Thebesian Drainage in the Left Heart of the Dog

By Thomas W. Moir, M.D., Thomas E. Driscol, M.D., and Richard W. Eckstein, M.D.

We have recently demonstrated direct right ventricular drainage of the septal branch of the common left coronary artery of dogs with normal pressure-flow relationship maintained between the coronary vasculature and the ventricular chambers. Using similar methods the search for Thebesian drainage of the common left coronary artery has been extended to the left heart of the dog, and the results of this investigation are herein reported.

Methods

These studies were performed in open-chest, mongrel dogs anesthetized with morphine and pentobarbital, and maintained on intratracheal positive pressure respiration. After anticoagulation with heparin, a Morawitz cannula with an occlusive balloon-tip was placed in the orifice of the coronary sinus via the right atrial appendage, and its outflow was diverted via a long (2 m) external circuit to a previously cannulated left external jugular vein.

A short segment of the right carotid artery was excised and replaced by a T cannula with a one-way flap valve at its central end. This valve allowed blood to flow from the aorta into an overhead reservoir from which blood was returned to the animal through the cephalic segment of the interrupted carotid artery. With this arrangement blood returned to the animal from the reservoir via the cerebral circulation rather than draining directly back into the aorta. After the valve was in place the aorta was ligated distal to the left subclavian artery and blood was diverted into the overhead reservoir, the height of which was adjusted to maintain a mean aortic pressure of 100 mm Hg. The purposes of these arrangements were to slow the circulation time by reducing the cardiac output, to maintain a constant aortic pressure, and to prevent distortion of dilution curves recorded from the aorta by blood returning directly to the aorta from the overhead reservoir.

The left carotid artery was cannulated and used to perfuse the coronary artery under study. In some animals a common left coronary arterial cannula was placed in the coronary ostium via the left subclavian artery and tied in place. Care was taken that none of the branches of the common left coronary artery were obstructed by the cannula. In other animals the left circumflex, the anterior descendens, or the septal artery was ligated at its origin, cannulated, and perfused from the carotid artery. The left anterior atrial artery was either cannulated directly if sufficiently large, or indirectly by cannulating the isolated segment of the circumflex artery from which it arose. In the latter situation the circumflex arterial segment beyond this point was separately cannulated and perfused.

Polyethylene sampling catheters (PE-260) were placed in the root of the aorta, the left atrium, and in some animals in a pulmonary vein, and led through a split sodium iodide scintillation crystal. The catheters were connected to a mercury suction bottle which withdrew blood through the scintillation crystal at a standard rate of 40 ml/min.

When these arrangements were completed 50 to 300 u.c of I^131 serum albumin, contained in a volume of less than 0.5 ml, was instantaneously injected into the cannula tubing of the perfused coronary artery and sampling from the site of interest was begun. Time-concentration curves of radioactivity were measured by a ratemeter with a time constant of 0.5 seconds, and a scale factor of from 10,000 counts/min (10 K) to 100,000 counts/min (100 K), and were recorded on a Rectiriter at a paper speed of 12 inches/min. After each determination, transit time through the sampling catheter was measured and the appearance time of the time-concentration curve correspondingly corrected.

From the Department of Medicine, Western Reserve University, School of Medicine, Cleveland, Ohio.

Supported by Grant H-4156 from the National Institutes of Health, U. S. Public Health Service.

Dr. Moir is a Markle Scholar in Medical Science.

Dr. Driscol was a Research Fellow of the Cleveland Area Heart Society during this study.

A preliminary report of this study was presented to the American Heart Association, and abstracted in Circulation 24: 1000, 1961.

Received for publication August 29, 1963.
Simultaneous with the coronary artery isotope injection, cardiogreen dye was injected into the jugular vein and time-concentration curves for cardiac output determination were recorded from the aorta by constant sampling through a densitometer.* The cardiac output determinations averaged 358 ml/min with a range from 136 to 960 ml/min, and were used to quantitate the primary peaks of radioactivity recorded from the aortic root. The amount of isotope represented by the first isotope peak at the aortic sampling site was determined by use of the formula, \( I = C_a T \times F \), where \( I \) is the amount of isotope at that site calculated as the product of the area of the time-concentration curve, \( C_a T \), and the cardiac output, \( F \). Since the amount of isotope injected was known, \( I \) could then be expressed as a per cent of the injected dose appearing early in the aorta. Assuming complete mixing, this represents the amount of direct left heart drainage from the coronary artery under study. Quantitative curve analysis was done only in those determinations in which separation of the early peaks of radioactivity from recirculation peaks allowed extrapolation of the initial downslope. Attempts to quantitate early appearance of isotope in the left atrium were unsuccessful because of marked variation in the time-concentration curves incident to poor mixing in this chamber.

