DIAGNOSTIC PROCEDURES AVAILABLE FOR THE INVESTIGATION OF PATIENTS WITH CARDIAC DISEASE

BY

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One of the most noteworthy changes in the practice of medicine in this century has been the increasing pace of instrumentation. This is nowhere more evident than in the practice of anaesthesia. The practice of cardiology has changed in a comparable fashion. We have progressed from stethoscope and three-lead electrocardiogram to a bewildering armoury of gadgets, each with its technique for recording some phenomenon and with a jargon for lending an appearance of weight to its results. In this review an attempt will be made to distinguish between information on which a decision for or against surgery may depend (here called critical information) and observations which contribute new information, or confirm a diagnosis, but do not sway a surgical decision. In attempting this the author is conscious that opinions and practice are not uniform in this field. It is therefore necessary that the reader salts the ensuing account to his taste and accepts the awkward fact that a technique regarded as necessary in one centre may be considered to be at best unreliable in another. It should also be recalled that implicit in this account is the relation of the phenomena described to the patient's history, physical signs, temperament and environment.

RADIOLOGY

Simple radiology of the heart, including screening, may provide critical information of unique importance. The most common example of this is the demonstration of calcium deposits in the mitral or aortic valves in rheumatic heart disease. This provides unequivocal evidence of disease of the valves and, in a patient whose symptoms merit surgery, of the need for valve replacement as the operation of choice. There are rare exceptions to this, e.g. an aortic valve may show heavy calcification in a patient whose history of angina and electrocardiogram may support a diagnosis of aortic stenosis; yet measurement may show no gradient, the cause of the confusion being atherosclerosis of the valve and hypertension with consequent coronary artery disease.

Apart from the demonstration of calcification, the X-ray appearance of the heart and lungs may suggest or support a particular diagnosis, but such evidence is usually confirmatory, rather than critical. For example, the demonstration of a "mitralized" heart with pulmonary venous congestion is consistent with a diagnosis of mitral stenosis but does not exclude incompetence which is clinically detected. It is important to look for radiological confirmation, however, in view of the pitfalls in diagnosis. Any inconsistency is an indication for a critical review of information available. For example, if a large left-to-right intracardiac shunt has been diagnosed then the heart must be enlarged and the lung fields plethoric. If they are not then the diagnosis is incorrect or incomplete. Similarly, marked cardiac enlargement with a small shunt may, for example, be a clue to the presence of a coincident valve lesion.

CARDIAC CATHETERIZATION AND ANGIOCARDIOGRAPHY

Cardiac catheterization has come into general use as the most valuable technique in cardiac diagnosis after a somewhat uncertain start about 30 years ago, when it began to be used regularly to elucidate cardiac function. A wide range of ancillary techniques has been developed, but the basis of the method remains essentially the measurement of pressure in the heart chambers, the detection of shunts by various means and the demonstration of anatomy by angiocardiography. When circumstances are favourable, it permits a very high degree of diagnostic precision and provides more critical data than any part of cardiac assessment other than the history of the patient.

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There is now a wide range of cardiac catheters. In one form or another they can be introduced into every cardiac chamber and so allow pressure measurement, sampling and injection of tracer substances. The manipulation of the catheter to the desired situation is an individual art with close affinities to angling, and the practice of cardiac catheterization has an element of risk to the patient and uncertainty as to its outcome, which some find distasteful and others fascinating. Diagnostic catheterization is done by a team, and the quality of the work depends upon the joint efforts of the cardiologist, the radiologist and their technicians. No comprehensive review of a complicated technique can be attempted here, but the consideration of how commonly encountered lesions can be demonstrated will illustrate the interplay of the methods used.

**Stenosis** at a valve is most convincingly demonstrated by the measurement of pressure on either side of the valve concerned. The effect of exercise on the pressure gradient can be investigated, and, if available, techniques for measuring cardiac output may lead to calculations of valve area (an exercise of dubious value). In many situations it is not possible to have a catheter on both sides of the valve and the catheter must be passed through the valve. This may obstruct the orifice and so falsify the results, but such an effect is probably uncommon. Careful withdrawal pressure recording may show that the narrowing is not at the valve but above or below it. Good tracings of this kind need a single end hole catheter unsuited to angiocardiography (fig. 1). Alternatively, obstructions at the pulmonary outflow may be convincingly shown by selective right ventricular angiocardiogram in the lateral plane. Mitral, tricuspid and aortic valve narrowings are not readily demonstrated by angiocardiography.

