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**THOMAS N. JAMES, M.D., F.A.C.P.**

*Director, Cardiovascular Research and Training Center, University of Alabama, School of Medicine, Birmingham, Alabama*

*Medical Department*

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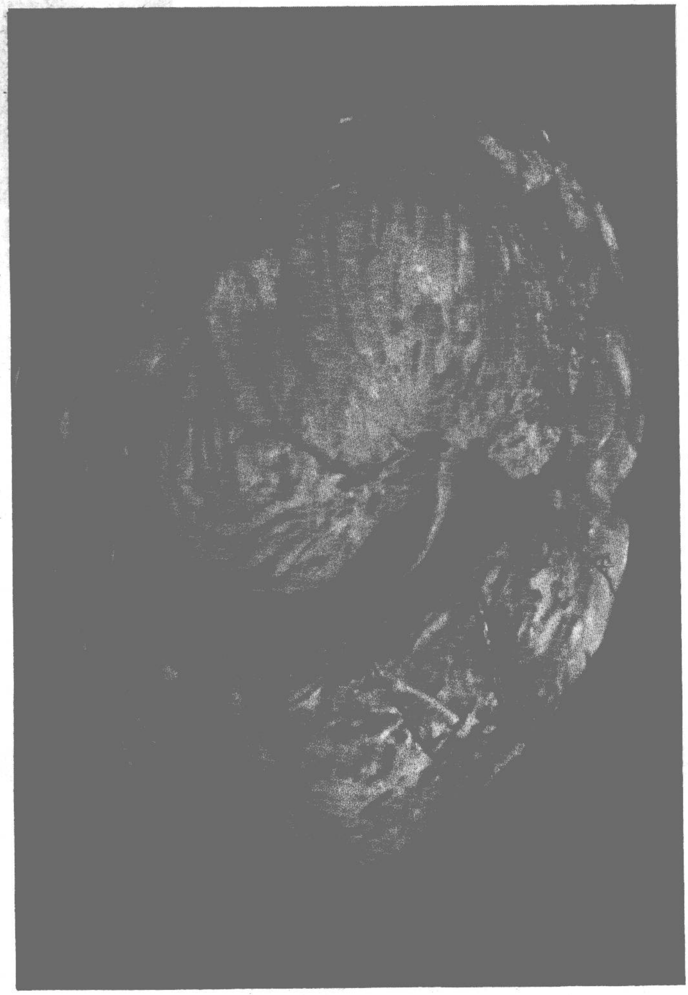

*The crown of the heart*

*To*

*Gleaves*

*and to our sons*

*Mark, Terry, and Peter*

# PREFACE

Judging from modern investigative efforts in the study of the heart—about which so much remains to be understood—one might conclude that most of the questions remaining to be answered are in the fields of physiology and biochemistry, and that little of the anatomy of this organ is still to be elucidated. This is not a new misconception, for Sir Arthur Keith in his Harveian Lecture of 1918 opened his address with a defense of the importance of anatomy. He explained that Harvey, contrary to common belief, was primarily an anatomist, being the leading lecturer in anatomy in London from 1615 to 1656. It was when the physiologists parted from the anatomists in the middle of the eighteenth century, says Keith, "that they stole our patron saint —Harvey."

This unfortunate schism has led to the present state of affairs, in which the functions of many structures of the heart, long since relegated to Latinized oblivion, remain unexplained, and in which many elegant physiologic explanations derived from animal experiments are assumed to be true in man, although they ignore the fact that the structures in the human being are different. Keith added that "Harvey realized more fully than any anatomist that structure is a sure guide to function; that no physiological theory can be true unless it gives a complete and final explanation of all points of structure."

An intimate knowledge of the anatomy of the coronary arteries, the "crown" of the heart, is a self-evident prerequisite for a fuller understanding of coronary artery disease, or for more intelligent planning of surgery of the heart.

Despite the increasingly urgent reasons for familiarity with the anatomy of these vessels, however, the last book in English predominantly concerned with this subject was that of Gross in 1921. Since then there have been periodic studies, almost all of which combined clinical and anatomic investigations. That this combination is desirable seems obvious on superficial consideration. In actual practice, however, such combined studies can seldom avoid sacrificing some anatomic accuracies. For example, most methods which permit histologic study of the myocardium require considerable distortion of the anatomy of the coronary arteries.

