaveric hearts kept in the Anatomy and Pathology laboratories at the University of Uberaba, which were dissected according to the research objectives. To select the sample, the preservation conditions of the cadaveric specimens were taken into account, as they were fixed and preserved in 10% formaldehyde solutions in their own plastic containers. All the anatomical specimens studied were analyzed for morphology and descriptive records were made using photographs, texts and tables.

Preserved cadaveric hearts were selected, mainly in relation to their vascularization and giving priority to those that were still covered by the pericardium. In addition, the exclusion criteria were hearts in poor condition, in which the vascularization was damaged, making it impossible to observe and conclude on the arteries under study.

Data collection was based on a script with previously prepared questions, based on the cardiac anatomy described in the literature. The questions were related to the coronary pathway and its respective branches, vascular dominance, arterial length and apparent cardiac hypertrophy. The data was collected on days and at times previously scheduled by the heads of the Anatomy and Pathology Laboratories at the University of Uberaba. The values obtained were organized in a Microsoft Office Excel spreadsheet by calculating means, standard deviations and simple percentiles. Photos were taken using the camera of an Apple cell phone.

Finally, a literature search was carried out for descriptions of the anatomical variations of the coronary arteries, comparing them with those found in the Anatomy and Pathology laboratory at the University of Uberaba, in order to analyze similarities and differences, as well as the most commonly observed pattern.

3. Results

The results obtained during the dissection of the hearts are shown in the tables below.

Table 1 – Coronary path.

Coronary path	Number	%
Regular pattern	36	90%
Irregular pattern	4	10%
Total	40	100%

Source: Authors.

Table 2 – Coronary origin.

Coronary origin	Number	%
Regular pattern	40	100%
Irregular pattern	0	0%
Total	40	100%

Source: Authors.

Table 3 – Coronary branching.

Coronary branching	Number	%
Regular pattern	27	67%
Irregular pattern	13	33%
Total	40	100%

Source: Authors.

Table 4 – Coronary dominance.

Coronary dominance	Number	%
Right dominance	35	87%
Left dominance	3	7%
Balanced dominance	2	5%
Total	40	100%

Source: Authors.

In the study, of the total number of hearts analyzed, four had irregular coronary arteries, representing a total of 10%. Of the alterations found, three had an involved anterior descending artery. In addition, there was one case characterized by the formation of an acute, contorted angle at the origin of the anomalous coronary aorta, which represents a potential mechanism to explain the presence of myocardial ischemia and sudden death (Angelini *et al.*, 2002; Braunwald *et al*., 2001).

In the evaluation carried out, there were no cases of irregular coronary origin, based on the classification proposed by Angelini et al. which mentions some anomalies such as single coronary artery, right coronary artery originating from the left coronary sinus, coronary ostium outside the aortic coronary sinus.

Based on the universally accepted coronary branching pattern, 13 alterations were found, representing a total of 33%. Among them, the main and rarest was the double origin of the anterior descending artery, with one branch originating from the right coronary artery and one from the left coronary artery. There were also five cases of trifurcation of the left coronary artery, with the intermediate branch, and one case of quadrifurcation, with two diagonal branches. Of the hearts analyzed, six showed duplication of the anterior descending artery, with two separate components in the anterior interventricular groove.

Regarding the pattern of coronary dominance, right dominance was predominant in 87% of cases, with 7% corresponding to left dominance and 5% to balanced dominance, characterizing the codominance pattern, in which both coronary arteries are responsible for irrigating the posterior interventricular sulcus.

Finally, according to this study, there was no apparent correlation between cardiac hypertrophy and the unusual origins of the coronary arteries, since of the six hypertrophied hearts included in the study, only one had irregular branching, leading to the conclusion that the hypertrophy was due to causes other than vascular.

Intermediate Branch

The left main coronary artery usually divides into two branches: the left anterior interventricular artery and the left circumflex artery. In situations of trifurcation, an additional branch emerges between the angle formed by the left anterior interventricular artery and the circumflex artery (Hosalinaver *et al.*, 2018).

