Differential Analysis of Opacification in Angiocardiography
A Graphic Interpretation of Cardiac Function

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Each individual exposure in an angiocardiogram gives a picture of the arrested motion of the heart in successive stages of opacification. By combining these isolated views in a graph, a continuous dynamic process can be visualized. The chambers of the heart can be analyzed separately, and by correlating the opacification in the various chambers, the function of the heart as a whole can be studied.

An interpretation of cardiac function as a whole demands study not only of the active cardiac contractions but also of their secondary effects upon the circulation of blood through the heart and great vessels.

The first component, cardiac contraction and relaxation and the resulting change in the size and shape of the cardiac chambers, can now be studied by a specially adapted method of angiocardiography which adds a dynamic concept to the anatomic features which are the usual aims of this procedure.

The second main component of the cardiac function is the effect of contraction on the hemodynamics; that is, the effect of the heart movements on the velocity, course and distribution of the blood flow. These factors can be assessed by following the flow of the radiopaque substance during its passage through the heart and the great vessels. As in the evaluation of the heart contractions, the recording must be sufficiently continuous to reproduce in the pictures all the necessary phases. The time relationships are also utilized. These are determined by simultaneously recording the electrocardiogram.

The same angiocardiographic procedure is thus suitable for the evaluation of both main components of the cardiac function. Artificial, unphysiological conditions must not be created in the performance of this examination, if a correct physiological approach to the interpretation is to be made.

Studies of the hemodynamics, as shown by the intracardiac course of the contrast medium, must take account of three main factors, namely, the velocity, the course and the degree of opacification. The points to be noted are as follows:

1) Velocity is measured by the first appearance of contrast material in previously nonopacified heart chambers. As the serial exposure frequency is known, the time required for the passage of contrast medium from one chamber to another can be determined. So too, the total duration of the opacification of a chamber can be determined.

2) Course or direction of the circulation is determined by the order in which the heart cavities and vessels successively become opacified.

3) Opacification. The degree or density of opacification adds a quantitative aspect to the two factors just discussed. The characteristic feature of the opacification of the normal heart is the progressive dilution that the opaque substance undergoes in its passage through the heart chambers, the lungs and the great vessels as it mixes with unopacified blood. An increase in the volume of blood between the site of injection and the site of observation causes a reduction in the concentration of

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opaque substance, while a decrease in the rate of flow results principally in a prolongation of opacification.

From the data yielded by angiocardiography, it may be possible to identify as the cause of an abnormal dilution pattern such factors as reduced cardiac output, an increased volume of blood in the heart and blood vessels or some alteration in the course of the circulation, as in the presence of abnormal shunts. For example in left to right intracardiac shunts two phenomena may occur in the right side of the heart which may give very different results though both are due to the abnormal course that blood takes through the shunt. There may be a "positive" effect or reopacification when the chamber from which the shunt originates contains contrast substance and its shunted blood increases the opacification of the chamber receiving the shunted blood. Or the effect may be of a "negative" sort when the chamber from which the shunt originates contains no contrast substance and its shunted blood dilutes the opacification of the opacified chamber receiving the nonopacified blood. Whether changes in opacity come as a result of abnormal pathways such as have just been discussed or whether changes in opacity result from the progressive dilution of the contrast substance that occurs in normal hearts, the degree of opacity in any given chamber at any given time can be estimated. It is an evaluation of the estimated opacity that permits one to apply quantitative methods to the study of the hemodynamics.

A common property of the three factors outlined above is the fact that they permit a graphic representation of their reciprocal relationships. Two of them, velocity and opacification, can be expressed in measureable units and thus drawn in a coordinate system. The third, the course of the blood flow, offers the anatomic base on which the two former purely functional factors can be plotted.

The number of photographs that may be made in a single angiocardiographic study, especially if a rapid exposure frequency is used, is large and awkward to handle. They offer a complexity of anatomical and functional features the separate components of which are difficult to interpret. For the purpose of practical evaluation, a graphic presentation of the hemodynamic factors, separately condensed in easily read curves on a chart, would have advantages which are fairly obvious and do not require detailed discussion. Suffice it to say that the method is particularly advantageous in demonstrating the presence of intracardiac shunts. It is also useful in determining circulation time.