This is a simple study of the gross anatomy of the coronary arteries in man, with additional information provided regarding the significant differences from canine coronary anatomy. Each artery and its major branches are dealt with separately in a chapter devoted to it. There is also a chapter on the anatomy of the veins of the heart and one on anastomoses. Numerous, detailed photographs with a generous use of color amplify the text. Although clinical implications have not been discussed, some will be obvious to all. It is hoped that even more will be clear to those who are acquainted with particular clinical problems and for whom this book may fill one of the gaps in factual data concerning the heart.

T. N. J.

*Detroit*

# ACKNOWLEDGMENTS

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The 106 specimens which comprise the basis for the study were obtained through the kindness of the pathologists at Tulane University and Ochsner Foundation Hospital. Particularly helpful were Drs. William Eckert, Wallace Clark, and G. M. Carrera.

Among the many people who have contributed materially to the completion of this book are Carole Ciurla, Maureen Reilly, and Mildred Freeman, who have typed and edited; William Loechel, Tom Stebbins, Don Alvarado, and Dorothy Robinson, who have created the illustrations; and George Adkins, John Kroll and his staff, and Art Bowden and his staff, who have taken many of the photographs. To all of these I am grateful for unstinted cooperation.

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Finally, for the assimilation and organization of all this material into its present form I must thank the staff of Paul B. Hoeber, Inc., whose enlightening advice and kind cooperation rendered my task much simpler.

T. N. J.

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*Chapter One*

# METHODS AND MATERIAL

Of the various methods available for studying the anatomy of the coronary arteries, the injection-and-corrosion method was chosen as the most suitable for the studies described in this book. The limitations of manual dissection of the coronary arteries, even when preceded by injection of dyes, are obvious. Injection of the arteries may be used in conjunction with methods other than dissection—for example, the clearing of the heart by dehydration followed by immersion in oils,[5] which, however, allows examination only of vessels near the epicardium. Injection of radiopaque material with stereoscopic examination of radiographs of the intact heart has the disadvantage of making the distinction between junction of vessels and crossings difficult, although stereoscopy is more satisfactory for this purpose than single-view radiographs. Schlesinger[3] solved this radiographic problem with his method for "unrolling" the heart prior to preparing radiographs, thus making a four-chambered organ almost flat; unfortunately, this makes examination of the blood vessels in the interventricular septum, the interatrial septum, and the atrial free walls unsatisfactory.

From the standpoint of optimal visualization of gross anatomic details of the coronary arteries, the injection-and-corrosion method is probably best.[9] Its chief disadvantage is that it precludes extensive histologic studies, although this failing can be partially overcome by the excision of small pieces of tissue after the injection is completed. Gross examination of the interior of the heart prior to injection can be supplemented if necessary by the use of endoscopes inserted through the valves. With the injection-and-corrosion method one may obtain an accurate, spatially oriented replica of the entire coronary-artery tree and, by simultaneous casting of the cardiac chambers, of its relationships to the endocardial surface of the heart.

Many different materials have been employed for injection of the coronary arteries, including gelatin mass, starch mass, wax, plaster of paris, glue, gum arabic,[9] low-melting-point metals,[2] nylon,[8] latex,[4] and others.[9] At present, one of the most satisfactory materials is plastic, e.g., Vinylite dissolved in acetone,[6] or certain polymers which can be hardened by addition of a catalytic substance.[1, 7]

All plastics are affected by some eventual shrinkage of the injected material as it sets or hardens. Vinylite solution was used for the injections in the study reported in this volume, and several means for minimizing shrinkage were employed. Use of more concentrated solutions of Vinylite is associated with less shrinkage, but because of the high viscosity of such solutions, this method allows penetration only of larger vessels during the injection. Tandem injection—injection of a thin solution initially, followed by injection of a thicker solution—is a second means of coping with this problem. Another is employment of a filler for the injection solution; this material must be inert and yet sufficiently capable of suspension to allow free flow. Kaolin has proved most suitable for this purpose. The color of the kaolin is important, for the more commonly obtainable tan product turns a dark brown on mixture with acetone and considerably modifies the final color of the Vinylite solution. A pale gray or white kaolin, which may be obtained either as the result of chemical bleaching or by a brief, discriminating search of the shelves of a local pharmacist, is preferable.

