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A CADAVERIC STUDY OF CORONARY ARTERY VARIATIONS

by

Mitchell Lee Milanuk

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A CADAVERIC STUDY OF CORONARY ARTERY VARIATIONS

Mitchell Milanuk, M.S.

University of Nebraska, 2017

Advisor: Keely Cassidy, PhD.

Coronary artery diseases, such as angina or myocardial infarction, are extremely prevalent and impact millions of people worldwide. Underlying the diseases, and how they affect each individual in a distinct manner, is the individual's coronary artery anatomy. The aim of the present study is to have an intimate knowledge of the normal and variant anatomy of the coronary arteries. As an attempt to gain such knowledge, complete analysis of the anatomical variations of coronary arteries was performed. Classical cadaveric dissection of sixty human hearts was performed in the gross anatomy laboratory at the University of Nebraska Medical Center (UNMC). Precise dissection allowed for complete mapping of the coronary arteries and their main branches, from origin to termination. Data regarding the origin of the coronary arteries and their main branches was collected and compared to primary literature and current medical textbooks. An emphasis was placed on analyzing the origin of the sinoatrial nodal artery (SANA) and atrioventricular nodal artery (AVNA) as well as the coronary artery dominance. Analysis of the data collected in this study highlights the disconnect between the information found in primary literature and that which is found in current medical textbooks. Said disconnect can impact a student's comprehensive knowledge of the coronary arteries.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Abbreviations

AIVA	Anterior Interventricular Artery
AV	Atrioventricular
AVNA	Atrioventricular Nodal Artery
CABG	Coronary Artery Bypass Graft
COA	Clinically Oriented Anatomy
CT-A	Computed Tomography - Angiography
IV	Interventricular
LCA	Left Coronary Artery
LCX	Left Circumflex Artery
MSCT-A	Multi-Scale Computed Tomography - Angiography
PIVA	Posterior Interventricular Artery
RA	Right atrium
RCA	Right Coronary Artery
RV	Right Ventricle
SANA	Sinoatrial Nodal Artery
SVC	Superior Vena Cava
UNMC	University of Nebraska Medical Center

Chapter 1: Introduction

Comprehensive anatomical knowledge is one of the most useful tools a physician can possess and utilize throughout their career. Anatomical sciences have been taught for centuries, with the first recorded school of anatomy being established in Alexandria, Greece around 300 BC (Sallam, 2002). Although anatomy has been studied for centuries, there remains areas where the "accepted anatomy" varies between primary literature and current textbooks. Understanding the normal anatomy and possible variations can help maximize knowledge and minimize the possibility for errors or complications a physician may encounter in clinic or surgery.

The branching of and area perfused by the coronary arteries in humans can vary greatly from one person to the next. Thus, the ischemic territory due to a myocardial infarction can be vastly different in two patients with a similar occlusion. Also, the conduction system of the heart may be affected if blood flow via the SANA or AVNA ceases as a result of an occlusion (Sutton, 1968). Thus, it is imperative to understand the branching pattern and origin of arteries such as the SANA and AVNA to determine the likelihood of specific components of the conduction pathway being affected. For example, ischemia to the heart's conduction system can lead to heart block if the atrioventricular node is damaged (Sutton, 1968). It is imperative that surgeons understand the variable anatomy of the coronary arteries when performing surgeries such as a mitral valve replacement due to the proximity of the AV node to the mitral valve (Pejkovic, 2008).

While the normal and variant anatomy of the coronary arteries has been researched and published in primary literature since the 1920's (Crainicianu, 1922), the information found in current textbooks often fails to agree with primary literature. Cutting-edge research is constantly being published but it is difficult for textbooks to stay up to date when they are only revised every few years. Clinically Oriented Anatomy (COA) by Moore, et al., a frequently utilized anatomy text among medical schools, was originally published in 1980 and has only been revised six times (1985, 1992, 1999, 2006, 2010, and 2014) since its original publication.

The field of anatomical variations is not especially lucrative when compared to other fields in science. This lack of financial incentive often deters graduate faculty or physicians from devoting their time and money to a project in this field. The necessity for a physician's detailed anatomical knowledge makes it imperative that the information they learn is as accurate as possible. This project aims to thoroughly identify the origin, course, and branching patterns of the coronary arteries in humans to further supplement the information presented in current anatomical textbooks.

The normal and variant anatomy of the coronary arteries have been studied for decades utilizing cadaveric dissection and various medical imaging techniques. One of the biggest benefits of cadaveric studies is that they are typically more simplistic because the artery is a three-dimensional structure and can be followed to its termination. On the other hand, imaging studies only provide a two-dimensional, static image making it more technically difficult to analyze data. A downfall of cadaveric studies is that they tend to have a smaller sample size due to the limited availability of cadaveric donors, whereas imaging studies can amass hundreds to thousands of participants.

In general, cadaveric studies typically follow one of three general methods. The first cadaveric method utilizes simple gross dissection (Kalpana, 2003). In this technique, the dissector follows the arteries to their termination, tracing any subsequent branches to their respective terminations. The second cadaveric method utilizes a colored opaque dye that is injected into the coronary arteries (Gross, 1923). The coronary arteries are dyed different colors, allowing for easier dissection and visualization of the territory supplied by each artery. The final cadaveric method consists of injecting a noncorrosive substance, such as celluloid, into the coronary arteries. This is followed by corrosion of the cardiac tissues by a digesting agent, such as concentrated hydrochloric acid (James, 1958). Each method has their advantages and disadvantages when studying the normal and variant anatomy of the coronary arteries.

Imaging studies have a tremendous advantage when studying coronary arteries because they do not rely on cadaveric donors. The studies can be performed on hundreds to thousands of living patients who are undergoing a specific imaging procedure in a medical facility. These studies have been performed using numerous different imaging devices, changing as new technology is developed. Angiography was one of the most common techniques used by early scientists but it has become less commonly used due to its inability to show the arteries in three dimensions. Angiography utilizes the injection of a contrast dye into the coronary arteries while simultaneously multiple x-rays are being acquired (Dabizzi, 1980). Current research typically uses computed tomography angiography (CT-A) (Kini, 2007) or multiscale computed tomography angiography (MSCT-A) (Saremi, 2008). CT-A and MSCT-A are non-invasive cardiac imaging techniques based on a rotating x-ray tube with 64 or more slices (Burgstahler, 2008). The arteries are injected with a contrast dye and the rotating x-ray tube gathers 64 or more two-dimensional images that are compiled to give a three-dimensional representation of the coronary arteries, making this technique more advantageous than angiography alone.

Coronary Artery Anatomy

The following anatomical descriptions have been adapted from the COA textbook by Moore et al. (2014) and Loukas (2013). The most proximal portion of the ascending aorta is termed the aortic root. The aortic root contains three sinuses of Valsalva, which are formed by the cusps of the aortic semilunar valve. The two sinuses (right and left sinuses of Valsalva) which are adjacent to the pulmonary trunk are known as coronary sinuses due to the origin of one coronary artery from each. The third sinus does not have a coronary artery originating from it so it is known as the non-coronary sinus.

Right Coronary Artery Anatomy

The right coronary artery (RCA) originates from the right sinus of Valsalva in the aortic root. The RCA almost immediately enters the right atrioventricular (AV) sulcus and courses between the right atrium (RA) and right ventricle (RV). Once in the right AV sulcus it travels circumferentially, issuing several branches which supply the RA and RV.

The first main branch issued by the RCA is the infundibular or conal branch. This artery typically originates from either a proximal location on the RCA or from a separate ostium in the right coronary sinus. The conal artery supplies much of the anterior, superior aspect of the right ventricular musculature.

Kalpana (2003) conducted a cadaveric study in which 100 hearts were manually dissected. In this study, Kalpana found that in 24% of hearts the conal artery originated from a separate ostium in the right coronary sinus. The remaining 76% showed the conal artery was the proximal most branch of the RCA. Other primary literature (Kini, 2007; Loukas, 2013) state that the conal artery arises from the RCA in only one half of the population. This artery is not frequently researched due to its indistinct landmarks and fragility.

The second main branch issued by the RCA, the SANA, travels superior and posterior, running adjacent to the RA and terminating near the base of the superior vena cava (SVC). This artery supplies the area known as the sinoatrial node or the pacemaker of the heart (Figure 1.1). The SANA is one of the more variant coronary artery branches. It originates from the RCA most frequently but can also originate from the left circumflex artery (LCX), LCA, or have a dual supply from RCA and LCX. The origin of the SANA is more frequently researched than the previous artery, statistics regarding its origin can be found in Table 1.1.

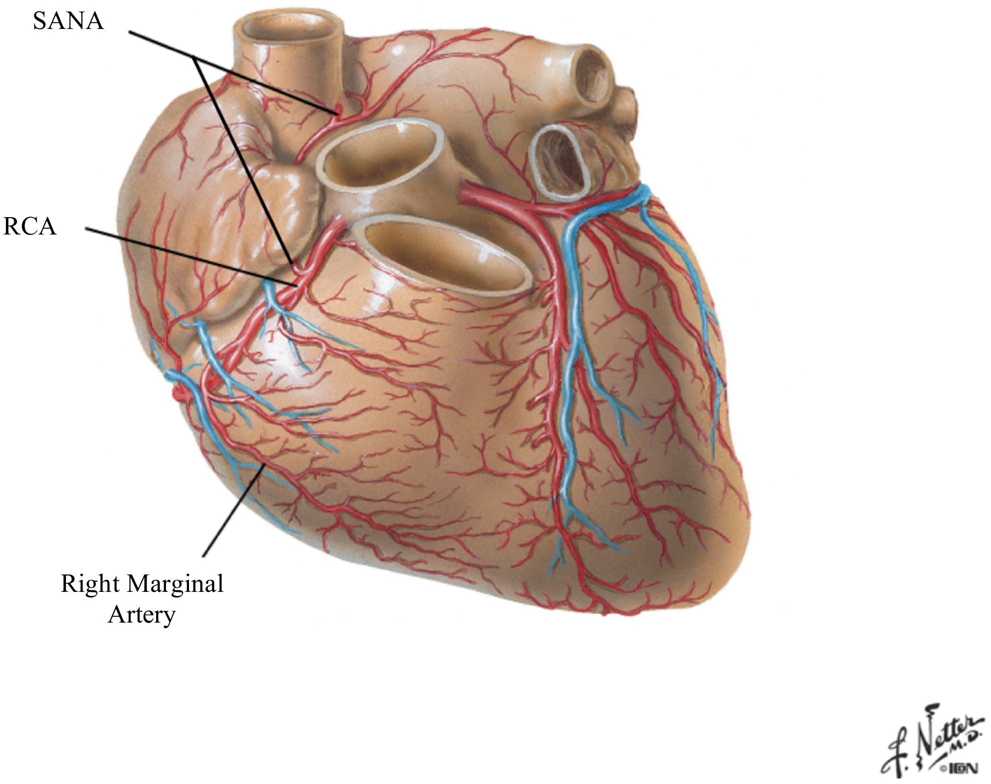


Figure 1.1: Illustration showing an anterior view of heart. The RCA and its early branches, the SANA and right marginal artery, can be followed to their termination. (Netter, 2014)

Vikse (2016) conducted a meta-analysis on the anatomical variations of the SANA. According to Vikse, the SANA originates from the RCA in 68% of cases, from the LCX or LCA (pooled) in 24.8% of cases, and received a dual supply in 2.9% of cases. This study provided great insight into the amount of research available on the origin of the SANA. Vikse compiled data that used both cadaveric and imaging techniques and originated in various countries. Kalpana's (2003) cadaveric study of 100 human hearts presented slightly different statistics, coming in at 56%, 35%, and 8%, respectively.

Primary Literature: Origin of Sinoatrial Nodal Artery

Study	Sample Size (n)	RCA	LCA/LCX	RCA and LCA/LCX
Divyaprakash, 2016	30	57.2	40.14	2.66
Darmender, 2014	77	59.74	37.66	2.6
Verma, 2014	43	52	24	24
Waheed, 2013	348	71.28	28.74	0
Pejkovic, 2008	150	63.33	36.66	0
Ramanathan, 2008	300	53	42.66	4.33
Saremi, 2008	102	65.7	27.4	5.9
Kini, 2007	42	55	45	0
Berdajs, 2003	50	66	34	0
Futami, 2003	30	73.3	3.3	23.3
Kalpana, 2003	100	56	35	8
Sow, 1996	45	64.45	24.44	0
Caetano, 1995	100	56	35	8
DiDio, 1995	300	58	42	0
Kyriakidis, 1988	309	59	38	3
Busquet, 1984	42	66	30	4
Hutchinson, 1978	40	65	35	0
James, 1961	106	54	42	4
James, 1958	43	61.54	38.46	0
Weighted Average		**60.59**	**35.94**	**3.12**

Table 1.1: Primary literature values for the supply of the SANA.

Saremi (2008) also studied the SANA but utilized a 64-section computed tomography (64-CT) scanner to collect data. Saremi's statistics for the branching of SANA showed 65.7% from RCA, 27.4% from LCX, and 5.9% from both RCA and LCX. A cadaveric study by Futami (2003) also studied the origin of the SANA artery but reported drastically different statistics than those found in the previously mentioned studies.

Futami's study determined that the SANA originated from the RCA in 73.3%, LCX in 3.3%, and from both RCA and LCX in 23.3%.

Moore, et al. (2014) reports that the SANA is supplied by the RCA in 60% of hearts and by the LCX in 40% of hearts. This textbook does fail to present the possibility of dual supply to the sinoatrial node. As seen in Table 1.1, some studies found dual supply present very frequently. This comparison emphasizes why it is imperative that the textbooks contain information consistent with primary literature.

According to data included Vikse's study, the statistics regarding SANA origin appear to be very variant. Kosar (2009) found the SANA to originate from the RCA in 96.26% of the 700 participants whereas Kawashima (2003) found it to originate from the RCA in 32.08% of the 106 participants. It should be noted that these studies represent the extremes found in literature, with most studies reporting between 55-65% of SANAs originating from RCA. Extreme variation between studies like Kosar and Kawashima only further stresses the importance of a healthcare professional fully understanding the variability of coronary artery anatomy.

The next, and largest branch issued by the RCA is the right or acute marginal artery. The right marginal artery branches from the RCA as it curves around the acute margin of the heart in the right AV sulcus. The right marginal artery descends towards the apex of the heart, supplying the lateral portion of the right ventricular musculature (Figure 1.1). After issuing the right marginal artery, the RCA curves posteriorly in the right AV sulcus until it reaches the crux of the heart. The crux of the heart is defined by the intersection of the posterior interventricular (IV) sulcus, the right AV sulcus, and the left AV sulcus. After reaching the crux of the heart, the RCA supplies the posterior interventricular artery

(PIVA). The PIVA descends in the posterior interventricular sulcus, supplying the posterior musculature of the right and left ventricles and terminating near the apex of the heart (Figure 1.2).

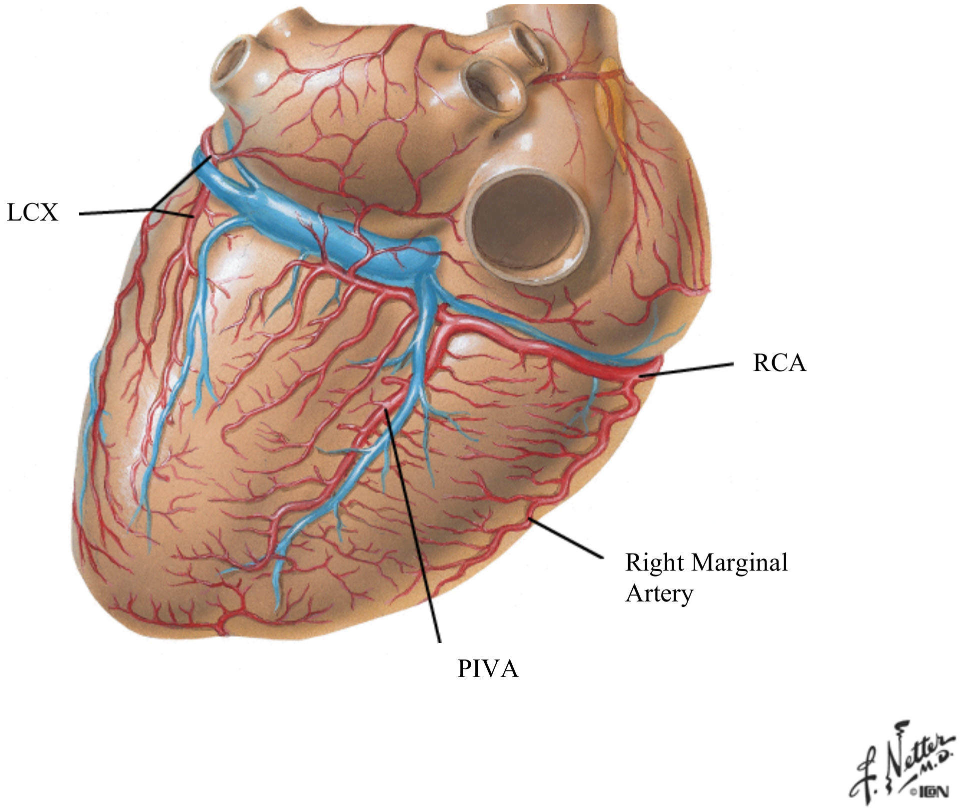


Figure 1.2: Illustration showing a posterior view of heart. The RCA can be followed to its termination as the PIVA as well as terminal branches supplying the left ventricle. (Netter, 2014)

Traditionally, if the RCA reaches the crux of the heart and supplies the PIVA the heart is said to be right dominant. Hearts are considered right dominant if the RCA reaches the crux and supplies the PIVA, left dominant if the PIVA is supplied by the LCX, or codominant if supplied by both RCA and LCX (Figure 1.3). Coronary dominance, like SANA origin, can be somewhat variant. In an angiographic study of 1853 participants Angelini (1999) found 89.1% of hearts to be right dominant, 8.4% to be left dominant, and 2.5% to codominant. While most studies found in primary literature

(Table 1.2) agree with these statistics, Divyaprakash (2016) and Darmender (2014) vary slightly, and Ramanathan (2008) varies drastically.