**Incompetence** of valves may be convincingly evident from the pressure tracing in the chamber proximal to the valve. It is, however, unwise to assume that a normal pressure tracing excludes incompetence. For example, significant mitral incompetence may cause little pressure change if the regurgitation is occurring into a very large left atrium. Angiocardiography provides clear evidence of incompetence (fig. 2). Under various circumstances the results may mislead—usually in the direction of a false appearance of a leak. Thus:
(i) To show incompetence by angiocardiography the contrast medium has to be injected distal to the valve concerned. To achieve this the catheter often has to be passed through the valve under consideration. The catheter may be stiff enough to hold the valve open and so cause a false incompetence.

(ii) The angiocardiographic injections, particularly if made into a ventricle may stimulate extrasystoles. These occur while the inlet valve (mitral or tricuspid) is open and so contrast medium may be driven back into the atrium, thus simulating incompetence.

(iii) The injection may be delivered too close to the valve concerned, so that a jet of injected contrast medium is shot through the open valve, in diastole in the case of an inlet valve; systole in an outlet valve.

SHUNTING

Septal defects may be demonstrated by a wide range of techniques. The simplest is blood sampling. Here the appearance of arterial blood on the right side of the heart, or cyanosed blood on the left, indicates intracardiac shunting. A simple calculation enables the size of the shunt to be quantitated. Unfortunately, the precision of this calculation is a function of the arteriovenous oxygen difference, being more reliable when this is large but inaccurate when this is small. In many cases, therefore, the size of the heart and appearance of the lung fields on X-ray is a better measure of the shunt than an apparently precise calculation (see discussion in Verel and Grainger, 1969).

Many tracer techniques for detecting shunts are in use. Most of these depend upon the measurement of circulation time within the heart. For example, ascorbic acid can be detected by a platinum electrode. A catheter with a platinum ring at the tip is passed into the heart. Ascorbic acid is injected, causing a deflection as the ascorbic acid leaves the catheter. The injection passes through the lung and, if a left-to-right shunt is present, re-enters the right side of the heart. The site of small defects can be detected with precision by repeated injections of ascorbic acid in different parts of the right side of the heart, its early appearance through the defect being indicated by a second deflection from the platinum ring. In the same way, hydrogen may be inhaled, enter the blood by passing through the alveoli and be detected in the right heart by a platinum black electrode on the catheter.

Angiocardiography provides a sensitive and reliable method of detecting shunts. In using this technique, the most convincing demonstration is achieved by making the injection into the chamber from which the shunt is occurring with the patient positioned so that the septum concerned is in the same plane as the X-ray beam. The main limitation of the technique is that shunting through one defect will obscure a subsequent shunt through
a second defect. For example, when a ventricular septal defect and patent ductus are both present, a left ventricular injection with the patient positioned obliquely will show the ventricular septal defect, but both aorta and pulmonary artery will then fill simultaneously with contrast medium. A second, aortic, injection made in the lateral position will then show the patent ductus.

Major anatomical defects are largely elucidated by angiocardiography. Full-sized films exposed in two planes are preferred in most units for the diagnosis of disordered anatomy—transposition of the great vessels, varieties of cor triloculare, anomalies of pulmonary venous drainage, etc.—because this technique gives superior detail on films which can be compared at leisure. Ciné or video tape are more useful for functional disorders such as incompetence or stenosis of valves.

Some apparently simple problems can present considerable difficulties. For example, common ventricle with double outflow is a lesion which can be difficult to demonstrate convincingly. Similarly, the exact nature of the defect in lesions of the endocardial cushions may only be made at operation.

The mortality of cardiac catheterization ranges from less than 1 to 2.5 per cent in different reported series (see Verel and Grainger, chapter 16). The risks are determined partly by the nature of the investigation, left atrial catheterization being associated with a relatively high risk; and partly by the type of patient investigated. For example, any unit which habitually investigates babies under the age of 3 months will have a higher mortality than one where only adults are encountered.

Deaths have been reported from ventricular arrest and fibrillation, air embolism, cardiac perforation and tamponade. The injection of contrast medium into hypertensive lungs carries a serious risk of death from pulmonary oedema.

Less serious complications include arrhythmias provoked by the catheter, transient heart block, vascular thrombosis, the avulsion of vessels and the perforation of vessels by catheters or guide wires.

