Detection of Right-to-Left Shunts with an Arterial Potentiometric Electrode

By Leland C. Clark, Jr., Ph.D., L. M. Bargeron, Jr., M.D., Champ Lyons, M.D., Merrill N. Bradley, M.D., and Katrina T. McArthur, M.D.

The platinized platinum electrode develops a rapidly responding and readily recorded potential in the presence of hydrogen dissolved in blood. A sensitive procedure for detecting and localizing left-to-right shunts in the catheterization laboratory and in the operating room has been developed with use of such an electrode on the tip of a cardiac catheter.

Hydrogen has been found to be completely cleared from intravenously injected saline solution saturated with hydrogen during its passage through the lungs. Therefore, a test for the detection of right-to-left shunts can be based upon the intravenous injection of saline solution saturated with hydrogen during continuous monitoring for hydrogen in the aorta with a platinum electrode. The localization of such right-to-left shunts, particularly difficult in infants, is determined by a series of injections into the various chambers of the heart. Further, because a platinized platinum electrode develops a potential in the presence of sodium ascorbate, an injection of this substance serves to verify the responsiveness of the electrode at any time.

It is the purpose of this report to describe the procedure and to illustrate its application in the diagnosis of right-to-left shunts with particular reference to infants.

Methods

Platinum electrodes for use in the artery were prepared by melting a small bead (0.03") on the end of a 45-em. length of 28-gage (0.0126") platinum wire. The wire is then threaded through polyethylene tubing (.023" I.D. by .038" O.D.) or polyvinyl tubing (.020" I.D. by .036" O.D.) and soldered to various lengths of silver wire. The bead is sealed in place with a silicone varnish (Dow Corning's 803 resin) or with an epoxy-type cement (for example, Hysol, Houghton Laboratories, Olean, New York). The bead is platinized and the electrode is sterilized by soaking in 70 per cent alcohol or by exposure to ethylene oxide. If vinyl tubing (VX020) Beeton, Dickinson, Rutherford, New Jersey) is used, the electrode may be autoclaved.

In patients, the electrode was threaded into an exposed radial artery, and the tip was advanced under fluoroscopy until it lay in the aorta. In animals, the electrode was fastened to 2 lengths of fine polyethylene tubing in such a way that injections of the hydrogen solution could be made above or below the electrode after it was threaded into the aorta via the femoral artery. This served to tell, whether the electrode was pointing up stream or down stream without fluoroscopy.

A silver reference electrode was brought into contact with the cleaned skin with a saline-soaked pad or electrocardiographic paste.

*The platinum electrode, used as described in this report, namely for the direct recording of potential changes with reference to a common silver electrode, is not to be confused with a similar electrode used for polarographic studies. An extensive study of intravascular polarographic electrodes has been underway in this laboratory for many months and will be published soon. Intravascular polarographic electrodes require the application of polarizing voltages, and the measurement of minute currents; scrupulous care with insulation and careful attention to other variables, to be detailed elsewhere, are essential. Potentiometric electrodes, of course, must also be properly insulated but minor breaks in the insulation do not generate "false" currents, as in polarography, but instead cause a loss of signal strength.*

Figure 1

Diagram of circuit for using 2 hydrogen electrodes simultaneously.

---

From the Department of Surgery, University of Alabama Medical Center, Birmingham, Ala.

Supported in part by Grant H-3109 from the U. S. Public Health Service and a grant from the Alabama Heart Association.

Circulation, Volume XXII, November 1960
Figure 2

Hydrogen indicator curves in complete anomalous pulmonary venous return and atrial septal defect in 8-month-old infant weighing 5.7 Kg. The curves show responses of the arterial hydrogen electrode to an inhalation of hydrogen (upper left); to injections of hydrogen saturated saline into the right atrium (RA), left atrium (LA), and right ventricle (RV). The short vertical lines represent 1-second intervals.

The platinum and silver electrodes were connected directly to the DC input of a recording potentiometer (Varian), a multichannel oscillograph (Electronics for Medicine), or other instruments having a full-scale response of 100 millivolts. When more than one platinum electrode was employed, a single silver electrode was used as a reference for all (fig. 1).

When two electrodes are used simultaneously a common reference electrode may be connected as shown. This simplified hook-up is adequate for most work and may be used instead of the more complex circuit previously published, which included provision for a 50-mv. standardizing signal for each channel. If the reference electrode does not make good contact with the skin, AC interference may appear on the recorder and a brief upswing of the hydrogen curve may occur before it descends following a breath of hydrogen. As many as 4 hydrogen electrodes have been employed simultaneously with use of a single reference electrode.

The 90 per cent response time of the electrode for hydrogen is 0.1 second and for ascorbic acid 0.4 second as measured in a buffer at pH 7.38 at...
Figure 2a

Hydrogen breathing curves. The patient shown in figure 2 was studied with the venous hydrogen electrode catheter and found to have anomalous venous return. These curves are reproduced here. Tracings obtained with the catheter tip in the anomalous vein, the right ventricle, the inferior vena cava, and the pulmonary artery are shown above. The full-scale setting (black horizontal line at bottom of tracings) was 100 mv. The first downward curve in each of the 4 sets shown above is that of an electrode in the nasal passage which is used as an air-way signal. Note the sharp increase in potential in the tracing obtained from the pulmonary vein and, to a somewhat lesser extent, from all those chambers distal to the shunt.