The Method of Graphic Visualization

The graphic demonstration of the features to be found in the angiocardiogram aims to condense all the desired information into a single diagram. The method used is best explained by analyzing the charts reproduced in figures 1 through 7. The actual electrocardiogram of the patient is traced across the top of the diagram and each exposure is marked by a vertical line. The horizontal lines represent the six most important areas or structures traversed or passed by the contrast medium on its way through the heart and the great vessels. They are, in the normal successive order, the vena cava, the right atrium and ventricle, the pulmonary artery, the left atrium and ventricle and finally the aorta. The degree of opacification is estimated for each cavity in each exposure, the estimate being expressed on an arbitrary scale, 0 to 5, and accurately plotted by entering the determinations at corresponding height above the horizontal line of the graph and connecting the successive points by straight lines. The grey-toned area between this and the base line indicates both the occurrence of opacification in the different cavities and its varying intensity.

The reading and interpretation of the three factors bearing on the hemodynamics, namely, course, velocity and opacification, requires the use of both the vertical and the horizontal scales.

Course is read horizontally. By referring to the electrocardiogram at the top of the diagram, the order in which the cavities become opacified is determined. Divergences from the normal are directly revealed. Velocity is also read horizontally. This factor can be read from the graph by determining the number of vertical (exposure intervals) lines from left to right between the first appearance of opacification in the two or several cavities in question, and thus measured exactly if the exposure rate is known. As the opacification is referred to the actual electrocardiogram, the velocity can be expressed in terms of the number of complete or partial heart cycles or it can be expressed in absolute time units, if time is accurately shown on the electrocardiogram. Opacification and Distribution are evaluated by both the horizontal and vertical
Fig. 1. Normal Angiocardiogram. The basic pattern of the normal angiocardiogram is well illustrated in this graph. A casual glance reveals the successive opacification of the different chambers and great vessels; each section is opacified a little later than the preceding one. The abrupt rise, high peak, and rapid decrease in concentration are striking in the right heart; less so on the left, since the contrast material is diluted in passing through the pulmonary circuit. The circulation time through the heart and lungs can be accurately determined, as regards both actual time and cardiac cycles.

V. C. When the contrast substance arrives at the caval orifice it maintains a high concentration for about one and one-half cardiac cycles and disappears shortly thereafter.

R. A. After a rapid opacification, a high concentration of contrast is maintained for two cardiac cycles, and at the end of the fifth cycle the right atrium is empty, just as the left atrium begins to fill.

R. V. The first atrial systole completely opacifies the right ventricle, as does the second, but by the time the left ventricle is visualized, the right is empty.

P. A. After the first right ventricular systole, the pulmonary artery has a high concentration of contrast substance which is maintained for three cycles. At the end of the fifth cycle the pulmonary artery is no longer visible.

L. A. The left atrium begins to fill just four cardiac cycles after the right atrium. The concentration rises and falls less abruptly and never reaches as high a level as on the right.

L. V. The first left atrial systole produces poor visualization of the ventricle, and only after the fourth cycle is maximal concentration obtained. This is

Fig. 2. Tetralogy of Fallot. This graph demonstrates three of the four features of the tetralogy of Fallot: 1. The pulmonic stenosis results in poor opacification of the pulmonary artery in spite of good concentration of contrast substance in the right ventricle; 2. the ventricular septal defect is indicated by early visualization of the left ventricle, before the left atrium; and 3. the overriding aorta is shown by premature opacification of the aorta, before the left heart is filled with contrast medium. Reflux into the inferior vena cava is a result of functional disturbance of the right atrium due to increased resistance to systolic emptying.

scales. The horizontal length of the grey-toned bed, indicating opacification, shows the length of time the contrast medium remains in a cavity. The height of the shaded area indicates the concentration and density of contrast medium and enables an approximate estimation of this relationship to be made.

