CORONARY ARTERY DISEASE

Pathologic and Clinical Assessment

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CORONARY ARTERY DISEASE

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ICONES

ANATOMICAE

EX OPTIMIS NEOTERICORUM OPERIBUS

summa diligentia depromptae et collectae

OPERA ET STUDIO

LEOPOLDI MARCI ANTONII

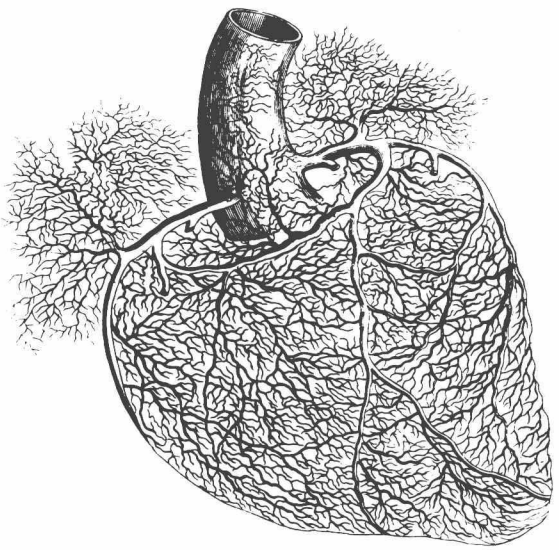
ET

FLORIANI CALDANI

VOLUMINIS TERTII

SECTIO PRIMA

Venetiis ex Calcographia Josephi Picotti Anno



A stylized drawing of the coronary circulation in L. M. A. Caldani*:
Icones Anatomicae: Quotquot sunt celebriores ex optimis neotericorum operibus summa diligentia depromtae et collectae. Tabulas selegerunt et nonnullas ex cadaveribus ad vivum delineatas addere curarunt Leopoldus Marcus Antonius et Florianus Caldani. Venetiis, ex calcographia Josephi Picotti, 1801–1813.

*CALDANI, Leopoldus Marcus Antonius (Bologna, 1725–1813), anatomist and physiologist followed Morgagni as Professor of Padua. He wrote *Institutiones Anatomicae* and *Institutiones Physiologicae* and compiled an atlas of anatomical engravings, *Icones Anatomicae*, that was printed after his death by the nephew Florianus.

RJB

To Irish with love, and to my family with deep respect.

ARM

To the memory of my father.

RR

To Isa and Paolo, Marco and Pietro for their devotion and understanding.

MPJ

To Eileen whose magnificent devotion, encouragement, and understanding have supported all my efforts toward the goals and ideals we share.

Foreword

Experience in the past has served to make for recognition of an association between morphological changes in the coronary arteries, on one hand, and the various syndromes now known as those of clinical coronary heart disease, on the other. From this foundation the physical sciences and the field of biochemistry have provided clinical medicine with valuable diagnostic tools, such as electrocardiography, angiocardiography, echocardiography, and serum cardiac enzymes. More than diagnostic tools, these fields have expanded understanding of mechanisms of coronary artery disease.

Progress in therapy, both pharmacological and manipulative, including surgical procedures, has made for relief of symptoms and, perhaps, extension of life for the patient with coronary heart disease.

In spite of the many advances in the understanding of coronary artery disease, including atherosclerosis, the most prevalent type, there remain innumerable questions—etiology, the bases for clinical manifestations, prevention in all of its aspects, treatment, etc.

If further progress is to be made, it is well for workers to take stock of where they are in the history of coronary heart disease. A perspective so derived serves to give the worker modesty and the realization that firm answers to questions are usually not easily obtained. Knowledge of the past and of the present is the most secure basis for progress in the future.

In the development of this extensive and enviable work, four highly experienced pioneer workers, two cardiologists, a cardiac pathologist, and a cardiovascular radiologist, have formed the nucleus. Realizing the vastness of the subject of coronary disease, they have sought out specialists from many geographic areas, each to add to this book his special knowledge and perspective. The authors have done a magnificent job in securing the objectives of the book.

