# RADIOLOGY of the HEART and GREAT VESSELS

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# ROENTGENOLOGY OF THE HEART AND GREAT VESSELS

By ROBERT N. COOLEY and ROBERT D. SLOAN

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## PREFACE

"When I first tried animal experimentation for the purpose of discovering the motions and functions of the heart by actual inspection and not by other people's books, I found it so truly difficult that I almost believed with Fracastorius, that the motion of the heart was to be understood by God alone. I could not really tell when systole or diastole took place, or when and where dilatation or constriction occurred, because of the quickness of the movement. In many animals this takes place in the twinkling of an eye, like a flash of lightning. Systole seemed at one time here, diastole there, then all reversed, varied and confused. So I could reach no decision, neither about what I might conclude myself nor believe from others."

WILLIAM HARVEY, *De Motu Cordis*

*(Leak Translation, page 25) Courtesy Charles C Thomas & Son, Publisher*

Just as William Harvey was initially pessimistic, so the present day radiologist who applies radiologic procedures to the diagnosis of clinical heart disease is inclined at some time or another to become discouraged. If one follows Harvey's account of his investigations, however, it is found that, "Using greater care every day, with very frequent experimentation, observing a variety of animals, and comparing many observations, I felt my way out of this labyrinth, and gained accurate information, which I desired, of the motions and functions of the heart and arteries." This approach is certainly applicable to the present day use of all radiologic procedures. They must be carefully and precisely applied. The information obtained thereform must be critically evaluated and correlated with that obtained from all other sources. Only then can the radiologist expect to find his way out of the labyrinth of subtle and fleeting shadows which comprise the radiologic examination of the heart and great vessels and bring with him the accurate information that these methods of examination can provide.

The past 15 years have brought about striking advances in the diagnosis and treatment of cardiovascular disease. The most spectacular accomplishments have been in the field of cardiac surgery, in attacks on specific structures such as the heart valves and in the establishment of anastomosis between the great vessels which tend to compensate for abnormal intracardiac obstructions and shunts. The indispensable prerequisite of such surgical feats is accurate diagnosis, and toward this end the radiologist has made significant contributions. One of the authors' objectives in this work has been to emphasize the role the radiologist is expected to play in the selection of patients for surgical treatment. This field of diagnosis is rapidly expanding so that the prerogatives and limitations of the radiologist are constantly changing. Criteria in use today may be modified or rejected within a short time; consequently it can hardly be expected that the authors' conclusions are inviolate and forever true.

This is not a compendious work. For the most part it reflects the thought processes and procedures which the authors use in their daily practice of radiology as applied to the diagnosis of abnormalities of the cardiovascular system. It is freely admitted that the authors have not had a detailed extended experience with all of the procedures and conditions which are described herein, and where necessary they have drawn to a considerable extent on the current literature. Many statements in the text are not accompanied by an acknowledgement and might reasonably be considered as original observations of the authors. This is not always the case. Numbers of statements have been a part of the authors' general knowledge of the subject for so long that their original source is obscure. Two general sources of information have been freely used, namely, *Heart Failure* by Fishberg and *Heart Disease* by White.

The authors are only amateur and occasional physiologists and pathologists. Their excursions into these fields will, therefore, seem clumsy and not always too accurate. The main objective here is to stimulate the radiologist to seek a reasonable explanation for his observations. Empiricism is deplored as it tends to restrict the exercise of reason.

The authors are deeply indebted to Dr. Ross Golden for providing many valuable suggestions in the wording of the text and in the preparation of the illustrations. Drs. Russell H. Morgan and Webster Brown read selected sections and offered most helpful criticism and advice. We also acknowledge with thanks the work of Mr. Leon Schlossberg and Mr. George Newman in preparing the illustrations and the efforts of Mrs. Irene O'Herir and Mrs. Ada Johnson in typing the manuscript.

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# PROCEDURES

## Fluoroscopy

Fluoroscopy should be the initial procedure in the roentgen examination of the heart and great vessels. It is relatively inexpensive, can be performed quickly and with minimum discomfort to the patient and with an experienced observer provides more information than any other single maneuver. The only real contraindication to its use is the inability of the patient to cooperate satisfactorily because of severe illness or debility. However, it must not be used to the exclusion of roentgenography; the two procedures are *complementary*. Also, in a busy department because of the time required for fluoroscopy and the radiation hazard it is usually reserved for those cases suspected of having a definite abnormality.

One much neglected advantage of fluoroscopy is the manner in which it brings the radiologist into intimate contact with the patient. Here the opportunity is given to question and examine first hand and to assess the patient's problems. Although accompanied by a satisfactory written history, a short period of questioning improves understanding and helps to cement a good doctor-patient relationship. Also pertinent and obvious physical findings may be checked. Deformities of the thorax which may alter the cardiac contours are easily appraised; familiarity with murmurs and thrills may be improved; the general appearance, habitus, occupational and social status may be quickly noted and serve the experienced radiologist in his evaluation of the patient.

It is the opinion of some clinicians that the radiologist should reach his conclusions only from objective findings and that he should make no attempt to obtain clinical information which might affect his opinion, or at least the clinical findings should not be known until all the objective radiologic changes have been elicited. Although there may be considerable merit in this position and while such a routine may be helpful in the training period of students, it may hamper the well qualified radiologist who has accustomed himself to differentiate between demonstrated facts and less reliable opinions. Objective findings are much more plentiful when they are carefully looked for; therefore, the patient's problems should be clearly in mind before the fluoroscopic examination is approached.