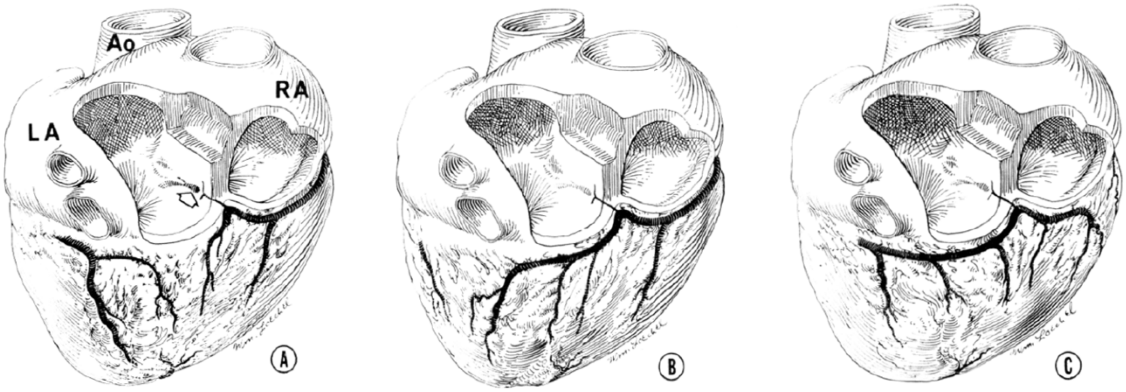


Figure 1.3: Illustration showing branching of PIVA in codominant (A), right dominant (B), and left dominant (C) hearts. (James, 1965)

Moore's COA reports coronary artery dominance to be 67% right, 15% left, and 18% codominant. Of all reported values from COA, this value is the most deviated from the reported literature. The drastic variation between values reported in COA and primary literature emphasizes that the information being taught to health professionals does not agree with primary literature. Dominance in hearts can greatly affect the territory affected by myocardial infarctions, making it vital that health professionals understand the likelihood of a right dominant ischemia pattern versus that of a left dominant or codominant heart.

Primary Literature: Coronary Artery Dominance				
Study	Study Size	Right	Left	Codominant
Divyaprakash, 2016	30	77.2	18.43	4.37
Darmender, 2014	77	83.11	16.88	0
Pejkovic, 2008	150	90	10	0
Ramanathan, 2008	300	53.66	22.33	24
Saremi, 2008	102	87.3	10.8	1.9
Futami, 2003	30	90	3.33	6.66
Kalpana, 2003	100	89	11	0
Arid, 2000	23	91.3	8.7	0
Angelini, 1999	1853	89.1	8.4	2.5
Cavalcanti, 1995	110	69.09	11.82	19.09
Weighted Average		**84.19**	**10.60**	**5.21**

Table 1.2: Primary literature values for the dominance of coronary arteries.

After the PIVA is issued by a right dominant heart, the RCA dives deep into the cardiac tissue, making an inverted loop as it crosses the crux of the heart and terminates on the posterior aspect of the left ventricle, supplying the left ventricular musculature. The extent of which the RCA supplies the posterior left ventricle varies from one heart to the next. Branching from the apex of the deep inverted loop of the RCA as it crosses the crux of the heart is the AVNA (James 1965). The AVNA dives deep into the interventricular septum traveling to the atrioventricular node, found in the wall of right atrium between the opening of the venous coronary sinus and the annulus of the tricuspid valve.

As seen in Tables 1.1 and 1.3, the origin of the AVNA varies a small amount amongst studies but not nearly as drastically as the origin of the SANA. Compiled statistics from primary literature show that the AVNA artery, on average, arises from the RCA in 81.53% of hearts, LCX in 17.37% of hearts, and from both RCA and LCX in 1.10% of hearts. Moore's COA (2014) reports that the AVNA originates from RCA in 80% of hearts and from LCX in 20% of hearts. While these statistics do not differ drastically than those found in the literature, Moore (2014) does fail to mention that the atrioventricular node can receive dual blood supply. This is a critical educational point because it is clinically relevant for a health professional understand the possibility of dual blood supply to the atrioventricular node.

Tables 1.2 and 1.3 show that the likelihood of the AVNA originating from RCA is nearly identical to the likelihood of the heart being right dominant (81.53% vs. 84.19%). This relation is most likely due to the fact that the artery that crosses the crux of the heart is in closest proximity to where the atrioventricular node lies, making it most efficient for this artery to supply the node.

Primary Literature: Origin of Atrioventricular Nodal Artery				
Study	Study Size	RCA	LCX	RCA and LCX
Divyaprakash, 2016	30	78.22	18.66	3.12
Verma, 2014	43	88	12	0
Pejkovic, 2008	150	90	10	0
Ramanathan, 2008	300	72.33	27.66	0
Saremi, 2008	102	87.2	10.8	2
Berdajs, 2006	55	73	27	0
Futami, 2003	30	80	10	10
Arid, 2000	23	91.3	8.7	0
Krupa, 1993	120	90	10	0
Hutchinson, 1978	40	80	20	0
James, 1958	43	83	7	10
Weighted Average		81.53	17.37	1.10

Table 1.3: Primary literature values for the supply of the AVNA.

Left Coronary Artery Anatomy

The left coronary artery (LCA) originates from the left sinus of Valsalva in the aortic root. The LCA is a short trunk that bifurcates in 47%, trifurcates in 40%, and quadrifurcates in 11% of specimens (Kalpana, 2003). Bifurcation of the LCA gives rise to the anterior interventricular artery (AIVA) and LCX, whereas trifurcation gives rise to the AIVA, LCX, and the left main diagonal branch. In the case of a bifurcated LCA, the AIVA curves around the base of the pulmonary trunk issuing the left main diagonal branch then continuing to the anterior interventricular sulcus. The AIVA artery then descends towards the apex of the heart, wrapping around the apex and ascending as much as to 2-5 cm up the posterior interventricular sulcus in approximately 80% of hearts (Kalpana, 2003). As the AIVA descends in the anterior interventricular septum it issues several sporadic branches termed diagonal branches. The left main diagonal artery, AIVA, and diagonal branches supply blood to the anterior portion of the left and right ventricular musculature (Figure 1.4).

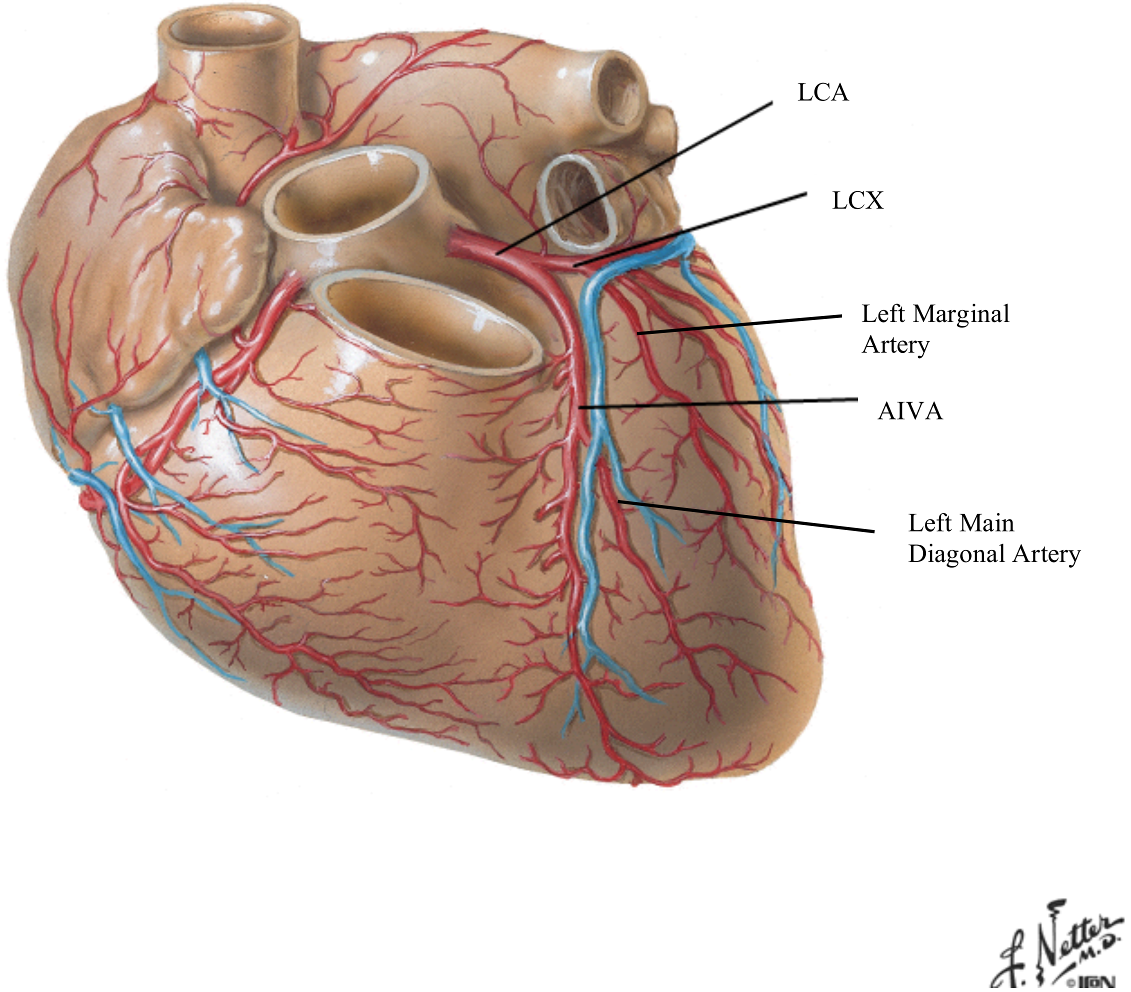


Figure 1.4: Illustration showing an anterior view of heart. The LCA can be seen bifurcating into the LCX and AIVA. The left main diagonal artery can be seen branching from the AIVA. (Netter, 2014)

After the LCA bifurcates, the LCX travels at an angle nearly perpendicular to the AIVA, running in the left AV sulcus. The first branch issued by the LCX is the SANA. As discussed previously, the SANA can be a branch from the RCA, LCA, or LCX. While RCA is the most common origin (68.0%), it can also originate from the LCX (22.1%), or the LCA (2.7%) (Vikse, 2016). Similar to the RCA, the LCX runs circumferentially in the left AV sulcus issuing sporadic branches that supply the left atrium and left ventricle. The next and largest branch issued by the LCX is the left or obtuse marginal artery. The left marginal artery branches from the LCX as it curves around the obtuse margin of the heart in the left

AV sulcus. The left marginal artery descends towards the apex of the heart, supplying the lateral portion of the left ventricular musculature (Figure 1.4).

After issuing the left marginal artery, the LCX curves posteriorly in the left AV sulcus until it reaches the crux of the heart, issuing small unnamed branches to supply the musculature of the posterior portion of the ventricular musculature as it goes. If the heart is left dominant (10.60%) or codominant (5.21%) the LCX will reach the crux of the heart where it will have a similar branching pattern as the RCA. After reaching the crux of the heart, the LCX supplies the PIVA which will descend in the posterior interventricular sulcus, supplying the posterior musculature of the right and left ventricles and terminating near the apex of the heart.

After the PIVA has been issued by a left dominant heart, the LCX may dive deep, making an inverted loop as it crosses the crux of the heart where it terminates on the posterior aspect of the right ventricle, supplying the right ventricular musculature. The extent of which the LCX supplies the posterior right ventricle can vary from one heart to the next. Branching from the apex of the deep inverted loop in the LCX as it crosses the crux of the heart may come the AVNA. The AVNA dives deep into the interventricular septum traveling to the atrioventricular node. The LCX is the sole blood source for the atrioventricular node in approximately 17.37% of hearts. If the heart is right dominant, the LCX wraps around in the left AV sulcus and sends its terminal branch towards the apex before reaching the crux of the heart.

The anatomy of the coronary arteries is one topic in gross anatomy that is not always well defined. Many current textbooks report the anatomy and its variability but fail to utilize the most recent literature when reporting statistical values. This failure to incorporate current literature is troublesome, considering the fact that future healthcare professionals are being trained on said statistics. In the ever-changing field of medicine, it is imperative that healthcare professionals possess a thorough and current anatomical knowledge to perform at their best. One clinical topic that requires a thorough and current anatomical knowledge of the coronary arteries is heart block. Heart block occurs when the signal from the sinoatrial node or atrioventricular node fails to reach the ventricles, typically due to ischemia caused by a myocardial infarction (Burns, 2013).

Heart block can manifest as a result of several different causes in the conduction system but disruption of the atrioventricular node is the one common cause that can be easily predicted based on the anatomy of an occluded coronary artery. Understanding the normal and variant anatomy allows a health professional to understand or predict the probability of complications caused by ischemia after a myocardial infarction

This project analyzed the normal and variant anatomy of the coronary arteries based on information found in primary literature and graduate level anatomy textbooks. The results showed that textbooks tend to present statistics that do not agree with those found in primary literature and tend to omit certain branching that may be important to a healthcare professional’s education.

This research contains 4 chapters. This chapter presented a review of the literature regarding the normal and variant anatomy of the coronary arteries. It outlined the stereotypical course of the coronary arteries, detailing the branching and variability along the way. The second chapter explains the methodology of research used in this project in greater detail, including the exact procedures carried out during dissection of the cadaveric human hearts used in this study. The third chapter contains the findings and analysis of the data collected. This chapter examines the results collected and in the present study to data found in primary literature and current medical textbooks, determining the statistical relevance amongst each. The fourth and final chapter of this thesis synthesizes all the previous components of the research and forms evidence-based recommendations for the future of anatomical variation research.

Chapter 2: Methods

The Cadaveric Donors

This study utilized 61 cadaveric donors which were provided by the Anatomical Board of the State of Nebraska to the UNMC gross anatomy laboratory. The selection of donors to be utilized in this study was not influenced based on age, sex, ethnic background, or country of birth. Every donor that was accepted into the UNMC gross anatomy laboratory was included in the study. While this study did not have inclusion criteria, the Anatomical Board of the State of Nebraska does require that donors meet certain requirements. Donors may not be accepted if they have organs removed for transplantation or autopsy (with the exception of the eyes), have a contagious disease, or are morbidly obese. Also, donors may not be accepted if they have experienced severe trauma, drowning, burning, homicide, motor-vehicle accident, or death from suicide.

No identifying information was associated with the donors while in the gross anatomy laboratory. Donors were identified based on their associated table in the lab and by the tag assigned to them by the Anatomical Board. A brief medical history associated with each donor was attached to their respective table, but this information was not collected for the current study. Throughout dissection by professional students, the medical history of many donors was found to be incomplete, making it an unreliable source of information. All identifying information was kept by the Anatomical Board so a complete medical history cannot be associated with the donors in the present study. Donors were preserved using a solution containing 33.33% isopropyl alcohol, 8.3% ethylene glycol, 2% formalin, and 6.7% phenol. Of the 61 cadaveric donors provided by the Anatomical Board, the thorax of one male donor was not able to be dissected due to preservation complications. According to information provided by the Anatomical Board, the remaining sixty donors (thirty males, thirty females) varied in age from 44 to 100. The male donors varied in age from 60 to 97 with a mean and median age of 80.63 and 81, respectively. The female donors varied in age from 44 to 100 with the mean and median age of 79.9 and 80.5, respectively.

Initial Dissection by Professional Students

Classical cadaveric dissection is a simple technique in which the specimen is dissected using common dissection tools such as a scalpel, hemostat, dissection scissors, etc. The unwanted tissue, such as adipose tissue obscuring the structures that are the focus of the dissection, is removed using the dissection tools until the desired anatomical structure can be visualized. Once the structure is visualized, the dissector continues to use their tools to reveal the structure in its entirety. This technique requires extreme caution when removing unwanted tissue because the desired structures can be easily damaged or destroyed. A skilled cadaveric dissector can often trace, uncover, and preserve the entirety of structures such as blood vessels without need for additional resources, such as injecting an opaque dye into the arteries.