In this variant, as described in Figure 2, the left coronary artery can trifurcate into the anterior descending artery (ADA), the circumflex artery (ACX) and an intermediate branch. This usually supplies the lateral and inferior walls, acting as a diagonal marginal branch, while the arteries that normally supply this territory are small or absent (Chiribiri *et al.*, 2011).

There are rare cases in which the left main coronary artery is quadrifurcated, as shown in the Figure 3, with the presence of bifurcating branches and two diagonal branches (Ortale *et al.*, 2005).

Figure 2 - Trifurcation of the left coronary artery (LCA) .

ADA:anterior descending artery; **RD**: diagonal branch; **ACX**: circumflex artery.
Source: Authors.

Figure 3 - Quadrifurcation of the left coronary artery (LCA).

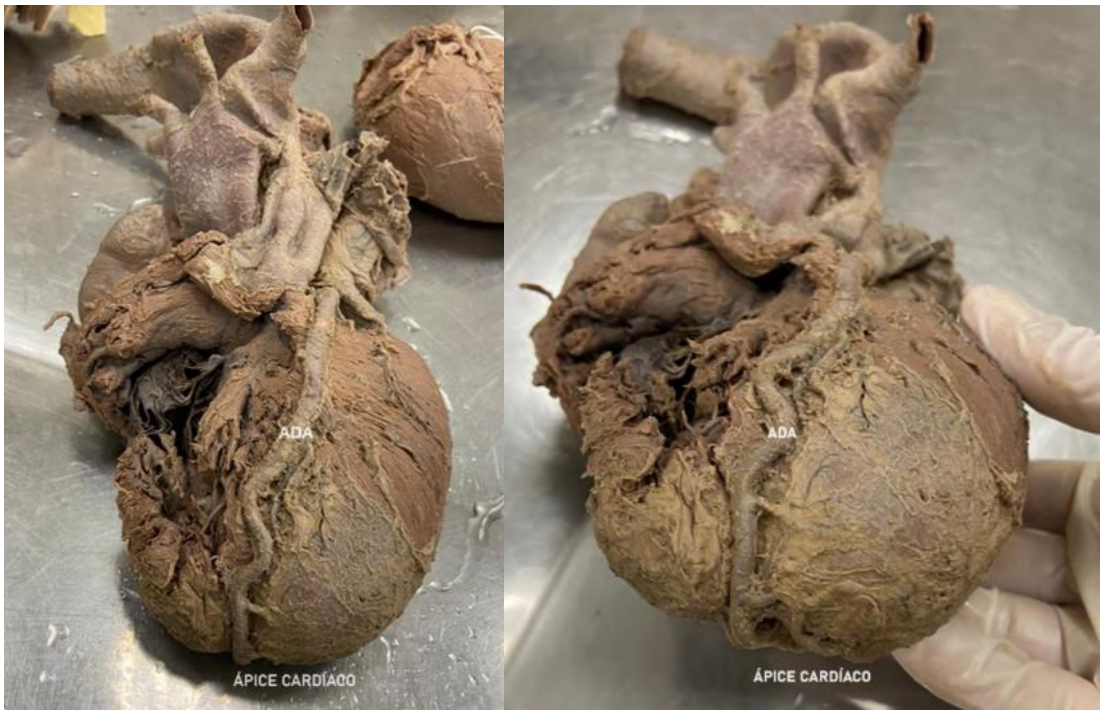
ADA:anterior descending artery; **RD**: diagonal branch; **ACX**: circumflex artery.
Source: Authors.