**Equipment.** Most fluoroscopic equipment in the United States, while not standardized, is similar in operation and does not require a detailed description. As far as the fluoroscopic image is concerned, there is little difference between the cheaper self-rectified and the more elaborate full wave rectified units. A tilt-table is useful because fluoroscopy in the recumbent position is frequently necessary and helpful. A spot film device may rarely provide an addition to routine roentgenography but is not essential. A light stationary grid improves contrast in heavy patients and should be available.

The traverse of the fluoroscopic screen in most conventional tables is 8 to 12 inches, and the screen is centered permanently to the central beam. Consequently, these tables are unsuitable for orthodiagraphy without a special pantograph-like attachment which many of the commercial companies provide.

Newer fluoroscopic units have a target-table top distance of about 18 inches whereas in older units this distance is 12 to 15 inches. The longer distance is preferable because of a moderate reduction in radiation intensity to the patient. Also, magnification and distortion are lessened, but this improvement is slight. In European countries fluoroscopy is frequently conducted at a target-screen distance of 2 meters. Evaluation of heart size is thus somewhat easier; however, the experienced fluoroscopist working at shorter distances soon learns to compensate for the magnification factor and can thus make a reliable estimate of the cardiac diameters.

When small children are to be examined, it is convenient to have a step so as to bring them into the field of operation of the fluoroscope. Also, since some children may be induced to sit when they will not stand, a high chair with radiolucent back is a welcome addition.

Most chest fluoroscopy in adults is done at 3 ma., 80 to 90 kv., 2 mm. Al filter, target-table top distance of 18 inches. With these factors and a 100 square inch field, the patient will receive about 6 to 9 roentgens per minute (Morgan, 1951). The kilovoltage may be reduced to 60–70 kv. for children and infants.

Other characteristics of a fluoroscope which are helpful are: 1. shutters which move easily and are correctly centered; 2. a screen which is light or well balanced and yet does not drift or move without pressure; 3. a monitor timer which should be arranged to interrupt the procedure after an elapsed fluoroscopic time of five minutes.

Fluoroscopic screen intensification systems merit a brief description, particularly since two commercial companies in the United States have made these instruments available for general use. The Westinghouse Flurodex and the Phillips Roentgen Image Intensifier have a roughly comparable appearance and performance and will be considered together. Both of these intensifiers can be adjusted or adapted to use with conventional fluoroscopic equipment. The aperture or image-receiving area is a 5 inch circle which, of course, is somewhat smaller than that desired by most radiologists in their survey of the adult heart. The brightness or intensification gain is significant and is of the order of 300 times in the Flurodex and about 1000 times in the Phillips System. This degree of brightness is still not comparable with that of conventional x-ray film viewed under standard conditions (see *Limitations of Fluoroscopy*, p. 6). Both systems are, of course, more cumbersome and less maneuverable than conventional fluoroscopic equipment; also, the visible image appears either on a mirror (Westinghouse) or on binocular eyepieces (Phillips) which means that the radiologist must modify his fluoroscopic habits and routine. Practice in the use of these instruments will undoubtedly reduce these objectionable features to some extent. For further details the reader is referred to the brochures provided by the North American Phillips Company, Mount Vernon, New York, and the Westinghouse Electric Company, X-Ray Division, Baltimore, Maryland.

A system using a television type of image intensification has been developed by Morgan and Sturm at The Johns Hopkins Hospital. The aperture or receiving surface is of the order of 8 by 10 inches and is thus more suitable for heart fluoroscopy. The visible image is viewed on a television type screen which is movable and can be placed in any convenient location in relation to the radiologist; also, similar screens can be placed in distant lecture rooms for teaching purposes. The brightness gain is of the order of several thousand times so that the images are easily visible under ordinary lighting conditions. The latest models of this intensifier compare favorably in maneuverability and bulk with the Westinghouse and Phillips instruments.

Because of the significant gain in image brightness, cardiac fluoroscopy using screen intensification systems can be satisfactorily conducted in many instances using tube currents of .5 to 2 ma. at potentials of 60 to 70 pkv. X-ray intensities and dose can thus be reduced by a factor of 50 per cent or more. In children and particularly in those cardiac patients who may be subject to multiple roentgen procedures (right heart catheterization, angiocardiography) such a reduction in total x-ray dose is highly desirable.

**Technique.** For dark adaption, red-tinted eye covering or goggles should be worn for 15 minutes followed by a two minute period in total darkness. This practice should be rigidly adhered to.

The patient is first viewed in the posteroanterior projection in the erect position. The abdomen is scanned quickly in order to exclude gross abnormalities or displacement of the abdominal viscera. The right side of the diaphragm is observed for motion while the patient takes a deep breath and exhales. The costophrenic sinus is examined carefully. The right lung field is then scanned slowly while one looks for abnormal opacities, and the prominence of the vascular markings is evaluated at this time. The upper mediastinum is viewed briefly, including the aortic knob. The width and position of the knob and the amplitude of pulsations are noted. The left lung is covered from apex to base, and then the motion of the left diaphragm is studied in a manner similar to that used on the opposite side.

