SECTION ON
CARDIOVASCULAR DISEASES

Surgical Anatomy of the Coronary Arteries

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Investigations of the last decade have led to a considerable change of certain concepts regarding coronary heart disease. This change has come in waves from many directions but particularly from the surgical laboratories. In the quest for new frontiers in the exciting developments of cardiac surgery during this period, contributions in physiology and pathology have been keeping pace with surgical techniques, and now it has even become possible to review critically and with great reward, the basic anatomy of the coronary arteries; both in the normal state, and in the anatomical changes associated with arteriosclerosis of these vessels.

When the standard anatomy and atlases with which we are so familiar were prepared, it was in a time when the average length of life was in the neighborhood of 45 years. The degree and widespread incidence of arteriosclerosis which is prevalent today was then less marked, and to the pathology laboratories, came in large numbers the tissues of younger individuals dying of such diseases as pneumonia, tuberculosis and even syphilis. It is understandable that under such circumstances the clarity of the picture of arteriosclerosis could not approach that of today.

In order to resolve the confusion that was caused by seeing different pictures at operation than was expected by prior knowledge of anatomy obtained from standard sources, a critical study of Schlesinger preparations and 200 fresh hearts obtained at autopsy, was undertaken to see what could be learned about the anatomy of the coronary arteries in all types of hearts.

Six hundred x-ray plates of Schlesinger injected hearts, prepared in accordance with Schlesinger's original method, were made available for study. The majority were excellent preparations, showing both arteries clearly. Many, however, demonstrated only one of the two sides filled, and there were many in which the injection was felt to be inadequate for our purposes. Three hundred were selected as being well enough prepared to be meaningful, and these were carefully studied for several features which they could exhibit as follows:

(1) Relative frequency of left and right coronary preponderance, and its relation to arteriosclerosis.
(2) Number and diameter of the branches of the two main vessels.
(3) The presence of, and types of, intercoronary anastomosis.
(4) Special features that might have a bearing upon surgical approach to the problem of arteriosclerosis.

Presented in part as an exhibit at the American Medical Association Convention, San Francisco, June, 1958, and at the American Heart Association Convention, San Francisco, 1958.
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In complete accord with Schlesinger's observations, it was found that no two human hearts were alike regarding the picture of their coronary tree, and that each one was an individual unto itself. In general, the findings were identical with those of Schlesinger and Zoll in that it was found that the right coronary artery is far and away, in the largest proportion of cases, the larger artery of the heart, and must be given greater consideration in our thinking regarding coronary occlusion. It was found that the coronary arteries may be delicate and numerous in number, or may be sturdy and infrequent in their initial branching; one may compare the two types with the branching of a Mariposa pine and a Douglas fir, and that in between these two extremes there are many degrees of intermediates. It is worth while to mention that seldom did a heart exhibit both types of branching in the same specimen. Rather, the type of branching was consistent for any heart in both coronaries. As one will see in the foregoing material, the amount of blood supply to any one portion of the heart was a remarkably constant feature, no matter from which artery it happened to arise. A system of nomenclature of the coronary vessels was devised for the purpose of classifying them as to number and location.

In general, the arteries were of a fairly comparative mean caliber. The term MICROARTERIOSIS CORONARIAE for the hearts in which main arteries and branches were of small caliber and branched finely, and the term MACROARTERIOSIS for the reverse was adopted.

![Variations of Coronary Anatomy](VARIATIONS_OF_CORONARY_ANATOMY)

**FIGURE 1**

**FIGURE 2**
Embyology

Embryology texts demonstrate the coronary arteries early in the life of the embryo as small vessels arising from the right and left side of the truncus arteriosis and branching both anteriorly and posteriorly. In the formation of the aorta and the pulmonary artery, rotation and asymmetrical growth of the vessel walls must account for the positioning of the coronary arteries in the adult heart.

