RADIOLOGY IN CARDIAC DISEASE

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Radiology has been used on an increasing scale in the diagnosis and prognosis of cardiac disease for the past 30 years, and has become an invaluable support to the clinician. Big advances in the last few years have been the result not only of new techniques, such as cardiac catheterization and angiography, but of a new and more interested attitude to cardiac radiology in general.

It was, for instance, common in the past for a cardiologist to base his opinions solely on the subjective and sometimes misleading evidence afforded by fluoroscopy; whereas a general physician would often confine himself to a single anterior-view skiagram, which in many cases would be quite inadequate. A modern routine radiological examination would not be complete without the use of both methods.

The Routine Cardiac Radiological Investigation

Fluoroscopy, which is used first, is particularly valuable in showing the movements of the heart and great vessels. The shape of the heart can be studied while the patient is rotated during the screen examination. The contour and position of the barium-filled oesophagus should be recorded at the same time. From the results of the fluoroscopy, it will be possible to decide whether skiagrams in one or other of the oblique views will be required in addition to the routine anterior view.

The anterior-view skiagram is taken at a tube-film distance of 6 ft., the patient standing with breath held in fairly deep inspiration. From this can be obtained the measurement of the transverse diameter of the heart, which is one of the most useful contributions of radiology to the study of cardiac disease. Taking into consideration a constant distortion of some 0.8 mm., the routine anterior-view skiagram is as accurate a method for this purpose as orthodiagraphy and often quicker and more convenient.

The Size and Shape of the Heart

Of the various heart measurements available, that of the transverse diameter (T.D.) is the most useful, probably because it is also the most accurate. The points on the X-ray image, between which the line of measurement has to be drawn, are usually more easily defined in the case of the transverse diameter than in the various other diameters.

Whatever method is used to acquire the T.D., simple or elaborate, the important task of interpretation remains. Even assuming the accuracy of the measurement, it is difficult to decide what the limits of the normal are, and whether pathological enlargement of the heart is present or not in any particular patient under examination for the first time. The vastness of the literature on this subject (over 150 references are given by Roesler, 1943) is but a reflection of the difficulties involved.

Two methods of assessing the limits of the normal are now used:—(1) The cardio-thoracic ratio; and (2) Tables of averages for people of given height, weight and age.

With increasing experience, it has become apparent that in certain cases the cardio-thoracic ratio can exceed 50 per cent. without there being any pathological enlargement of the heart. This may be so in the case of infants, when it may be impossible to obtain a skiagram during full inspiration; in obese patients of hypersthenic build, especially when the diaphragm does not descend far during inspiration, and in some people over 60 years of age. If the radiological factors are imperfect, such as a tube-film distance of less than 5 to 6 ft., or a posterior view necessitated by the illness of the patient, the ratio is of course artificially raised. If these possible sources of error are taken into consideration, the cardio-thoracic ratio is a useful yardstick by which to assess the significance of any given transverse diameter of the heart.

Tables correlating height, weight and age with the transverse diameter of the heart, such as those of Hodges and Eyster (1926), are possibly a rather more certain method for detecting pathological enlargement; but as these only deal in averages, allowances have to be made for individual patients.

All such methods of assessing the limits of the normal are, of course, made unnecessary if a previous skiagram of the patient in a healthier or normal condition is available for comparison. This is by far the most reliable test, and pathological enlargement of the heart can be detected in this way before the cardio-thoracic ratio exceeds 50 per cent., or before there is an appreciable in-
crease over the predicted measurement derived from the height-weight-age tables. It is therefore recommended that an initial skiagram be taken when the patient is first seen, be it with rheumatic carditis, hypertension or any other condition likely to cause heart enlargement.

When an increase of 1 to 2 cm. is observed in the later skiagram, the question of the accuracy or consistency of the normal T.D. measurement naturally arises. A general test of this factor was made by the author recently, using the routine yearly chest skiagrams of a group of nurses and medical students. These skiagrams were all made under identical conditions. The T.D. measurements were taken for three consecutive years and variations in each individual noted.

The smallest variation recorded was 1 mm., the largest 2 cm. The average for 100 subjects was 0.56 cm. The subject with a variation of 2 cm. was obese; in the middle skiagram which showed the largest measurement, the diaphragm was higher than in the other two pictures, suggesting that she did not inspire as fully. Being herself a radiographer, she must be considered average as far as co-operation is concerned. A number of subjects were rejected from the test because for one reason or another the heart borders were not sharp on the skiagrams and errors of measurement up to 2 cm. or more might be expected.

