# THE USE OF HYDROGEN INHALATION IN THE DETECTION OF INTRACARDIAC SHUNTS

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Detection of an increased oxygen saturation of the blood in the right side of the heart was the first method of demonstrating intracardiac left-to-right shunts. However, the sensitivity of this method is limited and small shunts are often not detected. Other techniques which are used include foreign gases such as nitrous oxide,[1,2] helium,[3] and radioactive krypton,[4-6] as well as dye dilution[7] and thermo-dilution methods.[8-10] The complexity of instrumentation, the difficulties in handling radioactive materials, the need for highly trained personnel and the time involved in sampling, have precluded the general acceptance of any one method for screening left-to-right shunts.

Clark and Bargeron[11-14] introduced a potentiometric method using a hydrogen-platinum electrode system. The chief advantages of this technique are that it is simple, reliable, inexpensive and extremely sensitive.[15-17] A platinum-tipped electrode, when exposed to blood containing hydrogen ions, produces an oxidation potential with respect to a reference electrode, which is simple to record even in the presence of the potentials generated by the heart.

When hydrogen gas is inhaled, it immediately crosses the pulmonary membrane, is dissolved in blood and appears in high concentration in the left heart. After passing through the systemic circulation it appears in lower concentration in the right heart. In the absence of a shunt, a platinum-tipped electrode placed in the right heart will register this lower concentration with a delay after inhalation of at least 4 seconds. When a left-to-right shunt is present, the high concentration of hydrogen is detected almost immediately by an electrode situated distal to, or at the level of, the shunt.[15-20]

The purpose of this paper is to describe briefly our experiences with this technique in the detection of left-to-right intracardiac shunts.

## MATERIAL AND METHOD

Hydrogen curves were recorded in a total of 40 patients (Table I) whose ages ranged from 4 to 59 years. Twenty-nine had congenital heart disease, 4 of whom had previously been submitted to cardiac surgery. Eleven patients, 4 with rheumatic disease and 7 with hypertrophic obstructive cardiomyopathy, had no clinical evidence of a shunt. Eleven patients had left heart catheterization by the Brockenbrough technique,[21] and hydrogen curves were obtained immediately before and after this procedure.

In any standard catheterization laboratory the only new equipment required is a platinum-tipped catheter.[22] We have used a USCI end-hole catheter which has a platinum ring approximately 1½ mm. from the tip. This ring is in electrical continuity with the external end of the catheter which, in turn, is connected by a low-resistance wire to the measuring system. In early reports[11,12] of the technique, the platinum ring was blackened with 5% platinic chloride, but we have found that 'bright' platinum rings are equally sensitive.

Hydrogen curves can be satisfactorily recorded with any standard electrocardiographic apparatus,[16,23] and we have used the Sanborn direct writer which is incorporated in our pressure equipment. The equivalent of a CR lead is used. The electrocardiogram is set on standard II; the right arm lead is the reference electrode, while the left leg lead is used as the exploring electrode and is attached to the external end of the catheter by alligator clips.

The hydrogen is contained in a small anaesthetic bag which is connected to a large 3-way valve and face mask. The time of the inhalation is marked by a manual signal.

The catheter is introduced into the heart and the external end connected to the measuring system. An intracardiac electrocardiogram should then be recordable. The sensitivity of the circuit can be tested by wedging the catheter in a pulmonary vein, when an early deflection should be obtained immediately after inhalation of hydrogen.[18,24] The sensitivity of the system is adjusted so that a low amplitude is selected if a shunt is expected, whereas a higher amplitude is preferred should no shunt or a very small one be anticipated. A low sensitivity has the advantage that small potentials and fewer artefacts are recorded and the onset of the hydrogen deflection is therefore more easily timed. All electrical apparatus, except the recording device, should be switched off at the time of inhalation. The mask is placed over the patient's face and air is breathed. When a satisfactory baseline is obtained, the valve is turned and hydrogen switched through for a single breath. The inhalation point is marked on the recording paper. In the absence of an early deflection denoting a shunt, a late circulation curve is always present if the sensitivity of the circuit is adequate (Fig. 1).