Coronary Orifices

1. Location as to Valve Leaflets

The actual location of the coronary orifice, within the aorta itself, is variously described in anatomical atlases and standard text books. Some have the coronary orifice arise in the sinuses of Valsalva, behind the valve leaflet and some, both the orifices from the anterior portion of the aorta. In all of the hearts studied, the coronary orifices arose above the line of reflection of the aortic valves. It is obvious that should this not be the case, it would constitute a physiological handicap, as upon opening the aortic valve, the occlusion produced by the valve leaflets against the coronary vessels would preclude flow during the systolic phase to the coronary orifices. Happily, this was not found to be so and the findings agree with those who place the orifices above the line of reflection of the valve. Actually, there was a considerable amount of variation in the height above the valve leaflet, some coming off as high as a centimeter above the line of reflection.

2. The Location of the Take-Off of the Coronary Arteries as Regards the Anterior Posterior Axis.

A considerable variation of the origin of the arteries was noted. Gray’s Anatomy was found somewhat confusing in that the text describes that the left coronary artery arises from the left posterior aspect of the aorta, but on the same page demonstrates in their color plate the origin of the left coronary from the anterior aspect of the aorta. The investigations indicated that in 93 per cent of the hearts their text is correct;

<table>
<thead>
<tr>
<th>TABLE 1—CODING OF CORONARY VARIATIONS</th>
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<tbody>
<tr>
<td>Study of 200 hearts at autopsy and 300 Schlesinger-injected hearts</td>
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<tr>
<td>Right Coronary Predominance 55 percent</td>
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<td>Branches to:</td>
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<tr>
<td>Right Ventricle 4.8</td>
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<td>Septum 3.2 [2.4 from Rt. Coronary,</td>
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<td>Left Ventricle 6.6 [6.2 from Left</td>
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<tr>
<td>Right Atrium 2.5</td>
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<td>Left Atrium 2.8</td>
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<td>Balance 9 per cent</td>
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<td>Branches to:</td>
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<td>Right Ventricle 4.8</td>
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<td>Left Ventricle 8.2</td>
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<td>Right Atrium 2.2</td>
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<td>Left Atrium 2.5</td>
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<td>Left Coronary Predominance 36 per cent</td>
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<td>Branches to:</td>
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<td>Right Ventricle 4.5</td>
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<td>Septum 3.2</td>
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<td>Left Ventricle 8.0</td>
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<td>Right Atrium 2.0</td>
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<td>Left Atrium 2.6</td>
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the standard take-off of the left coronary is in the left posterior aspect
of the aorta, at approximately 65 degrees from the posterior axis. Varia-
tions in location, however, are not rare and perhaps 15 degrees is a
standard deviation. A few arteries were found to extend as far forward as
65 degrees from the anterior axis and all variations between the two
points mentioned were noted.

The right coronary artery arose almost always from the right anterior
surface of the aorta. Similarly, some degree of variation was noted and
a normal standard deviation of approximately 20 degrees was observable
in the number studied. The center point of the angle of take-off was
approximately 35 degrees from the anterior axis.

The nature of the orifices was interesting as observed from the interior
of the aorta. The size of the orifice corresponded to the predominance of
the artery which will be discussed later. In many cases, two or three
orifices could be seen within the orifice of the right coronary, much as
one sees the orifices of the upper lobe bronchus during bronchoscopy, a
large intermediate branch going to the right atrium in practically every
case, a second branch traversing posteriorly and a third anteriorly and
in the atrial ventricular groove.

The left coronary ostium, however, was more often observed to be
single although in approximately 25 per cent of the hearts a double
orifice was noted, the small vessel in this case being the left atrial artery.
The bifurcation of the left common coronary occurred on an average of
one centimeter and a half from its origin, the course of the main stem
artery being almost tangent to the aorta coming to the junction of the
atrioventricular groove and the left border of the pulmonary artery

FIGURE 3
where it divided into the interventricular artery and the atrio-ventricular vessel (or in other terminology, the anterior descending coronary and the circumflex branch.)