Surrounding anterior descending artery

As far as the vascular supply to the inferior cardiac wall is concerned, there is a spectrum of normal variants. In cases where the posterior descending artery is smaller, multiple branches arise from the distal right coronary artery, circumflex artery and obtuse marginal branches, which supply the inferior wall. There is also the scenario in which the anterior descending artery (ADA) wraps around the cardiac apex and supplies part of the inferior apical wall, known as the "surrounding ADA", as shown in the Figures 4 and 5 (Apitzsch *et al.,* 2009).

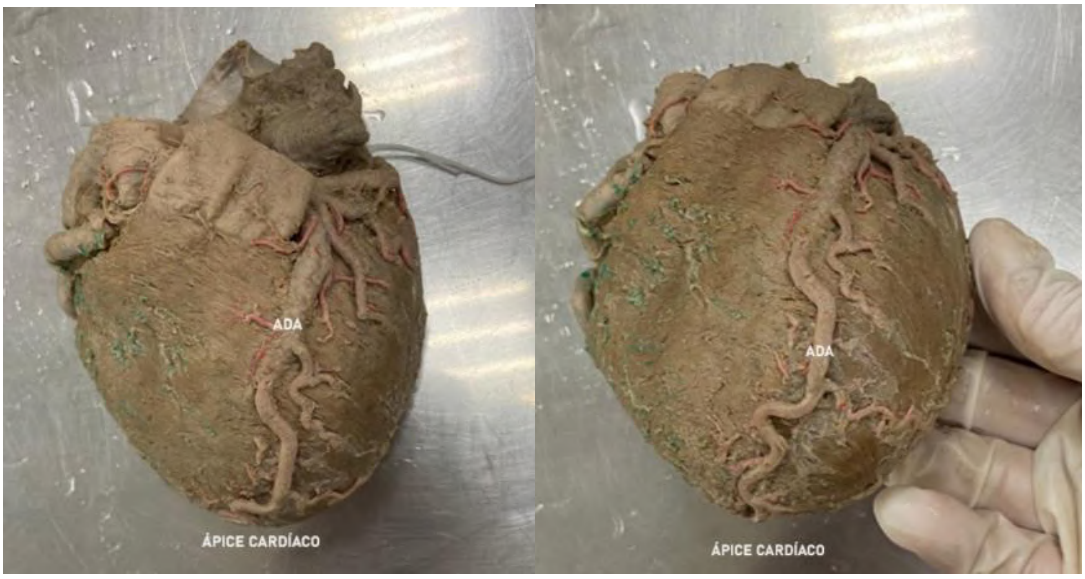
With regard to outcomes in patients with acute anterior wall myocardial infarction, anatomical features, such as a long ADA involving the apex of the left ventricle (LV), can play an important role. The territory affected by myocardial infarction is more extensive in patients with occlusion of the surrounding ADA, and obstruction of this artery is associated with subsequent apical remodeling of the left ventricle. Cardiac magnetic resonance imaging has shown that in patients who have suffered a myocardial infarction, the presence of an enveloping ADA was correlated with an infarction in the apical wall and a higher incidence of heart failure and stroke, regardless of the total size of the infarction (Ilia *et al.*, 2014; Kobayashi *et al.*, 2015).

Figura 4 - Surrounding anterior descending artery.



ADA:anterior descending artery; **Ápice cardíaco:** cardiac apex.
Source: Authors.

Figura 5 - Surrounding anterior descending artery.



ADA:anterior descending artery.
Source: Authors.