Potentially Misleading Aspects of the Technic

As the graphic demonstration is based on determinations of roentgenographic densities, qualitative and quantitative, a correct interpretation requires that potentially misleading factors be avoided as far as possible. These may be caused by the method of opacification, by the technic used in injection and recording.

The opacification must not be influenced by variable and misleading extracardiac conditions. Therefore, the “basic” conditions during examina-

the result of normal dilution in the pulmonary circulation.

Aorta: The pattern is similar to that in the left ventricle, except, of course, that the contrast substance arrives one step later.
**Fig. 3. Tricuspid Atresia. Atrial Septal Defect with Right to Left Shunt and Patent Ductus Arteriosus.** Absence of opacification of the right ventricle indicates tricuspid atresia. The early visualization of the left heart results from the right to left shunt through an atrial septal defect. The pulmonary artery is opacified from the aorta by way of a patent ductus.

**Fig. 4. Isolated Pulmonic Stenosis, Prolonged Pulmonary Circulation Time.** The slow disappearance of contrast from the right heart is the result of inadequate emptying incident to pulmonic stenosis. Delayed visualization of the left heart rules out a right to left shunt through a septal defect associated with pulmonic stenosis and indicates prolonged pulmonary circulation time. There is a reflux into the superior vena cava. The poor opacification of the right ventricle is the result of dilution with an abnormally large quantity of residual blood because of inadequate emptying.

**Fig. 5. Atrial Septal Defect, Left to Right Shunt.** The prolonged opacification of the inferior vena cava may be the result of its greater distance from the site of injection to the heart. In spite of a high concentration in the vena cava, the right atrium is only moderately well opacified, indicating influx of non-opacified blood from the left atrium. A further indication of shunt is the fluctuation in the concentration of the contrast substance in the right atrium, with dilution occurring during atrial systole. The main dilution takes place in the right ventricle indicating that most of the shunted contrast medium passes from the left atrium directly down into this chamber without being considerably mixed with the contents of the right atrium. The prolonged opacification of all the chambers beyond the vena cava results from the short circuit through the atrial septal defect. Note the low concentration of contrast medium in the aorta. The atrial systolic reflux into the superior vena cava indicates a functional disturbance of the atrium. Coincident right to left shunt can be ruled out by the opacification of the left heart at approximately the normal time; in the presence of such a shunt the two atria would be visualized simultaneously.

Operation must be uniform and comparable. It is well known that respiratory movements produce changes in the filling of the heart and the great vessels with resulting alterations in the apparent density of the contrast medium. The error introduced by deep and uneven breathing can be largely eliminated by the use of general anesthesia during the examination. In our series all children received 0.10 to 0.12 ml. per Kilogram of a 2.5 per cent solution of Avertin by rectum. During the sleep which resulted, respiration was even and shallow and introduced no error.

The second requirement is uniform injection.
FIG. 6. Ventricular Septal Defect, Left to Right Shunt. As in the normal case, the chambers are opacified in successive steps. Superficial examination of the graph reveals the difference from the normal pattern, and the source of the shunt can be localized accurately in the ventricle.

The vena cava and right atrium are quickly opacified and rather promptly emptied, but the strikingly poor and prolonged opacification of the right ventricle and pulmonary artery contrasts sharply with the normal. Note the systolic-diastolic fluctuation in opacification in the right ventricle resulting from the variations in rate of flow through the defect. The pulmonary circulation time is not prolonged, and strangely enough, the left atrium seems better opacified than the right ventricle and pulmonary artery. Note the reflux into the superior vena cava.

**Technique and Composition of the Contrast Medium.** In all examinations we have used Umbradil in 70 per cent solution at a temperature of about 37 C. The injections have been given intravenously in a cubital or a malleolar vein. The amounts used are shown in Table 1.

Satisfactory visualization of all heart chambers and the large vessels can usually be obtained with these amounts of contrast medium. The rate at which the material is injected has been kept constant as far as possible; cannulae of the same size have been used. In our opinion the injection of the contrast material into a vein at a considerable distance from the heart is less dangerous and causes less disturbance of the physiological conditions than intracardiac injection.