The observer then turns his attention to the heart. Momentarily the shutters are opened sufficiently to encompass the heart and aorta, and these are observed during inspiration and expiration. The remainder of the examination is done using a field about 30 square inches in size. The right border of the heart is studied in detail. The amplitude of pulsations of the right atrium and right hilus are evaluated for any rhythmic variations in contours or other changes. The lateral border of the ascending aorta is identified and studied. The left border of the heart is covered in the same manner, the field often being reduced to a narrow vertical slit in order to study pulsations. The patient is then requested to cross his arms and to rest them on his head (Fig. 1A) and is then turned into a slight degree of right anterior obliquity. As this obliquity is gradually increased, the anterior surface of the right ventricle and the pulmonary artery are brought into view. The patient continues to turn in short intervals until he reaches the straight lateral projection and the retrocardiac space is seen in its maximum width. Posterior projections of the left atrium or left ventricle may be visualized to a degree without barium in the esophagus. Also, an anterior extension of the heart into the retrosternal space may be evaluated. The patient is then rotated in a reverse direction back to the posteroanterior and then slowly into the left anterior oblique projection (fig. 1B). Again the contours are studied as the obliquity increases. In this view, the posterior wall of the left ventricle can be viewed to best advantage, and some estimate of its size can often be made. Also, the anterior surface of the ascending aorta is best studied in this projection; the pulmonary window may be visible, and the anterior surface of the right ventricle is brought into contour. Rotation is continued into the left lateral position where the appearance noted in the right lateral projection can be confirmed. The patient is then given a mouthful of barium paste, and after being turned into the posteroanterior projection, he is told to swallow. As the barium slowly traverses the length of the esophagus, the course and contours of

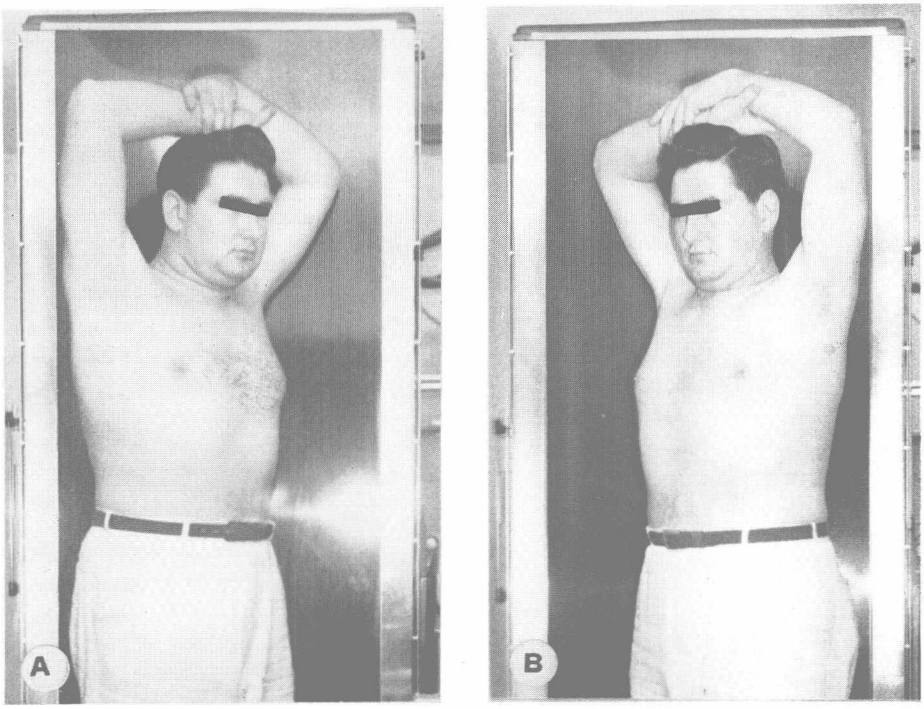


FIG. 1. POSITION OF PATIENT FOR FLUOROSCOPY IN (A) THE RIGHT ANTERIOR OBLIQUE AND (B) THE LEFT ANTERIOR OBLIQUE PROJECTIONS

this organ are determined in all projections both in inspiration and expiration. Finally, under certain circumstances, the patient is placed in a recumbent position, and the previous maneuvers are repeated partially or completely. Worthwhile observations concerning the presence of fluid in the pericardium or pleura may thus be made although changes in the contour of the normal heart in the recumbent position must be kept in mind. Occasionally, the patient may be too sick to stand, and the entire examination must be conducted in the recumbent position; under such circumstances the procedure is usually not too satisfactory.

Following fluoroscopy the observer should immediately record the abnormal findings. He should also write instructions for the technician who will take the necessary films. As an example, following the fluoroscopy of a case of mitral valvular disease with calcification, the directions would read:

1. PA chest—conventional
2. Right anterior oblique—50° rotation, 36″ distance, extension cone, 1/60 sec. exposure; center to mark on anterior chest
3. PA chest Bucky with barium
4. Both obliques with 55° rotation with barium
5. Right lateral with barium

**Limitations of Fluoroscopy.** The dimness of the fluoroscopic image imposes a severe limitation on the information which can be obtained. The luminosity of the screen during examination of the chest under average conditions is of the order of $10^{-2}$ foot lamberts. Hecht (1928) has shown that the human eye even with maximum adaptation has a small fraction of the visual acuity or ability to perceive detail that it has under average conditions of illumination (10 to 100 foot lamberts). Contrast between such structures as the pulmonary artery, the heart and the surrounding lung, etc., may be only one tenth of that seen on a well exposed film. Consequently, minor deviations in contour of any of these structures may be easily overlooked.

