A Simplified Indicator-Dilution Technic for the Localization of Left-to-Right Circulatory Shunts

An Experimental and Clinical Study of Intravenous Injection with Right Heart Sampling

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Indicator-dilution curves recorded from a systemic artery after injection in the right heart may show the presence of a left-to-right shunt but will not localize it. Injections into the left side of the heart with arterial sampling or into the pulmonary artery with right heart sampling provide accurate and sensitive methods for localization but the technics are inconvenient and sometimes impossible to apply. A simplified indicator method for the localization of left-to-right circulatory shunts is described.

Indicator-dilution curves are now a well-recognized and important method for the study of patients with congenital and acquired heart disease and have been found of particular value in the diagnostic evaluation of patients with cardiac shunts. The detection and localization of right-to-left shunts by this means was described by Swan, Zapat-Diaz, and Wood in 1953 and remains an important application of indicator-dilution curves. The precise characterization of left-to-right shunts, however, has been somewhat more difficult.

When an indicator is rapidly injected into a peripheral vein, the right side of the heart, the pulmonary artery, or the left atrium of a patient with a left-to-right shunt, it is at first dispersed within the large volume of blood that traverses the central circulation. The indicator takes 2 circulatory paths in the left side of the heart: a portion of it follows the normal route to the systemic arterial bed while the remainder is shunted from the left to the right side of the heart, through the pulmonary circulation and returns to the left side. A fraction is then again shunted from left to right. The resulting dilution curve, recorded from a systemic artery, is characterized by a normal ascending limb, a relatively low peak concentration and a descending limb which is prolonged by recirculating indicator. As long as the indicator is injected proximal to the origin of the left-to-right shunt, varying the site of injection usually modifies the resultant curve only by compressing or expanding it as the volume of blood between the sites of injection and sampling varies. The basic contour as described above, however, remains unchanged. Indicator-dilution curves obtained by peripheral venous, right heart, or pulmonary artery injection with systemic arterial sampling are thus of value in the detection of a left-to-right cardiac shunt when it exceeds approximately 20 to 30 per cent of the pulmonary blood flow. Such curves have not been useful in the localization of left-to-right shunts except in the study of patients with partial anomalous pulmonary venous drainage.

Reports from this clinic and elsewhere have demonstrated that systemic arterial dilution curves recorded following injections into the chambers of the left side of the heart and aorta are of considerable value in this regard. When the injection is
made distal to the origin of the left-to-right shunt, all of the dye follows the normal circulatory path across the aortic valve and into the peripheral circulation. The resultant arterial dilution curve has a steep ascent, a slightly slower descent, and returns to the baseline before the appearance of recirculating indicator. However, when the injection is made proximal to the origin of the shunt, only a portion of the indicator takes the normal circulatory path. The remainder passes across the defect and through the pulmonary circulation. The late appearance of this portion of the indicator in the peripheral artery abruptly interrupts the descending limb of the curve and results in either a secondary peak or in an abrupt change in the slope of the descending limb. While this method has received considerable practical application, it has the disadvantage of requiring either direct left heart catheterization or passage of the catheter into the left side from the right.

Recently, the introduction of triarboceyanine dye (cardigreen) by Fox and collaborators has made possible the recording of satisfactory dilution curves from the right side of the heart and pulmonary artery. Such curves have been utilized extensively by Wood and his associates for the localization of left-to-right cardiac shunts at the time of right heart catheterization. These investigators have usually injected the dye into the pulmonary artery while sampling from another catheter or from the proximal lumen of a double-lumen catheter at various sites up-stream (proximal) to the site of injection. The early appearance of dye in the right side of the heart signifies the presence of a left-to-right shunt, while the particular chamber in which the dye appears indicates the site of entry of the shunt. Our experience has confirmed the value of this technic in the detection and precise localization of even very small shunts. However, the insertion of 2 cardiac catheters or of a double-lumen catheter has, in our laboratory, often been found to be inconvenient or even impossible, particularly in infants and young children. The present report describes a simplified indicator method that obviates these difficulties.

