CT Evaluation of Coronary Artery Disease

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Springer

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Originally published as:
Malattia coronarica
Fisiopatologia e diagnostica non invasiva con TC
Paolo Pavone, Massimo Fioranelli

Library of Congress Control Number: 2008938918

ISBN 978-88-470-1125-0 Springer Milan Berlin Heidelberg New York
e-ISBN 978-88-470-1126-7

Springer is a part of Springer Science+Business Media
springer.com

Typesetting: C & G di Cerri e Galassi, Cremona, Italy
Printing and binding: Arti Grafiche Nidasio, Assago (MI), Italy

Printed in Italy
Springer-Verlag Italia S.r.l., Via Decembrio 28, I-20137 Milan, Italy

Preface

Coronary CT angiography (CTA) is rapidly changing the patient-care algorithms used to detect coronary artery disease, as well as the approach we take in risk-factor assessment and in the triage of patients. The rapid adoption of coronary CTA into clinical practice has been fueled by significant yearly advances in CT technology, which have improved the spatial and temporal resolution of this technique while simultaneously decreasing radiation exposure.

The growing utilization of coronary CTA has created a need for comprehensive didactic texts that explain the numerous applications of this new technology with respect to the pathophysiology of coronary artery disease, while also providing information on the approach to patients who have undergone previous bypass surgery or percutaneous coronary intervention. I believe this book accomplishes both of these goals, and does so in a reader-friendly format. The image quality of the many figures that accompany each chapter is excellent and reflects the use of state of the art technology. The techniques described for plaque detection and characterization represent the current thinking pervasive in the coronary CTA community. The comprehensive reference list at the end of the book offers the reader a wealth of resources for further study.

There is no doubt that this book will be popular with radiologists, cardiologists, CT technologists and anyone else seeking to acquire a comprehensive understanding of coronary artery disease and its depiction using coronary CTA.

Galloway, October 2008 *David A. Dowe, MD*

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Clinical Anatomy of the Coronary Circulation

Massimo Fioranelli, Carlo Gonnella, Stefano Tonioni

In the anatomic evaluation of the coronary arteries by multi-slice computed tomography (MSCT), the classification of the American Heart Association, which divides these vessels into 15–16 segments, including those segments with diameters > 1.5 mm, is often used (Fig. 1.1). In this chapter, a more complex classification will be applied as it provides a more detailed anatomic picture.

The right coronary artery (RCA) takes origin from the right aortic sinus of Valsalva and then divides to form two terminal branches, the posterior descending artery (PDA) and the posterolateral (PLV) branches. Along its

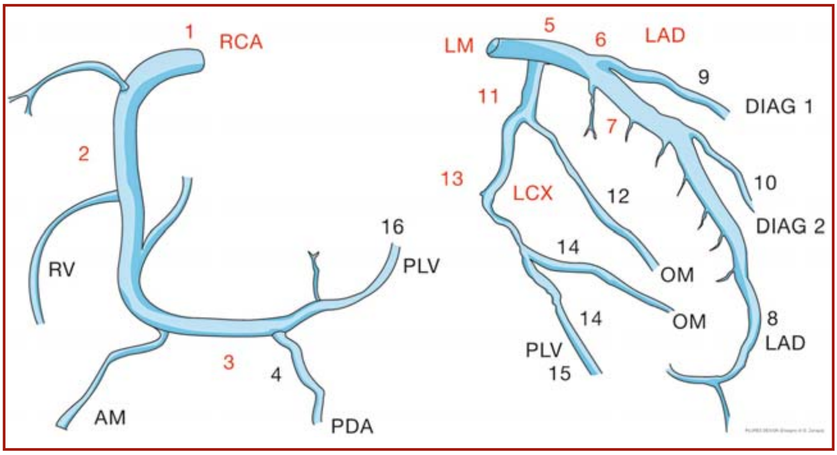

Fig. 1.1. The American Heart Association divides the coronary tree into *15–16* segments. *RCA* Right coronary artery, *RV* right ventricular branch, *AM* acute marginal branch, *PLV* posterolateral ventricular branch, *PDA* posterior descending artery, *LCA* left coronary artery, *LM* left main artery, *LAD* left anterior descending artery, *DIAG 1* 1st diagonal branch, *DIAG 2* 2nd diagonal branch, *LCx* left circumflex artery, *OM* obtuse marginal branches

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course, the RCA gives off several branches: the sinus node artery, right ventricular (RV) branches, acute marginal (AM) branch, and the atrioventricular node artery.