Classical cadaveric dissection of the donors was initiated by medical, allied health, and graduate students at UNMC. Once the professional students were finished studying the heart and coronary arteries in their respective courses, a more detailed dissection was performed for the sake of this study. The students followed the provided instructions found in their dissection guide (Appendix B), a brief overview of their procedures is as follows. Dissection was initiated by opening the pericardium to expose the heart, surrounded by epicardium. The heart was then removed from the pericardial sac by severing the aorta, superior vena cava, inferior vena cava, pulmonary arteries and pulmonary veins. Once removed from the pericardial sac, the epicardium (containing visceral pericardium and adipose tissue) was removed using blunt dissection. Complete removal of the epicardium revealed the coronary arteries and their branches.

Once revealed, the RCA, LCA, and their main branches were traced to their termination using blunt or sharp dissection as needed. Branches of the RCA that were followed to their termination include; SANA, right marginal artery, PIVA, and AVNA. Branches of the LCA that were followed to their termination include; AIVA, LCX, SANA, left main diagonal artery, left marginal artery, PIVA, and AVNA. The students also used blunt or sharp dissection to trace out veins of the heart including the small cardiac vein, middle cardiac vein, great cardiac vein, anterior cardiac veins, and the venous coronary sinus. After tracing the vessels to their terminations, students were instructed to cut into the myocardium to visualize the chambers of the heart. In order to visualize the left ventricle, most students were forced to cut through the LCA, just proximal to its bifurcation or trifurcation. While this was unfortunate, it did not affect the identification of the coronary arteries and their branching.

Additional Dissection

After the professional students completed their studies on the cadaveric hearts, further dissection of the hearts was initiated for this project. Tools needed for dissection included a pair of small, sharp dissecting scissors, a hemostat, and a blunt probe. Dissection began at the most proximal segment of the RCA and continued until its termination was revealed. Frequently, the arteries were only partially visible and were surrounded by excessive adipose tissue, making the exact branching pattern and path of the artery unclear.

Extensive dissection was required to clear all adipose tissue away from the arteries so their exact branching pattern could be visualized. As the adipose tissue was removed from the RCA, branches became more visible. Adipose tissue surrounding the branches was then dissected until the branch could be followed to its termination. This process continued until the entirety of the RCA and its branches were clearly visible and could be traced to their termination. After the RCA and its branches were finished the same procedures were carried out on the LCA and its branches until both coronary arteries and all their main branches were clearly visible.

Observation and Documentation

Once all dissection was completed, the branching patterns and coronary artery dominance were documented by pen and paper in table format. The branches documented include; SANA, AVNA, right marginal, PIVA, AIVA, LCX, left main diagonal, and left marginal artery. After the branching was documented, high-definition photographs were taken of each heart. Photographs were taken showing the anterior, posterior, right lateral, and left lateral surface of the heart. Photographs were also taken showing the course of the SANA and AVNA. After data collection was completed, all data was transcribed into a Microsoft Excel spreadsheet.

Statistical Analysis

Experimental data on the branching of coronary arteries was then compared, using Chi-square tests, to the data found published in primary literature to determine the similarities between the two groups. All contingency tables were set up and then analyzed using a Chi-square test calculator found on the Social Science Statistics website (Stangroom). Chi-square tests were first used to compare the cadaveric and imaging data found in literature. These tests were performed on data regarding the origin of the SANA, the origin of the AVNA, and the coronary artery dominance. These three categories were analyzed due to their more variant nature found in primary literature. After the Chi-square tests were ran to compare the literature values, the experimental values were then compared to the literature values using the same Chi-square tests. Three contingency tables were ran comparing the experimental data in each category. The first compared the experimental data to the cadaveric data, the next to the imaging data, and the last to data found in current medical textbooks.

Limitations

While this study was not able to utilize a dissection assisting technique, such as dye injection, the quality of dissection was not impaired by this setback. Dissection was carried out with extreme caution in order to prevent the severance of any small branches, such as the SANA or AVNA. The use of sharp, fine point dissecting scissors allowed for precise dissection without further damage to the structures being studied. While, the additional dissection carried out for this study was extremely precise and cautious, some structures were previously severed by the professional students.

Even though this study was carried out in an extremely detail oriented manner, there were some limitations that could not be avoided. The most important limitations of this study are the sample size and population. Only sixty cadaveric hearts were available to be studied, significantly fewer than most imaging studies could gather. While studying sixty hearts is a respectable sample size, the data is undoubtedly more reliable with a larger sample size. Also, the cadaveric donors may represent one demographic more than others as they were all residents of Nebraska or surrounding states at death. Lastly, the use of a visual aid, such as dye injection, was not an option due to the procedures followed by the professional students. This limitation did not vastly impact the dissection protocol but it could have been a great aid.

This study analyzed the normal and variant coronary artery anatomy of sixty cadaveric donors provided by the Anatomical Board of the State of Nebraska. The hearts were initially dissected by medical, allied health, and graduate students in the UNMC gross anatomy laboratory. After the students completed their studies of the hearts, further dissection was carried out to better reveal the branching patterns of the coronary arteries. After dissection was completed the branching patterns were recorded and photographs were taken of all the hearts.

Chapter 3: Results

This chapter will present original data on the origin of the coronary arteries and each of their main branches. It will begin by analyzing the RCA and each main branch it supplies, followed by the LCA and its main branches. All raw data can be found in chart format in Appendix C. Figures 3.1 and 3.7 display the raw data collected in this study regarding the origin of the main branches of the coronary arteries. Due to the fact that some arteries may originate from both the RCA and LCA, the data was unable to be split perfectly based on their coronary artery origin.

This chapter will also analyze the data gathered in this study regarding the origin of the SANA, AVNA, and coronary artery dominance and will use Chi-square tests to determine the statistical relevance when compared to data found in cadaveric studies, imaging studies, and current medical textbooks. Due to the variant nature of the population selection processes for imaging and cadaveric studies, a Chi-square test was first performed for each category to determine whether the two types of studies were significantly different. The data found in primary literature was either presented as raw numerical data or could be easily converted to raw numerical data by using the frequency and population size of the study. The information found in textbooks however, was simply given as a frequency with no citation providing the population size. As a result, a population size of sixty was used to calculate raw numerical data when comparing the textbook to the results of this study and primary literature.

Due to the varying nature of the participants, a Chi-square test was first performed to determine the difference between the data regarding the origin of the SANA in cadaveric and imaging studies. Each contingency table produced a Chi-square statistic and a probability (p-value) associated with that Chi-square statistic. The Chi-square statistic reflects the strength of the relationship between two groups, with a greater Chi-square statistic implying there is a greater difference between the two groups. For a relationship to be considered significantly different, the contingency table must produce a Chi-square statistic associated with a probability that is less than 0.05 (Albrecht).

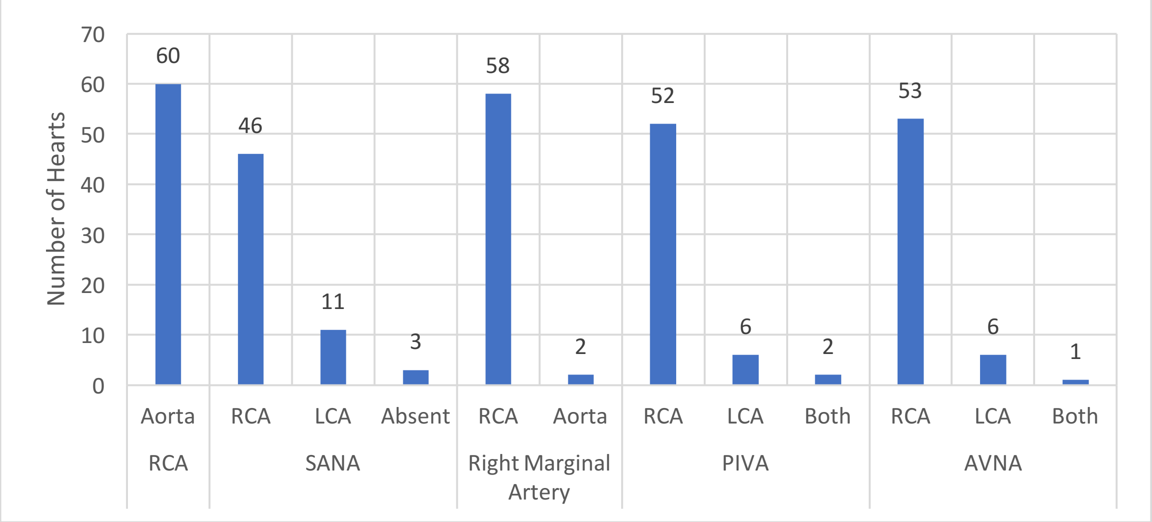


Figure 3.1: Analysis of the origin of the RCA and its major branches in human hearts. N=60

The Origin and Branches of the RCA

The RCA most commonly originates from the right sinus of Valsalva in the aortic root. While anomalous origins of the RCA do exist in primary literature, none were found in the population examined in this study. The RCA originated from the right sinus of Valsalva in all sixty cadaveric hearts studied. After originating from the aorta, the RCA almost immediately enters the right AV sulcus and courses between the RA and RV. The first main branch of the RCA that was examined in this study is the SANA, which ascends and courses across the RA until it reaches the sinoatrial node near the junction of the crista terminalis and SVC. The origin of the SANA is one of the most variant origins amongst the branches of the RCA and LCA. As seen in Figure 3.1, the SANA originated from the

RCA in forty-six of the sixty (76.7%) cadaveric hearts in this study, while eleven of the sixty (18.3%) originated from the LCA. Figure 3.2a and 3.2b show the origin of the SANA from the RCA and LCA, respectively. The remaining three hearts (5%) had significant scar tissue due to a coronary artery bypass graft (CABG) surgery and the SANAs were unable to be located upon further dissection (Figure 3.2c).

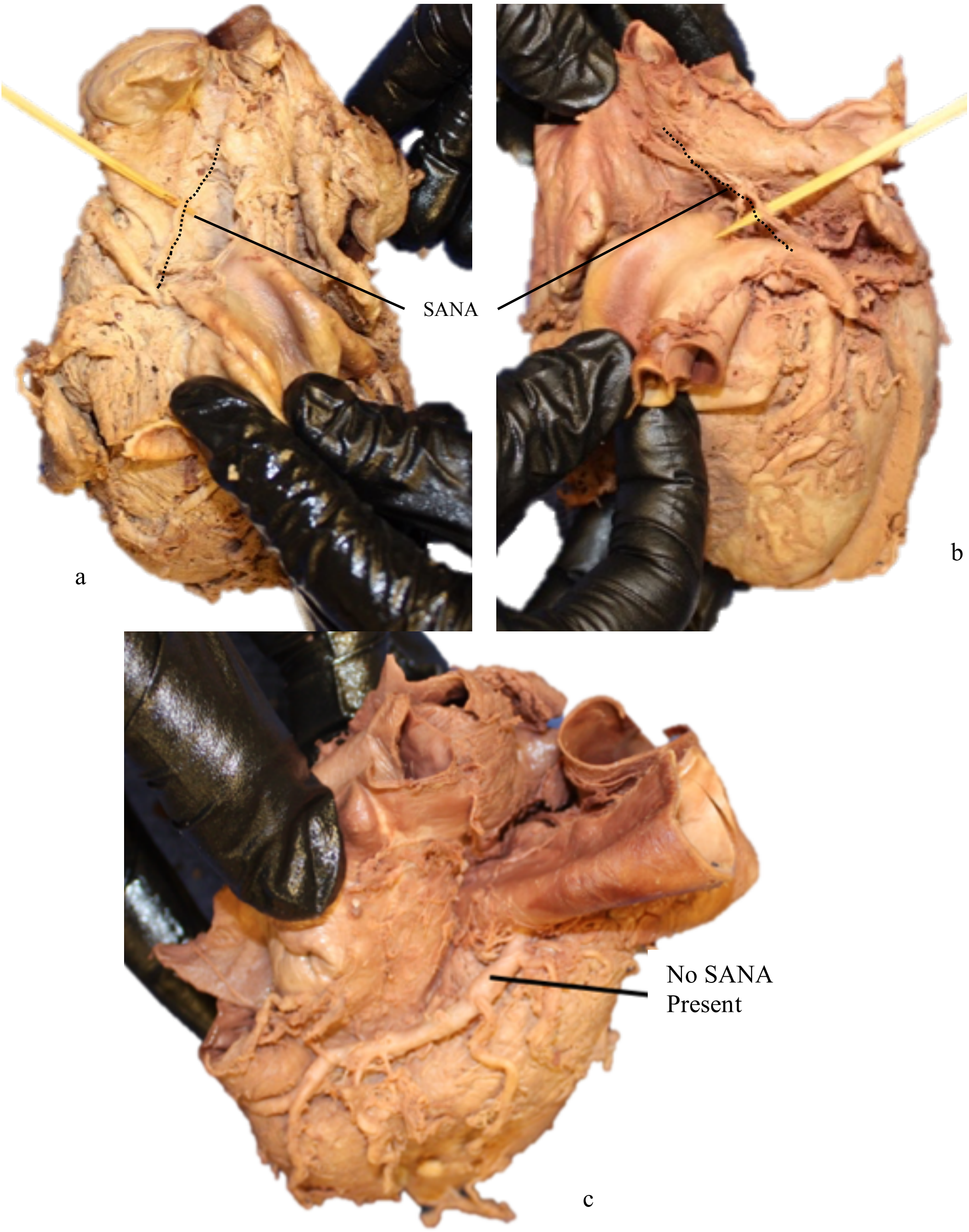
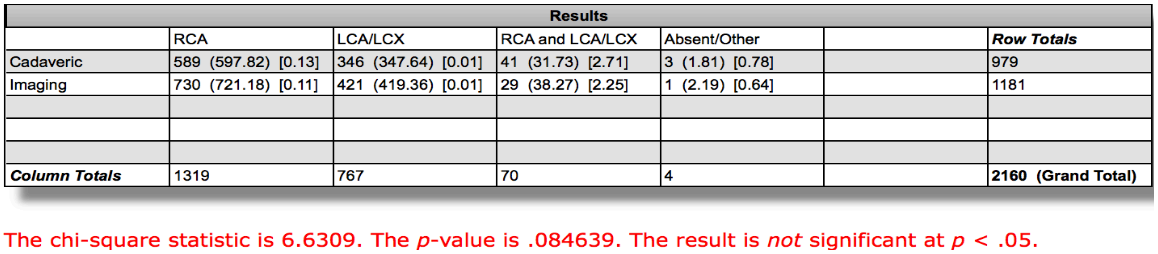


Figure 3.2: Superior view of hearts displaying the SANA when it a) originates from RCA, b) originates from LCA, and c) is absent.

The SANA has one of the most varying origins amongst the main branch of the coronary arteries. Upon examination of the primary literature regarding the origin of the SANA, a separate meta-analysis was discovered. This meta-analysis was extremely thorough and included data from both cadaveric and imaging studies that were found during the literature search. To prevent repetition of data, the meta-analysis was excluded from primary literature data when statistical analysis was performed using Chi-square tests. All contingency tables were performed using an online calculator (Stangroom) and screenshots of the results are included as figures below. Two groups were said to be significantly different if the p-value was less than 0.05, warranting rejection of the null hypothesis, which states that the two groups are not different. If the p-value was greater than 0.05 the two groups were said to be significantly different due to their failure to reject the null hypothesis. Failure to reject the null hypothesis implies that the null hypothesis stating that the two groups are not different must be accepted.

In cadaveric studies, the SANA originated from the RCA in 60.1%, LCA or LCX in 35.3%, and received dual supply in 4.2% of cases. On the other hand, imaging studies showed the SANA deriving from the RCA in 61.8%, LCA/LCX in 35.7%, and received dual supply in 2.5% of cases. Figure 3.3 shows a contingency table analyzing the relationship between the cadaveric and imaging studies. It produced a Chi-square statistic of 6.63 and p-value of 0.085. These values, by convention, imply that the two groups are not significantly different. While these groups do not show significant differences, a p-value of 0.085 signifies that they are nearing significant differences (p-value of 0.05). To avoid pooling groups that may be different, these two groups were kept separate for all subsequent analyses.