**ELECTROCARDIOGRAPHY**

The contribution of the electrocardiogram to the assessment of the state of the heart may be considered in three sections—as contributing confirmatory evidence, as providing evidence of the severity or progression of a lesion, and as an indicator of the presence of other lesions. The electrocardiogram alone rarely provides an absolute diagnosis, but is indispensable in the pre-operative cardiac assessment.

Confirmatory evidence is of many kinds, ranging from changes of congenital origin, e.g. the characteristic RSR'-pattern commonly seen in atrial septal defect, to the acute patterns associated with cardiac infarction, pulmonary embolism and the like. The confirmation afforded by the electrocardiogram, however, is usually qualified by the knowledge that few patterns are confined to a single pathological condition; for example, the RSR'-pattern mentioned earlier may be absent in patients with an atrial septal defect and is not rare in normal hearts.

Evidence of severity is found in voltage changes, particularly in the precordial leads, in strain patterns in the S-T segments, and in the extent to which the abnormal patterns are found in the twelve leads of the standard electrocardiogram. The evidence may be of critical importance in determining advice on investigation with a view to subsequent surgery. This is particularly likely in congenital heart disease where symptoms are often denied by a patient (or the parents) as the reduced performance of the patient is accepted as normal. Thus a young woman presented in early pregnancy with a cardiac murmur suggesting pulmonary valve stenosis. She thought her slight breathlessness was normal for pregnancy. The electrocardiogram (fig. 3) showed severe right ventricular hypertrophy and strain. At catheterization a right ventricular pressure of 150 mm Hg was found. Here the clinical assessment was misleading and the electrocardiogram provided evidence of unique value.

Similarly, serial electrocardiograms may give evidence of a progressive lesion, either over years as in obstruction to the outflow of a ventricle, or over hours or days as in cardiac infarction, pulmonary embolism or pericarditis.

As an indicator of other lesions the electrocardiogram has an important but limited role. This ranges from the diagnosis of electrolyte imbalance by S-T changes found in a patient on diuretic therapy to the diagnosis of cardiac infarct due to
Electrocardiogram of patient with pulmonary valve stenosis, before (on left) and one year after operation (on right). Note particularly the changes in S III, with a fall in the voltage of the R wave, the appearance of an S wave, and the reversion of the T wave to normal after surgery.

coronal embolism in mitral valve disease. The value of the electrocardiogram in this sphere is limited partly by the non-specific nature of the electrocardiogram and partly by the limitations of the technique. Thus it is impossible to distinguish acute cardiac infarction from pulmonary embolism with sufficient certainty to permit a decision on operation. If surgery is contemplated, a pulmonary angiocardiogram provides the critical information, not the electrocardiogram. The limitations of the technique are well illustrated by a middle-aged woman referred for mitral valvotomy. After a technically successful operation she failed to maintain her systemic pressure. At necropsy an old extensive intramural infarction of the left ventricle was found. The pre-operative electrocardiogram gave no evidence of this.

VECTORCARDIOGRAPHY

The electrocardiogram is a voltage record made by a galvanometer. It therefore records the swings in potential to either side of the null point. In the vectorcardiogram, the recorder is the electron beam of an oscilloscope so arranged that the voltage changes of one electrocardiogram move the beam in one direction and the voltage changes of another simultaneously recorded electrocardiogram move the beam in a direction at right-angles. The two recordings thus make a pattern of loops for the P wave, the QRS complex, and the T wave. Attention is largely directed to the QRS loop.

The most used technique is the Frank lead system in which recordings are made in three planes at right-angles—the coronal plane (called the “frontal” vectors), the sagittal vector and the horizontal vector. The tracings may be used to diagnose cardiac infarctions. It may also indicate ventricular hypertrophy. It is of some value in diagnosing conduction defects within the ventricle, but these are more easily indentified by the conventional electrocardiogram. It is of little value in elucidating disorders of rhythm. A useful application is in picking out congenital lesions of the endocardial cushions, in which the frontal vector loop usually runs anticlockwise above the zero voltage line, instead of clockwise below it, as is normal.
So far the small returns from this time-consuming technique have not seemed to justify its introduction as a routine investigation.