Complexities are identified, unresolved problems are illuminated, and some solutions are offered in this comprehensive and unique text and reference work.

The future for the patient with coronary heart disease will be enhanced through the publication of this book. It may be viewed as a bright object woven of threads identified variously as old, current, and prospective.

Jesse E. Edwards, M.D.

Preface

Because clinical coronary arteriograms of high quality provide information similar to postmortem coronary artery casts, clinicians tend to ignore the potential contributions of pathologists or, even worse, to dismiss coronary necropsy studies as antiquated. Such attitudes can only impede the development of new information about the pathophysiology of coronary artery disease in man. Accordingly, it became the express purpose of this book to bring clinical and morbid pathology closer together in a synthesis of what is known about the coronary arteries in health and disease, together with the pertinent clinical and laboratory expressions of coronary pathology.

The foundation for the present undertaking centered in a weekly tutorial review of heart specimens drawn from two large teaching hospitals and a medical examiner's office. In parallel, the clinical records and the exquisite in vivo coronary arteriograms of patients evaluated at Loma Linda University Medical Center were subjected to detailed analyses, thus enabling the fusion of pathoanatomical and clinical data. The final result provides a coherent and contemporary survey of human coronary artery disease.

Each chapter bears the collaborative imprint of a cardiology-oriented scientist with nearly a quarter century's experience in relating structural and functional derangements to the specific site of obstructive coronary artery disease; an established cardiovascular pathologist; a European-trained clinical cardiologist-scholar with special interest in geriatric cardiovascular diseases; and an internationally recognized pioneer and scholar in coronary arteriography and in transluminal dilatation of atherosclerotic stenotic lesions. These authors, in turn, invited distinguished colleagues from the United States, Europe, and South America to elaborate from their unique experience in developing selected chapters. They include Drs. Manuel Viamonte, Jr., and Stuart Gottlieb of the University of Miami; Winston A. Mitchell and William H. Willis, Jr. of Loma Linda University; Attilio Maseri of the Universities of Pisa and London; Giorgio Baroldi of the Universities of Milano and Pisa; Giuseppe Conte of the University of Pisa; Alan K. Yates of Guy's Hospital, London; and E. J. Zerbini of the University of Sao Paulo, Brazil.

Taken as a whole, the book considers the embryology, anatomy, physiology, and pathology of the coronary arteries as related to the clinical (symptoms and signs), diagnostic (invasive and noninvasive), and surgical aspects of coronary artery disease. This eclectic approach is designed to serve a broad readership constituency in both the basic sciences (anatomists, physiologists, and pharmacologists) and in clinical medicine (senior house staff members, general internists, cardiologists (medical and surgical), radiologists, and pathologists (general, cardiac, and forensic)) who find themselves involved in investigating and managing the many faces of human coronary artery disease.

Acknowledgments

Acknowledgments are made of the assistance of Dr. Nancy L. Noble, the late Dorothy Denslow, and Mr. Raphael Alvarez who contributed over the years to the production and final compilation of material for the book. We gratefully recognize the critique by colleagues of selected chapters, Drs. Marie Valdes-Dapena, Casey Van Breeman, Duane Schultz, Dan Mintz, Ronnie Goldberg, Jim Henry, and Ross Adey. Special citation is made of Dr. J. Davis, Chief Medical Examiner of Dade County, Florida, for his long-standing commitment to scholasticism in clinical-pathological correlations in cardiovascular disease. The forebearance by Ms. Lee Ann Moffett in organizing and preparing the innumerable drafts and revisions of chapters was a source of major encouragement for completion of the book. The understanding and support of Drs. E. Sterling Nichol, William J. Harrington, and Verne R. Mason in providing the ambience at the Miami Heart Institute, Howard Hughes Medical Institute, and the University of Miami for initiation of the book is recognized. And, finally, the financial assistance of an admirable friend and patient, given to honor his beloved Bert by Ted Reducka, is recognized with deep appreciation.