Duplication of the anterior descending artery

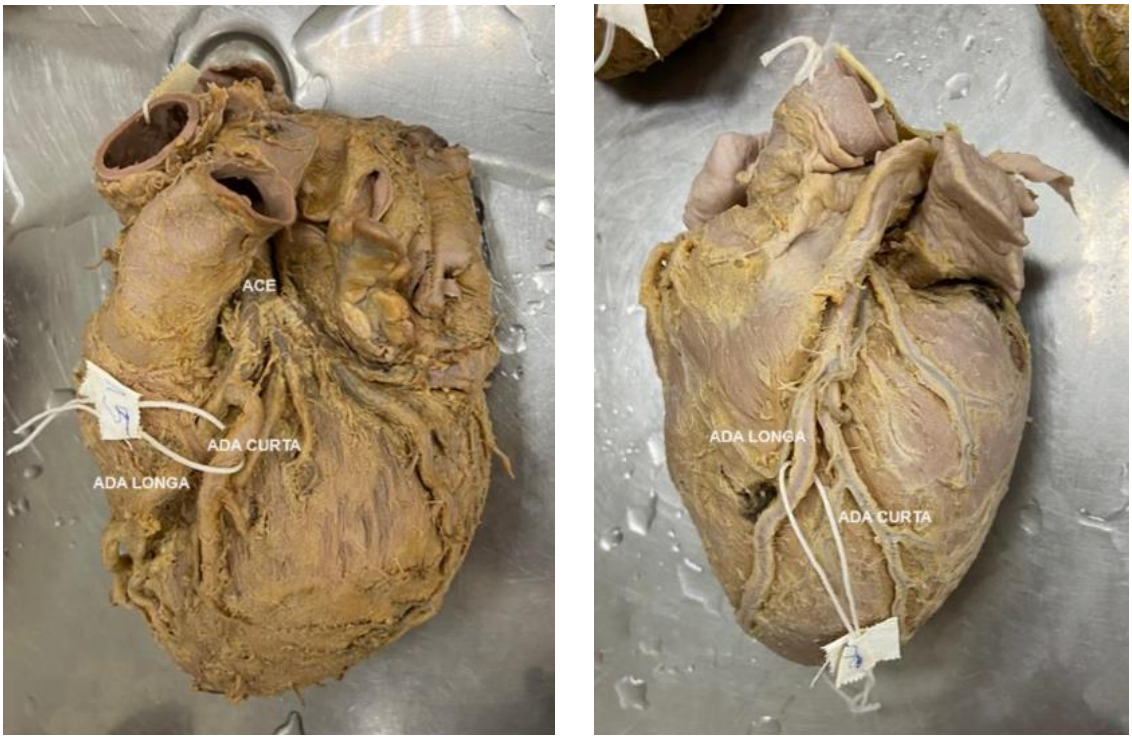
The term “double ADA” refers to a variation of the anterior descending artery, in which two different arteries partially or totally supply the same territorial regions. The anomaly is characterized by the presence of two separate components of the

ADA in the anterior interventricular septum, and is commonly referred to as short ADA and long ADA, as described in the Figures 6 and 7 (Saremi *et al.*, 2013; Bozlar *et al.*, 2015).

The incidence of double ADA varies from 0.68 to 6% in different case series (Bozlar *et al.*, 2015). It refers to a variation of the anterior descending artery, in which two distinct arteries provide vascular supply to part or all of their shared territorial areas (Saremi *et al.*, 2013).

Often, one of the duplicated arteries may originate from the right coronary artery (RCA) and run along a pre-pulmonary, septal or interarterial path. Although this anomaly has no significant hemodynamic implications, its presence can complicate surgical procedures, such as aorto-coronary bypasses or certain coronary artery interventions (Shriki e*t al.*, 2012).

Figures 6 and 7 - Duplication of the anterior descending artery.



ACE: left coronary artery; **ADA longa**: long anterior descending artery; **ADA curta**: short anterior descending artery.
Source: Authors.

Double origin of the anterior descending artery

The occurrence of the anterior descending branch originating in the right sinus of Valsalva or the right coronary artery is a rare anomaly, with an incidence ranging from 0.03% to 0.2% in patients undergoing routine catheterization (King *et al.*, 1985). With regard to the presence of a double origin for the anterior descending branch, as shown in the Figure 8, so rare cases have been documented in the current literature (Ferreira e*t al.*, 1988).