Whether this average variation of 0.56 cm. is due to differences between systole and diastole, rotation of the subject, differences in the depth of respiration, or true alterations in the heart size, is not revealed, but it is an indication of what to expect under average working conditions. The number of X-ray machines available in which the time of exposure is set in relation to the R wave of the electrocardiograph, is so small as to be of no help to most cardiologists, so that variations resulting from the systole-diastole difference in size are unavoidable. What is perhaps surprising is the relative constancy of the T.D. over some years, regardless of the life the subject leads, whether strenuous or quiet.

The shape of the heart is also a significant factor in diagnosis. The T.D. may be normal and yet alterations in contour may indicate a serious lesion. It is, however, important not to consider alterations of the heart shape in isolation, but to correlate them with the other radiological and clinical features. It is not safe for instance to use terms such as 'mitral heart' or 'hypertensive heart,' etc., in connection with the X-ray appearances seen on a single anterior-view skiagram. To take the first as an example: An identical prominence of the left border below the aortic knuckle may be seen in cases of mitral stenosis, patent ductus arteriosus or the so-called 'cor pulmonale' resulting from some long sustained pulmonary condition. In mitral stenosis, however, there will be posterior deviation of the oesophagus visible in the right oblique view, whilst clinical distinction between these three conditions should be easy.

An alteration in the position of the heart will often result in an alteration in its shape and of the T.D. For instance, slight displacement to the left from scoliosis, a depressed sternum or some pulmonary condition will often cause an undue prominence of the left border just below the aortic knuckle which might be mistaken for a heart lesion. When gross displacement is present, radiology may be of little value in estimating the heart size.

In short, it is essential to use the radiological method with care and discrimination. It is often unsafe to reach hasty conclusions as to whether the heart is enlarged or not from the sole evidence of an anterior-view skiagram, or whether an abnormality of shape seen in this view is indicative of some particular lesion. In the majority of cases the full routine radiological examination is essential and in particular circumstances additional and more elaborate radiological investigations are also justified. These include special-posture radiography, tomography, kymography by the multiple-slit method, kymoscopy, cardiac catheterization and angiocardiology.

Special-posture Radiography

Special-posture radiography is sometimes valuable when mediastinal or pleuro-pericardial adhesions are suspected. Three views are used; two anterior views with the X-ray beam parallel to the floor, the patient lying on the table on his left side for the first film, on his right for the second; and a lateral view with the patient supine. These may show restricted postural movement of the heart or puckering out of the cardiac outline at the point where an adhesion is situated. Such cases are not common, but the technique is simple and should be kept in mind.

Tomography

It is often possible to demonstrate valvular calcifications by tomography (Davies, 1949), but since these are more certainly identified by the characteristic movement of the shadow on fluoroscopy, it is probably not worth the expenditure of time and films.

Tomography is, however, valuable in certain cases where a massive shadow is seen on the routine skiagrams in the region of the heart or great vessels, and the nature of the shadow is uncertain. Tomograms may show the relation of the abnormal shadow to the trachea and main bronchi, or to the pulmonary vessels. Delineation of the early
division of the right and left pulmonary arteries and final junctions of the pulmonary veins may also give useful information in some cardiac conditions. For instance, tomography is often better than the plain skigrams to show whether the main vessels are dilated or not in a case of patent ductus arteriosus. Dilatation may be an additional point in favour of tying the ductus in some cases.

Kymography

Kymography by the multiple-slit method (Stumpf kymogram) is simple and inexpensive, and the fact that it is not more generally used is probably due to the difficulties of interpreting the resulting skigrams. The heart movements, being complicated, are never parallel to the kymograph grid intervals throughout the exposure, so that the resulting curves are grossly distorted. Nevertheless a constant and fairly characteristic picture is seen in normal people, so that any alterations to this picture may give useful information in some pathological conditions (Simon, 1939).

By observing the timing and shape of the notches, the various parts of the heart can be differentiated in a way impossible by plain radiography. For instance, the aorta and pulmonary artery show a rapid out-thrust movement and slow recoil starting just after the inward movement of the left ventricle. On the other hand, auricular movements are later in time and show a more pointed curve. If, therefore, there is a prominence of the left heart border below the aortic knuckle, it is often possible to see from a kymogram whether this represents an enlarged pulmonary artery or a left auricular appendage. Fig. 1, a kymogram of a case of idiopathic dilatation of the pulmonary artery, shows that the prominence on the left border moves in phase with the aorta and is therefore an enlarged pulmonary artery.