Abbreviations

The following abbreviations are used to identify the arteries and the major branch arteries:

Anterior View

Ao: Aorta
LCA: Left main coronary artery
LAD: Left anterior descending artery
D: Diagonal branch arteries from the LAD
CxA: Circumflex artery
MO, OM: Margo obtusus branch artery from the CxA
C: Conal branch artery from the right coronary artery
RCA: Right coronary artery
MA: Margo acutus branch artery from the RCA

Posterior View

PDA: Posterior descending artery

"Ad res pulcherrimas ex tenebris ad lucem erutas alieno labore deducimur;".....

SENECA, DE BREVITATE VITAE, XIV, 1–5

"We are led to these splendid realities illuminated by the labors of others;".....

Contents

CHAPTER 1

The Anatomy of the Coronary Arteries

The perception of coronary artery anatomy is remarkably affected by the requirements of the viewer. For the medical student, a simple cataloging of the arteries and their branches is sufficient; cardiology-oriented medical and radiological physicians require extensive and unique descriptions; pathologists in general are presently uncertain about their requirements; and cardiovascular surgeons focus chiefly around anatomical details essential for proper myocardial revascularization.

This chapter considers coronary artery anatomy from these varied viewpoints, starting with a simple primer.

A PRIMER ON CORONARY ARTERY ANATOMY (1–3)

This account deals in stereotypic patterns, leaving variations to subsequent sections. The first branches from the aorta are the RCA and LCA (Fig. 1.1). The RCA arises from the anterior or right sinus of Valsalva of the ascending aorta, and the LCA arises from the lateral or left sinus. Commonly, there are two right ostia, one giving rise to the RCA and the other to the pulmonary conus artery to the outflow tract of the right ventricle (4). As the RCA leaves the aorta, it passes anteriorly and superiorly and

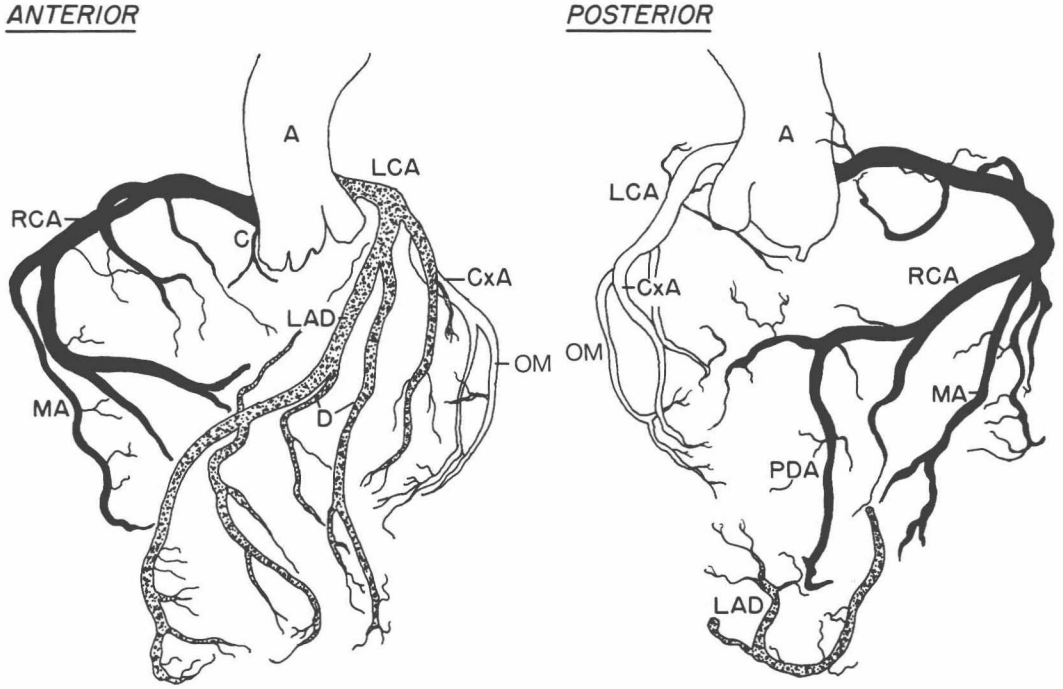


Figure 1.1. Stylized cast corrosion images of the human coronary arteries as viewed from the anterior (*left*) and posterior (*right*) surface of the heart.