The Atrial Arteries

The greatest surprise of the study was the distribution and the importance of the atrial arteries, not only as anatomical constancies but more interestingly, their role as a source of collateral circulation for the atrioventricular vessels. The atrial arteries averaged 3.5 in number to either side. Almost constantly there was an artery, which on the right side was derived from the first half centimeter of the coronary orifice itself, and on the left, from the first centimeter distal to the orifice. This vessel immediately coursed upward and distributed itself over the atrium; the first artery constituting in approximately 60 per cent of the instances, the largest artery of the atrium. The remainder of the atrial arteries originated in the atrioventricular groove from either the right or left atrioventricular arteries (right coronary or left circumflex) and coursed upward, distributing branches over the atra. The Schlesinger injections revealed a surprising number of interarterial and transarterial anastomosis in the atrial vessels, providing a ready-made collateral circulation whenever atheromas were present in the atrioventricular vessels. It was frequently apparent that segmental occlusions of the atrioventricular vessels occurred but did not disrupt the distribution of blood throughout the areas supplied by these vessels because the skip areas were furnished with a by-pass by route of the atrial vessels. As the atrioventricular vessels are in general the hinterland of atheroma formation, the role of the atrial vessels as collaterals cannot be overemphasized.

That considerable pressure differentials in various parts of the coronary tree exist was attested by the presence of tortuous collateral vessels.
forming transarterial and interarterial collaterals and sometimes extending for great lengths along the walls of the atria.

**Ventricular Arteries**

For the sake of descriptive nomenclature and the proper concept of the distribution of blood from the arteries of the ventricles, the terms of right coronary, left anterior descending and left circumflex should give way to more descriptive names of "left atroventricular artery," "left interventricular artery" and "right atroventricular artery." These names suggest and describe the location of the vessel and the distribution of the blood from it. It was interesting to note that the anterior interventricular artery (anterior descending) gave, in most cases, very few branches to the right ventricle. Dissection of the interventricular groove, demonstrated however, that the right branches of the vessel continued around the myocardium of the left ventricle in the septum and for the most part supplied the septal portion of the left ventricle. One notable exception, however, was an almost constant artery, Vieussen's Ring, along the apex of the right ventricle which supplied the outflow tract of the right ventricle and coursed behind the pulmonary artery. This vessel has been described in detail by James and Burch and the reader is referred to their excellent article for a complete elaboration of the functional importance of this vessel.

The same authors have pointed out the almost constant presence of the first branch of the right coronary artery ascending along the right atrium to the superior vena cava. The ramus ostii cavae superioris artery which in their series of 53 hearts was demonstrated in 49. We also found this vessel to be present in the greater proportion of cases, although the exception proved the rule and in many cases this area was supplied by the second or even the third atrial branch of the right

**FIGURE 6**
coronary. As James and Burch described, the right coronary artery quite commonly made a U-turn posteriorly, giving branches to the septum at this point and especially in that greater proportion of cases where branches of the right coronary passed the posterior interventricular groove and gave branches to the left ventricle.

The average number of arteries, penetrating the septum from the descending was counted and found to be 3.2, these constituting the larger arteries of the septum in the greater proportion of cases. The arteries from the left anterior descending were found to supply approximately \( \frac{3}{4} \) to \( \frac{4}{5} \) of the septum, being much longer than the arteries from the posterior interventricular artery which will be described later. Although sclerosis both of the segmental and continuous type were prominent in the surface vessels of the left anterior descending artery, the septal vessels rarely exhibited advanced arteriosclerotic changes.