The left coronary artery (LCA) arises from the left aortic sinus; the left main (LM) branch of the LCA ends in a bifurcation, giving rise to the left anterior descending artery (LAD) and the left circumflex artery (LCx); sometimes, a third ramus intermedius is present between these two branches. The LAD gives off septal (SP) and diagonal (DIAG) branches and ends at the the apex of the heart, sometimes reaching the posterior interventricular groove. The LCx has two or three marginal branches (OM), before either terminating or, in the case of left-dominant or balanced circulation, giving off a posterolateral branch or ending in the posterior atrioventricular groove. Figure 1.1 shows the myocardial areas perfused by the RCA, LAD, and LCx.

Angiographic Anatomy of the Coronary Circulation

In the following, the coronary anatomy is described using the classification proposed in the *Bypass Angioplasty Revascularization Investigation* (BARI) trial reported by Alderman and Stadius (1992), in which the coronary arteries are separated into 29 segments (Fig. 1.2).

The coronary trees have two principal components: (1) the arteries and the veins, which course and ramify on the surface of the heart (subepicardial system), and (2) their perforating branches (intramyocardial system).

The subepicardial system is formed by the right and left coronary arteries, arising from the right and left aortic sinus of Valsalva, respectively. The RCA is divided into three segments. The first segment (BARI 1) extends from the coronary ostium to the first RV branch; if the latter is not present, the segment is usually identified between the ostium and the acute margin of the heart. The second segment (BARI 2) extends from the first RV branch to the acute margin of the heart, which usually coincides with the origin of the AM branch (BARI 10). This vessel is the most constant branch of the RCA and it runs on the surface of the free wall of the right ventricle in the direction of the apex, at an angle proportional to the proximity of its origin. The third segment (BARI 3) begins at the acute margin of the heart and courses to the origin of the PDA (BARI 4), at the level of the crux cordis. At this level, in right-dominant circulation (85% of cases), the RCA divides into two terminal branches, the PDA and PLV branches (BARI 5), perfusing the diaphragmatic wall of the left ventricle. In the remaining 15% of cases, the circulation may be left-dominant or balanced: in left-dominant circulation, the PLV and PDA originate from the LCx; in balanced circulation, the PDA originates from the RCA, and the PLV from the LCx.

The concept of dominance is defined by the relationship between the RCA and LCx, according to the origin of the PDA and in relation to the arterial supply of the inferior wall of the left ventricle, but not in relationship to the extent of the circulatory system.

The PDA, also called the posterior interventricular branch, with its septal branches (BARI 9), is the most important branch of the RCA; it courses in the homonymous groove without reaching the apex of the heart, which is usually supplied by the recurrent branch of the LAD. The PLV immediately originates after the PDA, at the level of the crux cordis. It courses along the posterior atrioventricular sulcus, branching with its collateral vessels (BARI 6–8) at the diaphragmatic and inferioposterior wall of the left ventricle.

The RCA furnishes smaller branches such as the conus artery, sinus node artery, RV branches, and atrioventricular node artery (Fig. 1.3). The conus artery is the first vessel originating from the RCA. In 40% of the cases it directly originates from the right aortic sinus or from the aorta. The sinus node artery arises from the RCA (2/3 of the cases); in the 25% of cases, it may originate from the LCx, while in 10% the two vessels arise from both coronary arteries. The RV branches originate in the second segment of the RCA and run along the surface of the RV, anterior to the interventricular groove. The number