Furthermore, the heart is enclosed in a

smooth sac, the pericardium, which tends to round out and fill in the minor fissures and sulci which serve to demarcate the heart chambers. In addition, there are a number of overlying or surrounding densities which tend to obscure the cardiac contours such as large breasts, high diaphragm or elevation of one side of the diaphragm, areas of infiltration in the lungs, pleural fluid and excessive adipose tissue around the pericardium. Unfortunately, these last mentioned shadows occur commonly enough with an impaired or failing cardiorespiratory apparatus so as to make the examination in such instances more difficult.

Despite the limitations of small field size and lack of maneuverability, screen intensification systems have increased the information that can be obtained from cardiac fluoroscopy. Following a small experience with one of these instruments, the authors have been impressed by the clarity and improved definition of the hilar structures. Certainly pulsations of the hilar vessels are more easily evaluated than by conventional fluoroscopy. Also, the cardiac contours appear sharper and the estimation of individual chamber size would appear to be easier than before. Furthermore, cardiac calcifications such as occur in the valves should be more quickly and easily recognized, and even smaller deposits of calcium associated with coronary arteriosclerosis might be detected more often than is now possible using conventional fluoroscopes.

The magnification inherent in the fluoroscopic image may mislead the beginner, but with the experience obtained by comparison with teleoroentgenograms, it can be adequately evaluated. The study of pulsations is enhanced by the magnification since their apparent amplitude is increased.

Fluoroscopy can ordinarily be relied upon to determine the following:

1. Presence of calcification in: (a) heart valves; (b) pericardium; (c) coronary arteries (rare); (d) auricular walls including mural thrombi; (e) ventricular walls including cardiac aneurysm. Fluoroscopy is probably the most sensitive means of detecting these calcifications and is the best means of determining their anatomical location.

2. a. Gross enlargement of the heart; b. normal sized heart. Borderline heart size cannot be appraised quite as well by fluoroscopy as by roentgenography and both procedures leave something to be desired (see *Mensuration of the Heart and Great Vessels*, p. 73).

3. Gross deviations in contour associated with definite vessel or chamber enlargement or dilatation. The pulmonary artery and aortic size can be estimated with only a fair degree of reliability. Of the cardiac chambers, the size of the left atrium is easiest to evaluate; the right ventricle is the most difficult; the left ventricle and right atrium occupy an intermediate position.

4. a. Amplitude of pulsation of all contours. Chamber dilatation may thus occasionally be differentiated from hypertrophy, but these two factors are so often combined as to make the differentation unreliable. b. Timing of pulsations. This is possible only in a gross way and is much inferior to electrokymography or roentgenkymography.

5. Gross irregularities in rhythm.

6. Abnormal vascular shadows in lung and their degree of pulsations.

7. Displacement of the heart as in kyphosis.

8. Fixation of the heart as in adhesive mediastinitis or abnormal mobility as is seen in unilateral pneumothorax or foreign body in a bronchus.

### Roentgenography

Roentgenography is the most widely used method for determining the size, contour and position of the heart and great vessels. In the busy department it may be the sole procedure in the roentgen examination. It complements fluoroscopy in that it provides a permanent record which can be inspected whenever necessary.

**Teleoroentgenography.** The target-film distance is increased considerably over that usually employed in radiography in order to reduce the magnification of the heart shadow. Likewise the cardiac or object-film distance should be reduced to a minimum. In order to satisfy these two conditions, the x-ray tube is placed at a distance of 6 to 7 feet (180 to 210 cm.) from the film, and the patient is placed in the posterior-anterior position with the sternum as close to the film as possible. The distance between the anter-

TABLE I
PERCENTAGE MAGNIFICATION DUE TO GEOMETRICAL FACTORS

| AP diameter of chest | Target-Film Distances | | | |
|---|---|---|---|---|
| | 150 cm. | 180 cm. (6 ft.) | 210 cm. | Fluoroscopy* (approx.) |
| cm. | | | | |
| 12 | 3.1 | 2.6 | 2.2 | 5.6 |
| 15 | 3.8 | 3.1 | 2.3 | 7.1 |
| 20 | 5.0 | 4.1 | 3.5 | 9.8 |
| 25 | 6.2 | 5.2 | 4.4 | 12.4 |
| 30 | 7.5 | 6.2 | 5.3 | 15.4 |

* 30″ Target-screen distance.

ior chest wall and the film may thus vary between 0.5 and 2.0 cm., due to (1) the thickness of the front of the cassette (0.5 cm.) and (2) the covering of the cassette holder which may be 1.5 cm. thick. Thus, in the average individual who can stand erect in proper position, the plane of largest cardiac dimensions will lie about one third of the anteroposterior diameter from the anterior chest wall or between 6 and 13 cm. from the film (anteroposterior diameters of the adult chest range from 16–30 cm. Reference to table I shows that the percentage magnification in the average examination would thus be between 4 and 6 per cent. Also, it can be seen that increasing the target-film distance from 6 to 7 feet (180 to 210 cm.) would decrease the magnification by the order of 1 per cent, but this would require an increase in the amount of x-ray energy by 36 per cent. Table I also permits a rough comparison of the percentage magnification in fluoroscopy and teleoroentgenography under usual conditions. Also, it can be determined that when the transverse diameter of the heart on the teleoroentgenogram is 13 cm., the actual diameter would be between 12.2 and 12.4 cm.