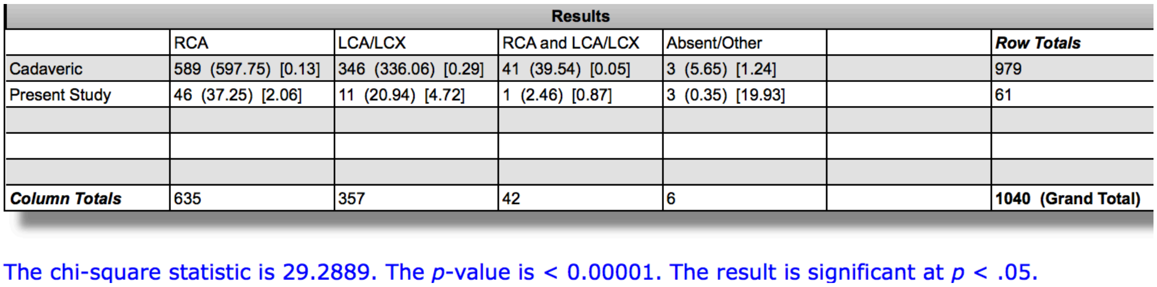


Results						
	RCA	LCA/LCX	RCA and LCA/LCX	Absent/Other		***Row Totals***
Cadaveric	589 (597.82) [0.13]	346 (347.64) [0.01]	41 (31.73) [2.71]	3 (1.81) [0.78]		979
Imaging	730 (721.18) [0.11]	421 (419.36) [0.01]	29 (38.27) [2.25]	1 (2.19) [0.64]		1181
Column Totals	1319	767	70	4		**2160 (Grand Total)**

The chi-square statistic is 6.6309. The *p*-value is .084639. The result is *not* significant at $p < .05$.

Figure 3.3: Chi-square test comparing the origin of the SANA in cadaveric vs. imaging studies.

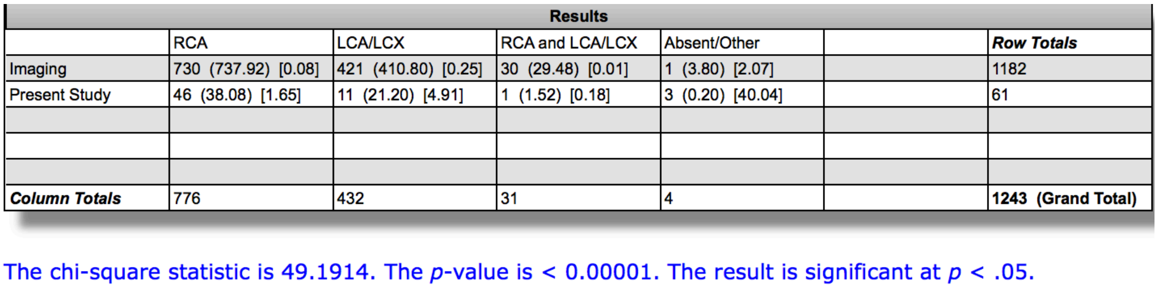
After determining that the cadaveric and imaging data should be considered separately, individual Chi-square tests were performed to analyze the data from the present study to that of cadaveric, and imaging studies (Figures 3.4, 3.5, respectively). The present study reported the SANA originating from the RCA in 76.7%, LCA/LCX in 18.3%, and receiving dual supply in 5% of cases. Although there were minor differences between the cadaveric and imaging studies found in primary literature, comparison of the cadaveric and imaging studies to the present study resulted in p-values drastically less than 0.05. This caused rejection of the null hypothesis, implying that the both are significantly different than the present study. Thus, the data collected in the present study on the SANA origin was significantly different from all published data on this topic in the primary literature.



Results						
	RCA	LCA/LCX	RCA and LCA/LCX	Absent/Other		***Row Totals***
Cadaveric	589 (597.75) [0.13]	346 (336.06) [0.29]	41 (39.54) [0.05]	3 (5.65) [1.24]		979
Present Study	46 (37.25) [2.06]	11 (20.94) [4.72]	1 (2.46) [0.87]	3 (0.35) [19.93]		61
Column Totals	635	357	42	6		**1040 (Grand Total)**

The chi-square statistic is 29.2889. The *p*-value is < 0.00001. The result is significant at $p < .05$.

Figure 3.4: Chi-square test comparing the origin of the SANA in the present study vs. cadaveric studies.



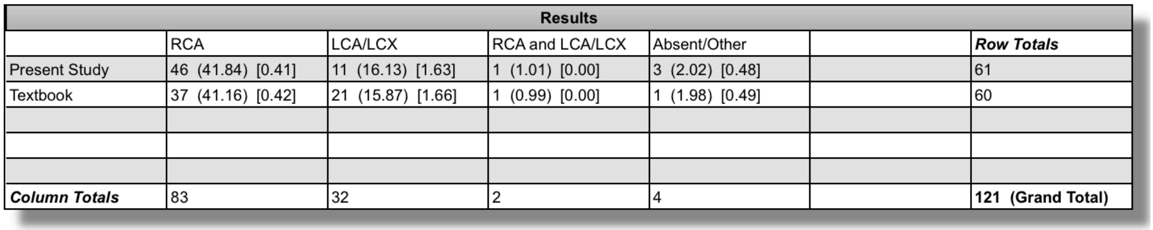
Results

	RCA	LCA/LCX	RCA and LCA/LCX	Absent/Other		***Row Totals***
Imaging	730 (737.92) [0.08]	421 (410.80) [0.25]	30 (29.48) [0.01]	1 (3.80) [2.07]		1182
Present Study	46 (38.08) [1.65]	11 (21.20) [4.91]	1 (1.52) [0.18]	3 (0.20) [40.04]		61
Column Totals	776	432	31	4		**1243 (Grand Total)**

The chi-square statistic is 49.1914. The *p*-value is < 0.00001. The result is significant at *p* < .05.

Figure 3.5: Chi-square test comparing the origin of the SANA in the present study vs. imaging studies.

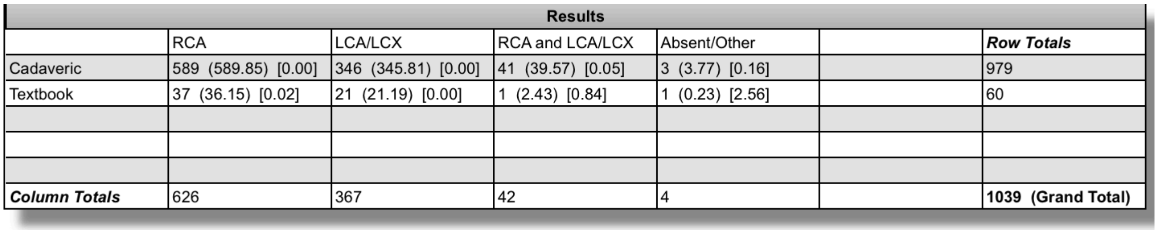
The present study shows significant differences regarding the origin of the SANA when compared to primary literature but fails to show the same differences when compared to the textbooks analyzed in the literature review. The textbooks included in this study were mainly written for graduate or medical school, the information found in these textbooks can be found in Appendix A.The textbooks reported the SANA originating from the RCA in 63.75%, LCA/LCX in 35%, and receiving dual supply in 1.25% of cases. Figures 3.6, 3.7, and 3.8 show the results of Chi-square tests comparing the information found in textbooks to the data found in the present study, cadaveric studies, and imaging studies, respectively. Failure to reject the null hypothesis deemed that the textbook data was not significantly different than the present study and cadaveric studies with p-values of 0.165 and 0.304, respectively. However, the textbook data was deemed significantly different than the data found in imaging studies with a p-value of 0.029. While it is not proven, this finding does seem to hint at the possibility that these textbook values originated from cadaveric studies. The data presented above does, however, prove that the values found in textbooks are significantly different than the data found in imaging studies.



Results						
	RCA	LCA/LCX	RCA and LCA/LCX	Absent/Other		***Row Totals***
Present Study	46 (41.84) [0.41]	11 (16.13) [1.63]	1 (1.01) [0.00]	3 (2.02) [0.48]		61
Textbook	37 (41.16) [0.42]	21 (15.87) [1.66]	1 (0.99) [0.00]	1 (1.98) [0.49]		60
Column Totals	83	32	2	4		**121 (Grand Total)**

The chi-square statistic is 5.093. The p-value is .165113. The result is *not* significant at $p < .05$.

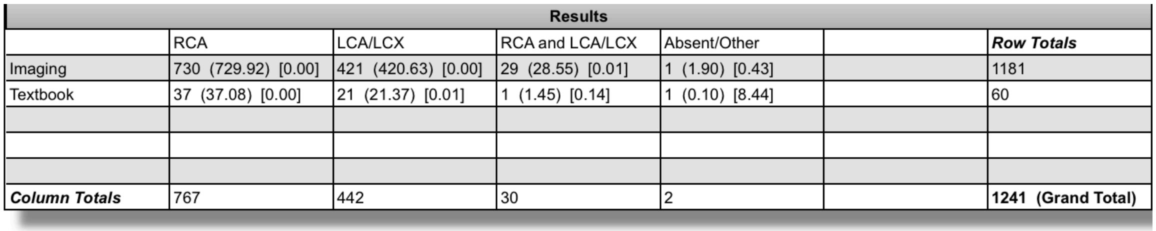
Figure 3.6: Chi-square test comparing the origin of the SANA in the present study vs. current textbooks.



Results						
	RCA	LCA/LCX	RCA and LCA/LCX	Absent/Other		***Row Totals***
Cadaveric	589 (589.85) [0.00]	346 (345.81) [0.00]	41 (39.57) [0.05]	3 (3.77) [0.16]		979
Textbook	37 (36.15) [0.02]	21 (21.19) [0.00]	1 (2.43) [0.84]	1 (0.23) [2.56]		60
Column Totals	626	367	42	4		**1039 (Grand Total)**

The chi-square statistic is 3.6292. The p-value is .304389. The result is *not* significant at $p < .05$.

Figure 3.7: Chi-square test comparing the origin of the SANA in cadaveric studies vs. current textbooks.



Results						
	RCA	LCA/LCX	RCA and LCA/LCX	Absent/Other		***Row Totals***
Imaging	730 (729.92) [0.00]	421 (420.63) [0.00]	29 (28.55) [0.01]	1 (1.90) [0.43]		1181
Textbook	37 (37.08) [0.00]	21 (21.37) [0.01]	1 (1.45) [0.14]	1 (0.10) [8.44]		60
Column Totals	767	442	30	2		**1241 (Grand Total)**

The chi-square statistic is 9.021. The p-value is .029013. The result is significant at $p < .05$.

Figure 3.8: Chi-square test comparing the origin of the SANA in imaging studies vs. current textbooks.

The next, and largest, branch issued by the RCA is the right or acute marginal artery. The right marginal artery branches from the RCA as it curves around the acute margin of the heart in the right atrioventricular sulcus. While little research was found in the primary literature about the origin of the right marginal artery, it was included in this study for thoroughness. The right marginal artery originated from the RCA in fifty-eight of the sixty (96.7%) hearts studied (Figure 3.1). The right marginal artery of the two remaining hearts (3.3%) originated directly from the aorta, crossing over the RV until it reached acute margin of the heart, where it then descended towards the apex (Figure 3.9).

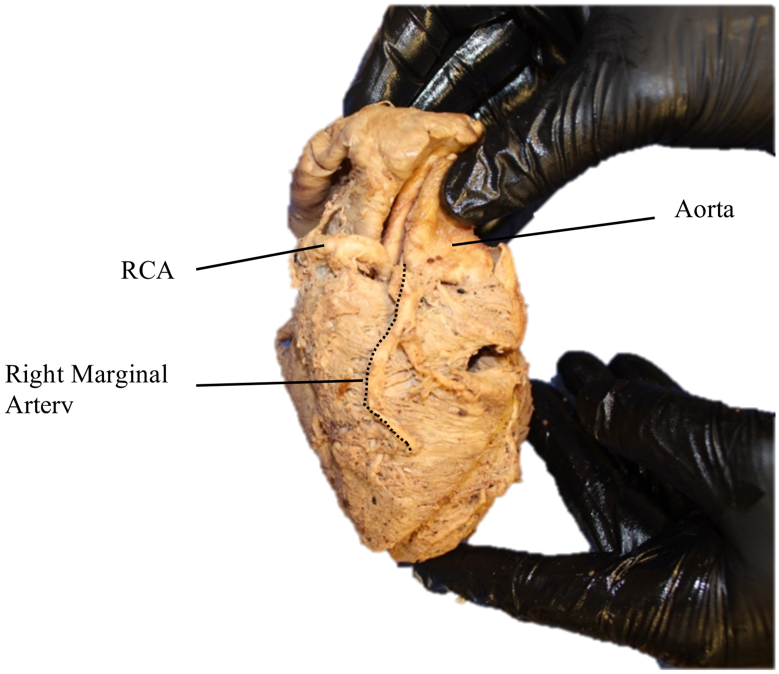


Figure 3.9: Lateral view of a heart displaying origination of the right marginal artery from the aorta.

After issuing the right marginal artery, the RCA curves posteriorly in the right AV sulcus until it reaches the crux of the heart where it may issue the PIVA, which descends in the posterior interventricular sulcus. The PIVA, like the SANA, is one of the more variant branches of the coronary arteries. In this study, it found to be directly correlated to the dominance of the heart. The PIVA originated from the RCA in fifty-two of the sixty (86.7%) hearts examined in this study, all of which were right dominant. The PIVA was issued by the LCX in six (10%) and received dual supply from the RCA and LCX in the remaining two hearts (3.3%) studied, resulting in six left dominant and two codominant hearts, respectively (Figures 3.1 and 3.21). Figures 3.10a, 3.10b, and 3.10c show origination of the PIVA from the RCA, from the LCX, and dual supply from RCA and LCX, respectively.

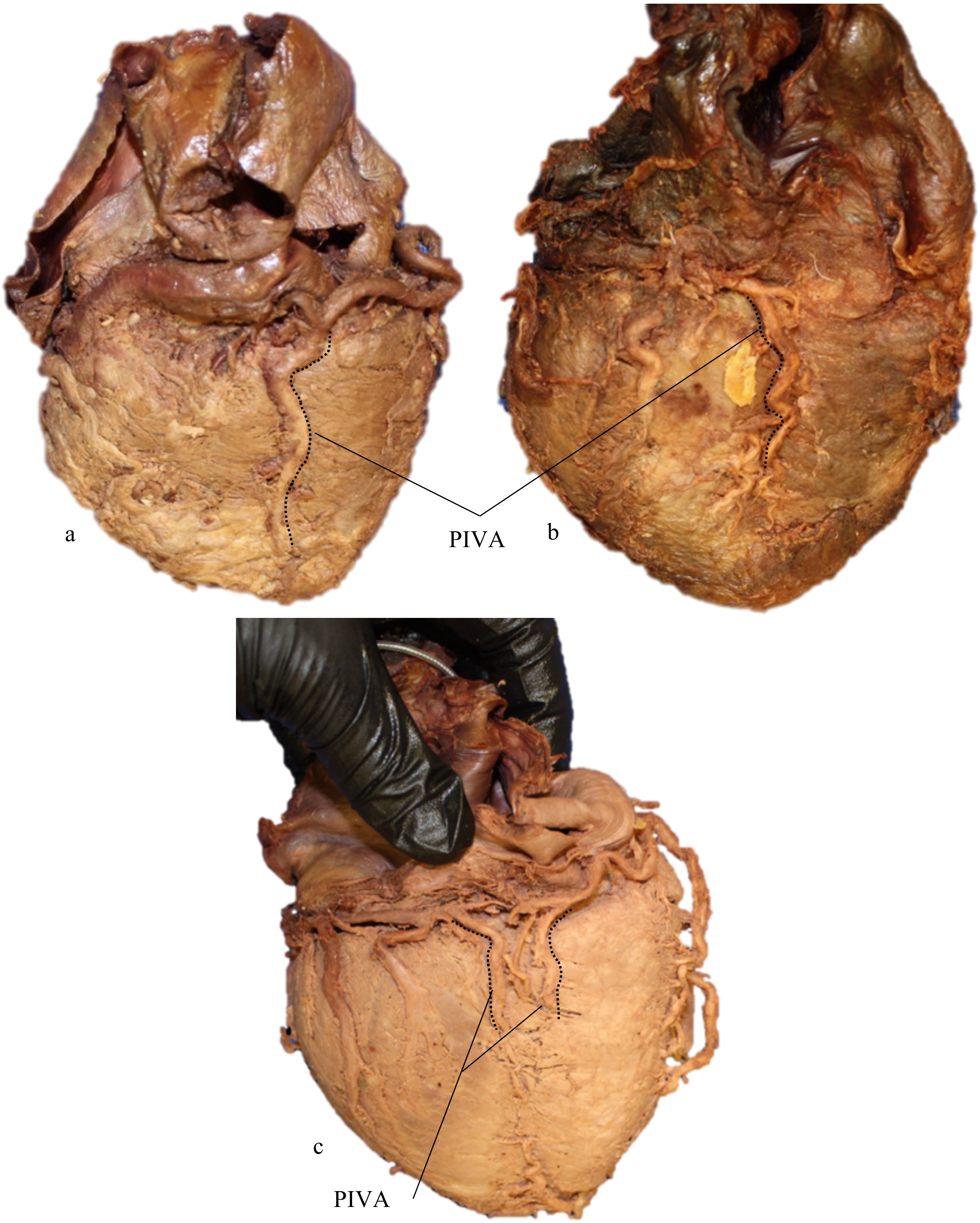


Figure 3.10: Posterior view of hearts displaying the PIVA when it originates from a) RCA, b) LCX, and c) both RCA and LCX.