The following perhaps over-simplified tabulation gives an indication of the present position of X-ray kymography:

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>It is of no value:</td>
<td>For examining babies, young children or older people who cannot suspend their breathing for at least three seconds.</td>
</tr>
<tr>
<td>It is much inferior to electrocardiography in confirming the presence and position of areas of cardiac infarction.</td>
<td></td>
</tr>
<tr>
<td>It is of some value:</td>
<td>In certain pericardial conditions. When a small pericardial effusion is present, the absence of pulsation may be a useful diagnostic feature.</td>
</tr>
<tr>
<td>When constrictive pericarditis is suspected.</td>
<td>The combination of a small heart and absence of movement may be a useful confirmatory sign.</td>
</tr>
<tr>
<td>Pleuro-pericardial adhesions may be demonstrated.</td>
<td></td>
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When a massive shadow has been seen, but differentiation between an aneurysm and a mediastinal tumour is difficult on both clinical and routine radiological examination. The presence or absence of pulsation of the shadow itself is not a helpful point, since a vascular tumour may pulsate, while an aneurysm with a clot in it may not; but the presence or absence of a normally pulsating aortic shadow independent of the main shadow will be of decisive importance and may make angiography unnecessary.

In some congenital cardiac conditions in older children and young adults.

The site of narrowing in co-arctation of the aorta may be indicated by the absence of pulsation below it; but it must be admitted that angiography will give more detailed information about the size and length of the defect.

In patent ductus arteriosus, abnormalities are seen (Smith et al., 1949) but they are not sufficiently marked or characteristic to be decisive in cases where there is clinical doubt about the diagnosis.

The presence of 'hilar dance' can be confirmed and recorded, but this is usually obvious on fluoroscopy.

On the whole, in spite of various disappointments, kymography is frequently worth doing since it is occasionally helpful, whilst the technique is easy and does not upset the patient.

Kymoscopy

By kymoscopy the movements of one particular part of the heart border are studied. A single-slit grid is used, only some 2 cm. in length. This is orientated under fluoroscopic control so that the slit lies as nearly as possible parallel to the movements of the particular part being studied. The resulting curves are more accurate representation of the movements of this part than can be obtained from a multiple-slit kymograph of the whole heart, in which the slits are inevitably out of line with many of the heart movements.

It would not be practicable to have a moving film behind the single-slit grid, but a selenium cell answers the purpose just as well. The X-ray beam is centred over the heart border, some of it traverses the lung lateral to the heart, passes through the grid slit and enters the selenium cell. As the heart moves to and fro it will allow more or less of the X-ray beam to reach the cell; thus the appropriate current changes are produced, and are in their turn recorded on a moving film. Two such cells may be used on different parts of the heart border simultaneously with the electrocardiograph (or phonograph). The curves resulting from all three of these examinations can be
recorded on the same film. The X-ray exposure is continued for two to three seconds as in the case of a kymograph.

Interpretation of the curves resulting from kymoscopy is not much easier than in the case of kymography, in spite of the greater accuracy.

Cardiac Catheterization: X-ray Safety Measures

The radiologist's contribution to cardiac catheterization would appear to be simple enough, but in practice there are one or two factors which require careful consideration by anyone using this method. One of these is the protection of the patient from excessive exposure to X-rays. A test to measure the output of X-rays should first be made under routine working conditions with a subject representing the patient. The X-ray beam should cover a large area of his back—about 12 in. by 10 in. Assuming the tube filtration is 1 mm. of aluminium (or its equivalent), a dose rate on the patient's back of some 20 r units per minute will be recorded. This dose rate will allow with safety a total exposure time of seven to ten minutes. If the dose rate is found to be higher than this at the test, then either the working conditions must be altered, or the time during which actual screening takes place must be reduced.

For young children, the figures must also be reduced. A reduction in milliamperes from 4 to 1½ will often give adequate illumination and at the same time allow some five minutes screening time.

These 'safe' times sound extremely low for a procedure which may occupy an hour or two, but the danger is real enough and risks of greater dosage should not be taken.