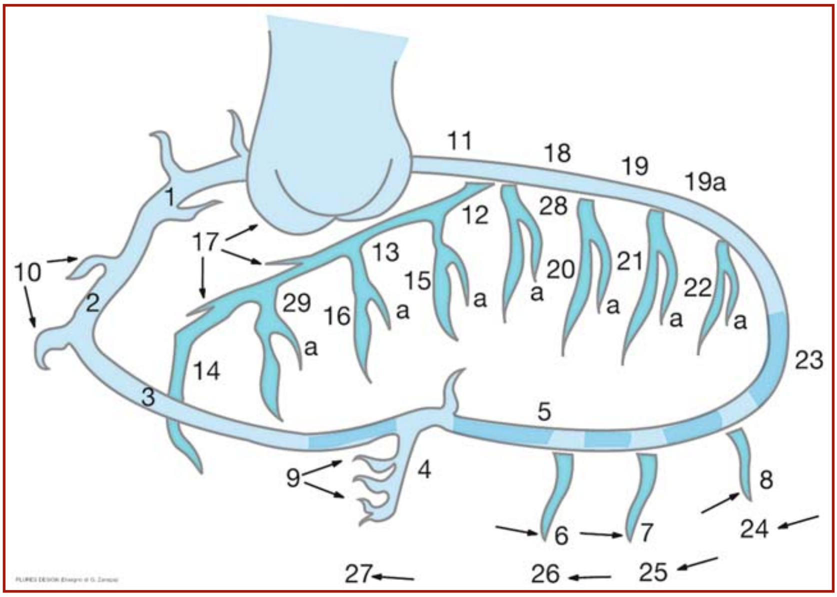

Fig. 1.2. Map of the coronary arterial tree according to the BARI Study Group. This map was used in CASS (Coronary Artery Surgery Study) and includes the diagonal, marginal, and Valsalva branches. The coronary arteries are divided into 29 segments: *1* Proximal segment of the right coronary artery (RCA), *2* middle segment of the RCA, *3* distal segment of the RCA, *4* posterior descending artery (PDA), *5* posterolateral branch of the RCA (PLV), *6* 1st posterolateral branch of the RCA, *7* 2nd posterolateral branch of the RCA, *8* 3rd posterolateral branch of the RCA, *9* inferior septal branches, *10* acute marginal branches of the RCA, *11* left main of the left coronary artery (LM), *12* proximal segment of the left anterior descending artery (LAD), *13* middle segment of the LAD, *14* distal segment of the LAD, *15* 1st diagonal branch (DIAG), *15a* lateral 1st diagonal branch, *16* 2nd diagonal branch, *16a* lateral 2nd diagonal branch, *17* septal branches of the LAD (SP), *18* proximal segment of the left circumflex artery (LCx), *19* middle segment of the LCx, *19a* distal segment of the LCx, *20* 1st obtuse marginal branch (OM), *20a* lateral 1st obtuse marginal branch, *21* 2nd obtuse marginal branch, *21a* lateral 2nd obtuse marginal branch, *22* 3rd obtuse marginal branch, *22a* lateral 3rd obtuse marginal branch, *23* LCx continuing as the left atrioventricular branch, *24* 1st left posterolateral branch, *25* 2nd left posterolateral branch, *26* 3rd left posterolateral branch, *27* left posterior descending artery (PD) (in left-dominant circulation), *28* ramus intermedius, *28a* lateral ramus intermedius, *29* 3rd diagonal branch, *29a* lateral 3rd diagonal branch