Branching from the apex of the deep inverted loop of the RCA as it crosses the crux of the heart is the AVNA. This artery supplies blood to the atrioventricular node and, like the PIVA, is very strongly correlated to the coronary artery dominance of the heart. The origin of the AVNA in the hearts examined in this study was very similar to the origin of the PIVA. The results showed that in fifty-three hearts (88.3%) the AVNA originated from the RCA, six (10%) from the LCX, and 1 (1.7%) received dual supply from the RCA and LCX (Figure 3.1). Figure 3.11 shows an example of each possible origin for the AVNA.

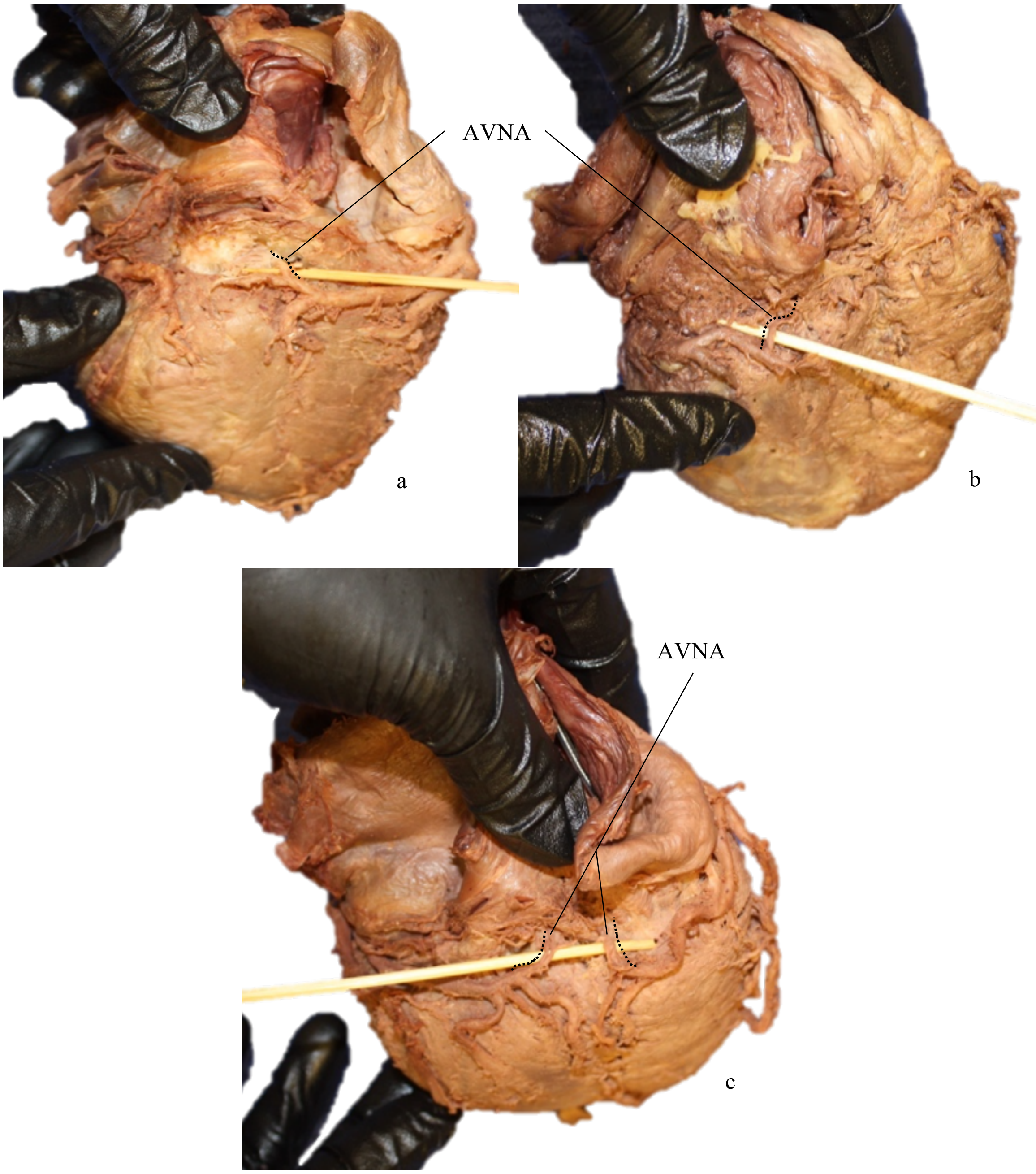
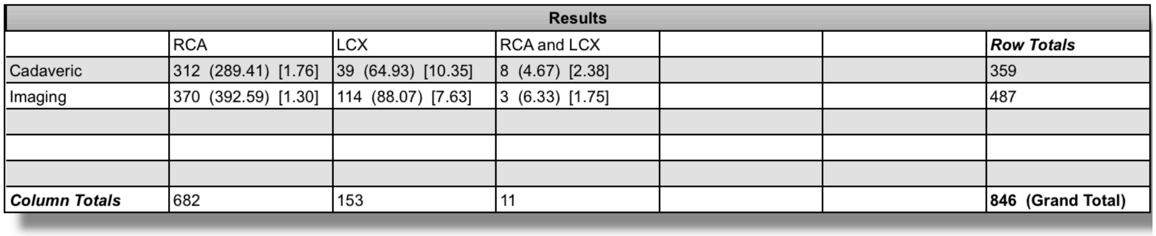


Figure 3.11: Posterior view of hearts displaying the AVNA when it originates from a) RCA, b) LCX, and c) both RCA and LCX.

In cadaveric studies, the AVNA originated from the RCA in 87.5%, LCX in 11%, and both RCA and LCX in 2.3% of cases. On the other hand, imaging studies showed the

AVNA deriving from the RCA in 75.9%, LCX in 23.5%, and both RCA and LCX in 0.6% of cases. Similar to those performed for the origin of the SANA, Chi-square tests were performed to compare data for the origin of the AVNA in the present study to cadaveric and imaging studies. A Chi-square test performed on the contingency table comparing the origin of the AVNA in cadaveric and imaging studies determined that the two groups are significantly different, with a Chi-square statistic of 40.26 and a p-value of less than 0.00001 (Figure 3.12). This suggests that, due to their significant differences, the cadaveric and imaging data should not be compiled into one group.

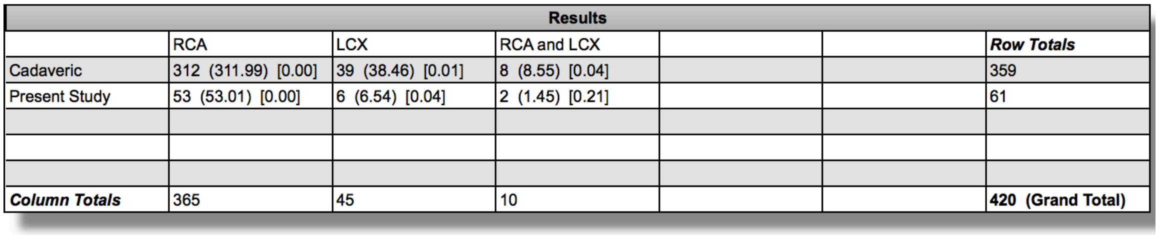


Results						
	RCA	LCX	RCA and LCX			***Row Totals***
Cadaveric	312 (289.41) [1.76]	39 (64.93) [10.35]	8 (4.67) [2.38]			359
Imaging	370 (392.59) [1.30]	114 (88.07) [7.63]	3 (6.33) [1.75]			487
Column Totals	682	153	11			**846 (Grand Total)**

The chi-square statistic is 25.18. The *p*-value is < 0.00001. The result is significant at *p* < .05.

Figure 3.12: Chi-square test comparing the origin of the AVNA in imaging vs. cadaveric studies.

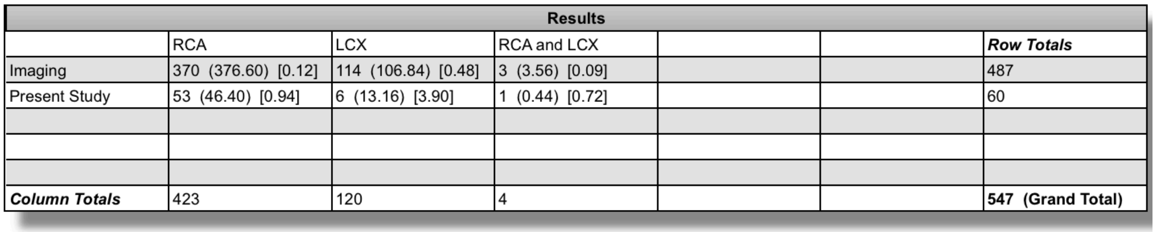
The present study reported the AVNA originating from the RCA in 88.3%, LCX in 10%, and dual supply in 1.7% of cases. Figures 3.13 and 3.14 show that, when compared to the present study, the imaging studies are significantly different (p-value of 0.044) but cadaveric studies are not (p-value of 0.864). These findings correspond to the expected results for this study. Since the present study is a cadaveric study, it is expected that the cadaveric studies would be more relevant to the present study than the imaging studies.



Results						
	RCA	LCX	RCA and LCX			***Row Totals***
Cadaveric	312 (311.99) [0.00]	39 (38.46) [0.01]	8 (8.55) [0.04]			359
Present Study	53 (53.01) [0.00]	6 (6.54) [0.04]	2 (1.45) [0.21]			61
Column Totals	365	45	10			**420 (Grand Total)**

The chi-square statistic is 0.2929. The *p*-value is .863752. The result is *not* significant at *p* < .05.

Figure 3.13: Chi-square test comparing the origin of the AVNA in the present study vs. cadaveric studies.

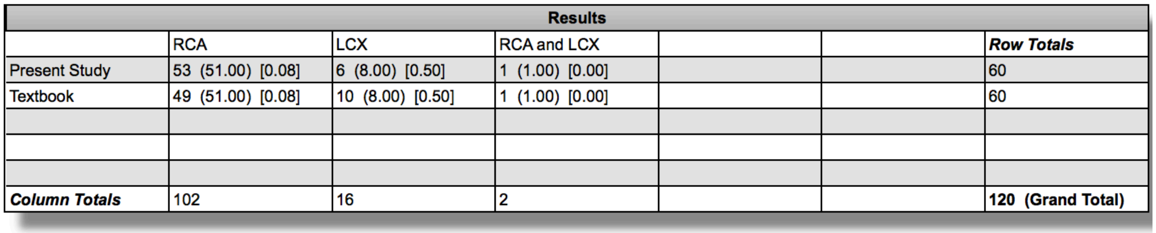


Results						
	RCA	LCX	RCA and LCX			***Row Totals***
Imaging	370 (376.60) [0.12]	114 (106.84) [0.48]	3 (3.56) [0.09]			487
Present Study	53 (46.40) [0.94]	6 (13.16) [3.90]	1 (0.44) [0.72]			60
Column Totals	423	120	4			**547 (Grand Total)**

The chi-square statistic is 6.2392. The *p*-value is .044174. The result is significant at $p < .05$.

Figure 3.14: Chi-square test comparing the origin of the AVNA in the present study vs. imaging studies.

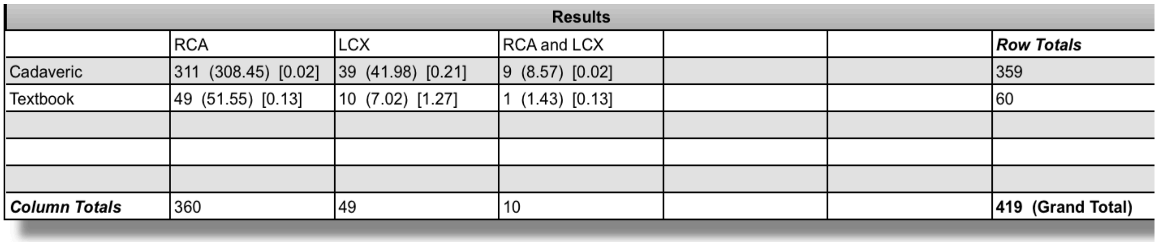
The data found in the current study and primary literature regarding the origin of the AVNA was also compared to information presented in current medical textbooks. The textbooks reported that the AVNA originated from the RCA in 81.25%, LCX in 17%, and from both RCA and LCX in 1.75% of cases. Figures 3.15, 3.16, and 3.17 show the Chi-square tests comparing the textbook data to that of the present study, cadaveric studies, and imaging studies, respectively. All three sets of data failed to reject the null hypothesis and are thus not significantly different than the information found in textbooks. The p values (0.561, 0.411, and 0.349) were all significantly higher than the 0.05 necessary to indicate that a lack of significant differences, suggesting that the data was not significantly different from the data found in the textbooks. In this circumstance, the current medical textbooks appear to agree with the data presented in primary literature and the current study.



Results						
	RCA	LCX	RCA and LCX			***Row Totals***
Present Study	53 (51.00) [0.08]	6 (8.00) [0.50]	1 (1.00) [0.00]			60
Textbook	49 (51.00) [0.08]	10 (8.00) [0.50]	1 (1.00) [0.00]			60
Column Totals	102	16	2			**120 (Grand Total)**

The chi-square statistic is 1.1569. The *p*-value is .560777. The result is *not* significant at $p < .05$.

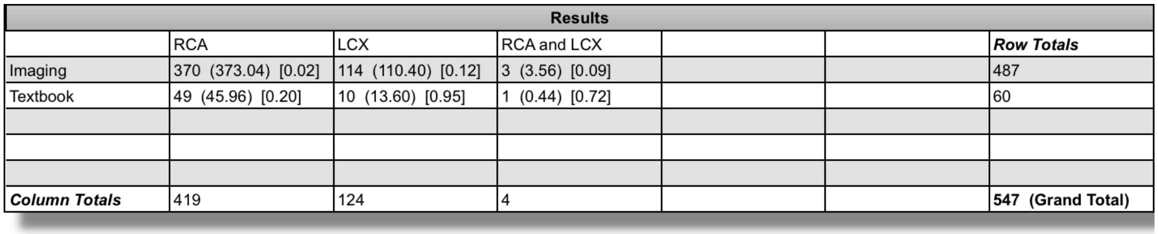
Figure 3.15: Chi-square test comparing the origin of the AVNA in the present study vs. current textbooks.



Results						
	RCA	LCX	RCA and LCX			***Row Totals***
Cadaveric	311 (308.45) [0.02]	39 (41.98) [0.21]	9 (8.57) [0.02]			359
Textbook	49 (51.55) [0.13]	10 (7.02) [1.27]	1 (1.43) [0.13]			60
Column Totals	360	49	10			**419 (Grand Total)**

The chi-square statistic is 1.7799. The *p*-value is .410684. The result is *not* significant at *p* < .05.

Figure 3.16: Chi-square test comparing the origin of the AVNA in cadaveric studies vs. current textbooks.



Results						
	RCA	LCX	RCA and LCX			***Row Totals***
Imaging	370 (373.04) [0.02]	114 (110.40) [0.12]	3 (3.56) [0.09]			487
Textbook	49 (45.96) [0.20]	10 (13.60) [0.95]	1 (0.44) [0.72]			60
Column Totals	419	124	4			**547 (Grand Total)**

The chi-square statistic is 2.1034. The *p*-value is .34935. The result is *not* significant at *p* < .05.

Figure 3.17: Chi-square test comparing the origin of the AVNA in the imaging studies vs. current textbooks.

The Origin and Branches of the LCA

The left coronary artery typically originates from the left sinus of Valsalva in the aortic root as a short trunk that then bifurcates or trifurcates. Bifurcation of the LCA produces two branches, the AIVA and LCX. Trifurcation of the LCA produces three main branches, the AIVA, LCX, and left main diagonal artery. As the data in Figure 3.18 suggests, the LCA originated from the aorta in all sixty hearts studied. Figure 3.18 also shows that the both the LCX and AIVA originated from the LCA in all sixty hearts studied.