When an indicator is rapidly injected into a peripheral vein of a patient without a left-to-right shunt, the dilution curve obtained by sampling blood from a vena cava, the right side of the heart, or the pulmonary artery is characterized by a rapid ascent and a smooth descent followed by the appearance of indicator which has recirculated normally through the systemic bed. A similar curve results when the site of sampling is proximal to the entry of a left-to-right shunt. However, when the site of sampling is down-stream (distal) to the entry of a shunt, the appearance in the right side of the heart of indicator which has been shunted from left-to-right interrupts the descending limb of the curve. This results either in a secondary peak or in a prolonged smooth descending limb. Thus, by alteration of the site of sampling within the venae cavae, right heart, and pulmonary artery the site of entry of the shunt may be correctly localized (fig. 1).
Materials and Methods

Atrial septal defects were created in 4 mongrel dogs by excising a portion of the atrial septum during a period of inflow occlusion. In 6 dogs ventricular septal defects were made by the method of Kay and Blalock.16 A circular punch was introduced through the wall of the right ventricle and advanced through the interventricular septum. Suction was then applied to the instrument and a portion of the septum was removed. In 5 of these dogs varying degrees of tricuspid regurgitation were also produced, since either chordae tendineae or papillary muscles were severed by the punch. All 10 dogs were sacrificed and the presence of the defect was confirmed at postmortem examination.

A total of 24 patients have been studied to date. In 8 there was no clinical suspicion of a left-to-right shunt and this impression was confirmed in each by a negative nitrous oxide test17 and at operation in 4. The remaining 16 patients had left-to-right shunts proved by this method. The diagnosis was further confirmed at open operation in 12 of these patients.

Cardiogreen dye14 was employed as the indicator, 1.25 mg. of dye per ml. being contained in 1.0 to 2.5 ml. of saline solution. In the experimental studies the dye was injected into a cannula inserted in the femoral vein. In the patients the dye was injected either into an antecubital vein or into an indwelling Courand needle in the femoral vein; the latter was found to be particularly convenient. Injections were made as rapidly as possible and were always completed in less than 1 second. Indicator-dilution curves were inscribed with either a direct-writing or a photographic recorder and a cuvette densitometer18 by withdrawing blood from the cardiac catheter with a motor-driven syringe at a rate of 20 ml. per minute. The catheters (no. 6F to no. 8F Courand) ranged in volume from 0.64 to 1.23 ml. The volume of the tubing between the proximal end of the catheter and the densitometer was held constant at 0.41 ml. The volume of the cuvette in the densitometer is 0.30 ml. The response of the densitometer to a sudden change in density is 95 per cent in 1 second and 99 per cent in 2 seconds.19 Since only the contours of the dilution curves were analyzed, the curves were not calibrated. In the patients and dogs with left-to-right shunts, curves were generally obtained by sampling both proximal and distal to the entry of the shunt. In patients without shunts generally only 1 curve was recorded from the pulmonary artery or the right side of the heart.

Results

In all 10 dogs the left-to-right shunt was detected; its site of entry was correctly localized in all but 1 instance. In this dog with an atrial septal defect, the dye curves obtained with both right atrial and inferior vena caval sampling were normal, while the curve from the right ventricle clearly showed the presence of a left-to-right shunt. It is believed that this error in localization was related to improper positioning of the catheter in the right atrium, so that it did not sample blood that had been shunted. This observation emphasizes the importance of sampling blood from as distal a site as possible in each chamber, e.g., in the right atrium near the tricuspid valve or in the outflow tract of the right ventricle.

The presence or absence of a left-to-right shunt was determined correctly in all 24 patients studied. In 4 patients the left-to-right shunts were relatively small with pulmonary/systemic flow ratios less than 1.3 as determined by the nitrous oxide test.17 Representative curves obtained from patients and dogs are illustrated in figures 2 to 6.