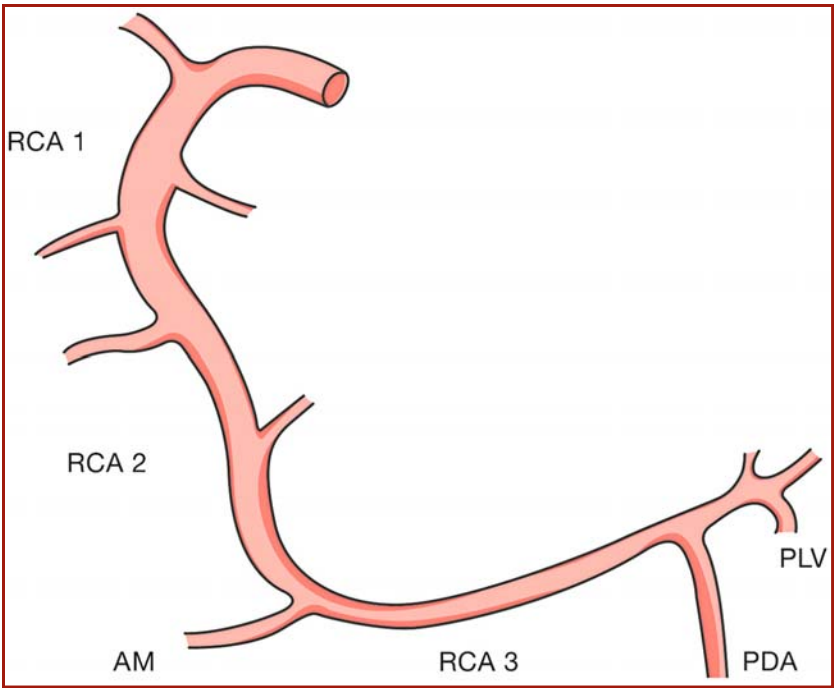

Fig. 1.3. Right coronary artery in left anterior oblique (LAO) view. *RCA* Right coronary artery (segments *1–3*), *AM* acute marginal branch, *PLV* posterolateral branch, *PDA* posterior descending artery

of these branches varies greatly and is inversely proportional to the diameter of such vessels. In 99% of the cases of right-dominant circulation and in 75% of the cases of balanced circulation, the atrioventricular node artery arises at the end of the third segment of the RCA. It is important in the angiographic identification of the crux cordis. In individuals with left-dominant circulation, it originates from the distal segment of the LCx. At the level of Koch's triangle is the subendocardial artery, situated between the septal cuspid of the tricuspid valve and the coronary sinus; it furnishes branches to the posterior interventricular septum and the atrioventricular node.

The LCA arises from the left aortic sinus, at a higher level than the RCA, and is divided into three segments (Fig. 1.4). The LM branch of the LCA (BARI 11) extends for a varying length (generally 2 cm, diameter 3–6 mm) from the ostium to the bifurcation of the LAD and LCx. In 30–37% of the cases, the LM artery gives off three branches, one of which, the ramus intermedius (BARI 28), runs toward the apex and supplies the anterolateral wall of the left ventricle.

The LAD is the most constant, in origin and distribution, among all the coronary vessels. It originates from the LM artery and runs in the anterior interventricular groove to the apex of the heart. In 70% of the cases, the LAD extends up to the posterior interventricular groove such that it furnishes branches for perfusion of the inferior interventricular septum and the apex; otherwise, these arise along the length of the PDA. The first segment of the LAD (BARI 12) runs from the bifurcation of the LM artery to the origin of

