

Detection of Right-to-Left Circulatory Shunts: A New Method Utilizing Injections of Krypton⁸⁵. (25283)

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Experimental and clinical experience with krypton⁸⁵, an inert radioactive gas, has demonstrated that determination of blood levels following its inhalation provides a rapid and sensitive method for detection, localization and quantitation of left-to-right circulatory shunts(1,2). During these studies it was found that when solutions of Kr⁸⁵ in normal saline were injected intravenously, virtually none of the gas could be detected in arterial blood since it had been largely eliminated in its first passage through the pulmonary circulation. These observations suggested that if a high arterial Kr⁸⁵ level was observed following intravenous injection it would be attributable to a right-to-left shunt permitting passage of venous blood into the pulmonary veins, chambers of the left heart or the aorta.

Materials and methods. Eleven mongrel dogs weighing 10-18 kg were employed. Right-to-left shunts were created by anastomosis of left atrial appendage to the pulmonary artery. Anesthesia was induced with intravenous thiopental and following tracheal intubation respiration was maintained with 100% oxygen supplied through a demand respirator. The ventilatory rate was adjusted to 16-24 cycles/minute. The left pleural cavity was entered through the fourth intercostal space, the pericardium widely incised and partially occluding clamps were applied to wall of pulmonary artery and the tip of left atrial appendage. An ellipse of tissue measuring approximately 10×3 mm was excised from the excluded segment of pulmonary artery and the tip of the appendage amputated. The anastomosis was then constructed with a continuous over-and-over suture of fine silk. Five animals were studied immediately and 6 at intervals of 6 to 10 days after operation. Upon completion of experiments the atrial appendage was transected in each animal and the patency of the anastomosis determined by inspection and by observation of presence or

absence of bleeding from pulmonary artery before death. In 4 dogs the shunt was completely occluded by thrombus and the data obtained in them was grouped with that of control animals. The solution of Kr⁸⁵ was prepared by injecting 15 ml of air containing 3.1 mc of the isotope into a 30 ml vial containing 15 ml of sterile saline solution. Since the solubility coefficient of the gas is 0.045(3) each ml of saline solution initially contained approximately 10 μ c of Kr⁸⁵. Thirty μ c of the gas (3-5 ml of solution) were withdrawn for each injection and the volume of saline replaced. In each animal a Cournand catheter was inserted through jugular vein and positioned to allow injections of Kr⁸⁵ into the pulmonary artery, right ventricle, right atrium or superior vena cava. Ten ml blood samples were drawn into heparinized syringes from the femoral artery at various time intervals after injection. The level of radioactivity in arterial blood was determined by counting whole blood sample for one minute in a continuous gas flow Geiger-Muller tube of 10 ml capacity.* The tube was rinsed with saline and compressed air after each determination. Blank samples were drawn immediately prior to each injection. In those animals studied acutely, injections were made both with the shunt open and closed so that each animal could serve as its own control. In 3 dogs without shunts, studies were made in presence of various ventilatory states. Kr⁸⁵ was injected intravenously during slow spontaneous respiration, during complete apnea and immediately after the left lung had been rendered completely atelectatic by compressing it and occluding the main bronchus. In one animal radioactivity of expired air as well as arterial blood was determined with the right-to-left shunt open and closed. The expired air was counted at 10 second intervals by a G-M

* Model M-4, Nucleonic Corp. of America.

