A Simplified Technic for the Detection of Patent Ductus Arteriosus and of Other Left-to-Right Shunts Originating from the Aorta

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The presence of an isolated patent ductus arteriosus can generally be determined by clinical examination. However, the differentiation of patent ductus arteriosus from the more unusual left-to-right shunts originating from the aorta is notoriously difficult, and in the presence of an associated intracardiac shunt the recognition of a patent ductus arteriosus may not be possible even by means of cardiac catheterization. The diagnosis of this malformation can be established by means of retrograde thoracic aortography or by indicator-dilution curves following central aortic injection.\(^1\), \(^2\) In this laboratory, however, these diagnostic methods have not been found to be practical as "routine" or "screening" procedures. In view of the importance of determining the presence or absence of a patent ductus arteriosus, particularly in patients for whom an open operation for an intracardiac defect is planned, efforts have been directed toward the development of a simple but accurate diagnostic technic.

The versatility, reliability, and technical simplicity of the technics utilizing injections of solution Kr\(^{85}\) for the characterization of intracardiac shunts\(^3\)–\(^6\) prompted their application to this problem. In the present study solutions of Kr\(^{85}\) were injected into the central aorta through a small radiopaque catheter inserted by way of an indwelling arterial needle and the appearance time of the isotope was detected in the expired air.

Patient Material and Methods

Twenty-two patients ranging in age from 2 to 59 years were studied. In eight of these the presence of an isolated patent ductus arteriosus was confirmed at subsequent operation. Three patients had rheumatic heart disease and there was no clinical suspicion of the presence of any circulatory shunt. In six patients an intracardiac shunt (atrial or ventricular septal defect) was present, and the absence of an associated patent ductus arteriosus was confirmed at operation. The diagnoses in the remaining patients were ventricular septal defect with aortic regurgitation, aortic stenosis and regurgitation, ruptured aneurysm of the sinus of Valsalva, aorticopulmonary anastomosis, \(^*\)and aorticopulmonary (Potts) anastomosis. In these patients the diagnoses were proved either at operation, at postmortem examination, or by means of retrograde thoracic aortography.

In general, central aortic catheterization was carried out by means of radiopaque poly-vinyl catheters.\(^*\) These catheters are 70 cm. in length, and were sterilized in ethylene oxide gas. When the femoral artery was large enough to permit introduction of a no. 16 Cournand needle, the internal diameter of the catheter employed was .022 cm. In most instances, however, a no. 18 Cournand needle was used with a catheter of .012-cm. internal diameter. The inner surfaces of the Cournand needles were polished to facilitate passage of the catheter and their bevels rounded to prevent shearing of the catheter upon withdrawal.

Solutions of Kr\(^{85}\) in isotonic saline were prepared as outlined previously.\(^6\) Immediately before and after each injection the patient was instructed to breathe rapidly through a mouth piece. The expired gas was led across the face of an end-window Geiger-Muller tube,\(^\dagger\) the output of which was integrated by a count-rate meter,\(^\ddagger\) and recorded continuously on a direct-writing oscillograph. In general, less than 30 \(\mu\)c. of Kr\(^{85}\) was employed for each injection, and the injections were made with the tip of the catheter at various levels in the aorta.

In seven of the patients, indicator-dilution curves were also obtained in order to characterize the lesions further. Blood was always sampled from the right brachial artery. The details of the technic employed for obtaining these curves have been described elsewhere.\(^7\)

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\(^*\) Manufactured by Albert E. Afford, 340 Marve Avenue, Haddonfield, New Jersey.

\(^\dagger\) Type TGC 2 Geiger Tube—Tracerlab, Waltham 54, Massachusetts.

\(^\ddagger\) Model 1020B—Nuclear-Chicago, Chicago, Illinois.
Results

When the Kr\textsuperscript{85} was injected into the aorta near the origin of the left subclavian artery in the eight patients with a patent ductus arteriosus, its appearance in expired gas ranged from 2.5 to 4.0 seconds after injection, and the concentration rose relatively rapidly to a high peak. When the injection was made into the aorta below the level of the diaphragm, however, the appearance times ranged from 8 to 20 seconds and the concentration rose slowly to a lower peak. The differences in the appearance times between the injections made into the aorta from a point proximal and a point distal to the ductus ranged from 5.5 seconds to 16.0 seconds and averaged 9.5 seconds.