Since Vinylite dissolves faster in warm acetone, a water bath facilitates the preparation of large quantities of the material for injection. The maximal solubility of Vinylite powder in acetone is about 35 per cent by weight at room temperature; a stock solution of this viscid mass is the most suitable for storage. For injection, it may be thinned to any desired concentration by addition of acetone. About 10 per cent by weight of added kaolin is the optimal amount for minimizing shrinkage. Most commercial dyes are suitable for coloring the solution, though experimenting with a small amount of the injecting solution prior to use in a heart specimen is recommended. The chief problem in coloring is running of the dye; it is best to use a dye which remains bound to the Vinylite solution and does not stain adjacent tissue, including other vessels.

Hearts require relatively little preparation for injection; only assurance that sufficient lengths of the great vessels are provided is in order. Sufficient lengths of these vessels provide two advantages: (1) The vessels may be more easily cannulated or ligated for injection of the cardiac chambers; (2) less cutting of the myocardium and coronary vessels—a leak from which renders the pressure-controlled injection unsatisfactory—is apt to occur.

After removal from the body, the heart should be washed and all clots removed; tap water is satisfactory for this purpose. The coronary arteries are best irrigated one at a time, so that small clots are flushed out of the opposite artery. The heart may then be cannulated for injection, or it may be frozen for study at a later date. Thawing of the heart many months later provides a perfectly suitable specimen for injection, and the myocardial histologic characteristics are still satisfactory for most purposes.

Flanged glass cannulae (Fig. 1) should be inserted in the right and left coronary arteries and tied in place, with the ligatures being passed around the artery as close to the aorta as possible and with as little dissection as possible. Such dissection is easier in the thawed heart than in the fresh one. Glass tubing 2.5–3.0 mm. in outside diameter is suitable for cannulating the great majority of adult coronary arteries. Some[6] prefer the use of flanged polyethylene tubing for cannulation. Polyethylene tubing, commercially available in smaller diameters than glass tubing, is particularly useful in cannulating small hearts, e.g., those of infants or small animals.

After preparation of the arteries, the chambers of the heart are cannulated. A curved glass cannula inserted through the inferior vena cava, tied in place and lying loosely in the coronary sinus, is the best means for injection of Vinylite for casting the chambers and veins. Glass tubing with an outside diameter of 8–10 mm. is suitable for chamber cannulation.

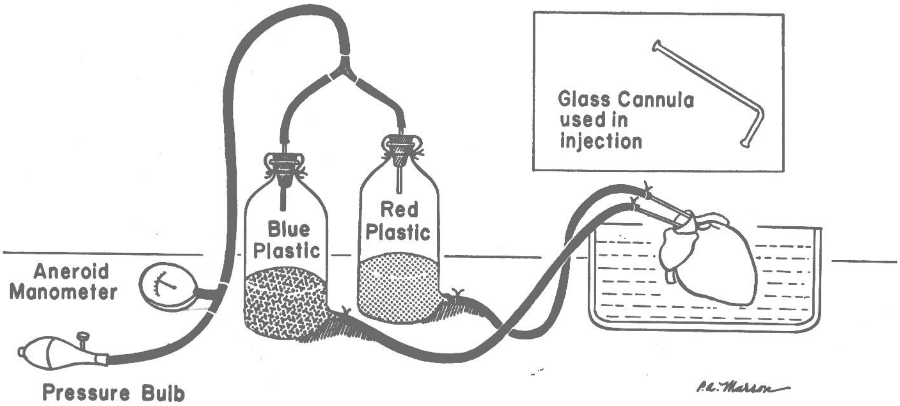


Fig. 1. *Diagram showing the simple apparatus employed for injection of the coronary arteries.*

For study of the vessels of the interventricular and interatrial septa, it is preferable to cast the two chambers of one side of the heart rather than both sides. The right chambers are better for this purpose for two reasons: (1) If uncast, they are more prone to collapse out of shape than those of the thicker left side, which retains its shape satisfactorily even when uncast. (2) The veins may be filled directly from the right atrium rather than by separate cannulation.