The following precautions will also increase the margin of safety: Catheterization should, if possible, be arranged well in advance, and at least a fortnight should elapse between a preliminary diagnostic routine fluoroscopy and this investigation. Under no circumstances should a second catheterization be done within a fortnight of a previous one. At least one member of the team should be fully dark adapted by the use of suitable dark glasses, so that he is able to see as soon as the room is fully darkened. He (preferably the radiologist) should control the size of the X-ray beam so that it is no larger than necessary. The actual time during which the screening current is on should be recorded and the operator informed if there is any danger of exceeding the safe time limit. Assuming only one or two such investigations a week, there is no danger to the physician introducing the catheter; but if more are done, he should have some protection from scattered radiation. The standard lead-rubber apron will usually suffice for this purpose. There is no danger to the occasional helper or observer.

Should a general anaesthetic be used, the usual precautions should be taken to preclude an explosion initiated by a static electric spark; this may occur even with modern shock-proof apparatus.

Technique of Cardiac Catheterization

A suitable vein is selected in the elbow region, usually the left; the skin over it is anaesthetized, the vein dissected out and a small incision made in it through which the catheter is gently introduced. Rough handling at this stage may induce venospasm and necessitate abandonment of the investigation. Once the catheter has been introduced into the vein and pushed upwards, its progress is carefully controlled under fluoroscopic vision. First the lower neck and retroclavicular area on the side of introduction are screened to ensure that the catheter travels towards the superior vena cava, and not up into the neck, across to the other side or down the lateral thoracic vein as sometimes happens. If the X-ray beam is cut down to a small area the screening time spent on this part of the procedure can be ignored since the rest of the exposure will be on a different skin area. Careful inspection of the position and direction of the slightly curved tip will be a guide to the physician in his manipulations, and will enable him to judge the appropriate moment at which to introduce it further.

As a rule the catheter is quite easily recognized on the screen, but in a large adult it may be difficult to see it through the spine unless the eyes of the observer are fully dark adapted. Occasionally a catheter is not as radio-opaque as it should be but of recent months manufacture has improved and this is rarely a difficulty. If for any reason there should be difficulty in seeing the catheter, a skiagram should be taken and rapidly developed. This will nearly always show the catheter, and thereafter the observer, knowing where to look, will be able to pick it up on fluoroscopy.

In many cases the catheter will enter the right auricle with ease; then, with a little further manipulation, the right ventricle, the main pulmonary artery and finally the right or left branch (Fig. 2). An endeavour should be made to reach this point at an early stage, and then to take the pressure readings and blood samples from the pulmonary artery and heart chambers while the catheter is being withdrawn under fluoroscopic control.

Sometimes the vigorous movements of the tip of the catheter will indicate its successful entry into the right ventricle; but if there is any doubt, this can be checked by a pressure reading. Once the
Fig. 1.—Kymogram in a case of dilatation of the pulmonary artery. The aortic pulsations are seen in frame 3. The pulsations of the prominence (frame 8) are of similar type and phase, proving the prominence to be an enlarged pulmonary artery.
FIG. 2.—Skiagram showing a cardiac catheter with its tip in the right pulmonary artery in a case of pulmonary stenosis.

FIG. 3.—Skiagram showing the cardiac catheter coiled up in the greatly enlarged right auricle, in a case of primary pulmonary hypertension.
Fig. 4.—Skigram showing a cardiac catheter with its tip folded up in an aneurysm of the left pulmonary artery.

Fig. 5.—Cassette changer for angiocardiography. The cassettes are stacked in the lead-covered box A. 1 and 3 are in the lead-covered tunnel but at 2 there is a radio-translucent window over which the patient lies. The cassettes are moved across by the plunger C, D. J is a check stop which comes up just before the cassette reaches it. B is the reception box.

After M. McGregor (1949)

Fig. 6.—Cassette changer for angiocardiography. The lead-lined, ray-proof lid on which the patient lies is raised to show the position of the cassettes marked C. The one on the left is entering the reception box. X is the radio-translucent window under the patient's thorax. Y is the space in which the cassettes are loaded. One revolution of the handle moves a 12 in. by 10 in. cassette 12 in. and then stops it abruptly, at which point the exposure is made. The next revolution pushes it on into the spring-loaded reception box, and at the same time moves the next cassette under the window X.

By courtesy of A. E. Dean & Co.
catheter is in the right ventricle, it is advisable to keep an eye on the heart movements for fear of possible adverse effects of the catheter on the heart action. Any irritability and irregular contractions of the heart can be easily seen on the screen and are a warning not to keep the catheter in this chamber too long; they do not occur when the catheter is in the auricle.

