The Identification of Right-to-Left Shunts in the Central Circulation by the Injection of Ether

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Several methods are now used in conjunction with cardiac catheterization for localizing and quantitating right-to-left shunts. These include the recording of indicator-dye concentration curves after selective intracardiac dye injection,\textsuperscript{1-4} the external recording of radioactivity following injection of radioactive materials,\textsuperscript{5,6} and the use of cardioangiograms or cineangiograms to picture the course taken by contrast media introduced selectively through the cardiac catheter.\textsuperscript{7}

Such methods may provide both qualitative and quantitative information, but in some instances they embody either theoretical or practical disadvantages to the patient. These include the theoretic hazards inseparable from the use of radioactive materials, the cost of special equipment and its early obsolescence owing to improvements in design, and finally the small increase in risk associated with repeated angiograms.

We believe that we are justified in reporting our results using a qualitative, simple, and safe method of identifying the origins of right-to-left shunts. This information, in addition, permits accurate selection of the best site from which to perform intracardiac injections of contrast media. While the use of indicator-dilution curves has been recommended for such preliminary localization of shunts,\textsuperscript{8} the test to be described requires no special equipment. Although it does not lend itself to quantitative interpretation, the ether test will always give a definite positive or negative result.

Method and Material

The tests were performed as described by Donzelot et al.\textsuperscript{9} Anesthetic ether was drawn into a 1-ml tuberculin syringe in amounts of 0.05 ml for infants and small children and 0.1 to 0.2 ml for adults. During the injection, the syringe was tilted in such a way that the layer of ether was injected first, followed by saline. The injection and response times were not recorded because of the purely qualitative nature of the response.

Rapid injections of these small amounts of ether through the cardiac catheter into the pulmonary circulation normally caused the patient to cough but produced no other subjective effect. Such a response was termed "negative." In the presence of a right-to-left shunt, however, such an injection resulted in a dramatic complaint by the patient of "pins and needles" or "pricking and burning" around the mouth, nose, and forehead. When the right-to-left shunt occurred through a patent ductus arteriosus, the patient complained of similar sensations in the buttocks and feet. Such responses are termed "positive."

The application of this test to infants and children depends on the use only of sedation as opposed to general anesthesia. All of our patients in this age group were sedated as recommended by Keith, Rowe, and Vlad.\textsuperscript{10} In infants, a positive ether test was indicated by a sharp cry, often accompanied by an abrupt grimace.

In every patient a negative test was demonstrated by injection of ether distal to the site of the right-to-left shunt. The tests were performed with the catheter tip in the right or left pulmonary artery, main pulmonary artery, outflow and inflow areas of the right ventricle, right atrium, and superior vena cava. If a test was positive at any one of these positions, no more proximal tests were made.

The results to be described were obtained from our first 562 patients in whom cardiac catheterization was carried out in the course of investigation of suspected congenital heart disease. Cyanosis, evidence for arterial desaturation revealed by ear oximetry, or systemic levels of systolic pressure in the right ventricle at catheterization were accepted as indications for ether tests. These tests were performed on 109 patients. The results reported here, with one exception, are from ether tests on 57 of these patients whose diagnoses were confirmed at operation or by necropsy. The exception is presented separately as a case report.

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Results

The results are summarized in table 1. In 43 patients, ether tests were positive from one of the following points of injection: main pulmonary artery, right ventricle, right atrium, venae cavae, or subclavian vein. In 42 instances the site of right-to-left shunting, predicted from the ether test, was confirmed. The most common lesion in this group was tetralogy of Fallot (19 patients). Five patients had pulmonary stenosis associated with atrial septal defects and four others had transposition of the great vessels. Three patients had pulmonary hypertension with right-to-left shunts through ventricular septal defects. There were two examples of pulmonary stenosis associated with both atrial and ventricular septal defects, two with huge atrial septal defects with bidirectional shunts, and two with aortopulmonary windows. Single examples of a variety of combined lesions were found in the remaining six patients.