25 C. The potential developed in ascorbate solution is approximately doubled if the platinum has been platinized.

After placement of the platinum electrode in the aorta its responsiveness was tested by inhalation of hydrogen and by injection of sodium ascorbate (25 mg.) in saline. If typical sharp responses did not develop, the electrode was moved slightly, since it occasionally was found to be out of the main blood stream and pressing against an arterial wall or to have entered a small arterial branch.

Circulation, Volume XXII, November 1960
Figure 3
Comparison of hydrogen solution and vitamin C indicator curves in a patient with partial anomalous pulmonary venous return and septal defect. The upper curves were obtained following injection of hydrogen solution into the right atrium, left atrium, and the right ventricle; the lower curves were obtained following injection of ascorbate in these chambers. The injections of ascorbate directly followed those of the hydrogen solution in each case. Note the complete lack of response of the arterial hydrogen electrode following injection of the hydrogen solution into the right ventricle (RV) and the delayed appearance time of the ascorbate. The wavy line along the top of the tracing is from the nasal electrode; it can be seen that the infinitesimal quantity of hydrogen cleared from the hydrogen solution by the lungs is not detected by the nasal electrode. The patient is a 7-year-old girl weighing 42 pounds, who exhibits cyanosis of the nailbeds and lips on exertion. Chest films showed slight cardiac enlargement and increased pulmonary vascularity. The findings on catheterization were consistent with the diagnosis indicated. Sedation: Nembutal and Demerol.

The dose of hydrogen solution and ascorbate most generally suitable was 8 ml. per M.² of body surface although smaller doses may be used. The hydrogen solution was prepared by bubbling hydrogen through normal saline or half saline half glucose solution in a sterile sintered glass Buchner funnel. This procedure saturates the solution with hydrogen and removes the oxygen, further increasing the voltage developed by the platinum electrode. The solubility of hydrogen in aqueous solutions, unlike that of oxygen, does not increase rapidly as the temperature is lowered. Nonetheless, it is preferable to saturate the solution at room temperature, rather than in an ice bath, to avoid the possibility of gas embolism.

Results
Initially a response of approximately 10 mv. was obtained from the aortic electrode in dogs given intravenous hydrogen solution. This response was found to be due to lung damage, induced by a faulty respirator, and to a less extent to a pH effect on the platinum electrode. The electrode responds to a drop in pH as it does to hydrogen. Subsequently hydrogen solution at doses of 0.2, 0.5, and 1.0 ml. per Kg. in dogs showed only an insignificant response (less than 3 mv.); even this could be abolished by adding a few drops of a phosphate buffer (pH 7.4) to the hydrogen solution. In all cases, potential changes greater than 50 mv. were produced by injection of the hydrogen solution directly into the aorta and just above the electrode.

When a lung segment was deliberately damaged by manual compression, positive (right-to-left shunt) arterial responses were observed following injection of hydrogen solution into the vena cava or the right atrium.

The curves in figure 2 illustrate the responses obtained from the arterial electrode.
in an infant having a right-to-left shunt. Positive arterial curves were obtained following a breath of hydrogen, and injections (via a patent foramen ovale) into the left atrium indicating that the electrode was properly placed. Positive responses were obtained also following injection into the right atrium but not into the right ventricle, indicating a shunt at the atrial level. (Figure 2a shows the curves obtained at routine hydrogen electrode catheterization.)

The potential curves recorded from the arterial electrode following the injection of hydrogen solution and vitamin C into the right and left atrial and into the right ventricle are compared in figure 3. Repeated injections of hydrogen solution into the right ventricle failed to indicate the presence of hydrogen in the aorta, whereas vitamin C always appeared. Positive responses for both vitamin C and hydrogen solution were obtained after injections into the left atrium.

Figure 4
Hydrogen indicator curves in 4-month-old boy with tetralogy of Fallot. The upper left curve, after a breath of hydrogen, served to verify the reactivity of the arterial electrode. Injections of hydrogen solution into the left atrium (LA), through a patent foramen ovale (lower right curve) also verified the reactivity of the electrode and is shown for comparison. The positive responses obtained following injections into the right atrium (RA) and the right ventricle (RV) indicate the shunt is in, or distal to, the ventricle. Vertical lines are 1-second intervals.
CLARK, BARGERON, LYONS, BRADLEY, McARTHUR

Figure 4a

Hydrogen saturated sodium ascorbate solution as an indicator. To obtain the upper right curve, 2 ml. (50 mg.) of sodium ascorbate in saline were injected into the right ventricle. In the lower right, the ascorbate was saturated with hydrogen before injection. Note the increase in the initial hump on the curve. This increase corresponds with the hydrogen peak (fig. 4) in which the same patient is presented. On the left, the curve obtained by injecting hydrogen saturated ascorbic acid into the left atrium is shown for comparison; the portion indicated by "a" is an artifact. Vertical marks are 1-second intervals.

and right atrium. Together these tests demonstrate the presence of a right-to-left shunt through an atrial septal defect. A double-humped vitamin C curve was not observed, probably because the shunt was small and circulation time short.