The left coronary artery was found to be the dominant artery in only 23 per cent of the hearts studied. This is slightly lower than Schlesinger's original figures. The left interventricular artery gave an average of 3.1 branches to the left ventricle and only in 7 per cent of the cases gave off the posterior interventricular artery, where it gave branches to the septum. It is interesting to note that in the Stereoscopic Atlas, the study of the injection heart in three-dimensional roentgenography showed the coronary circulation to the left ventricle coming almost entirely from the left coronary artery. It is an unfortunate circumstance that the heart selected for this work was so left-coronary predominant that this beautiful demonstration might lead to the erroneous conclusion on the part of those who studied this atlas, that this represented the standard situation, for it is the rare exception and in our studies, 93 per cent of the time did not exist. The left coronary terminated, as a rule, making an oblique descent toward the posterior interventricular groove, there being in the back of the heart, between the two ventricles and the atrioventricular groove, a relatively avascular triangle; also avascular in nature, which

![Image](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21348/ on 04/04/2017)
was observed to be an anatomical no-man's land of coronary circulation. Although Gray's anatomy and Cunningham and several of the English anatomy texts show a linear communication between the left and right coronaries, along the interventricular groove posteriorly, this was not observed in a single instance in the series of hearts studied and due to the triangular no-man's land in this region, it was concluded that this was either an extremely rare anomaly or a figment of the artist's imagination, not corrected by the anatomist.

The Right Coronary Artery

The right coronary artery arises, as described previously, from the right anterior aspect of the aorta, overhung by the right auricular appendage and visible when this structure is pulled upwards. The first branch of the right coronary is almost always the right atrial artery, there being an average of 3.5 arteries given to the right atrium along its course. Depending upon the origin of the artery, it descends downward and to the right to the atrioventricular groove, and very short descent and then courses to the right and around the groove to the region of the avascular triangle, posteriorly. Here a branch always courses along the right side of the triangle into the interventricular groove passing down the posterior interventricular groove toward the apex of the heart as the posterior interventricular artry, giving off an average of approximately 2.3 branches to the septum in this region. As previously described, these branches are shorter than those given by the anterior interven-
tricular artery and supply approximately the posterior third of the septum (Figures 1 and 2). In the majority of cases, however, the right coronary passed under the posterior interventricular vein, sending a branch across the top of the posterior interventricular triangle to the left ventricle and supplies an average of 1.8 arteries to the left ventricle posteriorly. As many as six arteries supplying the left ventricle from the right coronary were observed and it was not uncommon to see two or three large arteries crossing the anatomical no-man's land to the left ventricle posteriorly. In the instances when the right coronary crossed the interventricular groove posteriorly, arteries to the left atrium also were observed arising from the transcendent branch. During its course across the right ventricle the right coronary artery gave an average of 4.8 branches to the right ventricle.

It was interesting to note that although analyzed separately and using separate slips of paper for the computation of the number of arteries to each part of the heart, the hearts exhibiting right coronary preponderance balance and left coronary preponderance all ended up with the identical average number of arteries to the various chambers of the heart and this rather striking correlation suggested that the left ventricle needed in the realm of approximately twice as much arterial supply as did the right no matter which artery was in size preponderant. This of course is in correspondence with the physiological roles of the two ventricles.

Classification as to Depth of Vessel

In studying the relation of the vessels to the myocardium itself, it was apparent that a distinction could be made. The coronaries may be divided into the epicardial coronaries and the intramuscular coronaries according to whether they ran on the surface of the heart or were embedded between muscle layers. In general, the epicardial coronaries were found to be more tortuous and where atherosclerosis was present, to be involved to a considerable extent; whereas the intramuscular coronaries were found to be linear in conformation and to be not subjected to atherosclerosis to the degree as the epicardial coronary. In the case of any given artery descending toward the apex from the atrio-ventricular groove an average of 3.1 convolutions on the right ventricle.