In some animals oximetric study of aortic blood before and after occlusion of the left circumflex and left anterior atrial arteries was done by constant sampling through the densitometer.

**Results**

The common left coronary artery or its major branches were cannulated in 45 dogs and time-concentration curves of radioactivity were recorded from the root of the aorta after intracoronary injection. The septal artery was studied in 10 dogs and in only one animal was direct left heart drainage as represented by early appearance at the aortic sampling site noted. The anterior descendens artery was studied in 7 dogs and no early radioactive peaks were detected in the aorta. The left circumflex artery was studied in 13 animals, the left anterior atrial artery in 8 animals, and the common left artery in 7; in every instance early peaks of radioactivity were detected in the aorta although not all were suitable for quantitative analysis.

Figure 1, upper panel, is a representative curve recorded from the root of the aorta after isotope injection into the left circumflex artery of a dog with a normal cardiac output. An initial peak of radioactivity is present with an appearance time of five seconds and represents radioactivity that has drained directly into the left heart. The second peak of radioactivity represents isotope that has drained into the coronary sinus, escaped the coronary sinus cannula, and has recirculated to the left heart. The third and largest peak of radioactivity represents the major portion of the isotope that has drained into the coronary sinus cannula and has been delayed in returning to the heart by the external circuit connecting the sinus to the jugular vein. Curves of this contour were consistently seen after isotope injection into the left circumflex artery, the left anterior atrial artery, and the common left artery cannulated at its origin.

Figure 1, lower panel, illustrates the separation of the peaks of radioactivity obtained by slowing the circulation time. The resultant prolongation of the downslope of the first peak made it possible to estimate the magnitude of the drainage represented by this time-concentration curve by the method of curve analysis described.

---

* Gilford Instrument Laboratories, Incorporated, Oberlin, Ohio.
THEBESIAN DRAINAGE IN LEFT HEART OF DOG

247

FIGURE 2
Time-concentration curves recorded in pulmonary vein, left atrium, and aortic root after circumflex injections. Scale factors 100,000 and 30,000 counts/min.

Figure 2 illustrates the early appearance in the left atrium as well as the aorta and the absence of a primary radioactive peak in the pulmonary veins. This confirms the interpretation that the first aortic peak is the result of direct left heart drainage from the circumflex artery.

In figure 3, panel A indicates that in 8 animals an average of 6% of isotope injected into the circumflex artery can be accounted for by the early time-concentration curve in the root of the aorta. In these preparations the circumflex artery was cannulated above the origin of the left anterior atrial artery. If, however, the left anterior atrial artery was occluded during the circumflex artery injection, or if the circumflex was cannulated below the origin of the left anterior atrial artery, marked attenuation of the early aortic curve occurred. As illustrated in figure 3, panel B, this reduced the magnitude of drainage accounted for in the aorta from 6% to less than 2%.

Since these data indicated that the majority of the early left heart drainage from the circumflex artery was via its left anterior atrial branch, direct study of the latter artery was undertaken. Figure 4 indicates that a major amount of isotope injected into this vessel drains directly into the left heart as represented by the early time-concentration curve in the aorta.

In order to determine the fraction of total common left artery flow represented by this direct left heart drainage isotope injections were made into the artery, cannulated at its origin above all branches. Figure 5 shows that about 2% of isotope injected into the common left coronary artery can be accounted for by the early peak of radioactivity at the aortic root.

Oximetric studies from the aorta before and after occlusion of the left circumflex and left anterior atrial arteries failed to show any significant change in oxygen saturation of the aortic blood.

Figure 3 A. Amount of isotope accounted for by early aortic radioactive peak after left circumflex injection. Average value indicated by dashed line. Number of animals in parentheses. B. Amount of injected isotope accounted for in aorta from left circumflex injection after left anterior atrial artery occlusion or from injections below origin of left anterior atrial artery.
Discussion

This study has demonstrated that in the normally beating dog heart there is Thebesian drainage into the left heart from the common left coronary artery. When the average value of this drainage, 2%, is added to the 13% of common left flow shown previously to drain directly into the right ventricle via the septal branch,\(^1\) it is clear that a significant amount of outflow of this artery escapes coronary sinus drainage. The usual discrepancy of 15% to 20% between the volume of common left coronary inflow and coronary sinus outflow is primarily due to these additional drainage channels.