## RESULTS

Left-to-right shunts were readily demonstrated in the 25 patients with congenital heart disease who had not been submitted to surgery. These included 1 patient with tetralogy of Fallot in whom no definite left-to-right shunt was found on oxygen studies. In a 4-year-old boy with a ventricular septal defect, the possibility of associated partial anomalous pulmonary venous drainage was confirmed by an early hydrogen deflection curve when the catheter electrode was situated in the superior vena cava. Another case of a ventricular septal defect, in which the pulmonary artery pressure was raised to 60/35 mm.Hg. had an early deflection of the hydrogen curve from the right atrium. Oxygen studies showed that the left-to-right shunt was confined to ventricular level and this was confirmed

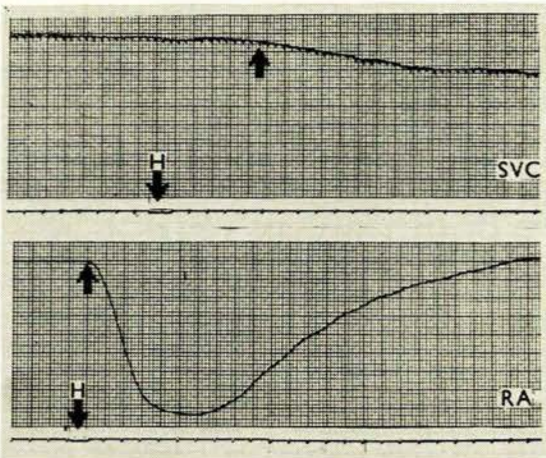


*Fig. 1.* Two hydrogen curves in a case of atrial septal defect. SVC = platinum electrode in the superior vena cava — this demonstrates a 'circulation curve' with a shallow delayed deflection. The hydrogen appearance time (HAT) is 6·2 seconds. RA = platinum electrode in the right atrium — this demonstrates a 'shunt curve' with a deep early deflection. HAT = 1 second. H (1st arrow) = point of hydrogen inhalation and second arrow is the beginning of the deflection. Time interval between the heavy lines is 1 second.

by a left atriogram. It is probable that mild functional tricuspid regurgitation was responsible for the 'false positive' in this instance. In 9 patients, comprising 4 with rheumatic heart disease, 4 with hypertrophic obstructive cardiomyopathy and 1 with a ventricular septal defect, hydrogen curves showed no shunt at atrial level either before or immediately after the use of a Brockenbrough catheter. However, 2 cases, one of hypertrophic obstructive cardiomyopathy and the other of ventricular septal defect, showed early deflections after left heart catheterization indicating that a left-to-right shunt had been produced.

A shunt was not detected in 3 of the 4 patients (Table I) after surgery. In the remaining patient, however, a 32-year-old

TABLE I. HYDROGEN STUDIES: 40 CASES

| *Shunts* | *Pre-operative* | *Postoperative* |
|---|---|---|
| Atrial septal defect | | |
| Secundum .. .. .. | 11 | 3 |
| Ostium primum .. .. | 2 | — |
| Ventricular septal defect .. .. | 9* | — |
| PDA .. .. .. .. .. | 2 | 1 |
| Fallot's tetralogy .. .. .. | 1 | — |
| *Non-shunts* | | |
| Rheumatic heart disease .. .. | 4 | — |
| Obstructive cardiomyopathy .. | 7 | — |

* 1 with associated partial anomalous pulmonary venous drainage.

woman who had had a septum secundum defect closed 3 years previously under cardio-pulmonary bypass, a well-marked early deflection (Fig. 2) denoted a definite left-to-right shunt. Oxygen studies were within normal limits in this patient, with an increase in oxygen content between superior vena cava and pulmonary artery of only 0·10 vols.%

A small atrial septal defect (i.e. pulmonary to systemic flow of less than 1·5 : 1), or an isolated anomalous pulmonary vein, are extremely rare lesions,[25-28] but the clinical differentiation of such lesions from a normal heart with a physiological pul-

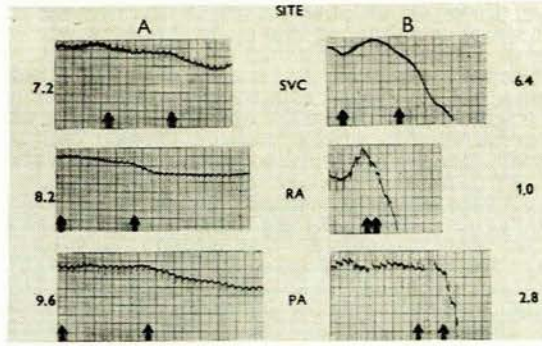


*Fig. 2.* Hydrogen curves in 2 postoperative cases of atrial septal defect. *A.* These curves demonstrate that the shunt is completely closed with circulation curves in SVC, RA and pulmonary artery (PA). The HAT are 7·2, 8·2 and 9·6 seconds respectively. *B.* A circulation curve in SVC (HAT = 6·4 seconds) and early deflections in RA (HAT = 1·0 seconds) and PA (HAT = 2·8 seconds) indicate a shunt at atrial level.