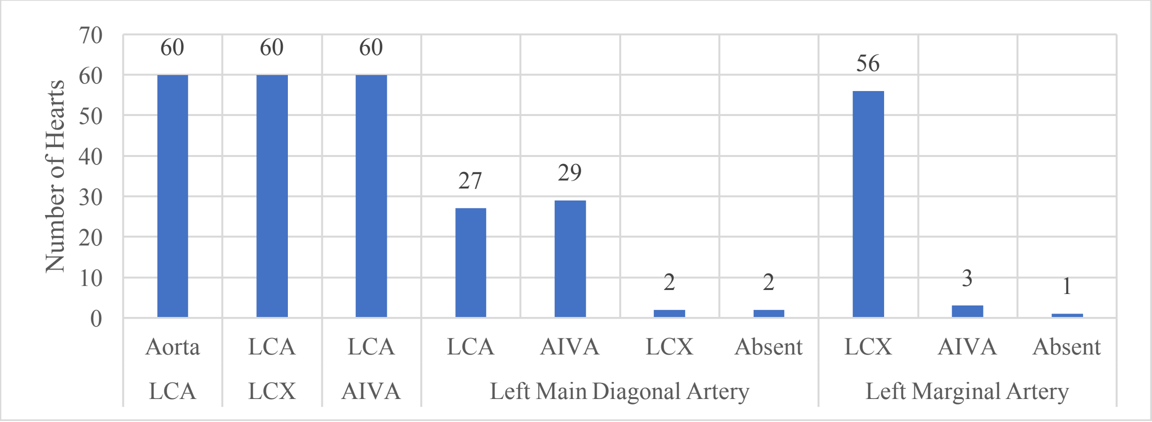


Figure 3.18: Analysis of the origin of the LCA and its major branches in human hearts. N=60

The left main diagonal artery, unlike the previous three mentioned, was quite variable in origin. Trifurcation of the LCA produced a left main diagonal artery that originated from the LCA in twenty-seven (45%) of the sixty hearts studied. The remaining thirty-three hearts (55%) had a bifurcation of the LCA but the origin of the left main diagonal artery varied amongst three different categories. The left main diagonal originated from the AIVA in twenty-nine of the thirty-three hearts (87.9%) with a bifurcated LCA. It originated from the LCX in two (6%) and the remaining two hearts (6%) had no sign of a left main diagonal branch. Figure 3.19 shows an example of each possible origin of the left main diagonal artery.

The most frequent branch issued by the LCX is the left or obtuse marginal artery. This artery, like the right or acute marginal artery, branches from the main coronary artery and courses the margin of the heart as it descends towards the apex. The hearts examined in the present study showed that the left marginal artery consistently originated from the LCX. Of the sixty hearts studied, the left marginal artery originated from the LCX in fifty-six hearts (93.3%), from the AIVA in three hearts (5%), and was absent in one heart (1.7%) (Figure 3.18). Unlike the SANA, location of the left main diagonal artery and the left marginal artery was not affected by scar tissue. The hearts in which these arteries were absent did not show any sign of scar tissue but rather the artery was simply not present. Said hearts did however have other smaller, unnamed branches supplying the regions expected to be supplied by the left main diagonal artery and left marginal artery. Figure 3.20 shows an example of each possible origin as well as a heart with no left marginal artery.

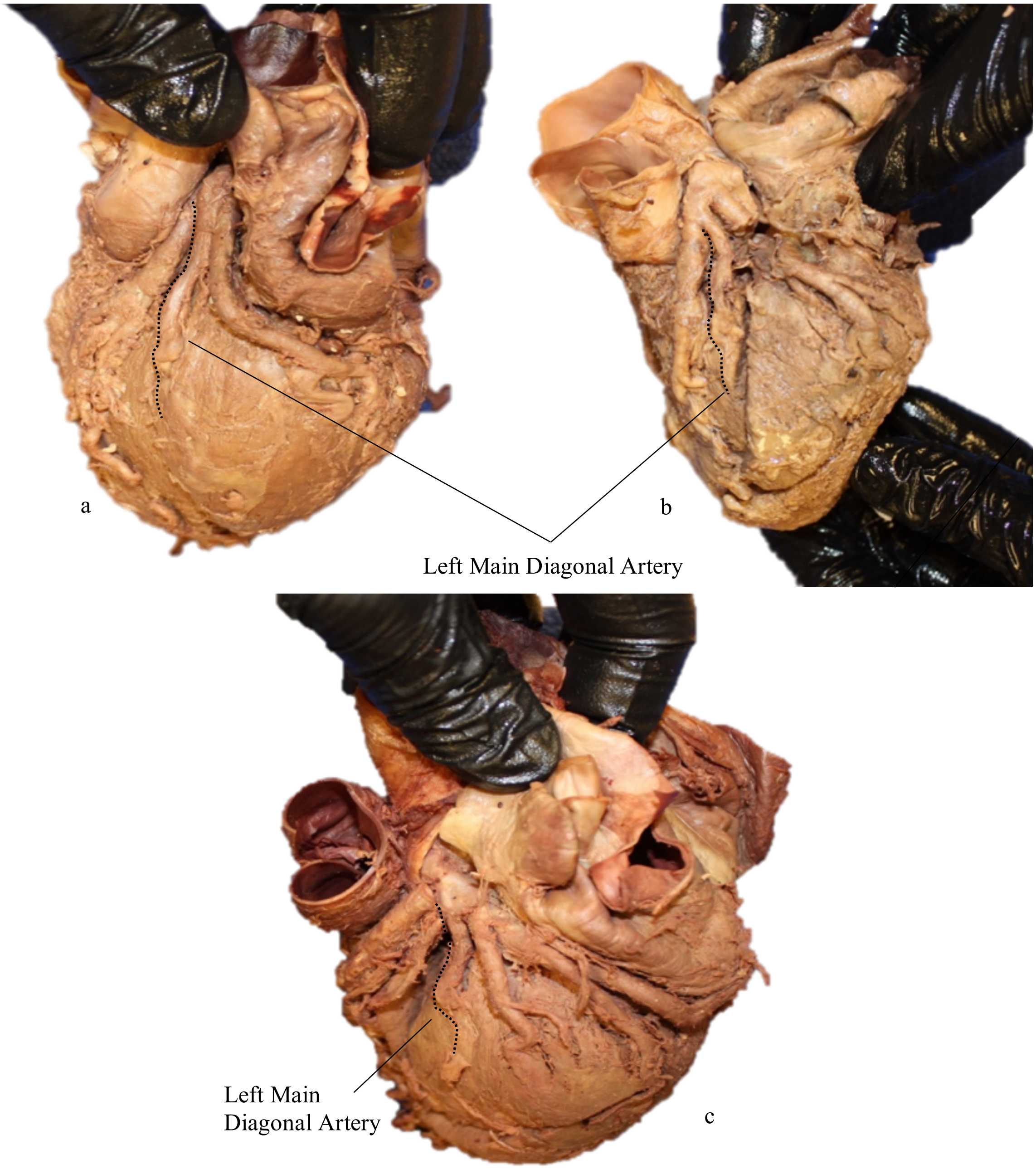


Figure 3.19: a. Left lateral view of hearts displaying the left main diagonal artery when it originates from a) trifurcation of the LCA, b) AIVA, and c) LCX.

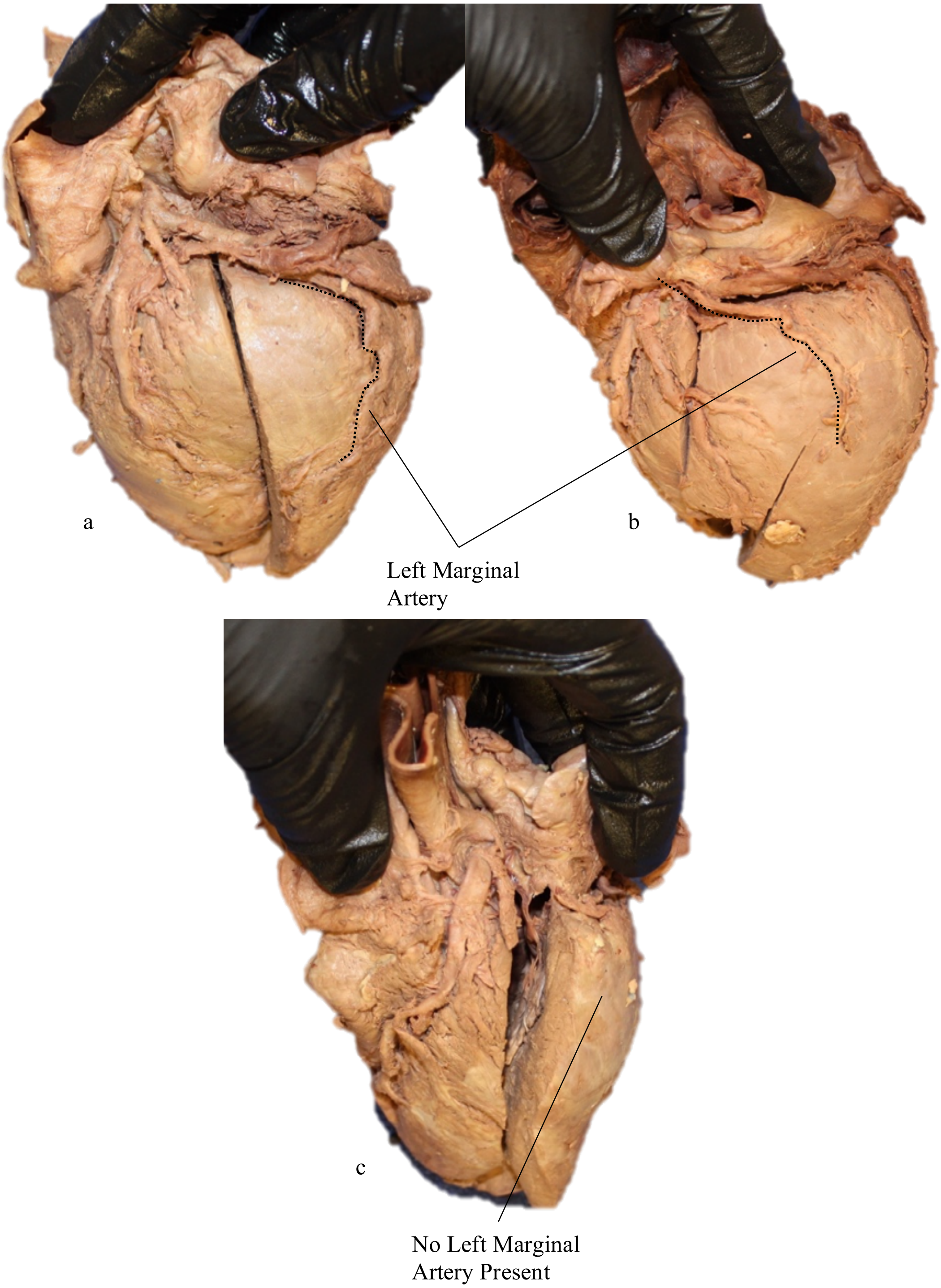


Figure 3.20: Left lateral view of hearts displaying the left marginal artery when it a) originates from LCX, b) originates from AIVA, and c) is absent.

Coronary Artery Dominance

As previously mentioned, the coronary artery dominance is highly correlated to the origin of the PIVA and, to a lesser extent, the origin of the AVNA. By definition, the dominant coronary artery is the artery that reaches or crosses the crux of the heart and supplies the PIVA, thus giving a direct relationship between PIVA and dominance. As demonstrated in Figure 3.21, of the sixty hearts studied, fifty-two (86.7%) were right dominant, six (10%) were left dominant, and two (3.3%) were codominant. The origin of the AVNA was also very highly correlated to the coronary artery dominance, varying only by one heart. While there were two codominant hearts, there was only one heart with dual supply of the AVNA, thus preventing a perfect correlation in this sample group.

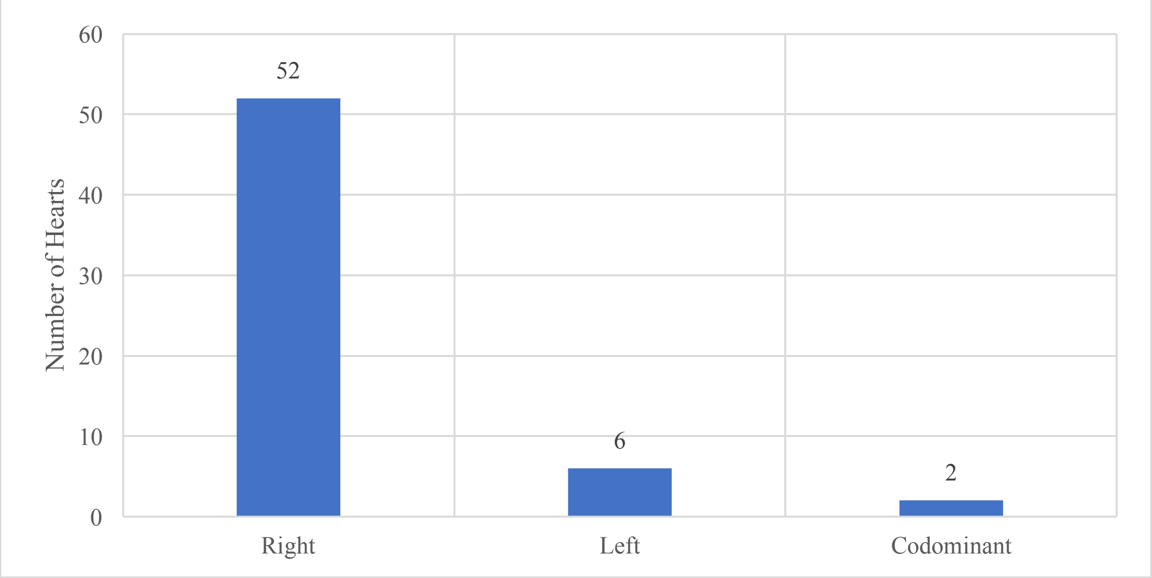
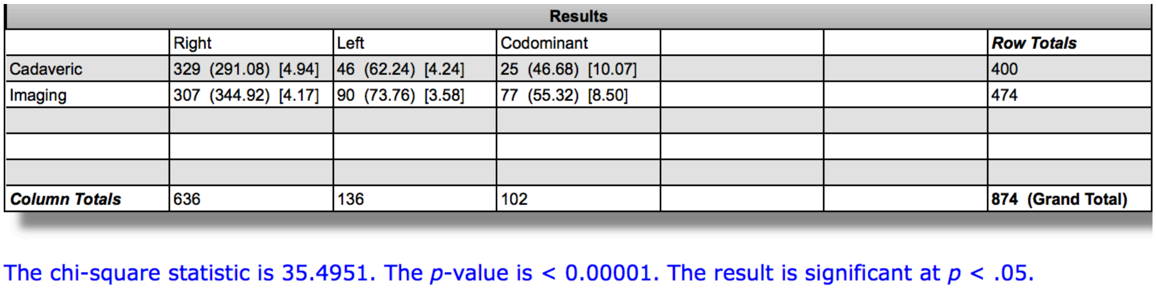


Figure 3.21: Analysis of the coronary artery dominance in human hearts. N=60

In cadaveric studies, the coronary artery dominance was right dominant in 82.2%, left dominant in 11.5%, and codominant in 6.2% of cases. On the other hand, imaging studies showed the coronary artery dominance was right dominant in 64.7%, left dominant in 19%, and codominant in 16.3% of cases. The coronary artery dominance found in this study, like the origin of the SANA and AVNA, was also compared to primary literature and current medical textbooks using Chi-square tests. First, the cadaveric and imaging studies found in primary literature were evaluated for significant differences. As shown in

Figure 3.22, the cadaveric and imaging studies are significantly different with respect to the coronary artery dominance, resulting in a Chi-square statistic of 35.50 and a p-value less than 0.00001.



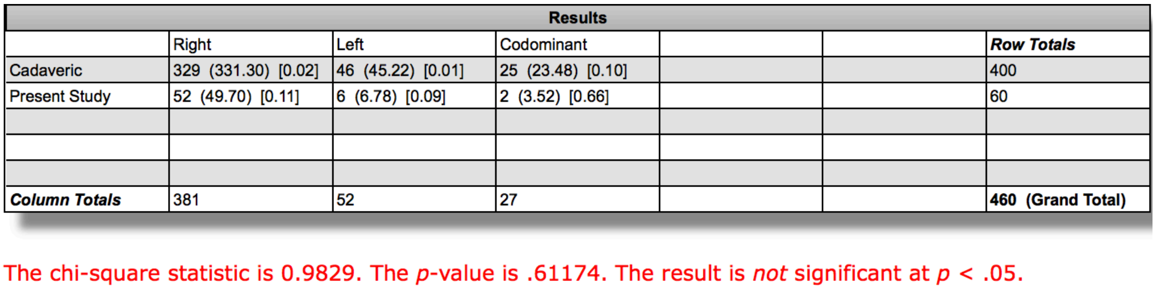
Results

	Right	Left	Codominant			***Row Totals***
Cadaveric	329 (291.08) [4.94]	46 (62.24) [4.24]	25 (46.68) [10.07]			400
Imaging	307 (344.92) [4.17]	90 (73.76) [3.58]	77 (55.32) [8.50]			474
Column Totals	636	136	102			**874 (Grand Total)**

The chi-square statistic is 35.4951. The *p*-value is < 0.00001. The result is significant at *p* < .05.

Figure 3.22: Chi-square test comparing the coronary artery dominance in imaging vs. cadaveric studies.

The present study reported the coronary artery dominance to be right dominant in 86.7%, left dominant in 10%, and codominant in 3.3% of cases. Similar to the origin of the AVNA, when the coronary artery dominance data gathered in this study was individually compared to cadaveric and imaging studies, one was found to be significantly different while the other was not. Figures 3.23 and 3.24 show that, when compared to the present study, the cadaveric studies are not significantly different (p-value=0.612) but the data from imaging studies are significantly different (p-value=0.002). Again, these findings correspond to the expected results for this study. It is expected that, since the study at hand is a cadaveric study, the cadaveric studies would align more closely with the present study than the imaging studies.