When the Kr\textsuperscript{85} was injected into the aorta at the level of the left subclavian artery in the eight patients without left-to-right shunts from the aorta, the appearance times in the expired gas ranged from 11 to 17 seconds, averaged 13.4 seconds, and the concentration rose relatively slowly. The appearance times were similar when the injections were made into the aorta at the level of the diaphragm and ranged from 11 to 19 seconds and averaged 14.5 seconds. In these patients the differences in the appearance times between the upper and lower aortic injections ranged from 0 to 6 seconds and averaged 1.0 second.

Illustrative Clinical Applications

Case 1

S.G., no. 02-S7-58, an 8-year-old boy with known congenital heart disease, complained of increasing fatigability and dyspnea. On physical examination he was underdeveloped and presented with physical findings that suggested a ventricular septal defect associated with aortic stenosis. Right heart catheterization carried out at a university medical center revealed equal pressures in the pulmonary and brachial arteries and an oxygen “step-up” in the right ventricular outflow tract and pulmonary artery. At the National Heart Institute retrograde aortic catheterization was carried out and Kr\textsuperscript{85} was injected into the aorta at the level of the left subclavian artery and at the level of the diaphragm. The expired air Kr\textsuperscript{85} curves (fig. 1) revealed an appearance time of 3.0 seconds with a rapid rise to a high peak concentration when the injection was made into the aortic arch; the appearance time was 11.0 seconds with a gradual rise to a relatively low peak concentration when the injection was made into the aorta at the level of the diaphragm. These studies were interpreted as indicating the presence of a left-to-right shunt originating from the aorta at the level of the left subclavian artery, or proximal thereto. At operation a moderate-sized patent ductus arteriosus was closed. The aortic valve gradient measured at the operating table fell from 100 mm. Hg prior to ligation of the ductus to 50 mm. Hg following closure.

No extensive diagnostic procedures were indicated in this seriously ill patient in whom the presence of pulmonary hypertension and of a left-to-right shunt had been established previously. The Kr\textsuperscript{85} injections clearly indicated that a left-to-right shunt originated from the aorta. The pulmonary hypertension was thought to account for the absence of any diastolic murmur. Thus, the application of this simple diagnostic technic proved useful in developing a rational therapeutic plan for this patient.

Case 2

T.R., no. 02-79-56, a 56-year-old man was first told of a heart murmur at the age of 46 years. Nine years later he was admitted to a university hospital for an unrelated illness and a continuous murmur was noted in the upper parasternal area; right heart catheterization indicated that a moderate-sized left-to-right shunt entered the pulmonary artery. At the time of referral to the National Heart Institute, the diagnoses suggested were patent ductus arteriosus, ruptured aneurysm of an aortic sinus of Valsalva, and coronary arteriovenous fistula.

At retrograde aortic catheterization the appearance times in the expired air of Kr\textsuperscript{85} which had been injected into the ascending aorta and into the abdominal aorta, were identical (14 seconds), excluding the presence of a left-to-right shunt originating from the aorta (fig. 2). Indicator-dilution curves recorded oximetrically from the right ear following the injection of cardio-green dye at various levels in the descending aorta showed that a moderate degree of aortic regurgitation was present;\textsuperscript{8} dye injected at a point 16 cm. below the origin of the left subclavian artery regurgitated to the origin of the innominate artery and was immediately detected in the right ear. Right heart catheterization revealed no evidence of any left-to-right shunt by means of the inhaled Kr\textsuperscript{85} test.\textsuperscript{9}

In spite of the strong clinical suspicion that a left-to-right shunt originated from the aorta in this patient, the retrograde aortic catheterization with Kr\textsuperscript{85} and cardio-green injections excluded its

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Figure 1
Expiratory Kr\textsuperscript{85} time-concentration curves obtained from patient S.G. The curve on the left followed injection into the aorta near the origin of the left subclavian artery, while the curve at the right followed injection into the aorta at the level of the diaphragm. The vertical arrow represents the instant of injection and the oblique arrows indicate the appearance time in the expired air. Calibration of count-rate meter was identical for both curves.

presence and indicated the existence of aortic regurgitation; the absence of any left-to-right shunt was further confirmed at right heart catheterization. This patient represents the unusual occurrence of the auscultatory finding of a "continuous" murmur resulting from an aortic valve lesion, which is presumably rheumatic in origin.