It may be possible in some cases to introduce the tip of the catheter into the coronary sinus (Bing, 1949). Its presence there may be inferred radiologically if the tip is seen not to proceed any further. Definite confirmation can usually be obtained only by the appearance of the blood sample which will be dark.

Skiagrams may be useful to mark the exact site at which pressure readings were taken or blood samples withdrawn. They are often not essential and, with a view to limiting the amount of X-rays on the patient's skin, may in most cases be limited to one or two. When the tip of the catheter is in one of the pulmonary arteries or in the superior vena cava, the position is so obvious on the screen that a skiagram is unnecessary.

When congenital abnormalities are present the simple routine described above may not be possible. The catheter may pass out of the right auricle through an anomalous vein or into the left auricle through an interatrial septal defect. If this happens a pressure reading or blood sample may be taken there and then before reaching the pulmonary artery. Sometimes the catheter curls up in a greatly enlarged right auricle (Fig. 3). In such a case the number of attempts to get it into the right ventricle must inevitably be limited by the X-ray safety factors already mentioned.

Should venospasm occur it may be impossible to introduce the catheter any further; it may even be difficult to withdraw it. The spasm can be diminished sufficiently to permit withdrawal by the injection of 1.7 cc. of coramine down the catheter.

**Indications for Cardiac Catheterization**

The chief clinical indications for cardiac catheterization are as follows:

1. Cyanotic heart disease. In the tetralogy of Fallot it is often necessary to confirm the diagnosis. In a typical case, a high pressure reading will be found in the right ventricle and a low one in the pulmonary artery distal to the point of the stenosis. Incidentally the point at which the pressure in the pulmonary artery falls markedly below that in the

**Fig. 7.—Skiagram showing coarctation of the aorta.** The narrow area is seen opposite the arrow. The tip of the No. 8 catheter introduced into the radial artery is shown near the top of the aortic arch. 40 cc. pyelosil injected in 15 seconds.
right ventricle, will often mark the site of the stenosis. A skiagram showing the position of the tip of the catheter when this occurs may help the surgeon in his selection of the type of operation (Brock, 1949). On the other hand high pressure in the pulmonary artery (over 50 cm. of water) will be a contraindication to a Blalock type of anastomosis.

(2) In some cases of interatrial septal defect, to confirm the diagnosis and differentiate it from an Eisenmenger complex. In a typical interatrial septal defect with a left to right shunt, the oxygen content in the right auricle will be appreciably higher than in the superior vena cava.

(3) In a doubtful case of patent ductus arteriosus catheterization may help if a left to right shunt can be demonstrated in the pulmonary artery. If, however, there is much regurgitation of blood from the pulmonary artery into the right ventricle the findings will simulate a high ventricular septal defect and thus be misleading.

(4) If there is doubt whether a shadow seen on radiological investigation is a neoplasm or an aneurysm of the pulmonary artery (Fig. 4).

**Angiocardiography**

The two essentials for successful angiocardiography are an adequate concentration of the contrast medium in the heart and great vessels, and the correct timing of the skiagrams. The former depends on the rapidity of the intravenous injection, which should be given through a wide-bore needle at the rate of 40 cc. in two seconds. In order to observe the bolus of contrast medium on its way through the various chambers of the heart and into the main vessels, it is necessary to take a series of six to eight skiagrams at very short and precise intervals. To achieve this some device is needed to speed up the process of film changing so that a rate of at least one exposure per second is attained. Three different ways of doing this are at present in use:

(1) **Cine camera photography of the screen image.** Speeds up to one frame per second have been reached by this method and no doubt faster speeds will be developed in the future, possibly by the use of an electron acceleration screen to increase the brightness of the screen image. Such increases in speed may yet make this the method of choice but, at present, losses of detail and contrast, due to the fact that the photographs are indirect, make it inferior to other methods available.

(2) **A device to ensure rapid changing of ordinary X-ray films and cassettes.** There are four types of device available giving speeds easily up to one exposure per second for six or eight seconds. In the first type, the cassettes are stacked in an X-ray protected box to one side of the patient and are pushed one by one through a tunnel underneath him (Fig. 5). Each cassette stops abruptly when it is beneath the patient, remains stationary during the exposure and is then pushed on into an X-ray protected reception box by the next incoming cassette. The reception box end of this device should be on the side of the patient chosen for injection since it is flush with the table top and will therefore not be in the way of the outstretched arm. This is a simple device and if the cassettes are light in weight there is little risk of their jamming.