Short exposure times are essential if a sharp image of the heart and great vessels is to be obtained. Roesler (1943) stated that critical examination of a series of consecutive films exposed at one-tenth, one-fifteenth or one twentieth of a second on the same individual at random periods during the cardiac cycle will show varying degrees of unsharpness due to motion. This unsharpness varies, of course, with the phase of the cardiac cycle during which the exposure happens to occur, e.g., in diastole there may be a period of as much as .2 seconds during which the heart contour scarcely changes. At one-twentieth second the number of unsharp films will be minimal but one-fortieth second exposures are necessary to produce uniform films of a high degree of sharpness. On the other hand, exposure times greater than one-tenth second uniformly produce films showing some motion. Practically, this may lead to occasional difficulty in differentiating small areas of infiltration in the lung from normal vascular structures, and the exposure time in general depends on the degree of precision that one desires to obtain. Clear demonstration of valvular calcifications may require one-sixtieth second exposure. Exposure times of one-fortieth second or less are desirable but unfortunately require large capacity generators and impulse or electronic timers which are not always available. A rotating anode tube with small focal spot improves definition. Scatter is reduced by the use of a cone that limits the beam to the thoracic area.

Respiratory motion is eliminated by having the patient stop breathing. The exact phase of respiration at which breathing should be arrested is important since the position of the diaphragm determines to a degree the contours and size of the heart and great vessels (figs. 15 and 16) (pg. 49). In many departments, chest films are exposed after the patient has inspired fully and is holding his breath. Thus the diaphragm is lower, and the transverse diameter of the heart is decreased and the longitudinal diameter increased as compared with those seen during normal basal respiration. Occasionally, these changes may be increased further since many patients maintain inspiration by closing the glottis which in turn increases the intrathoracic pressure. This in turn decreases the amplitude of the cardiac pulsations and also the size of the heart contour. The advantage of full inspiration is that it can be obtained easily in patients of limited intelligence without practice and is usually easily reproducible. Where large numbers of individuals are to be examined, this leads to savings in time and effort.

Ideally, respiration should be halted midway between normal inspiration and expiration so that the heart and great vessels would present a more normal contour. Certainly where precise and accurate evaluation of the cardiac contour is desired, exposure at the end of normal inspiration is desirable and has been used by most investigators. Of great importance, however, is the reproducibility of any chosen respiration position since a precise comparison of films made over a period of time in different phases of respiration may lead to considerable error.

Since in infants and young children respiration will not stop voluntarily, the position of the diaphragm may vary from full inspiration to full expiration. This makes evaluation of the cardiac contours more difficult and comparison of a series of films may be quite deceptive. Attempts have been made to overcome this difficulty by using an air-filled circular rubber bag placed around the lower thorax. Expansion of the thorax during inspiration could thus initiate an exposure. Obviously, such a device is too cumbersome for routine use. A careful technician may obtain a satisfactory inspiratory film by watching the respiratory movements of the exposed chest and thus timing the exposure for the end of inspiration.

Changes in the cardiac contour and frontal area of the heart due to cardiac phase are generally disregarded. The transverse diameter of the heart in normal individuals may vary as much as 3 to 6 per cent between maximum systole and diastole depending upon the position and contour (longitudinal or transverse heart). Variations in frontal area are probably somewhat less when computed by the method of Hodges and Eyster and in particular are not so greatly affected by the position of the heart since pulsations along the broad diameter tend to compensate somewhat for the lack of pulsations along the long diameter and vice versa. However, Hodges (1946) recommends using the larger contour of a stereoscopic pair as more nearly approaching the diastolic size of the heart. Estimations of heart volume using a combination of posteroanterior and lateral teleoroentgenograms may likewise show a variation in estimated heart volume between systole and diastole of 125 to 150 cc., or approximately 20 per cent of the estimated systolic volume. The degree of variation in frontal area is manifestly different in different individuals and even in the same individual at different times. In general, the larger the heart, the less the amplitude of the pulsations. On the other hand, the slower the pulse, the greater the amplitude of pulsations providing the cardiac output remains constant. This phase variation in frontal area, cardiac contour and transverse diameter have been accepted by many investigators as part of the inherent error in the use of teleoroentgenography.

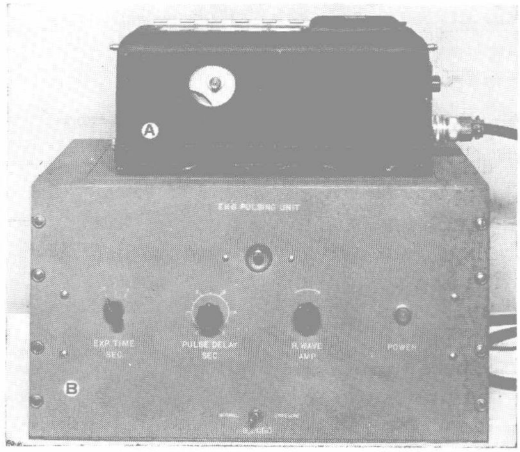


FIG. 2. UNIT FOR OBTAINING EXPOSURES IN EITHER MAXIMUM SYSTOLE OR DIASTOLE

An impulse is initiated by the maximum deflection of the electrocardiograph (usually the R wave in lead II). The transmission of the impulse can then be delayed for varying intervals up to .5 sec. The recording instrument is above (courtesy of Dr. R. H. Morgan).