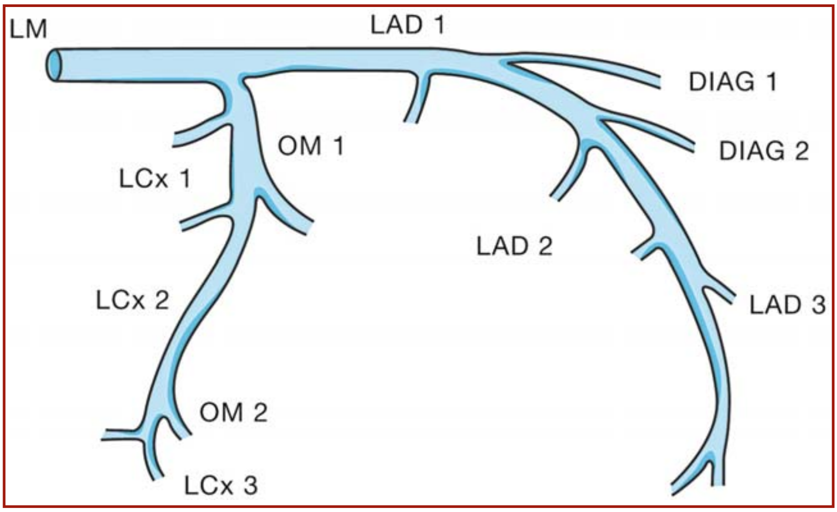

Fig. 1.4. Left coronary artery in caudal right anterior oblique (RAO) view. *LM* Left main artery, *LAD* left anterior descending artery (segments *1–3*), *DIAG 1* 1st diagonal branch, *DIAG 2* 2nd diagonal branch, LCX left circumflex artery (segments *1–3*), *OM 1* 1st obtuse marginal branch, *OM 2* 2nd obtuse marginal branch

the first septal branch (SP, BARI 17). The second segment (BARI 13) extends from the origin of the first septal branch to the origin of the third septal or second DIAG branch. The third segment (BARI 14) ends at the apex, surrounding and sometimes traveling up to the posterior wall. When the third SP or second DIAG branch is not identified, the end of the second segment of the LAD is conventionally defined as the half-length between the first SP and the apex. The LAD furnishes branches for the anterior interventricular septum and the anterolateral wall of the left ventricle. There are generally three SP branches and they originate at right angles from the LAD.

The first SP branch is constant in its origin and course; thus, it is important to identify its passage between the proximal and middle segments of the LAD. Some segments may run intramyocardially, but generally they develop caudally, along the interventricular septum, and supply the proximal two-thirds of the anterior septum. The second and third SP branches are more variable, with narrow diameters; they supply the distal third of the anterior septum. There are usually three DIAG branches (BARI 15, 16–29), each of which originates at an acute angle from the LAD; their pathway is to the anterolateral wall of the left ventricle. The diameter of these vessels is inversely proportional to the number of branches.

The LCx develops from the LM artery and runs in the posterior atrioventricular groove; after a short tract under the left atrium, it continues in the left posterior atrioventricular groove and contacts the mitral annulus. The LCx splits into three segments. The first (BARI 18) extends from the origin to the first marginal branch (OM, BARI 20). If the first OM is absent or not clearly identifiable, the zone of transition among the first and second segments is conventionally identified by a point corresponding to the half-length between the origin of the LCx and the origin of the second OM (BARI 21). The second segment (BARI 19) runs from the origin of the first OM to the origin of the second OM. If the second marginal branch is absent, the zone of transition is defined by the half-length between the origin of the first OM and the point where the circumflex artery terminates. The third segment (BARI 19a), in right-dominant circulation, extends from the origin of the second OM to the termination point of the vessel; in left-dominant or balanced circulation, to the point of origin of the left ventricular branch or the posterolateral branch in the posterior atrioventricular groove (BARI 23). In left-dominant circulation, the LCx gives rise to the left ventricular branch or PLV, with its side branches (BARI 24–26) and to the PDA (BARI 27), with its septal branches (BARI 9).

The LCx gives rise to the sinus node artery, left atrial branch, and marginal branches. In 25% of the cases, the sinus node artery arises from the proximal segment of the LCx, near the ostium. The atrial branch originates at the end of the proximal segment and runs to the inferoposterior wall of the left atrium. Of the three OM branches, the first one is usually larger and constant; it terminates on the posterolateral wall of the left ventricle toward the apex. Its development is inversely proportional both to the extent of the RCA on the posterolateral surface of the left ventricle and to the number and development of the diagonal branches of the LAD.

Intramyocardial Vascularization and the Venous Circulation

After oxygen and nutritional substrates have been extracted by the myocardium, a portion of the desaturated blood is transported directly into the ventricles through the Thebesian veins. Nevertheless, most of the blood, through the venules and myocardial veins, goes to the epicardial veins, which drain in the coronary sinus, located in the inferoposterior region of the right atrium.

The epicardial arteries are muscular vessels with a wall thickness of about 100 μm; they are made up of three overlapping layers: intima, media, and adventitia. These arteries, which transport oxygenated blood to the arteries, arterioles, and capillaries, traverse the surface of the heart covered by epicardium or sometimes by subepicardial adipose tissue. Muscular bridges of variable length, in which the epicardial vessels become intramyocardial, are present in 5–22% of the cases at the anterior LAD and in 86% in the other coronary arteries (Fig. 1.5).