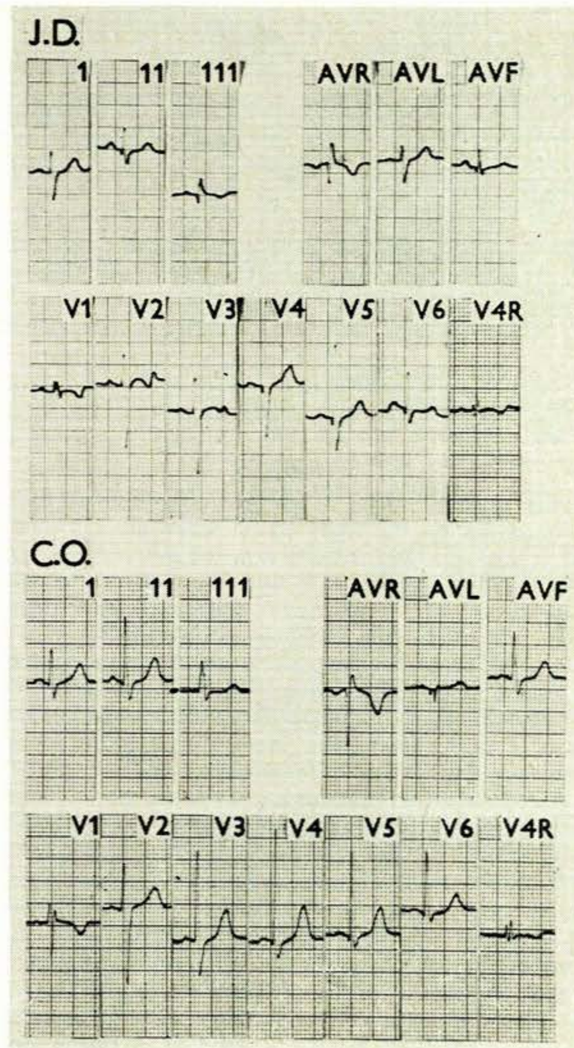


*Fig. 3.* The electrocardiograms of patients J.D. and C.O. Both have an intermediate axis and partial 'right bundle-branch block'. J.D. has a small atrial septal defect whereas C.O. is normal. (See Fig. 4.)

monary ejection systolic murmur and an unusually widely split second sound is difficult or impossible. We have recently encountered this problem and a brief description of the following 2 female patients serves to illustrate the value of the hydrogen inhalation technique under such circumstances:

J.D., aged 5 years, and C.O., aged 19 years, were referred for assessment of a systolic murmur. Neither had cardiac symptoms. The main features on clinical examination were a grade 2[29] pulmonary ejection murmur and unusually wide splitting of the second heart sound. In each instance the degree of splitting decreased during expiration, but the second sound did not close completely. Radiological examination was normal. Their electrocardiograms (Fig. 3) showed an intermediate axis and 'partial right bundle-branch block'. The findings were therefore extremely similar and we were unable to decide whether the diagnosis was one of a small left-to-right shunt at atrial level or that of a normal heart. At cardiac catheterization the oxygen saturation difference between the mixed venous and pulmonary samples was 0·41 and 0·23 vols.% in J.D. and C.O. respectively. These values are within normal limits.[30] However, the hydrogen studies (Fig. 4) demonstrate a definite left-to-right shunt at atrial level in J.D. but no shunt in C.O.

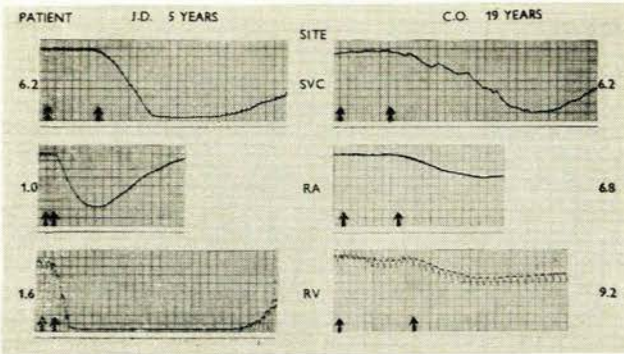


*Fig. 4.* The hydrogen curves on the same cases as Fig. 3. J.D. has a small atrial shunt (shunt ratio 1·2 : 1) shown by HAT in SVC 6·2 seconds, RA 1·0 seconds and right ventricle (RV) 1·6 seconds. In C.O. no shunt is present and the HAT are 6·2, 6·8 and 9·2 seconds respectively.