In figure 4 are shown the curves obtained following hydrogen breathing and hydrogen solution injection in an infant with tetralogy of Fallot. In this patient a "control" injection distal to the shunt could not be made because the catheter could not be passed safely through the severe infundibular stenosis. The responses to the injections indicate a shunt at or beyond the ventricular level. To illustrate further the application of the present technic a series of injections of sodium ascorbate and hydrogen saturated solutions was employed. Figure 4a shows that the initial hump on the ascorbate curve, clearly evident in this patient, is increased by adding hydrogen to the ascorbate solution.

Discussion

The complete clearing of hydrogen from intravenously injected solutions makes possible a delicate test for right-to-left shunts. The rapid and sensitive response of the electrode makes it possible to obtain diagnostic curves in infants. The response of the electrode to ascorbate is slower than to hydrogen but is still rapid enough to be used to confirm the reactivity of a given electrode in a particular patient. It is hoped that a redox-active solution can be found that will produce even sharper responses.

Since the diagnosis rests essentially on both positive and negative responses, a series of injections into various chambers is required. That a negative response is not due to a failure of the detecting electrode can be assured by testing the electrode by hydrogen breathing, by injecting sodium ascorbate solution, by injecting hydrogen solution into the left atrium, and by injecting hydrogen solution.
proximal to the suspected shunt. That a positive response is not due to a defect in the lungs can be ruled out in a given patient by a negative response proximal to the shunt. It appears from the experimental work as well as from the clinical tests that "false positive" arterial responses do not occur in the absence of lung disease.

The sensitivity of the test can be realized from the observation that as little as 0.1 ml. of hydrogen solution injected directly into the aorta is easily detected by the arterial electrode. This amount of hydrogen solution contains only 0.002 ml. of dissolved hydrogen.

The procedure is relatively simple and inexpensive. The hydrogen is nontoxic and rapidly cleared from the circulation, thus permitting as many injections as consideration of fluid volume allows. Sodium ascorbate solutions appear to be completely innocuous. There is the hazard of working with hydrogen. Reasonable caution must be used particularly in the storage of large (and possibly leaky) hydrogen tanks.

By placement of the indicator detector (the platinum bead) in the aortic arch concentration changes are more rapidly and faithfully recorded than in a system in which samples are withdrawn through a long narrow arterial catheter.

Summary
Saline solution saturated with hydrogen is completely cleared of hydrogen in passing through the normal lung. The presence of dissolved hydrogen, which can be detected with a platinum electrode, in the aorta following the injection of hydrogen saturated solutions into the right heart is therefore diagnostic of a right-to-left shunt. Localization of the shunt is made by a series of injections into the various chambers of the heart. Since the electrode also responds to increased concentrations of sodium ascorbate, this substance can be used as an indicator in itself and as a test to establish the functional ability of the aortic electrode. The sensitivity and speed of the response of the electrode, together with the relative simplicity and inexpensiveness of the procedure, makes the technique readily adaptable to routine diagnostic catheterizations in infants.

Acknowledgment
The authors wish to thank the Upjohn Company for the ascorbic acid (1000 mg. per 10 ml., sodium bisulfite 10 mg., buffered with sodium bicarbonate) used in this work. Special thanks are given to Paul Boyles and Joe Gilmer for technical assistance. Clarence Forrest and Phillip Kelly assisted in the experimental work.

Summario in Interlingua
Un solution salin que es saturate con hydrogено perde su hydrogено completa in su passage a transverso le pulmon normal. Per consequente, le presentia de hydrogено dissolute, detegibile per medio de un electrodo de platino, in le aorta subsequente al injection de solutiones a saturation hydroginica in le corde dextere suffice a stabilir le diagnostoe de derivation dextero-sinistre. Le localisation del derivation pote esser effectuate per medio de un serie de injectiones in 1 varie cameris del corde. Viste que le electrodo responde etiam a augmentate concentrationes de ascorbato de natrium, iste substantia pote esser utilisate como indicitor per se e como un test pro stabilir le capacitate functional del electrodo aortie. Le sensibilitate e le rapiditate del responsa del electrodo, insimul con le simplicitate relative e le basse costo del technica, recommenda lo al uso in catheterismo diagnostic routinari in infants.

References
2. —, and —: The detection and direct recording of left-to-right shunts with the hydrogen electrode catheter. Surgery 46: 797, 1959.
Detection of Right-to-Left Shunts with an Arterial Potentiometric Electrode
LELAND C. CLARK, JR., L. M. BARGERON, JR., CHAMP LYONS, MERRILL N. BRADLEY and KATRINA T. McARTHUR

doi: 10.1161/01.CIR.22.5.949
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1960 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/22/5/949

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation 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 is online at:
http://circ.ahajournals.org//subscriptions/