Figure 2 is an illustration of an apparatus designed by Morgan which permits exposures to be made at any predetermined phase of the cardiac cycle. The smaller instrument (A) is a paper recording electrocardiogram which permits a determination of the R–T interval for each individual. The apparatus (B) will create an impulse which provides an exposure at the exact instant of maximum deflection of the electrocardiogram (this is usually the R wave in lead I) or at any preselected period up to .5 seconds thereafter.

Since systole occurs simultaneously with the uptake of the T wave, the delay is equal to the R–T interval. Charts are available, however, which relate the R–T interval to the pulse rate, and these can be used routinely in lieu of the recording electrocardiogram.

Tube-film distances may be reduced for oblique and lateral projections where distortion and magnification are not essential factors. Thus there can be a considerable reduction in the amount of radiation necessary to produce the exposure. However, it is inadvisable to reduce the distance to less than 4 feet (120 cm.). Positioning for oblique films is best determined by previous fluoroscopic control, and a protractor mounted on the cassette holder is valuable in reproducing the desired degree of obliquity. Where there has been no fluoroscopic control, the right anterior oblique is customarily taken at 45 degrees and the left anterior oblique at 50 degrees. Routinely oblique and lateral films are exposed with barium paste in the esophagus.

Where the cardiac contour is the center of interest, some degree of overexposure is desirable. Films exposed correctly for revealing minor lung densities may not give good contrast along the cardiac borders particularly in the hilar and immediate supradiaphragmatic areas. Also, it is advantageous to view the barium-filled esophagus through the heart mass. A satisfactory plan is to expose one posteroanterior film with conventional technique and another using a high speed Potter-Bucky diaphragm with an increase of 15 to 20 kilovolts with barium in the esophagus.

Roentgenography is advantageous over fluoroscopy in that (1) it does not expose the patient or operator to significant amounts of radiation; (2) it conserves the physician's time; (3) it provides a permanent record. Consequently in many busy departments it is the only routine method of examination, fluoroscopy, kymography, etc., being reserved for those cases where more detailed information is necessary. Roentgenography can be relied upon to demonstrate the following:

1. a. Gross cardiac enlargement; b. Normal sized heart. Borderline heart size is difficult to evaluate, and even when precise roentgenographic studies are applied to a single doubtful case, it is probably of little value in determining whether the heart is enlarged or not.

2. Cardiac calcifications. Roentogenography is inferior to fluoroscopy as a rule and special techniques are necessary to demonstrate calcified valves (correct degree of obliquity and short exposure times).

3. Gross deviations in cardiac contour associated with definite chamber or vessel enlargement or dilatation. The information is about equal to that obtained from fluoroscopy, but the two procedures should be combined.

4. Displacement or fixation of the heart and mediastinum. Exposures in inspiration and expiration and lateral decubitus views in inspiration and expiration are necessary.

*Classification of significant cardiovascular abnormalities that may be detected from fluoroscopy and conventional films of the chest.*

- I. Calcification
  - A. Mitral valve—diagnostic of rheumatic mitral valvular disease
  - B. Aortic valve–diagnostic of rheumatic aortic stenosis or rarely congenital aortic stenosis
  - C. Mitral or aortic annulus fibrosis—may be the cause of a murmur but of little clinical significance
  - D. Left atrial wall—suspect mural thrombus
  - E. Right atrial wall—suspect mural thrombus—apparently quite rare
  - F. Left ventricle
    - 1. Myocardium suspect
      - a. Infarction
      - b. Infarction with aneurysm
      - c. Tumor—rare
      - d. Hyperparathyroidism—calcium rarely visible
    - 2. Ventricular cavity—suspect a mural thrombus—rare
  - G. Right ventricle—opposite interventricular septal defect—rare
  - H. Aorta
    - 1. Ascending aorta—quite suggestive of syphilitic aortitis
    - 2. Arch—diagnostic of atheroscle-

rosis but of minimal clinical significance

3. Para-aortic mass—calcium curvilinear in contour—suggestive of aneurysm although it may be a dermoid or other tumor or rarely a calcified lymph node

I. Pericardium—suggestive of constrictive pericarditis (50 to 55 per cent have calcification)

II. Cardiac Enlargement

A. Symmetrical—suggests (a) diffuse inflammation or infiltration of myocardium or (b) pericardial effusion (lung usually clear)

B. Asymmetrical including specific chamber enlargement

1. Left ventricle—suggests hypertension or aortic valvular disease (aortic insufficiency is more common and produces more pronounced enlargement than stenosis)

2. Combined left atrial and ventricular enlargement suggest some degree of left ventricular failure secondary to 1 above or when left atrial dilatation is relatively more pronounced, suggests predominant mitral insufficiency. Patent ductus arteriosus may cause left atrial and left ventricular enlargement.

3. Enlargement of all chambers with predominance of left ventricle suggests hypertension or left-sided valvular lesion with heart failure particularly when accompanied by chronic passive congestion of lungs (Exception may be Bernheim's syndrome. See text). If lungs are clear, suggests combined valvular lesions of both sides of heart.

4. Left atrial enlargement only is highly suggestive of predominant mitral stenosis.

5. Left atrial and right ventricular enlargement accompanied by chronic lung stasis suggests predominant mitral stenosis of considerable duration.

6. Left atrial, right ventricular and right atrial enlargement with relatively clear lungs suggests right-sided heart failure secondary to mitral valvular disease; combined tricuspid and mitral valvular disease may present the same pattern.