Case 3
A.G., no. 02-80-15, a 59-year-old woman, was known to have had a heart murmur all of her life. Exertional dyspnea began at the age of 40 years, and she had been in overt congestive heart failure for the 4 years preceding her admission. On physical examination the findings were typical of a patent ductus arteriosus with a large left-to-right shunt and moderately severe congestive heart failure. At retrograde aortic catheterization, Kr\textsuperscript{85} injections resulted in an early appearance time (4 seconds) following injection at the level of the left subclavian artery, and a delayed appearance time (20 seconds) following injection at the level of the diaphragm (fig. 3A). When cardio-green dye was injected into the aorta at the level of the diaphragm, the recirculation curve appeared 28 seconds later in the right brachial artery. In contrast, when the injection was made into the aorta at the origin of the left subclavian artery the appearance time of the dye was 13 seconds (fig. 3B); this was interpreted to indicate that the left-to-right shunt began at a point distal to the origin of the innominate artery. The earlier appearance of dye resulted from the shunting of blood through the pulmonary circulation. Had the shunt originated from the root of the aorta the appearance time of dye in the right brachial artery would have been almost immediate, as was observed in patient E. S. (fig. 4).

Case 4
E.S., no. 02-83-50, a 32-year-old woman was known to have had a continuous heart murmur since birth. Six years prior to study she was thought, at another hospital, to have a patent ductus arteriosus but none was found at thoracotomy. At this time, a continuous thrill was palpated over the right ventricular outflow tract, but its origin was not clear. On examination at the National Heart Institute, the physical findings were also considered typical for patent ductus arteriosus; a grade IV/VVI continuous murmur was heard best in the second intercostal space along the left sternal border, and the peripheral pulses were bounding. Retrograde aortic catheterization revealed prolonged appearance times after Kr\textsuperscript{85} injections into the aorta, both at the diaphragm and at the origin of the left subclavian artery. When the injection was made just above the aortic valve, however, the appearance was rapid (1 second) and the concentration rose abruptly. Indicator-dilution curves were then obtained by sampling blood from the right brachial artery (fig. 4). Injection into the aorta at the level of the diaphragm showed only the presence of recirculating dye, appearing 15.5 seconds after the injection;

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which was shunted from the ascending aorta through the pulmonary vascular bed. The third peak, at 16 seconds, corresponds to the systemic recirculation curve seen in the other dilution curves.

The studies in this patient demonstrate that a left-to-right shunt originating from the aorta at the level of the left subclavian artery, i.e., a patent ductus arteriosus, can be clearly differentiated from a shunt originating from the root of the aorta. When the shunt originates from the aortic root, as in this patient, the various anatomic lesions which are responsible cannot be differentiated by either Kr$^{85}$ or indicator-dye injections and thoracic aortography is indicated. In patient E.S., an aneurysm of the aortic sinus of Valsalva which had ruptured into the right ventricle was demonstrated by the latter technic.

Case 5

G.B., no. 03-02-65, a 6-year-old white boy was known to have had a heart murmur since the age of 3 years. He suffered from moderate limitation.
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of activity and frequent respiratory infections. On examination, a grade III/VI systolic murmur was heard most prominently along the left sternal border and the second heart sound in the pulmonic area was greatly accentuated. At the time of retrograde aortic catheterization, Kr\textsuperscript{85} injections revealed a rapid appearance (2.5 seconds) following injection both at the aortic valve and at the level of the left subclavian artery, and an appearance time of 8 seconds following injection into the abdominal aorta (fig. 5A). In order further to localize the origin of the shunt, indicator-dilution curves were obtained from the right brachial artery (fig. 5B). Injection into the aorta at the level of the diaphragm revealed only systemic recirculation. Injection into the aorta at the origin of the left subclavian artery revealed an early peak due to dye that had regurgitated back to the origin or the innominate artery and then passed into the right brachial artery; a small interruption of the descending limb due to a small fraction of dye that had shunted through the pulmonary circulation was also present. Injection just above the aortic valve revealed, (1) a small primary curve resulting from dye passing directly into the brachial artery, (2) a larger curve resulting from the shunting of a larger fraction of dye through the pulmonary circulation, and (3) a third peak resulting from systemic recirculation (fig. 5B). The presence of a patent ductus arteriosus could be excluded, since only a very small fraction of dye injected at the level of the left subclavian artery was shunted through the lungs, while a much larger shunt was evident in the curve resulting from injection into the aortic root. The diagnosis of an aortico-pulmonary window was subsequently established by means of a retrograde thoracic aortogram and was confirmed at open operation.

Discussion

The chief value of retrograde aortic catheterization with injections of solutions of Kr\textsuperscript{85} is in determining the presence or absence of a left-to-right shunt originating from the aorta. Perhaps the most important application of this technic will be in the study of patients with intracardiac shunts who are potential candidates for operation utilizing cardiopulmonary bypass. The presence of the intracardiac shunt may mask an associated aortico-

Figure 4
Indicator-dilution curves with brachial artery sampling following injection into the aorta at three different points. The three peaks in the curve resulting from aortic root injection are numbered, and described in detail in the text.