The three other devices are variations of this one. In the first, the lead-backed cassettes are stacked directly beneath the patient and are pushed up against the table top one by one for each exposure. Once exposed, they move off towards the head or foot of the table and fall into the reception box. In the second variant the cassettes are mounted on a large wheel which is rotated beneath the patient, the exposure being made as each cassette comes into position beneath the patient. Stopping and restarting the wheel at the correct moment presents some difficulty, which in turn limits the speed to one exposure per second. It is, however, a suitable device for use with a sitting patient. In the third variant the cassettes are moved in line along a flexible band, passing in a tunnel under the patient (Fig. 6). Here, again, the difficulty is to start, move and stop the cassettes sufficiently quickly.

(3) **Roll film radiography.** A somewhat higher speed of working is made possible by the use of a 12 in. wide roll film. The intensifying screens have to be separated after each exposure to allow the roll of film to move, and then pressed against the film again when it is stationary for the next exposure. Elaborate mechanical coupling is needed for this, as for the other methods described, and there is no indication yet which will be the simplest and most effective routine method for the future.

Having solved the problem of correct timing by one of the foregoing methods, the rest of the technique of angiocardiography is fairly straightforward. The view (posterior, lateral or oblique) must be chosen according to which lesion is suspected clinically. For Fallot's tetralogy, a posterior view is most useful; for coarctation of the aorta, an oblique view is best. If the first series of skiagrams is not satisfactory, it is safe to give a second injection 20 minutes later and take a second series in another view. It is possible, by using two X-ray tubes and generators, and two cassette changers, to take two series simultaneously, one in a posterior and the other in a lateral view; but the apparatus for this is com-
plicated and on occasion an oblique view may be preferable to the lateral one, so that the simpler method is more satisfactory as a routine.

The examination is usually done with the patient lying down, since an anaesthetic is often required, but an adult may sometimes sit up for it if the apparatus is adaptable to that position. The cassettes are numbered with lead figures, so that the films can be re-assembled in the order in which they were exposed.

The tube-film distance is reduced to 3 to 4 ft. to ensure rapidity of exposure. A well-exposed film is necessary to show up the contrast medium clearly; for a child of 2, for instance, an exposure of 200 milliamperes, .05 second and 65 K.V.P. would be necessary for the posterior view; in an adult, .1 second and 75 K.V.P.

The first film is taken towards the end of the injection in most cases, but if the abnormality is thought to be in the aortic region, the first film can be taken one to two seconds later.

The total dosage of X-rays received by the patient's skin during the eight exposures is so slight that it can be ignored, even if the examination follows directly after cardiac catheterization. It would correspond to less than 20 seconds screening and is in any case not directly on the same skin area.

The X-ray beam should be coned down so that the personnel are safe from everything but scattered radiation. If anyone is giving several injections during a week, a light lead-rubber screen can be placed to protect the hands and the routine lead-rubber apron can be worn to protect the body. By now most cassette changing devices are mechanical, so that other personnel need not be in the danger zone. The anaesthetist will be protected by the lead top of the reception box in some methods, but he can wear a lead-rubber apron if necessary.

Intra-arterial Angiography of the Aorta

In the case of patients suffering from coarctation of the aorta, it is often difficult to get sufficient contrast medium into the required area by intravenous angiography, and more definite information may be given by retrograde arteriography. A catheter is introduced into the radial artery and passed onwards into the aorta. The contrast medium is then injected and the serial radiographs taken. Since it is only possible to introduce a small-sized catheter, a much slower rate of injection is inevitable, but nevertheless a satisfactory picture is usually obtainable (Fig. 7).

The Lung Changes in Cardiac Conditions

In one's enthusiasm for these elaborate X-ray investigations of the heart, simple inspection of the lung fields, particularly on the skiagram, should not be neglected. If this is done in an orderly manner (as when inspecting a skiagram for a lung lesion), features may often be discovered which are of help in the diagnosis or prognosis of cardiac lesions.

First, the position of the diaphragm should be noted. A high position may cause the heart to lie more horizontally than usual and thus to appear larger than it, in fact, is. Excess of air below the left dome, or air translucencies in an unusual position should be noted. Deviation of the trachea will suggest the possibility of slight heart displacement, which must be taken into consideration when assessing the significance of its size and shape.