7. Right ventricular enlargement with (a) clear avascular lungs suggests pulmonic stenosis; (b) engorged lungs suggests congenital left to right shunt such as interatrial septal defect, anomalous pulmonary venous return or the Lutembacher syndrome; (c) emphysema of lungs, fibrosis or extensive infiltration suggests cor pulmonale.

8. Right atrial and right ventricular enlargement suggests some degree of right ventricular dilatation or failure secondary to conditions listed under 7 above; structural tricuspid insufficiency may be present but this is a rare lesion.

9. Right atrial enlargement suggests Ebstein's anomaly or tumor of right atrium.

III. Changes in aortic shadow

A. Elongation—suggests atherosclerosis and is often accompanied by some degree of hypertension.

1. Tortuosity is due to pronounced elongation—causes deviation of esophagus—may be difficult at times to differentiate from aneurysm or mediastinal mass.

B. Dilatation—when definite is highly suggestive of syphilitic aortitis—most common in ascending portion. Minor degree of dilatation may be seen with hypertension alone (dynamic dilatation). Aorta may be large in certain congenital anomalies such as truncus arteriosus and extreme tetralogy of Fallot.

1. Localized dilatation and irregularity of contour are highly sug-

gestive of syphilitic aortitis and/or aneurysm.

2. Diffuse dilatation suggests aneurysm.

C. Calcification—see above under I.

D. Abnormal position—suggests anomaly as right aortic arch, aortic ring, etc. May cause abnormal indentation or constriction of esophagus and/or trachea.

IV. Lung changes which suggest cardiac abnormality.

A. Diffuse pulmonary fibrosis, emphysema, cystic disease or extensive bronchiectasis—suspect cor pulmonale.

B. Increased prominence of pulmonary vascular structures (pulmonary engorgement) suspect left to right shunt such as interatrial or interventricular septal defect, patent ductus arteriosus, the Lutembacher syndrome, anomalous pulmonary venous return, rupture of aortic aneurysm into right atrium or pulmonary artery. There may be increased pulmonary vascular markings in transposition of the great vessels and some cases of truncus arteriosus. (See also increased pulsations)

C. Diminished pulmonary vascularity suggests pulmonic stenosis or atresia usually congenital in origin. If there is an associated unusual contour of the hilar shadows, suspect collateral circulation with pulmonic stenosis.

D. Diminished pulmonary vascularity localized to one lung or a portion of one lung suspect emoblism and/or thrombosis of a major pulmonary artery.

E. Chronic passive congestion—suspect left ventricular failure or mitral valvular disease.

F. Chronic lung stasis (see text)—suggest mitral valvular disease.

G. Pulmonary edema suggests left ventricular failure or mitral valvular disease. May be due to a number of other causes (see text).

H. Diffuse distribution of miliary densities suggests hemosiderosis with mitral valvular disease.

I. Localized irregular-shaped lesions which appear to have a connection with hilar structures suggest pulmonary arteriovenous fistula; if lesion diminishes definitely in size with Valsalva maneuver, this is added evidence of such a lesion.

J. Multiple small to medium sized flame or triangular shaped opacities scattered thru both lungs suggest bacterial endocarditis such as might occur with patent ductus arteriosus.

V. Abnormal pulsations which suggest cardiac disease.

A. Increased amplitude of pulsation of:

1. Left ventricle suggests aortic insufficiency, patent ductus arteriosus, mitral insufficiency and occasionally hypertension.

2. Right ventricle (amplitude is difficult to evaluate) suggests interatrial septal defect or anomalous pulmonary venous return.

3. Entire heart suggests hyperthyroidism and some cases of beri-beri. Also excursions may be quite large in some cases of bradycardia and heart block; may also be seen in pneumopericardium.

4. Pulmonary artery and hilar shadows. This usually indicates an increased pulmonary blood flow. In an exaggerated form it is known as a "hilar dance" and may be associated with some degree of pulmonary insufficiency. Most frequently seen in Lutembacher syndrome and interatrial septal defect—also in patent ductus arteriosus, anomalous pulmonary venous return and transposition of the great vessels.

5. Superior vena cava (this structure normally does not pulsate) suggests tricuspid insufficiency.

6. Aorta suggests aortic insuffi-

ciency, aortitis, hypertension, hyperthyroidism and patent ductus arteriosus.

B. Decreased pulsations
   1. Entire heart suggests diffuse myocarditis, pericardial effusion or constrictive pericarditis.
   2. When localized to a single chamber is usually associated with a pronounced dilatation and failure of that chamber. Diminished pulsations may be localized in constrictive pericarditis.

C. Paradoxical pulsations. These are almost always limited to the left ventricle and are due to a cardiac aneurysm.

D. Expansile pulsations of left atrium with left ventricular systole may be indicative of mitral insufficiency but this evidence is often unreliable because of a considerable range of pulsation of the normal left atrium.

E. Pulsations of lungs, trachea or or ribs synchronous with heart suggest adhesive pericarditis.

### Laminography

Laminography is a conventional or routine procedure in most diagnostic departments and therefore does not merit any special description. In connection with the cardiovascular system, it is carried out in a routine manner. It is helpful in the following conditions: 1) arteriovenous fistulae of the lungs; 2) rarely, in coarctation of the aorta.

