RADILOGICAL KINETICS AND PULMONARY ARTERIAL PRESSURE IN CONGENITAL HEART DISEASE*

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The movements of the pulmonary artery can be observed clinically only if certain modifications of the radiological methods are employed. Fluoroscopy allows only a personal subjective observation which is therefore subject to criticism. Radiokymography and electrokymography, on the other hand, provide tracings that render an objective and detailed study possible, not only in respect of the shape of the tracings but of their time relation. These tracings can be preserved, reproduced, published, and compared. Similarly, analysis of intra-arterial pressure curves recorded in the course of cardiac catheterization gives information regarding the circulatory conditions in this vessel and especially regarding the haemodynamics.

We have applied these investigations on the kinetics and haemodynamics of the pulmonary artery in a certain number of cases of congenital heart disease and have analysed the results; the idea appears new to us for we have not found any references to this subject. The references given at the end of the paper are to publications dealing simply with electrokymography.

One should, to begin with, emphasize that a priori the comparisons which we have studied, though they relate to two very different phenomena, are not comparisons of fundamentally different nature.

In studying the kinetics of the pulmonary artery, we are dealing with the displacements of its contours that are visible radiologically. These may be only transmitted pulsations but we think that in the great majority of cases they actually correspond to an arterial pulse, that is to say to the succession of expansion and retraction of the vascular wall (change of volume) during the passage of each pulse beat. These vascular pulsations observed and recorded radiologically are, in fact, conditioned by ventricular activity. The vigorous contraction of the ventricle, of good tone and well filled, produces a wave of considerable amplitude and in turn a marked pulsation, but this only on condition that there is no obstacle to the free passage of the blood stream and that no shunt reduces it by a fraction. This pre-supposes at the same time a perfect arterial elasticity which is able to absorb and then restore part of the kinetic energy that has been liberated. Conversely, the loss of elasticity slows the wave and reduces the amplitude of the pulsations; in its extreme form complete rigidity would be associated with complete absence of pulsation in the artery. From these considerations it follows that a large amplitude of pulsation is evidence of a large arterial output running freely through elastic vessels.


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In similar fashion the intra-arterial pressure results from the force of contraction and the ventricular capacity, given normal arterial elasticity and provided no obstruction or shunt is placed in the circulatory circuit. An obstruction such as a stenosis raises the pressure behind it and depresses it distally. A shunt modifies the currents in variable fashion, determined by the interplay of pressures to which it leads. The arterial elasticity comes into play in the sense that to maintain an equal output through a more rigid vessel demands a raised pressure.

The kinetics and the pressures are thus two different phenomena but often they are in close relation to the flow. Now this idea of flow is precisely the predominant one in the particular types of congenital heart disease we have studied. Apart from the physio-pathological methods that allow its measurement, the flow is determined by various factors, and it is certainly not without interest to take these into consideration.

**Material.** The material studied consists of patients who have been subjected at the same time to electrokymography of the pulmonary arterial movements following the technique described by Donzelot et al. (1955), and to registration of their intra-vascular pressure by the customary method of cardiac catheterization. The use of standard methods allows us to dispense with a description of the apparatus or the technique used in the course of these two investigations. We would emphasize only that the two examinations have not been made simultaneously, but have been made on the same subjects, at intervals of a few days. The two tracings, therefore, whose characters we are about to compare, have not been recorded synchronously, but their analysis is made with reference to the electrocardiogram of which the same leads have been recorded with the electrokymogram and with the pressure curve. We hope, in future studies, to be able to record an electrical polygram, hemodynamic and kinetic, a project that requires only a judicious blending of the different methods of registration.

Our researches have been carried out on 40 patients, of whom 13 had pulmonary stenosis (or trilogy), 8 tetralogy of Fallot, 15 atrial septal defects, 2 patent ductus, and 2 Eisenmenger's complex.

**Results**

I COMPARISON OF THE ELECTROKYMGRAM AND PULMONARY ARTERY PRESSURE CURVES IN NORMAL SUBJECTS

In normal subjects the registration radiologically of the movements of the pulmonary artery does not entail any difficulty. This may not apply to cardiac catheterization which we only carry out when the patient is considered to be able to profit directly from this special investigation. In the absence, therefore, of catheterization in normal subjects, we have used the tracings of normal pressures from young subjects whose cardiac lesion had not progressed enough to affect their pulmonary arterial tree.