**The Recording Procedure** whereby the length of exposure and the intervals between successive exposures are kept uniform for each case have been described in detail elsewhere. The more important steps follow: (1) Variations in exposure time are avoided by using an electronic timing device. (2)

Fluctuation of line voltage is prevented. (3) The angiograms are taken in both the right and left anterior oblique projections simultaneously, at a rate of 10 to 12 exposures per second. (4) The time of each exposure is recorded on the simultaneously recorded electrocardiogram by an automatic marker connected to the control stand of the x-ray apparatus. (5) All the films are to be uniformly developed and processed.

The two oblique projections were used consistently. The determinations were made primarily from the right anterior oblique views since in this projection the atrium and ventricle do not overlap. However, by frequent reference to the left anterior oblique projections it was possible to ascertain when the contrast substance appeared in the left

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<th>Table 1.—Amount of Contrast Media Used</th>
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<td>Weight in Kg</td>
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<td>Injection in Cubital Vein</td>
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heart. It is obviously more difficult to estimate accurately the degree of opacification in the left heart, but by frequent comparison of the two views, satisfactory results were obtained.

The determination of the degree of opacification was based on estimation of contrast density in the different pictures. After the presence of contrast medium was determined, the degree of density was subjectively estimated, and given a quantitative value based on a scale of density values of 0 to 5. Densitometric instrumental procedures were regarded as unsatisfactory. While the mixing of blood and contrast substance in the pulmonary artery and often in the right ventricle, and always in the left side of the heart would permit the use of this method, the uneven mixing of contrast medium and blood in the right side of the heart, especially the right atrium, results in a pattern of opacification too uneven for the practical use of densitometry. For this reason subjective estimation by a trained radiologist is believed to be the best method of arriving at a quantitative value for the density of opacification in each chamber in each exposure. All readings were made independently by two persons, one experienced in angiocardiography and one not. The resulting figures were averaged. In no case was there serious disagreement between the two sets of figures.

**Discussion**

The completed charts give an adequate diagrammatic representation of the phenomena of premature and prolonged opacification, re-opacification, dilution, and systolic-diastolic variation in opacification. In reading the graphs, each chamber should be judged concerning the time, duration and degree of opacification. Premature opacification, by which is meant, the appearance of the contrast substance in one chamber before it reaches the chamber whose opacification normally precedes it, is positive evidence of a right to left shunt into that chamber. Delayed opacification may indicate a proximal stenosis, and absence of opacification, atresia. Prolonged opacification or re-opacification of the right heart is presumably evidence of a left to right shunt, provided it is not due to the slow arrival of contrast substance through the vena cava. Left to right shunt is usually manifested by dilution of contrast substance and therefore lessening of the degree of opacification of the chamber which receives the shunted blood; this will often be accompanied by an abnormal systolic-diastolic variation in the degree of opacification. Functional disturbances of the right atrium may result in reflux into the vena cava into which no contrast substance was injected; hence both venae cavae are shown to have been opacified in some of the graphs.

**Summary**

This paper discusses the possibility of studying the cardiac movements and their relation to the resulting circulatory hemodynamics by biplane angiocardiography at a high exposure rate with synchronously recorded electrocardiograms. A method is described whereby the information yielded by this combination of studies can be put in the form of a simple, convenient graph. Graphs obtained from the study of subjects with normal and with abnormal hearts are presented to show how the data included in the graphs can be used to give important information concerning the structure and function of the heart.

**Summario in Interlingua**

Es discutite le possibilitate de studiar le movimentos cardiac e lor relation al resultante hemodynamica circulatori per medio de angiocardiographia biplan a alte frequenta de exposition con synchrone registraziones electrocardiographic. Un metodo es describite per que le information obtenite in un tal combination de studios pote esser colligite in le forma de un simple e commode graphico. Le autores presenta specimenes de tal graphicos obtenite ab subjectos con normal e anormal cordes. Illos servi a demonstrar como le datos incorporate in iste genere de graphiche pote esser usate pro revelar importante informaciones in re le strucitura e le function del corde.