Thirteen of the 43 patients under discussion had arterial oxygen saturations of 90 per cent or greater at the time of catheterization. The specificity of the test was illustrated by the demonstration of positive tests in these patients. In eight of the 13, the arterial oxygen saturation at rest was 95 per cent or more. Despite the minimal degree of right-to-left shunt in these patients the presence and site of the shunt were correctly identified.

The single instance in which the site of right-to-left shunting was wrongly interpreted from the ether test was in a patient with tetralogy of Fallot. Only one injection of ether was made into the right ventricle (from a position in mid right ventricle) and this resulted in a negative ether test. Subsequently, a positive result was obtained from an ether test in the right atrium, and the shunt was wrongly interpreted as being at atrial level. Had a test been made in the inflow region of the right ventricle, we believe that this mistake would not have occurred.

A group of 11 patients with negative results were all persons in whom high right ventricular systolic pressures indicated the possibility of small right-to-left shunt. In each instance, the negative result of the ether test was confirmed at operation or autopsy.

False-negative results were recorded in three instances among the earlier patients in the series. Two of these patients had tetralogy of Fallot. In retrospect, it seems probable that the injection from the right ventricle was made from a position distal to the septal defect in one patient, and in this instance no test was made from the right atrium. For the second patient it seems likely that too small an injection of ether was made (0.05 ml.) in a two-year-old child who was heavily sedated. The third patient had an endocardial cushion defect with pulmonary hypertension and cyanosis. Ether tests were done from the pulmonary artery and right ventricle, and both were negative. No test was done from the right atrium and, in this instance, the right-to-left shunt may well have been at this level. Thus we think that two of the three false-negative results would not have occurred had we performed a complete series of ether tests as was the case in our later patients.

A further instance in which ether tests proved valuable is illustrated by the following report of a patient not included in the above series.

Case Report

A 36-year-old man was investigated for cyanotic congenital heart disease and was found to have severe pulmonary stenosis with an interatrial septal defect. Ether tests were performed during cardiac catheterization and proved to be negative.
from the right ventricle and positive from the right atrium. In addition he also had a left superior vena cava.\textsuperscript{11} The intracardiac defects were repaired with the use of cardiopulmonary bypass. Slight cyanosis (85 to 90 per cent) persisted, however, for a few days following surgery. Six months later he returned for further investigation, in the course of which a second cardiace catheterization was performed. Ear oximetry had been done with values of 98 per cent at rest, dropping to 93.5 per cent on exercise, suggesting a residual small right-to-left shunt. During the catheterization it was found that the right ventricular systolic pressure had fallen from a preoperative level of 130 mm. Hg to 66 mm. Hg, and ether tests from the right ventricle, right atrium, and superior vena cava were all negative. The final test was performed with the catheter tip in the left subclavian vein with a prompt positive result. The termination of the left superior vena cava had not been searched for at operation, but the results of the ether test provided strong evidence that the small residual right-to-left shunt was due to drainage of venous blood from this vessel directly into the left atrium.

**Discussion**

Donzelot et al.\textsuperscript{9} described selective ether tests, which they believed provide accurate information and are simple to perform. The amounts of ether recommended were somewhat greater than those we used, but there were few complications in Donzelot's series. Minor difficulties included headache, nausea and occasional vomiting; three infants from his series of 633 cyanotic patients had convulsions and one patient had a transient hemiplegia.

We observed no ill effects whatsoever in our smaller series and would endorse the opinions held by these previous workers that the test is simple, safe, gives accurate results, and allows immediate interpretation—an important consideration when intracardiac angiograms are being planned.

**Summary**

A method is described for localizing central right-to-left shunts by means of anesthetic ether injected through a cardiac catheter at various sites during cardiac catheterization. The presence and location of right-to-left shunts were correctly demonstrated in 42 of 43 patients in whom the diagnosis was later confirmed at operation or autopsy. The instance in which the site was interpreted incorrectly is explained.

Three false-negative results were obtained from the test and reasons for these are also given.

In our view the test is simple, safe, gives accurate results, allows immediate interpretation, and requires no special equipment. It has proved to be a most useful test for preliminary localization of shunts prior to selective angiocardiography.

**References**

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