New Technique for Determining Cardiac Output with Use of a Miniature Esophageal Scintillation Detector

By Antonio Hernandez, Jr., M.D., David Goldring, M.D., Michel Ter-Pogossian, Ph.D., and John Eichling, M.S.

SUMMARY
A miniature scintillation detector recently designed and constructed in this laboratory can be inserted into the esophagus and under fluoroscopic vision positioned so that radioactivity emitted from the blood in the descending aorta can be detected and a time-concentration curve recorded from which cardiac output can be determined. Twenty simultaneous determinations of cardiac output by the isotope-dilution method with the esophageal scintillation counter probe and the dye-dilution technique were done in 10 dogs. There was a good correlation between the two methods. Among the technical advantages of the isotope-dilution method over the dye-dilution method are avoidance of arterial puncture, only one sample of venous blood required, an easily performed procedure, and ability to permit repeated determinations of cardiac output with a minimum of manipulation and trauma.

Additional Indexing Words:
Cardiac output
Radioisotopes
Technetium\textsuperscript{99m}

The determination of cardiac output, especially in the infant and young child, remains a challenging problem because the widely favored methods, that is, the Fick and the dye-dilution techniques, are dependent on sampling of arterial blood. The real and potential hazards of frequent sampling of arterial blood for repetitive determinations of cardiac output are obvious. There has, therefore, been a continuing search for a method with a high factor of safety for the study of cardiac output in infancy and childhood.

The availability of radioactive isotopes enabled a number of investigators to use them as indicators in the study of blood flow. External precordial radioactivity detectors positioned over the heart and blood vessels have enabled a number of investigators to detect left-to-right shunts and demonstrate characteristic curves in a number of cardiac malformations.\textsuperscript{1-8} Huff and his co-workers,\textsuperscript{9} as well as Pritchard and his group,\textsuperscript{7,8} have been able to calculate cardiac output from time-concentration curves with the aid of external counting detectors and found good correlation with both the Fick and the dye-dilution methods.

The problem of selectively detecting radioactivity within a known arterial segment, however, has made the external counting technique unreliable.\textsuperscript{9} Slight changes in the positioning of the detector may give false values for cardiac output. Changes in the distance of the precordial detector from the chest will also cause changes in the values for cardiac output. Thus, for serial determination of cardiac output the precordial scanning technique has serious limitations.

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A miniature scintillation detector has recently been designed and constructed in our laboratory which can be inserted into the esophagus and under fluoroscopic vision positioned so that radioactivity emitted from the blood in the descending aorta can be detected and a time-concentration curve recorded, from which cardiac output can be calculated. The purpose of this investigation is to report the results of cardiac output determinations in dogs obtained with the isotope-dilution method using the esophageal scintillation detector and to compare these values with those for cardiac output determined by the dye-dilution technique.

**Methods**

The esophageal scintillation counter probe used for the detection of radioactivity is made up of a phosphor, which is a cylindrical thallium-activated cesium iodide crystal, 3/16 inch in diameter, and ½ inch long. The crystal is mounted on the end of a flexible noncoherent glass fiber light guide, 30 inches long. The light guide couples the fluorescence of the crystal to an end-window photomultiplier tube (Amperex 152 AVP, ½ inch in diameter and 4 inches long). The phototube is mounted with a preamplifier inside a cylindrical aluminum case, 1 inch in diameter and 12 inches long. The field of view of the crystal is properly limited by a small aperture in a tantalum shield that surrounds the crystal. The shield thickness is 1.2 mm, affording an attenuation of 75-fold for the 140 kev (kilo-electron volts) gamma radiation of technetium$^{99m}$. Light-tightness is provided by a 1-mil thick aluminum foil covering the aperture in the shield. The probe assembly is waterproof and thus may be cold-sterilized. Figures 1 and 2 are photographs of the esophageal scintillation probe. The radioactivity detected by the scintillation probe is measured by a count meter and recorded on a linear recorder. Cardiac output was calculated from the time-concentration curve according to the method of Huff and co-workers.$^6$ The area under the primary curve is measured by a planimeter in square inches. The descending limb is extrapolated on semilogarithmic paper and the value of the extrapolated portion is replotted on the original tracing. The amplitude of the curve (fig. 3) showing the level of the radioactivity at time of equilibration is then measured in inches. The ratio of the average activity during the primary curve to the activity at equilibrium divided by the chart speed will give the time needed for one blood volume to pass a given point of the detector. The cardiac output can then be determined by dividing the blood volume by the time it takes one blood volume to equilibrate.

Twenty-two determinations of cardiac output were done in 10 anesthetized adult mongrel dogs (weighing 9.3 to 19.9 kg) by using the esophageal scintillation detector with serum albumin labeled with technetium$^{99m}$ as the indicator. Twenty determinations of cardiac output were made simultaneously by the dye-dilution method in these animals. The dogs were anesthetized with sodium pentobarbital (25 mg/kg of body weight) given intravenously, intubated, and allowed to breathe room air. A jugular vein was then cannulated with a cardiac catheter which was positioned so that the tip of the catheter was in the mid-right atrial cavity. This catheter was used for injecting the indicator substance. The femoral artery was also cannulated, and the tip of the catheter was positioned just above the diaphragm.
Figure 3
A representative time-concentration curve as recorded with the esophageal scintillation probe. Ceq marks the time when the injected isotope has reached equilibrium in the blood.

Figure 4
A chest roentgenogram of a dog showing the position of the probe in relation to the descending aorta which is opacified with contrast material. Arrows point to the tips of the cardiac catheters, one in the descending aorta and the other in the right atrial cavity.