Figure 5A
Expiratory Kr\textsuperscript{85} curves obtained from patient G.B. The scales at either side represent the calibrations of the count-rate meter. C.P.M. refers to counts per minute.

Figure 5B
Indicator-dilution curves with brachial artery sampling following injection into the aorta at three different points.
pulmonary shunt, since the diastolic murmur characteristic of the latter lesions is often absent in patients with pulmonary hypertension. On the other hand, patients with large, isolated intracardiac left-to-right shunts often have diastolic murmurs due to excessive blood flow across the mitral or tricuspid valve. The auscultatory findings in such patients may falsely suggest the presence of a patent ductus arteriosus, particularly when their heart rate is rapid. Because of the difficulties in determining the presence or absence of a second left-to-right shunt the data obtained at the time of right heart catheterization do not usually provide conclusive evidence regarding a shunt originating from the aorta.

When operations are carried out with the aid of cardiopulmonary bypass, the presence of an unsuspected patent ductus arteriosus, or other left-to-right shunt originating from the aorta, results in considerable technical difficulty, and occasionally a fatal outcome; large amounts of blood are pumped into the pulmonary circulation from the extracorporeal circuit and may flood the operative field before the surgeon can close the ductus or complete the repair of the intracardiac defect. Many of the open operations are performed through a median sternotomy, and ligation of a ductus arteriosus may prove difficult from this surgical approach.

The procedures described in the present report may be added to the standard right heart catheterization; their application requires only minimal additional time and does not add significantly to the risk of the procedure. If the indwelling arterial needle is inserted into the femoral artery at the beginning of the catheterization, even an additional arterial puncture can be avoided and no blood sampling is necessary. It would seem appropriate, therefore, to use the aortic Kr$^{85}$ injections as a screening test whenever it is felt desirable to determine whether or not a left-to-right shunt originates from a point distal to the aortic valve. When the test is negative, the presence of such a shunt may be excluded with a considerable degree of reliability; the sensitivity of the injected Kr$^{85}$ technic has been discussed in detail elsewhere, and it is notable that in the series of patients described herein, the test did not fail to detect any left-to-right shunt originating from the aorta. When, on the other hand, the presence of such a shunt is indicated, other methods are usually required to determine whether it results from a patent ductus arteriosus, or any of the less common lesions at the base of the heart, i.e., aortopulmonary window, ruptured aneurysm sinus of Valsalva, ventricular septal defect with aortic incompetence, coronary arteriovenous fistula, etc. The indicator-dilution method, utilizing right brachial artery sampling, is helpful in defining the site of origin of the shunt. When the dilution curves show that the shunt originates from the aorta near the origin of the left subclavian artery (fig. 3B) the diagnosis of a patent ductus arteriosus is established. However, when the shunt originates proximal to this point (figs. 4 and 5B) thoracic aortography is usually necessary in order to define the specific malformation responsible.

Summary

A simplified technic for the detection of left-to-right shunts originating from the aorta is described. A thin, radiopaque catheter is introduced into the aortic arch through a Courmand needle placed in the femoral artery, and injections of a solution of Kr$^{85}$ are made. In the presence of a shunt the injected Kr$^{85}$ is rapidly detected in the expired air but in the absence of a shunt the appearance time of Kr$^{85}$ in the expired air is delayed. When an aortic shunt is present it may be localized by means of injections of cardio-green dye at various points in the aorta by sampling the blood from the right brachial artery. The value of these technics is illustrated by descriptions of their application in five patients with various forms of congenital or acquired heart disease.

References

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Aneurism of the Aorta; Singular Pulsation of the Arteries, Necessity of the Employment of the Stethoscope

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Mr. J. D.—e, a builder, (Cole's Lane), called on me, for the first time, in the early part of June. His complaint commenced about four months before that period, with sense of oppression and straitness in his chest, succeeded by cough, occasionally convulsive; the cough and oppression of chest always relieved by mucous expectoration. He might, at that time, have been selected as a man presenting the very vigour of health, finely made, full in flesh, of a florid complexion, and active in his limbs. . . .

On stripping him, the first remarkable appearance that caught the eye, was a singular pulsation of all the arterial trunks of the upper part of the body. As his arms hung by his side, the whole tract of the branchial and carotid arteries was thrown out in strong relief, at each impulse of the heart, as if the vessels, from having been previously comparatively empty, had become suddenly filled.—The Lancet 1:586, 1829.
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