ULTRASONICS
This is a technique relatively new to cardiology in which very high frequency sound waves are generated from a small device and projected as a fine beam a millimetre or so in diameter. If projected through the heart from the chest wall, sound waves are reflected back from tissue planes and their incidence is recorded on an oscilloscope, calibrated to show the distance between the generator (closely applied with a suitable jelly seal to the skin), and the structure causing the reflection. In addition to distance, some indication of the thickness of the reflecting tissue in the heart is obtained. The principle is similar to that used in recording the contour of the ocean bed by an ultrasonic instrument on a ship.

It is too early to make a firm assessment of the usefulness of this technique, but it appears likely that ultrasound will achieve a permanent place in cardiac diagnosis for such purposes as the demonstration of pericardial effusion, the recording of typical movements of the mitral valve, whether normal, stenosed or leaking, and the detection of clot in the left atrium (fig. 4). Its use for gauging the thickness of the ventricular wall has been suggested.

ISOTOPE SCANNING
It is possible to inject radioactive substances into the circulation and detect their presence with a

![Ultrasound record of the mitral valve from a normal patient (left) and a patient with mitral stenosis (right). In mitral stenosis the valve movement is diminished and the rate of closure is slower than normal. The polaroid record picks out the essential features of the tracings. An oscilloscope beam sweeps a storage type phosphor on which the structures encountered by the beam are traced much as in a radar scan. The horizontal dots in the normal trace show the time. They do not appear on the trace of mitral stenosis, but the speed is identical. The line labelled “valve” is the movement of the anterior cusp of the mitral valve. The rows of vertical dots show distances of 1 cm. In these tracings the normal valve moves through 3 cm, the stenosed one through less than 2 cm. The closing rate (downward movement) is reduced in the stenosed valve, but the opening movement (upwards) is rapid although reduced in amplitude.](https://academic.oup.com/bja/article-abstract/43/3/268/295281)
suitable collimated counter placed over the heart or lungs. The technique may be used to demonstrate intracardiac shunt. The counter is positioned over the lungs and a substance which largely remains in the circulation is injected. If a left-to-right shunt is present, the recirculation of radioactivity through the lungs leads to a more gradual fall-off in radioactivity than normal. The technique is not very sensitive and does not distinguish between a small shunt due to a small defect and a small shunt due to high pulmonary vascular resistance.

A more useful isotope technique is the scintiscan. In this a radioactive suspension of particles large enough to embolize in the pulmonary capillary bed is injected intravenously in a quantity enough to allow a scanner to record the distribution in the lung. The number of capillaries obstructed by the injected material is too few to cause symptoms. A finely collimated counter is then passed over the lung fields and the distribution of radioactivity recorded, the intensity of radiation in any area being indicated by a suitable code of line thickness, colour or number.

Areas of avascular lung are clearly demonstrated (fig. 5). The technique does not distinguish between loss of capillary filling due to embolism and loss due to other causes, such as lung cysts.

PHONOCARDIOGRAPHY

The adequate recording of cardiac sounds requires expensive, sensitive microphones, high-frequency recorders, and much time and patience. The technique has led to great refinement in the use of the stethoscope and, by permitting an analysis at leisure of sounds heard in very close proximity, has given insight into normal and abnormal cardiac function of the greatest value. Despite this, the information provided by the phonocardiograph is seldom if ever of critical value. This is

**FIG. 5**

Angiocardiogram and scintiscan in a patient with massive pulmonary embolism. Note the scintiscan shows blood is reaching only the right upper lobe. This is confirmed by the angiocardiogram. Here the injection has filled the outflow tract of the right ventricle. The left pulmonary artery is completely blocked. A little blood is passing into the upper lobe branch of the right pulmonary arteries but the lower lobe branches have not filled.
partly due to the capacity of the human ear to learn from the phonocardiograph record what to expect and so to render the recording unnecessary, and partly to the ease with which recordings may be distorted. There does not exist any simple method of standardizing the recorder such as exists for the electrocardiograph.

BALLISTOCARDIOGRAPHY

The ballistocardiograph is a suspended platform on which the movements imparted to the horizontal subject by the movement of blood in the circulation are recorded. The main deflection of the ten or so movements recorded in each cardiac cycle is due to the passage of the bulk of the systolic volume down the aorta. Characteristic tracings may be recorded in coarctation of the aorta, aortic valve disease, cardiac infarction, and so on. It does not provide critical information, but has a place in the range of techniques available for measuring cardiac function.

FURTHER READING

Radiology

Cardiac catheterization and angiography

Electrocardiography

Vectorcardiography

Phonocardiography

Ultrasonics

Ballistocardiography