These studies additionally show that the left heart drainage from the common left coronary artery is via the left circumflex branch and the left anterior atrial artery. Drainage into the left heart from the anterior descendens artery could not be demonstrated, and only small and occasional drainage from the septal artery was shown.

\[\text{FIGURE 4}\]
Amount of isotope accounted for by early aortic radioactive peak after left anterior atrial artery injection.

\[\text{FIGURE 5}\]
Amount of isotope accounted for in aorta after injection into common left coronary artery, cannulated above origin of all branches.

The left anterior atrial artery, a branch of the left circumflex originating within 1 cm of the common left bifurcation\(^2,3\) appears to be the major but not the sole source of left heart drainage from the circumflex artery since residual drainage is present when it is occluded or when isotope injections are made downstream of its origin. It is probable that the remainder of the left heart drainage from the circumflex is through other left atrial branches, or possibly through ventricular branches.

Presumably a major part of this left heart drainage is into the left atrium since early radioactive peaks are recorded there as well as in the aortic root. Unfortunately, mixing characteristics are such in the left atrium that reliable time-concentration curve analysis is
not possible. Consequently, a derived figure for possible left ventricular drainage by quantitative comparison of left atrial and aortic root dilution curves could not be obtained. Although the question of left ventricular drainage from the circumflex branch of the common left coronary artery cannot be answered by this study, a significant barrier to its solution is apparent. The presence of drainage upstream from the ventricle will vitiate any demonstration by dilution techniques of left ventricular drainage from the circumflex artery.

Failure to show significant drainage into the left heart from the anterior descendens artery is at variance with the dye dilution studies of Watanabe. However, the majority of his studies were done with the heart fibrillating or in excised, perfused preparations. In his studies of the beating heart in which dye dilution curves were recorded from the aorta after injections into the left anterior descendens artery and compared with curves similarly recorded after right atrial injection, the appearance time differences were variable and unconvincing. In addition, the author did not indicate whether such injections were made above or below the septal artery which in 50% of dogs has its origin from this artery. Unfortunately, the total common left and the left circumflex arteries were not studied in Watanabe’s investigation. Although some of his data are compatible with potential drainage pathways into the left ventricle from the left anterior descendens artery, our study indicates that such drainage is not functional in a normally beating heart.

It was hoped that the oximetric studies of aortic blood before and after occlusion of the circumflex and left anterior atrial arteries would help define the venous or arterial character of these drainage pathways. However, no significant change in oxygen saturation of aortic blood was found after these maneuvers. Nonetheless, no conclusions are justified from these data since the amount of blood draining into the left heart from the common left system (2%) is small compared to the diluting volume of the cardiac output.

Summary

Direct left heart drainage from the common left coronary artery has been demonstrated in the normally beating dog heart by an isotope dilution technique. The major portion of this drainage has been shown to be through the left circumflex branch of the common left coronary artery. The left anterior atrial artery, a branch of the left circumflex, has in turn been shown to be the major pathway of drainage from the latter. Left heart drainage could not be demonstrated from isotope injections into the left anterior descendens artery, and in only one preparation could such drainage be documented from the septal branch of the common left artery.

The magnitude of left heart Thebesian drainage has been estimated by analysis of time-concentration curves recorded from the aorta. An average of 2% of total common left coronary artery inflow drains directly into the left heart. Although the major drainage is probably into the left atrium, left ventricular drainage has not been excluded.

Acknowledgment

The authors wish to thank Mr. John Dattilo and Mrs. Jacqueline Chadwick for their devoted and expert help during the course of this study.

References

Thebesian Drainage in the Left Heart of the Dog
THOMAS W. MOIR, THOMAS E. DRISCOL and RICHARD W. ECKSTEIN

Circ Res. 1964;14:245-249
doi: 10.1161/01.RES.14.3.245

Circulation Research is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1964 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7330. Online ISSN: 1524-4571

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circres.ahajournals.org/content/14/3/245

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation Research can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation Research is online at:
http://circres.ahajournals.org/subscriptions/