then makes an acute turn to the right and passes inferiorly into the atrioventricular (A-V) sulcus. The first branches of the RCA are the conus A, the artery to the sinoatrial node (S-A node A), and branches to the anterior right ventricle. The RCA mainstem progresses to the acute margin of the heart, where it gives rise to the right acute marginal A and middle atrial branches. It then proceeds around the posterior aspect of the heart, giving off branches to the posterior right ventricle. The artery then leaves the A-V sulcus at the crux, viz. the intersection of the A-V and interventricular planes, and arches superiorly over the posterior portion of the right atrium, then passing inferiorly into the interventricular groove, or sulcus, as the PDA in the majority of human hearts.

The provision of the PDA by the RCA constitutes the anatomical criterion for classifying the coronary circulation as a *predominant right coronary circulation.* (The dominance distinction is somewhat arbitrary because, for practical purposes, the LCA always supplies the greater part of the left ventricular mass.) The PDA passes one-half to three-quarters of the way toward the apex in the interventricular groove and in some hearts (25%) to the apex itself. When the RCA mainstem terminates between the acute marginal artery and the PDA, it gives rise to a group of posterior right ventricular branches which diverge toward the posterior interventricular groove but fail to reach it. This constitutes a nondominant RCA which provides no or a negligible part of the left ventricular or interventricular septal blood supply. In many hearts the RCA continues beyond the crux to provide one or more posterior left ventricular branches. The PDA generally gives rise to the A-V node artery and to short branches that supply the posterobasal third of the interventricular septum.

The ostium of the LCA is generally single, and the LCA extends into the A-V sulcus for distances varying from 0.5 to 3.0 cm before giving rise to the LAD and the CxA arteries. In some hearts the LCA appears to pass directly into the LAD, with the CxA arising at a right angle from the parent vessel. Not uncommonly, the LCA trifurcates with a third (intermediate) branch passing generally to the superior aspect of the obtuse margin or more anterolaterally to the surface usually reserved to the diagonal branches. Still more complex patterns of left mainstem branches may occur. Rarely, the LCA gives rise to the S-A node A and the Kugel's A (5), although more commonly the alternative S-A node arises from the proximal third of the CxA whereas the Kugel's A arises from the proximal third of the RCA.

The LAD curves around the base of the main pulmonary artery, enters the anterior interventricular groove, and proceeds around the apex, ascending for varying distances toward the crux in the posterior interventricular groove where it anastomoses with the PDA. In strongly dominant right systems, the PDA may recurve the apex to meet the LAD on the anterior surface. Branches to the anterior right ventricle (RV) begin at approximately the pulmonary valve level and form a curve around the RV outflow tract meeting the conus A as the circle of Vieussens. Other branches to the RV arise from the mid-portion of the LAD and extend to meet the anterior ventricular arteries from the RCA.

Two or more large branches leave the LAD and supply the anterior and lateral wall of the left ventricle (LV). These are the anterior left ventricular arteries, commonly referred to as diagonal branches of the LAD in the clinical description of the coronary arteries.

A series of branches to the interventricular septum arises from the LAD as it courses toward the cardiac apex. The largest, the first septal perforating A, most commonly arises a short distance after the LAD reaches the interventricular groove and descends toward the apex within the interventricular septum. At times these branches closely parallel the LAD itself. The other interventricular septal branches (three or more) arise at right angles to the LAD and pass into the septum, giving off numerous secondary branches. These septal connections firmly fix the LAD into the anterior interventricular groove.