### Orthodiagraphy

This procedure consists of projecting the cardiac contour onto the fluoroscopic screen by means of a small bundle of almost parallel central beam x-rays. Magnification is thus reduced to a minimum. In order to provide a permanent record the fluoroscopic image must be transferred to tracing paper. Where the screen is held in permanent alignment to the x-ray tube a pantograph attached to the screen mounting will serve to transfer the fluoroscopic image to nearby tracing paper. Such an apparatus is provided by several American x-ray manufacturers and is attached to erect fluoroscopes which have a horizontal traverse of about 16 inches. Many conventional tilt-table fluoroscopes are unsatisfactory for orthodiagraphy since their horizontal shift is insufficient to encompass the entire thorax without moving the patient.

In another type of apparatus, the x-ray tube moves independently of the screen. Consequently, the screen can be fixed and immobile while small segments of the cardiac contour are successively examined. A thin semi-transparent film is fixed securely to the screen, and the cardiac contours can thus be recorded directly.

**Technique.** The patient is placed in a standing position and must be kept immobile for the duration of any one tracing. With the shutters narrowed to a very small slit, the apical contour is visualized and recorded. Successive small segments of the heart and great vessels are treated in the same way, care being taken to make the recordings as near in the same phases of shallow respiration and cardiac cycle as possible. Systolic contours are routine. After the cardiac contour has been obtained, the diaphragm and the bony thorax are sketched in. A posterior-anterior tracing is usually obtained but contours in any degree of obliquity can be plotted.

The use of this procedure is not widespread because (1) it is time consuming and subjects the patient and the operator to abundant amounts of radiation; (2) considerable skill and experience are required to produce accurate tracings; (3) contours obtained by skilled operators from the same patient may differ significantly; (4) orthodiagraphic apparatus is not widely available in the United States; (5) much of the same information can be gained quicker and with less radiation exposure by teleoroentgenography.

### Roentgenkymography

This procedure records the movements of the visible cardiovascular contours in previously designated planes during a predetermined period of time varying from one to three seconds. These contours have (1) height which can be treated quantitatively,

(2) shape which may be correlated with some normal or abnormal activity of the heart and (3) timing which permits a comparison of the activity of several contours during the same time period. Since the general outline of the heart is recorded at the same time, the particular small segment of the heart responsible for a given contour can be easily identified, and under usual circumstances this can be correlated with the movement of a single chamber or vessel.

**Apparatus and Technique.** SINGLE SLIT APPARATUS (Sabat as described by Roesler, 1943). This consists of a lead sheet in which a slit of the order of 0.3 to 1 cm. has been cut and which is placed between the patient and a moving x-ray film. The motion of the film is at right angles to the length of the slit, and the distance travelled is of the order of several centimeters. Thus, as x-rays are allowed to traverse the thorax, the film moves and the segments of the heart contour underneath the slit cast a continuous shadow on the moving film; consequently, a continuous record of the movements of the small segments (right and left borders) of the heart silhouette is made. Movements in the plane of the slit only are recorded, and the duration of the record is equal to the exposure time.

MULTIPLE SLIT APPARATUS. Here in a typical arrangement the lead sheet contains about 30 parallel slits each 0.4 mm. in width and approximately 1.2 to 1.3 cm. apart. Consequently, the movement of as many as 14 to 15 small segments of the contour of heart and great vessels can be recorded at once. The film, on the other side of the grid from the patient, usually moves downward, and the traversed distance is always slightly less than the distance between the slits so that there is no overlapping of shadows. Exposures are of one to three seconds depending somewhat upon the pulse rate and the number of cardiac pulsations one wishes to survey (this is rarely more than two). The slits are frequently placed in a horizontal position, but the apparatus should be mounted so as to permit rotation into any degree of obliquity. Thus, motion of the heart or any other structure in any desired plane can be studied. Exposures are made at 36 to 42 inches focal spot-film distance, and the film is centered as for a teleoroentgenogram. Because of the large absorption of the lead grid generators of at least 200 ma. capacity are required.

**Interpretation.** Although roentgenkymography can demonstrate the amplitude, relative timing and contour of the cardiac pulsations, the exact relationship of these findings to other events occurring during the cardiac cycle is frequently confusing. This is due in part to the fact that the recorded waves are due to summation of the entire motion of the heart in a single plane due to (1) rotation, (2) displacement obliquely along the cephalocaudal axis, (3) displacement along the transverse axis and (4) actual expansile pulsations. Therefore, it may be incorrect to attribute the waves recorded along any designated heart segment as being due entirely to the activity of a single chamber or vessel. This at times is strikingly shown by the pulsations recorded along the lower right cardiac border where the contour is mainly that of the right atrium. The pulsations, however, are ventricular in timing amplitude and shape and are thought to be due to transmitted pulsations from the right ventricle. Occasionally, however, typical atrial pulsations may be identified in this segment either alone or superimposed on the ventricular curves. Likewise, there are considerable differences in the planes and amplitude of pulsation of the apical contours of normal hearts. In the transverse heart in the erect position, pulsations at the apex are along a transverse axis whereas in the long narrow heart lateral excursions are minimal to absent and the main excursion is obliquely along the cephalocaudal axis. Because of this range of variations in the pulsations of the normal heart and the inability to study pulsations in all planes, conclusions drawn must be conservative and preferably based on considerable experience with the procedure.

Although casual inspection of a kymogram may suffice to determine the presence of gross pulsations such as occur in the aorta or in some aneurysms, a systematic approach to the interpretation is quite necessary. Such an approach has been frequently neglected