Normal embryological development of the coronary circulation involves the formation of collateral vessels, that link the different sections of the arterial circulation. The collateral circulation consists of four types of vessels: intramyocardial vessels originating from the same vessel (intracoronary circulation), intramyocardial vessels originating from two or more coronary arteries (intercoronary circulation), atrial vessels connecting with the vasas vasorum of the aorta or other arteries (extracardiac circulation), and intramyocardial vessels that directly communicate with the ventricles (arteriolar luminal circulation). In the normal adult myocardium, the collateral circulation consists of small-caliber vessels (< 50 μm in diameter) that contribute only marginally to coronary flow. In the presence of obstruction or myocardial ischemia, the diameter of the collateral vessels expands to 200–600 μm; the growth of a medial layer allows a significant quantity of blood flow. The development of collaterals results in the formation of connections among proximal and distal segments of a vessel crossing a stenosis.

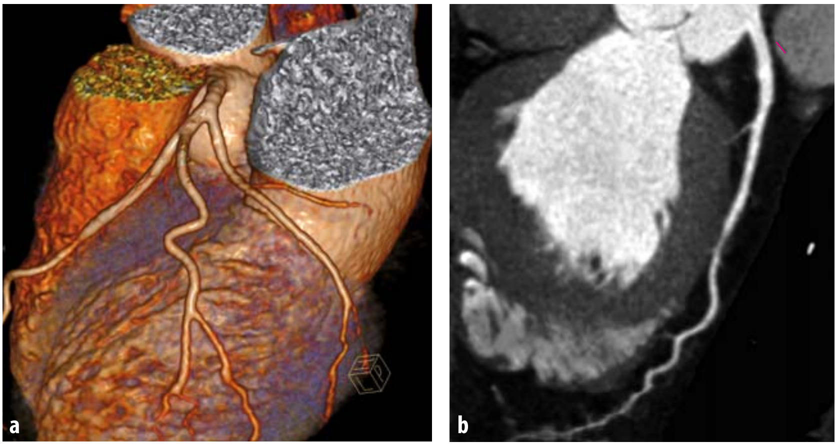

Fig. 1.5 a, b. Myocardial bridging of the left anterior descending artery reduces the arterial diameter

Variability of the Coronary Artery Circulation

The above-described anatomic scheme is highly variable. This is in contrast to other arterial vascular districts, which have a constant, readily identifiable anatomy, such as the carotid, or iliac-femoral arteries, where, except for differences of caliber, the morphology, origin, and anatomic course are the same between individuals. Variations in the coronary arteries include the type of dominance, differences in caliber, and alternative branch morphologies. This aspect of the coronary circulation must be kept in mind during diagnostic evaluation of the arteries, to avoid considering an artery that is small and poorly developed as a stenosis.

The variability of the coronary circulation is such that two patients rarely have the same coronary vascular anatomy. In this context, the use of terminology such as “strongly developed branch” or “hypoplastic vessel” identifies the development of the vessel but does not denote the presence or absence of atherosclerotic lesions. For example, in some patients, the course and caliber of the LCx are highly developed, while in others the artery may be small and perfuse only a small portion of the myocardium. These differences are compensated for by the development of other vessels, which balance the perfusion of a myocardial region by a hypoplastic artery perfusion. The morphology of an artery and the extent of the territory it perfuses are very important considerations in therapeutic planning. The larger the myocardial region perfused by an artery, the greater the justification for a myocardial revascularization procedure in the presence of a critical stenosis.

As shown in Figure 1.6, there are some cases in which the LAD is more developed than the LCx, but in other situations the LCx is more developed and perfuses the largest part of the left ventricle. The caliber of the branches originating from these two arteries depends on the size of the artery from which they derive; that is, the DIAG branches will be of larger caliber than the OM branches when the LAD is more developed than the LCx, while the OM branches will be more developed if the caliber of the LCx is larger.