Discussion

The practical advantages of the method described are that left heart catheterization, and the insertion of either 2 catheters or of a double-lumen one are obviated. By sampling both proximal and distal to the site of entry of the shunt each patient serves as his own control. Thus the contour of the dilution curve from the vena cava proximal to the entry of any shunt will be modified by the cardiac output and by the appearance of indicator recirculating normally through the systemic circuit. The latter often interrupts the bottom third of the descending limb. The vena caval curve may be compared with that obtained from the chamber which is distal to the site of entry of the suspected shunt. The indicator which has been shunted from left-to-right either greatly prolongs the descending limb (figs. 2 and 3) or abruptly interrupts its upper portion (figs. 4 and 5).
A gross approximation of the magnitude of the shunt may be achieved by noting the difference between the curves obtained from proximal with those obtained from distal to the entry of the shunt. It is pertinent that even shunts of small magnitude could be accurately detected.

The well-recognized fact that blood sampled from a vena cava or from the right atrium is not completely mixed\textsuperscript{10, 17, 20} limits the precision of shunt localization of the method described in a manner somewhat analogous to the oxygen method.\textsuperscript{20} However, the latter depends on the recognition of a difference in the oxygen content between successive cardiac chambers, while this indicator-dilution method is based on the determination of the presence or absence of abnormally recirculating indicator. In any event, in actual practice, dilution curves sampled from the vena cavae and right atrium exhibit smooth contours and the detection and correct localization of both atrial and ventricular septal defects have been accomplished repeatedly. Application of the present method may, however, be limited in patients with severe congestive heart failure or valvular regurgitation on the right side of the heart. Although the dilution curves are undoubtedly modified by the relatively large and variable volume of blood contained within the cardiac catheter and its connection to the densitometer,\textsuperscript{21} the detection and localization of a shunt are not based upon the configuration of a single curve, but rather on a comparison of curves obtained proximal and distal to the entry of the shunt.

In a small group of patients left-to-right shunts may be multiple or have unusual origins or terminations. In such patients, dye curves obtained from the right side of the heart after intravenous injection may be used in conjunction with curves recorded

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**Fig. 2 Top.** Dilution curves following peripheral venous injection of dye and sampling blood from the superior vena cava (SVC), and the right atrium (RA), of a dog with an atrial septal defect. Equivalent amounts of cardiogreen were injected and the sensitivity of the densitometer was held constant. The right atrial curve is characterized by a lower peak concentration and much longer descending limb than the vena caval curve. *Vertical arrows,* indicate instant of injection.

**Fig. 3 Middle.** Dilution curves in a dog with a ventricular septal defect and tricuspid regurgitation. Following femoral vein injection the control curve from the inferior vena cava (IVC) is normal. With right atrial (RA) sampling the descending limb is somewhat slowed and the right ventricular (RV) curve is grossly distorted. This indicates that a small left-to-right shunt enters the right atrium and a larger shunt enters the right ventricle. The presence of tricuspid regurgitation is proved by the immediate appearance of dye in the RA following its injection into the RV.

**Fig. 4 Bottom.** Dilution curves following femoral vein injection in a patient in whom the presence of a large atrial septal defect was proved at open oper-
Fig. 5 Top. Dilution curves following peripheral vein injection in a patient with a very small ventricular septal defect whose nitrous oxide test showed a pulmonary-to-systemic flow ratio of 1.14. The dilution curve was modified in a characteristic manner by the abnormally recirculating indicator. The chief advantage of this approach is that it obviates the necessity for left heart catheterization or the insertion of either 2 catheters or of a double-lumen catheter.

The accuracy of this dye-dilution method was proved in a group of dogs with experimentally produced left-to-right shunts, and its clinical applicability was demonstrated in 16 patients with and 8 patients without shunts.

**SUMMARY**

A simplified indicator-dilution technic for the localization of left-to-right shunts is described. Cardiogreen dye was injected into a peripheral vein and sampled from a catheter located in the vena cava, right heart, or pulmonary artery. When the site of sampling was distal to the entry of a shunt, the dilution curve was modified in a characteristic manner by the abnormally recirculating indicator. The chief advantage of this approach is that it obviates the necessity for left heart catheterization or the insertion of either 2 catheters or of a double-lumen catheter.

The accuracy of this dye-dilution method was proved in a group of dogs with experimentally produced left-to-right shunts, and its clinical applicability was demonstrated in 16 patients with and 8 patients without shunts.

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