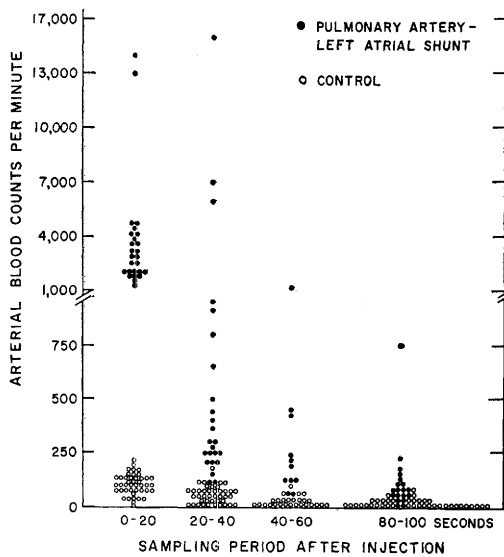


FIG. 1. Kr^{85} levels in arterial blood following intravenous or right heart inj. in dogs with and without right-to-left shunts.

tubef inserted into the endotracheal tube. Serial arterial blood samples were drawn at equivalent intervals.

Results. Background or blank counts did not exceed 50 cts./min. and these values were always subtracted from total counts. Following intravenous, right heart or pulmonary artery injection in animals without right-to-left shunts (normal or with an occluded anastomosis) the radioactivity of arterial blood never exceeded 206 cts/min regardless of sampling period (Fig. 1). With a patent right-to-left shunt counts of arterial blood drawn during the first 20 sec. after injection ranged from 1451 to 14,100/minute. The 2 highest values resulted when flow through the anastomosis was increased by temporary constriction of pulmonary artery distal to it. Arterial samples drawn at later intervals after injection contained less radioactivity than those obtained during the first 20 sec. and the difference between levels in normal and shunt dogs progressively decreased with time (Fig. 1). The advantage of the 0-20 sec. sampling period in detecting a right-to-left shunt is further demonstrated by curves relating arterial radioactivity to time (Figs. 2A and 2B). In this animal a count of 3900 was obtained at 15 sec. when the shunt was open while at this

same period after injection, the count was only 340 with the shunt closed. The latter value is somewhat higher than those observed in other control dogs since it represents an integrated 10-20 sec. value while an integrated 0-20 sec. sample was ordinarily drawn (Fig. 1). Both curves illustrate the rapidity with which the gas is cleared from the circulation when ventilation is normal; in the presence of a right-to-left shunt, however, the rate of disappearance is slower and a significant level of Kr^{85} is present in arterial blood as long as 3 minutes after injection. This persistence of the gas is attributable to recirculation through the shunt; only a portion of the isotope is removed by the lungs during each circulation.

The levels of Kr^{85} in expired air are also shown in Figs. 2A and 2B. In the absence of a right-to-left shunt (Fig. 2B) a large amount of gas appeared immediately and its concentration rapidly fell so that background level was reached within 45 sec. When a shunt is present a far smaller quantity of gas appears initially and exhalation of significant quantities is continued for nearly 3 minutes. These differences are also attributable to recirculation of krypton-rich venous blood through the shunt, its continued passage through the systemic circulation and gradual elimination by the lungs.

With slow spontaneous respiration instead of hyperventilation induced by the demand respirator, arterial counts in normal range were observed when no shunt was present. During complete apnea, induced with curare, an average count of 698/minute was obtained in the 0-20 sec. sample indicating that even without air exchange the major portion of gas was cleared by diffusion. With unilateral total atelectasis and bronchial occlusion an arterial level of 2666 c.p.m. occurred in the 0-20 sec. arterial sample indicating that perfusion of the unventilated lung was continuing and resulting in a sizable right-to-left shunt.

Krypton⁸⁵ is readily eliminated from pulmonary arterial blood because of its very low solubility and the high gradient in partial pressure of Kr^{85} existing between blood and alveolar air. This has been confirmed by

† Model D-34, Nuclear-Chicago Corp.