The CxA passes into the left A-V sulcus, giving off a branch (or branches) to the left atrium early in its course (the left atrial CxA) and frequently the S-A node A. The CxA also distributes branches to the superior and inferior aspects of the obtuse margin to the posterolateral surface of the LV. In approximately 15% of hearts, the CxA proceeds to the crux, where it makes a 90-degree turn and descends in the posterior interventricular groove as the PDA. Such an anatomical arrangement, in which the CxA provides the PDA, is commonly referred to as a *predominant left coronary circulation* (6).

Details of the arterial supply to the left ven-

tricular subendocardium, the RV, the papillary muscles of both ventricles, and the supraventricular and ventricular elements of the conduction system are considered in Chapter 5.

Clinical Angiographic Description of the Coronary Artery Anatomy

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LCA

The origin of the LCA is generally best demonstrated in a very shallow left anterior oblique and its continuation by the right anterior oblique 20-degree projection (Fig. 1.2). Its length varies from millimeters to 3 cm. When it is absent, the LAD and CxA originate separately from the left coronary sinus and both arteries must be catheterized to ensure adequate anatomical description. The LCA usually bifurcates into the LAD and CxA branches, although quite frequently it trifurcates, the third branch (the intermediate A) passing to the superior obtuse margin of the heart. Still more elaborate branching patterns are occasionally seen.

LAD

The proximal LAD is usually best seen in the projection that favors the LCA, unless it is obscured by overlapping branches of its own diagonal system or those of the proximal obtuse marginal system. In the latter instance, the true lateral projection often rescues visualization by "wishboning" the LAD and CxA branches maximally free of one another (Fig. 1.3*A–D*). The 30-degree hemiaxial tilting of the X-ray tube and image intensifier with the patient in 45 to 60 degrees of LAD is of immense value in more completely characterizing disease in the proximal third of the LAD or the diagonal branches which otherwise can be lost or foreshortened (7) (Fig. 1.4*A* and *B*). Distally, the LAD is best seen in the lateral projection which tends to isolate it on the anterior surface. The left anterior oblique 70-degree projection is also useful, particularly in demonstrating the origin of the principal diagonal artery and in distinguishing the terminal anastomoses of the LAD with the CxA and RCA; however, it does risk superimposition of the LAD across the spray pattern of its own septal arteries. In the right anterior oblique 20-degree projection, cursory inspection, at times, may confuse a diagonal branch lying in close relationship to the anterior interventricular groove with the LAD itself, but the presence of septal branches and, to a lesser degree, the characteristic terminal loop around the apex aid in identifying the LAD (Fig. 1.5*A* and *B*). The relative lengths of the PDA and the terminal segment of the LAD are inversely related in a manner that facilitates end-to-end anastomosis (Fig. 1.6*A–C*). The majority of LADs end on the posterior surface of the apex with short twigs to both ventricles. Not infrequently, the LAD ascends in the posterior interventricular groove one-third to one-half the distance to the cardiac crux as the posterior ascending artery, and rarely it may replace the PDA altogether (Fig. 1.7). On the other hand, very small "cap-like" LAD systems end on the anterior surface short of the cardiac apex and are commonly associated with unusually lengthy PDAs (Fig. 1.8*A* and *B*).

An interesting anatomical variation is the descent of some LADs from an epicardial position to a slightly subsurface position in the septum—either focally or segmentally or in more than one place—the so-called "myocardial bridging" or intramural LAD. The submerged artery commonly exhibits systolic compression ranging from mild to marked (Fig. 1.9) (see Chapter 9).

LAD Branches

The diagonal arteries pass obliquely across the anterolateral free wall of the left ventricle. At times, minor problems arise in distinguishing diagonal from superior obtuse marginal branches; these are usually easily settled by reference to the left anterior oblique 70-degree