The intramuscular arteries were found to perforate the anterior ventricular groove and run between the muscle layers of the right ventricle and the left ventricle in this locality. Throughout the walls of the ventricle, the vessels perforated the external bulbospiral muscle and ran along the plane of fission between the internal and external bulbospiral following the grain to a great extent. This intramuscular placement of the coursing arteries within the myocardium suggests that the pressure differentials within the arteries themselves would be subject to th rising intramyocardial pressures during systole, whereas the epicardial coronary vessels would be subject to this pressure only as a backflow.

Regarding Atheromas

Fifty-three per cent of the hearts studied exhibited some degree of atheromatosis of the coronary vessel, ranging from the mildest of the
infiltration of the walls with atheromatous material to practically complete occlusion. All vessels which were palpably firm were subjected to an endarterectomy, incising the artery longitudinally to the level of the yellow-appearing material and then using sharp and dull dissection, dissecting the atheromatous portions of the artery from the outer shell. A great variation existed not only in the length of the atheroma but in the character of the atheroma and the thickness of the arterial wall possessed by this process. Some of the atheromata shelled out easily and could be pulled out almost without dissection whereas others required sharp dissection of delicate character for their removal. Still others were for all practical purposes unremovable and their sclerotic and calcific processes involved practically all levels of the arterial wall at some point. Approximately 43 per cent of the vessels were felt to contain atheromata which were segmental and localized enough to be removed in this dissection, whereas the remainder of those in the atherosclerotic group fell into the category of diffuse and unremovable processes. Correlated with age, however, 75 per cent of the latter fell into the age groups over 60 and represented the effects of age and longstanding atherosclerosis.

**Coronary Collaterals**

In all of the Schlesinger injection studies where atheromatous occlusion was evident it was possible to demonstrate visible coronary collaterals in the films. Some specimens exhibited certain types of collaterals much better than others but in general it appeared that *wherever atherosclerosis occurred one type or other of collaterals appeared*. In those hearts devoid of atheromatous lesions no collateral vessels were noted in our series.

It was possible, by means of their location and function, to classify coronary collaterals into four designations as follows: (1) by-pass collaterals (2) interarterial collaterals (3) transarterial collaterals (4) scar collaterals (neo-angiogenesis) (Fig. 3).

1. **By-pass Collaterals**

Wherever a segmental atheroma occurred it was possible to see dilated channels about the segmental occlusion. In most cases discernable by-pass collateral channel or channels could be made out leading from the unobstructed upper portion of the vessel to the unobstructed lower portion of the vessel (Fig. 4). These were most easily visible where the obstruction was of short length. The term "by-pass collateral" was thought best to describe this variety which brings from the proximal portion of the vessel itself to the distal portion about the obstruction. These were especially prominent in the secondary ventricular arteries but even more dramatic in the atrial regions where anastomoses between the primary atrial branches would by-pass a segmentally blocked atrioventricular vessel (right coronary or left circumflex). The importance of these atrial collaterals in the by-passing of obstruction in the main coronary vessels cannot be too greatly emphasized.

2. **Interarterial Collaterals**

Anastomoses occurring between secondary arteries of the same coronary vessel were given the designation of "interarterial collaterals."
These were found in approximately 90 per cent of the instances where atheromas were present and constitute the greater proportion of coronary collaterals (Fig. 6). They vary from rather straight vessels to markedly tortuous vessels and may be seen both in the surface vessels as well as the intermuscular components.

3. Transarterial Collaterals

Those vessels extending from the right to the left coronary in the septal region in the posterior interventricular region and sometimes in the anterior interventricular region were designated as "transarterial collaterals" (Fig. 7). These also were quite frequent and occurred in approximately 60 per cent of the instances where atheromas were found. It was particularly gratifying to see to what extent these were found in the septa.