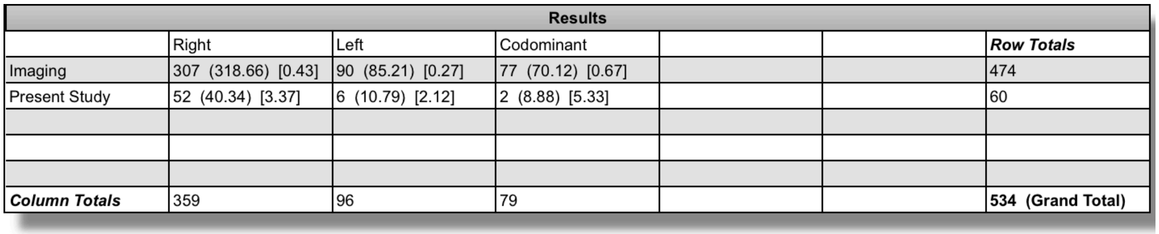


Results

	Right	Left	Codominant			***Row Totals***
Cadaveric	329 (331.30) [0.02]	46 (45.22) [0.01]	25 (23.48) [0.10]			400
Present Study	52 (49.70) [0.11]	6 (6.78) [0.09]	2 (3.52) [0.66]			60
Column Totals	381	52	27			**460 (Grand Total)**

The chi-square statistic is 0.9829. The *p*-value is .61174. The result is *not* significant at *p* < .05.

Figure 3.23: Chi-square test comparing the coronary artery dominance in the present study vs. cadaveric studies.

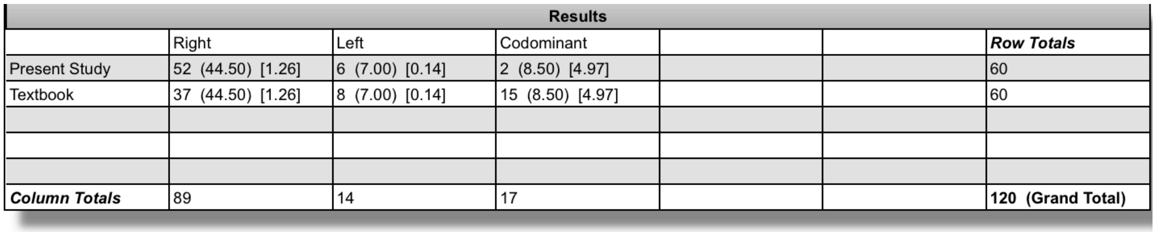


Results						
	Right	Left	Codominant			***Row Totals***
Imaging	307 (318.66) [0.43]	90 (85.21) [0.27]	77 (70.12) [0.67]			474
Present Study	52 (40.34) [3.37]	6 (10.79) [2.12]	2 (8.88) [5.33]			60
Column Totals	359	96	79			**534 (Grand Total)**

The chi-square statistic is 12.1933. The *p*-value is .00225. The result is significant at $p < .05$.

Figure 3.24: Chi-square test comparing the coronary artery dominance in the present study vs. imaging studies.

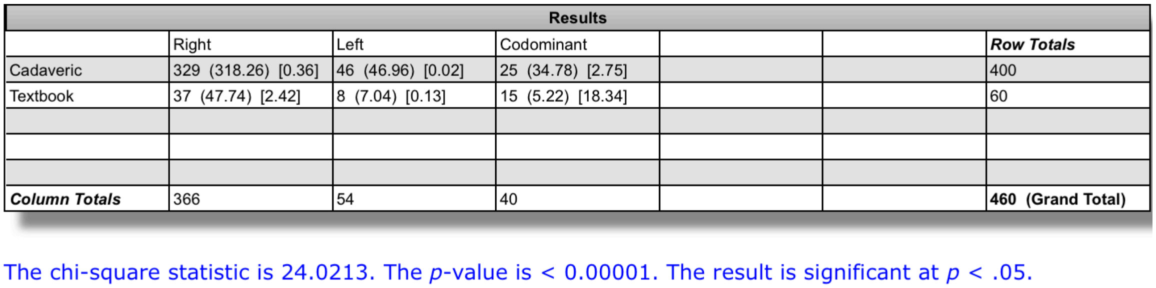
The textbooks reported the coronary artery dominance to be right dominant in 61.2%, left dominant in 14.3%, and codominant in 24.5% of cases. Contrary to comparisons of the SANA and AVNA origins to current medical textbooks, the coronary artery dominance data from the present study and cadaveric studies were found to be significantly different, with p-values of 0.0017 and <0.00001, respectively (Figure 3.25 and 3.26). Unlike the present study and cadaveric studies, the imaging studies failed to reject the null hypothesis implying that they are not significantly different than the textbooks, with a p-value of 0.185 (Figure 3.27). Contrary to that which was suggested in the case of SANA origin, the textbooks appear to align more closely with the data presented in the imaging studies found in primary literature. This statistical relevance suggests that the information in textbooks regarding coronary artery dominance may have originated from imaging studies.



Results						
	Right	Left	Codominant			***Row Totals***
Present Study	52 (44.50) [1.26]	6 (7.00) [0.14]	2 (8.50) [4.97]			60
Textbook	37 (44.50) [1.26]	8 (7.00) [0.14]	15 (8.50) [4.97]			60
Column Totals	89	14	17			**120 (Grand Total)**

The chi-square statistic is 12.755. The *p*-value is .001699. The result is significant at $p < .05$.

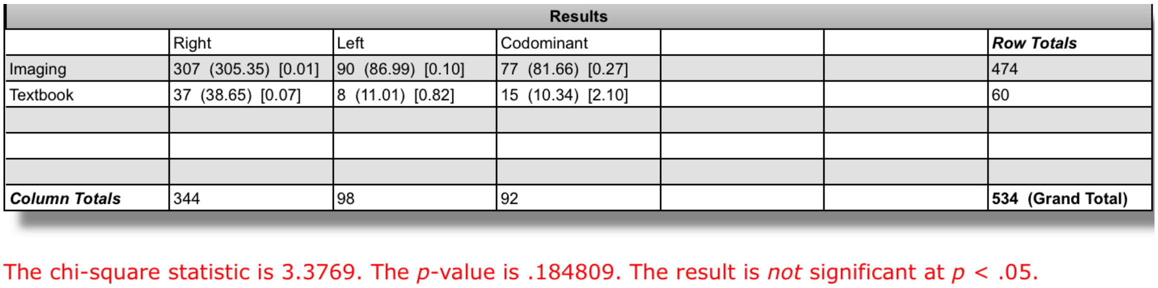
Figure 3.25: Chi-square test comparing the coronary artery dominance in the present study vs. textbooks.



Results						
	Right	Left	Codominant			***Row Totals***
Cadaveric	329 (318.26) [0.36]	46 (46.96) [0.02]	25 (34.78) [2.75]			400
Textbook	37 (47.74) [2.42]	8 (7.04) [0.13]	15 (5.22) [18.34]			60
Column Totals	366	54	40			**460 (Grand Total)**

The chi-square statistic is 24.0213. The *p*-value is < 0.00001. The result is significant at *p* < .05.

Figure 3.26: Chi-square test comparing the coronary artery dominance in cadaveric studies vs. textbooks.



Results						
	Right	Left	Codominant			***Row Totals***
Imaging	307 (305.35) [0.01]	90 (86.99) [0.10]	77 (81.66) [0.27]			474
Textbook	37 (38.65) [0.07]	8 (11.01) [0.82]	15 (10.34) [2.10]			60
Column Totals	344	98	92			**534 (Grand Total)**

The chi-square statistic is 3.3769. The *p*-value is .184809. The result is *not* significant at *p* < .05.

Figure 3.27: Chi-square test comparing the coronary artery dominance in imaging studies vs. textbooks.

This study examined the normal and variant anatomy of the right and left coronary arteries by using sixty cadaveric hearts provided by the Anatomical Board of the State of Nebraska to the UNMC gross anatomy laboratory. It found the site of origin for the RCA, SANA, right marginal artery, PIVA, AVNA, LCA, LCX, AIVA, left main diagonal artery, and left marginal artery. The origin of the SANA, origin of the AVNA, and coronary artery dominance were then analyzed for significant differences to the information presented in primary literature and current medical textbooks. Using the results of the statistical analysis, the next chapter will discuss the educational and clinical implications of the data gathered in this study.

Chapter 4: Discussion

This study utilized classical dissection of cadaveric donors in the UNMC gross anatomy lab to study the normal and variant anatomy of the coronary arteries. Throughout the years, anatomical variation studies of the coronary arteries have utilized many different cadaveric and imaging techniques. Due to resources available, this project utilized a cadaveric technique rather than imaging techniques. All subjects in this study donated their bodies to the Anatomical Board of the State of Nebraska, allowing for cadaveric dissection by medical, allied health, and graduate students at UNMC. The dissection protocol carried out by the professional students involved removing the hearts from the thoracic cavity and pericardium. During the dissection, many coronary arteries were severed to visualize the internal structures of the heart, thus preventing the use of certain cadaveric dissection techniques, such as dye injection or corrosion methods. As described in Chapter 1, cadaveric dissection aided by dye injection requires the coronary arteries to be completely intact for the dye to reach the whole coronary artery, preventing its use in this research.

The goal of this project was to study the normal and variant anatomy of the coronary arteries of a population of sixty human cadaveric donors and compare the data gathered to current primary literature and medical textbooks. Most studies in primary literature only examined the variability of the SANA, AVNA, or coronary artery dominance. This study sought to collect a complete analysis on the origin of all major branches of the coronary arteries. It included the origin of the more variable arteries such as AVNA and SANA but also examined the origin of less commonly studied arteries such as right or left marginal arteries. Data regarding the origin of all the main braches was recorded but insufficient primary literature prevented comparison of the data other than the origin of the SANA, origin of the AVNA, and coronary artery dominance to literature values.

The normal and variant anatomy of the coronary arteries have been sparsely studied for decades, dating back to the 1920's (Crainicianu, 1922). Classical cadaveric dissection began as the most commonly utilized technique but recent technological advances have allowed for the use of imaging techniques, such as computed tomography angiography. Imaging studies do have the ability to evaluate a larger population size but typically only evaluate those with some sort of cardiovascular condition. Thus, the selection of participants in an imaging study provides a sample that may not be representative of the human population as a whole. While it has not been proven, it is possible that those who a have coronary artery condition that requires the use of an imaging technique may be predisposed to said condition due to their coronary artery anatomy.

Statistical analysis did not show any one distinct pattern across all comparisons. For two groups to be considered significantly different, they must vary enough that the probability of the differences occurring by mere chance is less than 0.05%, thus rejecting the null hypothesis that the two groups are not different. If the probability rises above 0.05%, rejection of the null hypothesis will fail and the two groups fail to show significant differences.

Upon analysis, the most frequent result showed that, when compared head to head, the present study was significantly different than the imaging studies in all three categories. As discussed in the previous chapter, this is to be expected due to the varying nature of the population selection between the two types of studies. The only caveat was when analyzing the origin of the AVNA, the two were significantly different but both showed no significant differences to the textbooks. Another common result was that cadaveric and imaging studies showed significant or nearly significant differences in all three categories. Also, the present study generally showed no significant differences to the cadaveric studies. As discussed in the previous chapter, the only category where the present study was significantly different from the cadaveric studies was when comparing the origin of the SANA. When compared head to head these two showed significant differences but when compared to textbooks they both showed no significant differences to the textbooks.

Comparison of the information in textbooks to the present study and primary literature showed mixed results. Analysis of the SANA origin showed that the present study and cadaveric studies showed no significant differences to the textbooks while the imaging studies showed significantly difference. This finding may suggest that the information found in textbooks regarding the SANA origin originated from cadaveric studies. Unlike the SANA origin, analysis of the coronary artery dominance showed that the present study and cadaveric studies are significantly different than the textbooks while the imaging studies showed no significant differences. This data suggests that the information found in textbooks regarding the origin of the SANA may have originated from cadaveric studies while the information regarding coronary artery dominance may have originated from imaging studies. Finally, when analyzing the origin of the AVNA, the present study, cadaveric studies, and imaging studies all showed no significant differences to the textbooks.

Analysis of the primary literature used for this study brought to light some inconsistencies amongst studies. Many studies presented nearly identical statistics but two studies (Verma, 2014 & Futami, 2003) presented SANA and AVNA origin statistics that differed drastically from the other studies. Analysis of the procedures carried out by Verma and Futami did not bring to light any procedural flaws and thus fails to explain the significantly variable results. While it has not been heavily researched, a possible explanation for this phenomenon is genetic diversity since the studies at hand took place in India and Japan, respectively. An unavoidable limitation of the current study is the inability to incorporate diversity due to the small, localized population of cadaveric donors. While it is known that the donors were residents of the Midwest at the time of their death, it is unknown the extent of genetic diversity their heritage entailed. To account for this limitation, the present study could be repeated using a population elsewhere in the world to investigate what role genetic diversity may play in the branching of the coronary arteries.

The findings of the present study often agreed with the cadaveric studies while disagreeing with imaging studies, further strengthening the argument that the cadaveric and imaging studies should not be pooled together. Review of the primary literature regarding the variant coronary artery anatomy, along with the data presented in the current study, has illustrated that the information found in textbooks does not always align with the information found in primary literature. This finding is supported by the frequent rejection of the null hypothesis when comparing the information presented in textbooks to that which was found in the primary literature.

These discrepancies only further support the need to include data found in primary literature in order to present current information in textbooks. However, incorporation of the primary literature reviewed in this study into textbooks could be a bit challenging. In general, the information found in cadaveric studies tends to include a more accurate sample of the overall population. Due to technological advances, these studies do tend to be a bit older, which negates the argument of incorporating current literature. On the other hand, many of the imaging studies are more recent and very accurate due to developing technology but typically have a population that does not necessarily provide an accurate sample of the overall population. The most logical solution for this conundrum would be to increase the number of cadaveric studies being performed so there are current studies that are representative of the overall population that can be presented in current medical textbooks. Cadaveric donors, unlike the participants in imaging studies, are not selected as participants due to the possibility of a certain medical condition. Due to requirements of the Anatomical Board, the cadaveric donors may not be a perfect match but they are much closer to being representative of the overall population than participants in an imaging study. Conducting an imaging study using a population that is similar to the population in cadaveric studies would allow for a larger sample size that is more representative of the overall population.

Incorporation of information from current primary literature will increase the quality of education for those who utilize the current medical textbooks at hand. Investigation into the source of data presented in current medical textbooks, such as COA by Moore, et al., found that the textbook does not cite a source for the data presented. It should be recommended that, if the data presented in the textbooks originated from a source of primary literature, the original article should be cited and easily locatable. In order to further corroborate the findings of this study, it could be repeated using the cadaveric donors in the UNMC gross anatomy lab the following year as a means of providing a larger sample size. Also, the study could be repeated utilizing donors from different areas within the United States or donors from different areas of the world to determine the role genetic diversity may play.

Though this study did not always show exact correlation to the data found in cadaveric studies, it agreed much more frequently than the data found in textbooks. While more research must be conducted on the subject to validate the findings of this study, it does add evidence to support the data found in cadaveric studies regarding the normal and variant anatomy of the coronary arteries. Teaching from textbooks that incorporate information that is found in current primary literature can only increase the quality of education that future health professionals are receiving, thus increasing the level of care they can provide to their patients.

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Appendix A: Literature Review Frequency Tables

Primary Literature: Origin of Sinoatrial Nodal Artery

Study	Study Size	RCA	LCA/LCX	RCA and LCA/LCX
Divyaprakash, 2016	30	57.2	40.14	2.66
Darmender, 2014	77	59.74	37.66	2.6
Verma, 2014	43	52	24	24
Waheed, 2013	348	71.28	28.74	0
Pejkovic, 2008	150	63.33	36.66	0
Ramanathan, 2008	300	53	42.66	4.33
Saremi, 2008	102	65.7	27.4	5.9
Kini, 2007	42	55	45	0
Berdajs, 2003	50	66	34	0
Futami, 2003	30	73.3	3.3	23.3
Kalpana, 2003	100	56	35	8
Sow, 1996	45	64.45	24.44	0
Caetano, 1995	100	56	35	8
DiDio, 1995	100	58	42	0
Kyriakidis, 1988	309	59	38	3
Busquet, 1984	42	66	30	4
Hutchinson, 1978	40	65	35	0
James, 1961	106	54	42	4
James, 1958	43	61.54	38.46	0
Weighted Average		**60.59**	**35.94**	**3.12**

Table 1.1: Primary literature values for the supply of the SANA.

Primary Literature: Coronary Artery Dominance

Study	Study Size	Right	Left	Codominant
Divyaprakash, 2016	30	77.2	18.43	4.37
Darmender, 2014	77	83.11	16.88	0
Pejkovic, 2008	150	90	10	0
Ramanathan, 2008	300	53.66	22.33	24
Saremi, 2008	102	87.3	10.8	1.9
Futami, 2003	30	90	3.33	6.66
Kalpana, 2003	100	89	11	0
Arid, 2000	23	91.3	8.7	0
Angelini, 1999	1853	89.1	8.4	2.5
Cavalcanti, 1995	110	69.09	11.82	19.09
Weighted Average		**84.19**	**10.60**	**5.21**

Table 1.2: Primary literature values for the dominance of coronary arteries.