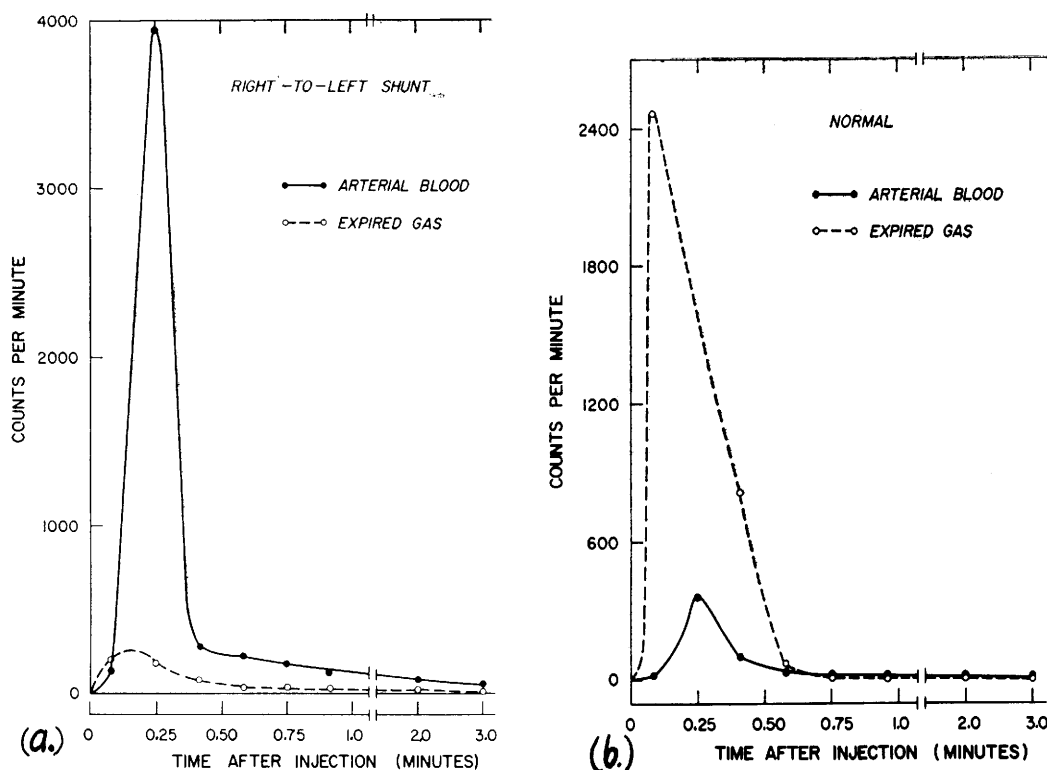


FIG. 2. Concentrations of Kr^{85} in arterial blood and expired air after intravenous or right heart inj. when a right-to-left shunt was functioning (a) and occluded (b).

recent studies of Chidsey and associates(4).

It is apparent that, in presence of a right-to-left shunt, regardless of its site, high levels of Kr^{85} are present in arterial blood after intravenous injection. This technic may be used to localize the site of origin of the shunt by selectively injecting the isotope into the chambers of the right heart and the pulmonary artery. Injections at or proximal to the shunt may be expected to give high arterial levels while those made distal to it should result in low arterial counts. Data obtained during catheterization in patients with congenital heart disease indicate that the method is useful in this respect.

Summary. Right-to-left circulatory shunts were produced in 11 mongrel dogs by anastomosis of the left atrial appendage to the pulmonary artery. When injections of Kr^{85} in

solution were made proximal to the shunt the level of radioactivity in arterial blood drawn during the first 20 sec. after injection was always greater than 1400 cts./min. In dogs without shunts, however, similar injections resulted in arterial blood counts of 206/min. or less. The technic thus provides a new method for detection and localization of veno-arterial shunts.

1. Sanders, R. J., *PROC. SOC. EXP. BIOL. AND MED.*, 1958, v97, 1.
2. Sanders, R. J., Morrow, A. G., *Am. J. Med.*, 1959, v24, 508.
3. Tobias, C. A., Jones, H. B., Lawrence, J. H., Hamilton, J. G., *J. Clin. Invest.*, 1949, v28, 1375.
4. Chidsey, C. A., III, Fritts, H. W., Jr., Hardewig, A., Richards, D. W., Cournand, A., *J. Appl. Physiol.*, 1959, v14, 63.

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