In human hearts, the anterior descending branch is notable for its consistent origin, course and distribution (Ilia e*t al.*, 1991). When there is an anomalous origin of the anterior descending branch from the right sinus of Valsalva or the right coronary artery, its course can follow two variants: it can pass between the aorta and the pulmonary artery, or it can be located anterior to the pulmonary artery trunk before reaching the anterior interventricular sulcus. When the anterior descending branch is duplicated, two branches supplement the standard distribution of this vessel (Batista *et al*., 2011).

Figure 8 - Double origin of the anterior descending artery.

ADA:anterior descending artery.
ADA 1: originating from the right coronary artery / **ADA 2**: originating from the left coronary artery.
Source: Authors.

Analyzing the figure above, it is possible to observe the double origin of the anterior descending artery, with a branch originating from the right coronary artery and a branch originating from the left coronary artery, being a variation rarely found in the literature.

There are differences in the literature regarding the clinical influence of this anomaly, which was initially considered benign (King *et al.*, 1985). However, some authors associate it with conditions such as stable angina, acute myocardial infarction and post-infarction angina. In studies carried out by Mello *et al*., two cases were described in which the clinical, electrical and scintigraphic evidence indicated myocardial ischemia, associated with the origin of the anterior descending branch in the right sinus of Valsalva. Oliveira *et al*. stated that the origin of the anterior descending branch on the right side is a significant anomaly capable of causing myocardial ischemia. Coyle *et al*. established a relationship between the origin of the anterior descending branch in the right sinus of Valsalva or in the right coronary artery and occurrences of acute myocardial infarction and post-infarction angina. Thus, the hypothesis of an anomaly in the anterior descending branch can be considered in the differential diagnosis of cases of angina and anterior wall ischemia (Coyle *et al.*, 2000).

The anomalous courses of the anterior descending artery (ADA) and circumflex artery (ACX) branches can result in acute transient occlusions of these vessels, due to variations in cardiac output caused by compression or distension of the vessels at the base, especially during exertion. These alterations are clinically reflected in symptoms such as stable angina, acute myocardial infarction (AMI) or even sudden death. This pathophysiological scenario of angina would justify the symptoms observed in the patient (Castro *et al.*, 1996).

4. Discussion

The most frequent anatomical variation of the left coronary artery in this study was trifurcation, found in 38.4% of coronary branching alterations, which shows a high prevalence of hearts with an intermediate branch. Quadrifurcation was the least prevalent, with only one heart having this dysmorphism.

When analyzing whether there could be any indication of a correlation between the origin of the coronary vessels and the apparent hypertrophy, a small correspondence rate of 16% was noted, and such an analogy cannot be affirmed.

Right dominance was the most common, with a prevalence of 87% among the hearts analyzed. Left dominance had a percentage close to 7% and mixed dominance was found in only two hearts, representing just 5% of the total.

Based on the universally accepted coronary branching pattern, 13 alterations were found, representing a total of 33%. Among them, the main and rarest was the double origin of the anterior descending artery, with a branch originating from the right coronary artery and a branch from the left coronary artery.

Segmentation of the coronary artery tree makes it possible to individualize and analyze these vessels and their branches in isolation. This process provides a more precise localization of abnormalities, whether congenital or acquired, broadening the understanding of the associated clinical consequences. It also contributes to more effective planning of therapeutic management, when necessary. Performing tests in which the coronary vessels can be observed with greater accuracy, such as coronary angiography, has been effective for these purposes.

5. Conclusion

Based on the results found in this study, it can be concluded that knowledge of anatomical anomalies and variations, especially the most prevalent ones, combined with techniques that enable them to be accurately traced and described, is indispensable for the adoption of an individualized approach.

Overall, the research will contribute to a better understanding of the importance of cardiac anatomy for the medical profession, for understanding clinical events, for carrying out and correctly interpreting exams and for the surgical approach to patients.

Finally, it is recommended that more studies be carried out on the proposed topic in order to obtain as much scientific evidence as possible and to help doctors choose the most appropriate and effective approach to coronary management.

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