The normal pulmonary artery electrokymogram has the same appearance as an ordinary arterial tracing with a sharp upstroke in systole (Fig. 1), a crest of somewhat variable form and a slower (more oblique) diastolic descent marked by a notch synchronous with the closure of the semilunar valves (cf. Donzelot et al., 1955).

The curve of pulmonary artery pressure has a form that can be superimposed on the other (Fig. 1). We find the same general form of curve and the same detail. The inclination of the upslope is similarly from 10° to 20° while the diastolic descent is at 30° to 45°, while the diastolic notch occurs about the middle third. In general, however, the foot of the upstroke is usually marked by a rebound or a little diphasic wave (the taking up of tension equals the isometric phase) which is not inscribed in the electrokymogram. Otherwise all the details have a similar character. They are delayed in relation to the electrokymogram by several hundredths of a second. The friction of the column of blood against the walls of the catheter, the friction of the liquid column in the lead tube, and the inertia of the apparatus suffice to explain the slight asynchronism.
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II COMPARISON BETWEEN THE ELECTROKYMOGRAM AND PULMONARY ARTERY PRESSURE CURVES IN SOME CASES OF CONGENITAL HEART DISEASE

It is convenient to distinguish among congenital heart lesions those which imply increased and diminished pulmonary flow. The Eisenmenger complex will therefore be considered separately.

Congenital Heart Disease with Decreased Pulmonary Flow

As we have published elsewhere (Donzelot et al., 1955) considerable modifications of the electrokymogram appear in cases of pulmonary valvular stenosis (Fig. 3): the beginning of the upstroke in systole may be delayed; the upstroke itself slower, appearing more oblique; the amplitude of the tracing reduced; the systolic-diastolic summit en dôme, in plateau, or even in a concave plateau (Fig. 3); and the diastolic notch diminished. All these pathological features are less in stenosis of slight degree and tend to disappear after a successful pulmonary valvotomy. In the tetralogy of Fallot, where the stenosis is more often infundibular, the curves lose entirely their frank arterial character, and are reduced to vague systolic undulations (Fig. 5). One can say, therefore, that the electrokymogram of pulmonary stenosis appears in different forms, the interpretation of which, although difficult, can afford valuable information on the degree of the stenosis, on the efficiency of the valvotomy (by comparison with tracings made before and after operation), and in a less decisive manner on the anatomical form, i.e. on the exact location of the stenosis.

The pressure curves also are very much modified. The pulmonary artery pressure in general is low and the form of the curve is not that of the usual arterial sphygmogram. Its amplitude is reduced and in extreme cases is limited to undulations of various form, in which one no longer recognizes either the sharp systolic upstroke or the slower diastolic fall (Fig. 2). If the stenosis is less marked, the alterations are less drastic, but in all the cases the pressure traces in relation to the kinetic traces show slight delay which is due, as in normal subjects, to the friction already described and to the inertia of the apparatus.
In a subject, suffering from an isolated infundibular stenosis verified at operation, the pressure curve (above) shows a sudden transition between the pulmonary artery and the right ventricle. The electrokymogram from the level of the middle arch (middle tracing) is retarded, lower in amplitude, and has a concave plateau. The electrokymogram at the level of the left pulmonary artery (below) is of smaller amplitude, delayed, and of indefinite form.

On the other hand, a most important contrast is yielded by the striking pressure gradient that exists between the low pressures of the pulmonary artery and the very high pressure of the right ventricle (Fig. 2 and 5). This discrepancy between the pressures in the two neighbouring chambers indicates that there is an obstruction between them which is difficult to overcome and reduces at the same time both the flow and the pressure on the distal side.

Can one get any further information from catheterization? Yes, in certain cases, when the catheter is withdrawn slowly from the pulmonary artery into the right ventricle, one sees on the tracing a double transition (Fig. 4). Following the small arterial pulsations and the low pressure in the pulmonary artery there suddenly appear waves of larger amplitude with higher summits and then a second transition leads to pulsations of large amplitude (systolic pressure very high and diastolic pressures low); the catheter is now in the right ventricle. This appearance, when it is well marked, is of itself certain evidence. It corresponds to the existence of an infundibular chamber bounded by the two stenoses, the one valvular and the other infundibular. It allows one to diagnose
Fig. 3.—Pulmonary valvular stenosis. The pressure curve (above) shows a sudden transition preceded by a zone of negative pressures (aspiration phenomenon: the tip of the catheter lies exactly at the level of a valvular stenosis of diaphragm type). The electrokymogram registered from the upper part of the middle arch (below) shows large pulsations of typical arterial form but delayed in all respects. A successful valvotomy was carried out shortly afterwards.