Figure 5
Correlation of 20 simultaneous determinations of cardiac output in dogs by the dye-dilution technique and the isotope method using the miniature esophageal probe.

$R = 0.975$
This catheter was used for withdrawing blood into the cuvette densitometer. The esophageal scintillation counter probe was then inserted through the mouth, and the tip was positioned under fluoroscopic vision so that the probe was about 1 cm above the level of the diaphragm with its window facing posteriorly toward the descending thoracic aorta. Figure 4 is a chest roentgenogram of a dog showing the relationship of the esophageal probe to the tips of the two cardiac catheters.

Indocyanine green dye (CardioGreen) in a concentration of 5 mg/ml and serum albumin labeled with technetium\textsuperscript{99m} were the indicators used in this study. The dose of the radioisotope used was 500 microcuries. The dose of the radioisotope and dye were mixed carefully in a syringe before injection and injected as a single dose. The catheter was immediately flushed with 15 ml of saline solution after each injection.

The time-concentration curve of the dye-dilution method was recorded in the usual manner and the cardiac output calculated using the Hamilton formula.\textsuperscript{10}

### Results

The results are summarized in Table 1. The calculated cardiac output by the isotope method ranged from 1.9 to 4 L per minute and for the dye-dilution method 1.8 to 4.3 L per minute. Figure 3 shows a reproduction of representative curves recorded from the esophageal scintillation counter. The resultant curves are clear-cut. The final portion of the descending limb that encloses the total area under the primary curve is a replot of the exponential curve which has been derived by plotting the descending limb on semilogarithmic paper and calculating for the final portion of the descending limb by assuming exponential disappearance of the indicator if there has not been recirculation. This calculated exponential decay is replotted on the original tracing.

### Table 1

Comparison of Cardiac Output Value Obtained by the Dye-Dilution and Isotope Methods

<table>
<thead>
<tr>
<th>Dog</th>
<th>Sex</th>
<th>Weight (kg)</th>
<th>Dye method (L/m)</th>
<th>Isotope method (L/m)</th>
<th>% Difference from dye method (std.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>15</td>
<td>2.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>16.8</td>
<td>3.1</td>
<td>3.2</td>
<td>+10</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>14.5</td>
<td>-</td>
<td>3.0</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>15</td>
<td>3.9</td>
<td>4.0</td>
<td>+3</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>19.9</td>
<td>2.9</td>
<td>2.8</td>
<td>-3</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>17.2</td>
<td>3.2</td>
<td>3.4</td>
<td>+36</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>14.1</td>
<td>3.6</td>
<td>2.7</td>
<td>-25</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>18.1</td>
<td>3.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>9.3</td>
<td>3.7</td>
<td>3.3</td>
<td>-11</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>14.5</td>
<td>3.7</td>
<td>3.3</td>
<td>-10</td>
</tr>
</tbody>
</table>

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The time-concentration curve of the dye-dilution method was recorded in the usual manner and the cardiac output calculated using the Hamilton formula.\textsuperscript{10}
DETERMINATION OF CARDIAC OUTPUT

Discussion

The values for cardiac output in this study fall within the usual range for cardiac output of anesthetized dogs. There was good agreement between the simultaneous values obtained by the two methods (that is, dye and isotope dilution) as shown by the correlation coefficient value of 0.975 (fig. 5). The range of deviation of the isotope method and dye-dilution methods was -26 to +36%. Only five values deviated more than ±20%, and the average deviation was ±4%.

The isotope-dilution method has certain technical advantages over the dye-dilution method in that arterial puncture is avoided and only one sample of venous blood is required at the time of equilibration of the isotope in the blood. The procedure is easily performed and repeated determinations of cardiac output can be accomplished with a minimum of manipulation and trauma. The advantage of this method over the precordial external counting technique is that the radiation sensor can be placed directly in front of, and closer to, the descending aorta. Since the window faces the aorta, little radioactivity is detected other than that emanating from the aorta. For serial determinations of cardiac output, the probe can be left in place and errors due to changes in position are minimized. The isotope used is technetium99m which is almost a pure gamma-ray emitter and has a very short half life (6 hours) so that exposure of the patient to excessive radiation is minimized. We are now in the process of evaluating this method in humans, and if it continues to be reliable, then the esophageal probe method can be used in a number of areas. This method will be especially useful in the follow-up studies of patients after open-heart operations. The probe can be left in place in the esophagus and serial determinations of cardiac output would be of help in monitoring the progress of the patient and in evaluating such therapeutic procedures as blood transfusion, fluid infusions, and administration of isoproterenol (Isuprel), digitalis, and diuretics. This method will also furnish information regarding the question of complete closure of interventricular septal defects or interatrial septal defects. The evaluation of the impact upon the cardiovascular system as reflected by cardiac output and blood volume of such extracardiac stresses as anemia, lower respiratory infections, exchange transfusion, and asthma, in the young infant would also be of great interest.

Acknowledgment

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History of Scientific Journals

The journals which had their origins in the period 1665-1790 can be divided into two major groups, which can be designated by several groups of opposing terms, e.g. primary and secondary, original and derivative, the literature of record and the literature of dissemination; these terms reflect the two roles of the medium as a repository and as a vehicle. These two roles have never been clearly differentiated either in the long history of the scientific periodical or in our current publication practices. In the first group we include those journals which were, for the most part, published independently and which contained original matter. These have been designated substantive journals. This group includes also the publications established to report the proceedings of the learned societies. The second group includes those journals which were established largely to provide access to materials that were not readily available by means of translation, summaries or reprinting. In this group we have designated as special classes, the abstract journal, the review journal, and the collection.—David A. Kronick: A History of Scientific and Technical Periodicals. New York, Scarecrow Press, Inc., 1962, p. 235.
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