The injection of anastomoses poses special problems, which are discussed in Chapter 12.

In preparing for injection of the chambers, the superior vena cava should be occluded as far from its atrial connection as possible, for there is an important vascular ring at that point. The main pulmonary artery should be occluded well above the level of the pulmonary valve ring for the same reason. After injection of the arteries and chambers is completed and the cast hardened, a small amount of plastic may be introduced into the aorta to fix the two cannulae and arteries to each other, and a plastic or glass bridge placed between them and the main pulmonary artery so that the coronary arteries will not fall away from the rest of the cast.

For injection of the chambers, the concentrated Vinylite solution (mixed with kaolin) should be left undiluted. For injection of the arteries, a solution of about 10% Vinylite and 10% kaolin is optimal. If small vessels are to be filled, a thinner solution may be used, but this produces the problem of a bushy cast, in which so many small vessels are filled that the main arterial trunks are obscured.

Injection of the arteries is best accomplished first, with the chambers being filled as soon as this is completed. A sphygmomanometer bulb connected by a "Y"-joint to the tops of two bottles is a convenient source of pressure for artery injection; a mercury or aneroid manometer inserted between the pressure bulb and the "Y"-joint allows control of injection pressure (Fig. 1). Rubber tubing is used to connect the spout of the suction bottle to each coronary artery cannula, and similar tubing connects the "Y"-joint to a one-hole stopper in each bottle. These stoppers must be wired in place because of the high pressures employed. The heart should be placed in a container of water during the injection, so that the chambers will not be compressed.

The injection pressure should be applied instantaneously. A deeper penetration by the plastic is possible if the coronary tree is filled with acetone just prior to injection of the Vinylite. This better penetration is not the result of dilution of the advancing injectate, for which there is too little intermingling of the two solutions, but rather the consequence of the fact that the distal coronary tree is thus occupied by a solution (acetone) which can be pushed on by the injectate more easily than air or water. If a "physiologic" injection is desired, pressure to both coronary arteries should be applied simultaneously. If maximal demonstration of anastomoses is desired, one should fill one coronary artery first and the other later.

For injection of the arteries in the study to be described, a pressure of 270–300 mm. of mercury was routinely employed. Since the purpose was the demonstration of anatomy, this level of pressure was quite satisfactory, as in no specimen was even a small artery ruptured. A higher pressure would undoubtedly have been tolerated by the arteries (and was in a few hearts), but it posed too many problems with the rubber stoppers in the injection bottles and was unnecessary.

The pressure of 270–300 mm. Hg should be sustained for at least 6 hours to assist in minimizing shrinkage; thus, as acetone evaporates from the injected solution and the mass shrinks, more mass is slowly injected from the bottle reservoir. Because of the initial viscosity of the injectate (usually about 10 times that of whole blood), as well as its rapid increase as the acetone vehicle evaporates, it is doubtful that the high pressure in the injecting system ever reaches very far into the arterial tree.

To inject the chambers and veins, a lower pressure is necessary. Use of pressures higher than 100 mm. Hg in the chambers produced the problem of rupture of the valve of the foramen ovale from the anterior edge of the fossa ovalis in the majority of hearts; this attachment remained intact at lower pressures. Moreover, at pressures between 90 and 100 mm. Hg, small veins begin to rupture, a phenomenon quite easy to detect on gross examination. This limitation of pressure posed a problem in the filling of small veins with the viscid mass which the larger volume of the cardiac chambers necessitated. With careful changing of direction of the intra-atrial cannula and some experience, however, quite satisfactory casting of most of the veins was possible.

The chambers and veins should be left under pressure for 24 hours. During this time the pliable cast of the arteries will have hardened and the heart will have assumed approximately its normal size. Use of pressures of 50–80 mm. Hg for casting the right chambers does