## DISCUSSION

Although a large shunt is readily recognized at routine catheterization of the right heart, when the left-to-right shunt is less than 20% of the systemic flow, oxygen saturations may not identify or localize the shunt.[16, 30] In these circumstances, the hydrogen potentiometric method quickly, accurately and positively establishes the presence and localization of the shunt. The sensitivity and accuracy of the method has been confirmed in many reports.[14-19, 31] After experimentally inducing left-to-right shunts in dogs, Hyman *et al.*[32] showed that hydrogen is more sensitive than indocyanine green. In fact, it is so sensitive that 0·002 ml. of hydrogen will produce a positive curve.[33]

False positives have been recorded in the pulmonary wedge position,[18, 24] but this should be easily avoided. Bopp *et al.*[17] have recently reported a false positive in a patient with tight mitral stenosis and multiple pulmonary infarctions in whom no inter-atrial communication or other malformation to explain this unusual result was found at necropsy. We think that this phenomenon can be explained from the work of Gilroy *et al.*,[34] who demonstrated engorged pleurohilar veins in cases of mitral stenosis. Unlike the true bronchial veins, the normal pleurohilar veins drain into systemic veins, but are in communication with pulmonary veins. In pulmonary venous hypertension caused by mitral stenosis, therefore, Gilroy *et al.*[34] postulated that 'considerable amounts of blood may take part in a circus movement through them (i.e. dilated pleurohilar veins) from right ventricle to right auricle'. This mechanism would clearly result in an early hydrogen curve in right atrium since an extracardiac left-to-right shunt is, in fact, present. Another cause of a false positive is the placing of the electrode in or very near the coronary sinus.[31] In addition, an incompetent pulmonary or tricuspid valve may erroneously suggest a shunt into the more proximal chamber than the true site.

The danger of explosion inherent in the handling of hydrogen, and the hazards of electrocution from intracardiac electrodes, may have precluded the general acceptance of this method.[19] However, it has been clearly demonstrated[35] that the zone of inflammability of exhaled hydrogen is distinctly small and only lasts a short period. The gas has an extremely low density and rapidly rises away from the operative field. Nevertheless, the precautions taken with the use of any inflammable anaesthetic must clearly be observed.[16] Ordinary electronic apparatus, motor-driven syringes and X-ray equipment, provided they are commonly grounded and outside the zone of inflammability, require no explosive safety precautions with this technique. The dangers of intracardiac electrodes are real,[36-38] but can be avoided by establishing a common ground for every electrical device in the vicinity of the patient. In addition, Vogel *et al.*[16] point out that the reference electrode should be left ungrounded as an added precaution.

The detection at cardiac catheterization of a left-to-right shunt following perforation of the inter-atrial septum with a Brockenbrough catheter has seldom been reported.[39] Brockenbrough *et al.*,[21] using the radioactive krypton method, were unable to demonstrate a shunt in 10 such instances. Ross *et al.*,[40] however, using radioactive krypton, demonstrated a left-to-right shunt in one patient with left atrial hypertension from mitral stenosis, and this small defect was later confirmed at surgery. It has been observed[41] that a defect in the inter-atrial septum is occasionally seen during surgery after left heart catheterization. It is therefore not surprising that a left-to-right shunt can sometimes be detected by this extremely sensitive technique.

A quantitative assessment of a left-to-right shunt cannot be made by the hydrogen inhalation technique. The most important use and advantage of the method is in the detection and localization of very small shunts.

## SUMMARY

The hydrogen potentiometric method for the detection and localization of intracardiac shunts is described. This method is simple, reliable, inexpensive and extremely sensitive. Quantitative assessment of shunts cannot be made at the present time. The method is safe providing precautionary measures are observed as in the use of any inflammable anaesthetic gas.

Forty patients with congenital and acquired heart disease have been investigated. In 11 of these hydrogen curves were recorded before and immediately after left heart catheterization by the Brockenbrough technique. In 2 of the 11 cases, a small left-to-right shunt was produced by the septal puncture.

False positives are recognized to occur with this method. These are usually due to technical errors, but haemodynamic factors may occasionally be responsible. The mechanisms of these are briefly discussed.

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