4. Scar Collaterals

In those Schlesinger injected hearts which showed evidence of myocardial infarction, a fourth type of collateral was distinguishable. These emanated from adjacent vessels near the infarcted area and, quite numerous and intertwining in nature, were found coursing into and through the scarred area. From the nature of their origin and course it was apparent that these were newly developed vessels, not enlargements of previously existing vessels, but spurious vasculature which like in developing scar tissue elsewhere in the body grows in response to necrobiotic. In such areas marked intercommunication and profuseness of the arterial channels is observable in many of the specimens. (Brofman' has suggested that during the course of a healing of an infarct the growing new vessels develop both arterial and venous channels which intercommunicate to such a degree that the effect of an arteriovenous shunt is present and has further demonstrated this by catheterization of the coronary sinus during various stages of the healing of a myocardial infarct, obtaining higher values of oxygen saturation particularly about the tenth day.)

It was increasingly apparent that, as Schlesinger has indicated, coronary collaterals grow in hearts that are subject to narrowings of the coronary arteries due to atherosclerosis and are a natural compensation mechanism for this disease entity. The one area where no collateral was evident was in the first few centimeters of the main stem coronary vessels. Due to the thickness of the walls of the vessels and a lack of adjacent musculature, no opportunity for the enlargement of existing microscopic or small vessels is present. It is in this area that remedial surgical steps are most promising.

SUMMARY

A classification of coronary arteries is suggested using the terms atrio-ventricular vessels and intraventricular vessels which are more indicative of their localization and function. The location of the coronary orifices above the leaflets of the aortic valve was clarified and the location of the orifices in regard to the anterior posterior axis was found to be quite variable. Classification of intercoronary collaterals is suggested, namely, by-pass collaterals, interarterial collaterals and transarterial collaterals which were found had developed as atheromas formed in the various parts of the coronary tree. A fourth type of collateral, scar collaterals or neo-angiogenesis, is discussed. The role of the atrial vessels as carriers of collateral circulation about the atrio-ventricular occluded vessels is emphasized.
ACKNOWLEDGEMENT: Acknowledgements to Dr. John J. Sampson who initiated the program of Schlesinger Injections at Mt. Zion Hospital, to Dr. Gerson R. Biskind, under whose direction the injections and skiagrams were prepared. To Louise Horn, medical illustrator, for conscientious and painstaking work. To Doctors Milton Pearl, Morris Culiner and others who over a period of years prepared the injected specimens.

RESUMEN
Se sugiere una clasificación de las arterias coronarias, usando los términos vasos atrioveneculares y vasos intraveneculares, que son mas indicadores de su localización y de su función. La ubicación de los orificios coronarios arriba de las hojuelas de la válvula aórtica se aclaró y las localizaciones del orificio respecto de la posición anteroposterior del axis se encontró que es bastante variable. Se sugiere la clasificación de colaterales intercoronarias, por ejemplo colaterales de desviación, colaterales interarteriales y colaterales transarteriales que se encontró se desarrollan cuando el ateroma se desarrolla en varias partes del árbol coronario. Se diserta sobre un cuarto tipo de colateral, las colaterales cicatriciales o por neangiogénesis. El papel de los vasos atrales como conductores de circulación colateral alrededor del atrioventricular ocluido se destaca.

RESUMÉ
L'auteur suggère une classification des artères coronaires, en utilisant les termes de "vaisseaux atrioventriculaires et vaisseaux intraventriculaires" qui donnent une indication plus précise de leur localisation et de leur fonction. Le siège des orifices coronaires au-dessus des valvules de la valve aortique a été déterminé et le siège des orifices par rapport à l'axe antérieur-postérieur a été trouvé être assez variable. L'auteur suggère une classification des collatérales intercoronaires, c'est-à-dire collatérales anastomotiques, collatérales interarterielles et collatérales transarterielles, qui furent trouvées comme développées par l'athérome dans les différentes parties de l'arbre coronarien. Un quatrième type de collatérale, les collatérales cicatricielles ou de néo-vascularisation, est discuté. Le rôle des vaisseaux atraux comme véhicules de la circulation collatérale aprèes occlusion des vaisseaux auriculo-ventriculaires est mis en évidence.

REFERENCES