Particular attention should then be paid to the pulmonary vascular pattern. It may be diminished in certain types of congenital cyanotic heart disease, or increased in other types or in any condition resulting in stasis of the pulmonary circulation. It is only fair to say that there are wide variations in the normal appearance of the pulmonary vessels, and early changes may therefore not be detected unless a previous skiagram is available for comparison taken before the onset of cardiac failure, etc.

Apart from changes in the density and size of the main vascular arborizations, two other generalized pulmonary abnormalities are sometimes seen in cardiac diseases. Firstly, there may be an alteration in the peripheral pulmonary pattern, so that arborizing vascular (or lymphatic) channels become visible in the lower axillary regions where, normally, there are no distinctive markings. This is sometimes seen, for instance, in chronic mitral stenosis. Secondly, fine discrete mottled shadows 0.5 to 1 mm. in size, caused by haemosiderosis, may occasionally be seen in well-compensated and long-standing mitral stenosis, when the cardiac findings may be relatively inconspicuous. These shadows must not be confused with those of miliary tuberculosis.

The shadow of a pleural effusion may be visible on the skiagram before there are physical signs to indicate its presence, and this will be a factor to be considered when planning treatment. At the onset of pulmonary oedema, physical signs usually precede radiological evidence of the condition, but sometimes a large area of clouding is seen in the lower half of the lungs when there is as yet no clinical evidence of oedema. Should the cardiac condition improve, these shadows will disappear rapidly. When uraemia supervenes in hypertension, large areas of opacity are sometimes seen spreading out from the hilum and are of grave prognostic significance.

Infarction during the course of a chronic cardiac condition may occur and be obvious clinically, and
yet there may be no radiological evidence of the site and size of the affected area. Even if a shadow is seen, it is usually ill-defined, and in the single posterior view, which is usually all that is available, there is no evidence of a pyramidal shape. If it is as small as 1 cm. it may be more or less circular, but when larger its ill-defined margins are often partly masked by a superadded pleural effusion.

When studying a skiagram of the lungs in a patient with cardiac disease, it must not be forgotten that other pathological conditions may co-exist. For instance, a bronchial neoplasm may arise in a patient with long-standing, but well-compensated, mitral stenosis; while ordinary inflammatory conditions may occur in the lungs independently of the cardiac lesion. A coal miner with pneumonokoniosis may develop mitral stenosis, in which case it may be difficult to differentiate the shadows of the pneumonokoniosis from those of a possible haemosiderosis. It is therefore essential to consider the X-ray appearances from a broad angle of general medicine.

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ANGIOCARDIOGRAPHY

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Angiocardiography is now an established diagnostic procedure in the fields of thoracic and cardiac surgery. By intravenous injection of an opaque substance combined with rapid serial radiography it is possible to study the heart chambers and great vessels during life. The method was conceived more than 20 years ago, though its application in clinical medicine is recent. Improvements in radiological technique have encouraged wider use of the procedure but the interest in the diagnosis of congenital heart disease and the advances in its treatment, are mainly responsible for modern development of this method of investigation.

History

In 1929 Forssman first injected an opaque substance into the living human heart. Like later workers in this field, notably Ameuille (1936), Forssman used sodium iodide for the intravenous injection. In the quantity and concentration employed this substance gave good angiograms of the pulmonary arterial tree, but it was not sufficiently opaque to outline the heart chambers or the aorta. For this reason little progress was made in this method of investigation until Castellanos (1938) and his co-workers in Cuba introduced the organic iodides as the contrast medium. With 35 per cent. neopax these workers were able to show the right heart chambers and the aorta and its larger branches in children with cyanotic congenital heart disease. But, because of dilution in the pulmonary circulation, satisfactory angiocardiograms of the left heart in acyanotic conditions could not be obtained.

In 1938 Robb and Steinberg prepared and used a 70 per cent. aqueous solution of the diethanolamine salt of 3, 5-diido-4-pyridone-N-acetic acid for the intravenous injection. With this substance they were able to outline, first, the right heart chambers and pulmonary arteries and later the left heart and aorta. The introduction of multiple cassette-changing devices has enhanced the value of angiocardiography, but in other respects the procedure described by Robb and Steinberg is more satisfactory than any other and is in general use today.

Contrast Media

Diodone or diodrast, the material originally prepared by Robb and Steinberg, is still the most widely employed contrast medium in angio-
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