Primary Literature: Origin of Atrioventricular Nodal Artery				
Study	Study Size	RCA	LCX	RCA and LCX
Divyaprakash, 2016	30	78.22	18.66	3.12
Verma, 2014	43	88	12	0
Pejkovic, 2008	150	90	10	0
Ramanathan, 2008	300	72.33	27.66	0
Saremi, 2008	102	87.2	10.8	2
Berdajs, 2006	55	73	27	0
Futami, 2003	30	80	10	10
Arid, 2000	23	91.3	8.7	0
Krupa, 1993	120	90	10	0
Hutchinson, 1978	40	80	20	0
James, 1958	43	83	7	10
Weighted Average		81.53	17.37	1.10

Table 1.3: Primary literature values for the supply of the AVNA

Textbook: Origin of Sinoatrial Nodal Artery			
Study	RCA	LCA	RCA and LCA
Clinically Oriented Anatomy, Moore	60	40	0
Pathophysiology of Heart Disease, Lilly	70	25	5
Anatomy: A Regional Atlas of the Human Body, Clemente	65	35	0
Essential Clinical Anatomy, Moore	40	40	0
Average	**63.75**	**35**	**1.25**

Table 1.4: Textbook values for the supply of the SANA

Textbook: Coronary Artery Dominance			
Study	Right	Left	Both
Clinically Oriented Anatomy, Moore	67	15	18
Clinical Anatomy for Medical Students, Snell	90	10	0
Atlas of Human Anatomy, Tillman	10	20	70
Pathophysiology of Heart Disease, Lilly	85	8	7
Essential Clinical Anatomy, Moore	67	15	18
Cardiovascular Dynamics, Rushmer	48	18	34
Average	**61.17**	**14.33**	**24.50**

Table 1.5: Textbook values for the dominance of coronary arteries.

Textbook: Origin of Atrioventricular Nodal Artery			
Study	RCA	LCX	RCA and LCX
Clinically Oriented Anatomy, Moore	80	20	0
Pathophysiology of Heart Disease, Lilly	85	8	7
Anatomy: A Regional Atlas of the Human Body, Clemente	80	20	0
Essential Clinical Anatomy, Moore	80	20	0
Average	**81.25**	**17**	**1.75**

Table 1.6: Textbook values for the supply of the AVNA

Multisource Comparison: Origin of Sinoatrial Nodal Artery			
Textbook	RCA	LCX or LCA	RCA and LCA
Literature Weighted Average	60.59	35.94	3.11
Textbook Average	63.75	35	1.25
Vikse, 2016	68	24.8	2.9

Table 1.7: Multisource comparison of the values for the supply of the SANA

Multisource Comparison: Coronary Artery Dominance			
Study	Right	Left	Both
Literature Weighted Average	84.19	10.60	5.21
Textbook Average	61.17	14.33	24.50

Table 1.8: Multisource comparison for the dominance of coronary arteries.

Multisource Comparison: Origin of Atrioventricular Artery			
Study	RCA	LCX	RCA and LCX
Literature Weighted Average	81.53	17.37	1.10
Textbook Average	81.25	17	1.75

Table 1.9: Multisource comparison of the values for the supply of the AVNA

Methodology	
Author	Study Type
Darmender, 2014	Cadaveric
Verma, 2014	Cadaveric
Kalpana, 2003	Cadaveric
Futami, 2003	Cadaveric
Arid, 2000	Cadaveric
Sow, 1996	Cadaveric
Caetano, 1995	Cadaveric
Cavalcanti, 1995	Cadaveric
DiDio, 1995	Cadaveric
Krupa, 1993	Cadaveric
Busquet, 1984	Cadaveric
Hutchinson, 1978	Cadaveric
James, 1961	Cadaveric
James, 1958	Cadaveric
Vikse, 2016	Meta-analysis
Divyaprakash, 2016	Imaging
Waheed, 2013	Imaging
Ramanathan, 2008	Imaging
Saremi, 2008	Imaging
Kini, 2007	Imaging
Berdajs, 2006	Imaging
Berdajs, 2003	Imaging
Kyriakidis, 1988	Imaging
Dabizzi, 1980	Imaging

Table 1.10: Primary literature methodology breakdown.

Appendix B: Professional Student Procedures

A. Strip the pleura from the anterior and lateral aspect of the pericardium. Open the **pericardium** in a curved line extending from the aorta to the apex of the heart and make additional cuts to display the entire anterior surface of the heart. Take care not to cut the **phrenic nerves** which lie laterally adherent to pericardium. Note the following structures (116-118):

1. **Parietal pericardium**
    a. **Fibrous layer** externally
    b. **Serous layer** internally
2. Visceral pericardium - continuation of serous layer onto the heart
3. **Transverse sinus** - insert finger within the pericardial sac so that ascending aorta and pulmonary trunk are anterior
4. **Oblique sinus** - insert hand upward and behind the heart into a blind recess bounded by the inferior vena cava and pulmonary veins. With a finger of one hand in the transverse sinus and the other hand in the oblique sinus a reflection of visceral pericardium prevents the touching of fingers. This web represents the remnant of the dorsal mesentery of the heart.

B. Identify the following large vessels as they leave or enter the heart and then cut them, making the **cuts inside the pericardial sac:**

1. **Ascending aorta**
2. **Pulmonary trunk**
3. **Superior vena cava**
4. **Inferior vena cava**
5. **Pulmonary veins -** There are usually four, but on occasion, an additional one may be encountered.

C. Remove the heart, leaving the parietal pericardium in situ. The heart may be replaced in position to verify textbook description of surfaces, margins etc.

D. Examine the surface of the heart noting the following (120-125):

1. **Apex**
2. **Base**
3. **Sternocostal surface**
4. **Diaphragmatic surface**
5. **Diaphragmatic, right, and left borders**
6. **Atrioventricular (coronary) sulcus**
7. **Anterior** and **posterior** interventricular sulci
8. **Right and left auricles**
9. **Crux of the heart** - intersection of AV sulcus and posterior interventricular sulcus.

E. Strip the epicardium (visceral pericardium and fat on the surface of the heart) from the heart to expose the coronary arteries and their major branches and the cardiac veins (132). Fingernails can be effective tools to accomplish this objective. Additional vessels to those listed have been described and named by clinicians. You are not expected to know about vessels which haven't been listed in this guide.

This is an important exercise because of the frequency of pathology in coronary arteries. Take the time to expose as many of the following vessels as possible and note relationships to parts of the heart.

1. **Left main coronary artery**
2. **Circumflex branch of left coronary** - lies in left AV sulcus
3. **Anterior interventricular branch of left coronary** - lies in the anterior interventricular sulcus. Referred to as the left anterior descending (LAD) by clinicians.
4. **Left diagonal branch** - trifurcation of left main or a branch of LAD or LC to anterior left ventricular surface
5. **Left marginal branch(es)** - one or more vessels along the left obtuse margin
6. **Great cardiac vein** - accompanies #3
7. **Right coronary artery** - thorough exposure of the anterior part of the right atrioventricular sulcus will tear **anterior cardiac veins** which bridge across it to reach the right atrium.
8. **SA nodal branch of right coronary** - a small branch that comes off just beyond the origin of the right coronary. It supplies the right atrium in addition to the SA node. Sometimes this artery arises from the left coronary close to its origin.
9. **Marginal branch of right coronary** - parallels diaphragmatic border.
10. **Small cardiac vein** - accompanies #9 and then #7 - difficult to find
11. **Posterior interventricular branch of right coronary** - lies in the posterior interventricular sulcus. Clinicians refer to this vessel as posterior descending. An **AV nodal branch** from the right coronary is given off in the vicinity of the origin of the posterior interventricular branch.
12. **Middle cardiac vein** - accompanies #11
13. **Coronary sinus** - lies in the posterior part of the atrioventricular sulcus. Great, middle and small cardiac veins are tributaries. Sometimes the posterior vein of the left ventricle is large.

F. After dissecting the vessels, cut through the arteries at several locations to identify evidence of atherosclerosis.

G. The description of arterial supply given above is of a right dominant heart. In approximately 10% of the population the posterior interventricular artery is a continuation of the circumflex branch. These individuals have what is known as a left dominant heart. The AV nodal artery in these specimens is a branch of the circumflex branch of the left coronary. The effects of occlusion of a main stem coronary artery would differ depending on dominance. A survey will be taken to ascertain the percentages of dominance in a limited population in the gross lab.

H. After exposure of the arteries and veins is complete make the following cuts in the wall of the heart:

1. *Right ventricle*
    a. **Cut #1** - Through the wall of the pulmonary trunk, between the cusps of the pulmonary valve, extending parallel to and 1-2 cm to the right of the anterior interventricular sulcus to the diaphragmatic margin of the heart.
    b. **Cut #2** - Along the margin toward the base to within one centimeter of the atrioventricular sulcus.
2. *Left ventricle*
    a. **Cut #3** - Through the wall of the aorta, between the cusps of the aortic valve, curving around and extending parallel to the anterior interventricular sulcus to the apex - avoid cutting the pulmonary trunk. The ventricular wall will be 1-1.5 cm in thickness. The cut will section the circumflex artery and the great cardiac vein.
    b. **Cut #4** - Optional cut to better open up the left ventricle.
3. *Right atrium*
    a. **Cut #5** - From the superior to the inferior vena cava along the right border of the atrium. Pass a probe through the vena cavae and atrium. Suspend the heart by the probe and then cut through the smooth part of the wall along the left side of the probe.
    b. From the inferior vena cava up to the auricular appendage.
4. *Left atrium*
    a. **Cut #6** - Between the openings of any two pulmonary veins.

I. Remove the large chunks of clotted blood (post mortem) and then rinse the remaining clotted blood from the heart in running water. Sometimes clotted blood will be difficult to remove completely from the ventricles because the clot surrounds the chordae tendineae. Additional clot removal can follow identification of the most prominent features.

J. Study the **right atrium** and note the following (125):

1. **Opening of the superior vena cava**
2. **Opening of the inferior vena cava**
3. **Crista terminalis** - thickened ridge from #1 to #2
4. **Valve of the inferior vena cava** - a small web that had significance in the embryo
5. **Atrioventricular orifice**
6. **Opening of coronary sinus**
7. **Valve of coronary sinus** - minor significance
8. **Fossa ovalis and limbus** Probe under limbus for possible patent foramen ovale.
9. **Pectinate muscles**
10. **Auricle**

K. Study the **right ventricle** and note the following (127):

1. **Atrioventricular (tricuspid) valve** - leaflets
2. **Chordae tendineae**
3. **Moderator band (septomarginal trabecula)** - sometimes not evident
4. **Papillary muscles** - Note that each is attached to two valve leaflets by chordae tendineae.
5. **Trabeculae carneae**
6. **Pulmonary trunk**
7. **Pulmonary valve**
8. **Conus arteriosus**

L. Study the **left atrium** and note the following (129):

1. Four pulmonary veins
2. Pectinate muscles - only in auricle
3. **Atrioventricular orifice**

M. Study the **left ventricle** and note the following (131):

1. **Atrioventricular (bicuspid, mitral) valves** - leaflets
2. **Chordae tendineae**
3. **Papillary muscles**
4. **Trabeculae carneae**
5. **Aortic valves**
   a. **Cusps** (2 coronary and 1 non-coronary cusp)
   b. **Nodules**
   c. **Sinuses of Valsalva**
   d. **Sinuses of Valsalva**
6. **Interventricular septum - muscular and membranous parts**

N. Find the approximate location of the two nodes of the **conduction system:**

1. **Sinoartrial node (137)** - junction of crista terminalis and superior vena cava
2. **Atrioventricular node** - between the coronary sinus orifice and the annulus of tricuspid valve.

Appendix C: Coronary Artery Branching Data Tables

	Dominance			LCA	LCX	AIVA	Left Main Diagonal Artery				Left Marginal Artery		
	Right	Left	Co	Aorta	LCA	LCA	LCA	AIVA	LCX	Absent	LCX	AIVA	Absent
1	X			X	X	X		X			X		
2	X			X	X	X	X				X		
3	X			X	X	X		X			X		
4	X			X	X	X	X				X		
5	X			X	X	X	X				X		
6	X			X	X	X				X	X		
7	X			X	X	X		X			X		
8			X	X	X	X			X		X		
9	X			X	X	X		X			X		
10	X			X	X	X	X				X		
11	X			X	X	X	X				X		
12	X			X	X	X	X				X		
13	X			X	X	X		X			X		
14	X			X	X	X	X				X		
15	X			X	X	X		X			X		
16	X			X	X	X		X			X		
17	X			X	X	X	X				X		
18	X			X	X	X	X				X		
19	X			X	X	X		X			X		
20	X			X	X	X		X			X		
21	X			X	X	X		X			X		
22	X			X	X	X	X				X		
23	X			X	X	X	X				X		
24		X		X	X	X	X				X		
25	X			X	X	X	X				X		
26	X			X	X	X		X			X		
27	X			X	X	X	X				X		
28	X			X	X	X		X			X		
29	X			X	X	X		X			X		
30	N/A			N/A	N/A	N/A	N/A				N/A		

	RCA	SANA			Right Marginal Artery		PIVA			AVNA		
	Aorta	RCA	LCA	Absent	RCA	Aorta	RCA	LCX	Both	RCA	LCX	Both
1	X	X			X		X			X		
2	X	X			X		X			X		
3	X	X			X		X			X		
4	X	X			X		X			X		
5	X		X		X		X			X		
6	X	X			X		X			X		
7	X		X		X		X			X		
8	X	X			X				X	X		
9	X		X		X		X			X		
10	X		X		X		X			X		
11	X	X			X		X			X		
12	X	X			X		X			X		
13	X	X			X		X			X		
14	X	X				X	X			X		
15	X	X			X		X			X		
16	X	X			X		X			X		
17	X	X			X		X			X		
18	X	X			X		X			X		
19	X	X			X		X			X		
20	X	X			X		X			X		
21	X	X			X		X			X		
22	X	X			X		X			X		
23	X			X	X		X			X		
24	X		X		X			X			X	
25	X	X			X		X			X		
26	X	X			X		X			X		
27	X	X			X		X			X		
28	X	X			X		X			X		
29	X		X		X		X			X		
30	N/A	N/A			N/A		N/A			N/A		

	Dominance			LCA	LCX	AIVA	Left Main Diagonal Artery				Left Marginal Artery		
	Right	Left	Co	Aorta	LCA	LCA	LCA	AIVA	LCX	Absent	LCX	AIVA	Absent
31	X			X	X	X	X				X		
32	X			X	X	X		X			X		
33	X			X	X	X	X				X		
34	X			X	X	X	X				X		
35		X		X	X	X	X				X		
36	X			X	X	X		X			X		
37	X			X	X	X		X			X		
38	X			X	X	X	X				X		
39	X			X	X	X	X				X		
40		X		X	X	X		X			X		
41	X			X	X	X	X				X		
42	X			X	X	X		X					X
43			X	X	X	X		X				X	
44	X			X	X	X				X	X		
45		X		X	X	X	X				X		
46	X			X	X	X		X				X	
47	X			X	X	X	X				X		
48	X			X	X	X	X				X		
49		X		X	X	X		X			X		
50	X			X	X	X		X			X		
51	X			X	X	X		X			X		
52	X			X	X	X		X				X	
53	X			X	X	X	X				X		
54	X			X	X	X		X			X		
55	X			X	X	X		X			X		
56	X			X	X	X		X			X		
57		X		X	X	X		X			X		
58	X			X	X	X		X			X		
59	X			X	X	X	X				X		
60	X			X	X	X	X				X		
61	X			X	X	X			X		X		

	RCA	SANA			Right Marginal Artery		PIVA			AVNA		
	Aorta	RCA	LCA	Absent	RCA	Aorta	RCA	LCX	Both	RCA	LCX	Both
31	X	X			X		X			X		
32	X	X			X		X			X		
33	X	X			X		X			X		
34	X		X		X		X			X		
35	X	X			X			X			X	
36	X	X			X		X			X		
37	X	X			X		X			X		
38	X		X		X		X			X		
39	X	X			X		X			X		
40	X	X			X			X			X	
41	X		X		X		X			X		
42	X	X			X		X			X		
43	X	X			X				X			X
44	X	X			X		X			X		
45	X	X			X			X			X	
46	X			X	X		X			X		
47	X	X			X		X			X		
48	X	X			X		X			X		
49	X	X			X			X			X	
50	X			X	X		X			X		
51	X	X			X		X			X		
52	X	X			X		X			X		
53	X	X			X		X			X		
54	X	X			X		X			X		
55	X	X			X		X			X		
56	X	X			X		X			X		
57	X	X			X			X			X	
58	X		X		X		X			X		
59	X	X				X	X			X		
60	X	X			X		X			X		
61	X		X		X		X			X		