Fig. 4.—Double pulmonary stenosis (infundibular and valvular) in the tetralogy of Fallot. The pressure curves (above) show a double transitional zone (reduced to one-half). The electrokymogram from the middle arch (below) is of small amplitude and indeterminate form. (Scale 1/1.)

the existence of a double stenosis, but such an eventuality cannot be objectively demonstrated constantly and with precision in every case in which there is in fact a double stenosis.

In the majority of cases, on withdrawing the catheter from the pulmonary artery to the right ventricle, the records show a sudden transition that does not extend beyond a single cardiac cycle; the obstruction has been crossed at a single step. But this appearance, while indicating with certainty the presence of a stenosis, does not localize its site; the form of the curve is the same whether one is dealing with a valvular stenosis (Fig. 3) or a narrowing of the infundibulum (Fig. 5).

It is in fact the comparative study of the electrokymogram that enables us to bring a new precision to this matter. Actually the analysis of our tracings seems to establish this fact: when cardiac catheterization shows a sudden and single transition between the pulmonary artery and the right ventricle, the electrokymogram of a valvular stenosis (with a diaphragm type of sigmoid apparatus) recorded from the level of the middle arch or at the origin of the left pulmonary artery comprises
pulsations that are certainly delayed and as certainly of reduced amplitude, but always of an arterial form (Fig. 3), with a very characteristic modification—the flattening in a dome-shaped manner of the systolic peak of the curve. In every case in which these two findings have been combined, operation or post-mortem verification has confirmed that the stenosis was of valvular type. They were all cases of pure pulmonary stenosis or of Fallot’s trilogy.

If, on the other hand, and with the same types of pressure curves, the electrokymogram consists of a series of less marked undulations of smaller amplitude, and now without a frank relationship between their form and the electrical sequence, the stenosis is infundibular (Fig. 5). Thus, in one of our patients who presented as a pure pulmonary stenosis and where catheterization had shown a marked pressure gradient between the pulmonary artery and the right ventricle with a single such transition, and where the electrokymogram was uninterpretable, valvotomy was decided upon. The operation showed the case to be one of very low infundibular stenosis.

This appearance of the electrokymogram is unfortunately common to cases of infundibular stenosis and to those which are double without showing the double transition of a well-developed chamber between the strictures (Fig. 5). In such cases, therefore, the diagnosis of the anatomical deformity or of the seat of the stenosis cannot be determined and some doubt persists. Considered separately the kinetic tracings and the pressure curves have each certainly some value, but the juxtaposition seems to us capable of affording important diagnostic precision in a certain number of cases, information that is of capital importance in deciding on the type of surgical approach.

**Congenital Cardiac Lesions with Increased Pulmonary Flow**

(a) *Patent Ductus*. In cases of persistent ductus arteriosus the electrokymogram of the main trunk (middle arch) or left branch of the pulmonary artery permits recognition of two specific signs:
the rounding off, often en dôme, of the end of the systolic upstroke and the appearance of an unusually early diastolic rebound occurring in the first third or first half of the diastolic descent (Fig 6).

These characteristics have been found by us also in tracings of the intra-pulmonary arterial pressure. The curve of the change of volume (electrokymogram) and the pressure curve are in fact superimposable. Immediately after tension has been taken up in the ventricular wall, the systole shows a sudden ascent or upstroke, then it falls away to the right without any rebound notch to mark the transition. The whole contour of the tracing remains in fact of arterial form but with a broadened, rounded, dome-shaped summit. In a similar way the diastolic rebound often appears very large and its timing is early; this fact appears to us to be seen most clearly when there is pulmonary hypertension with a large flow through the persistent ductus (Fig. 6).

![Fig. 6.—Patent ductus arteriosus. Tracings of pressure and electrokymogram have the same form; notch on the first third of the downstroke.](image)

The late arrival of the aortic wave reaching the pulmonary artery at the end of systole and provoking, through the rise in pressure that it causes, a premature closure of the semilunar valves seems to us to be the origin of the two pulmonary artery phenomena that have been described. Change of volume and arterial pressure, in fact, proceed with remarkable parallelism.

(b) Atrial Septal Defect. The electrokymogram is of large amplitude and frequently shows a double diastolic rebound. The pressure curves show two inconstant characters; a rounded or even dome-shaped curvature of the systolic summit and it may be a double diastolic rebound.

What can one conclude from comparison of these tracings? The amplitude of the electrokymogram corresponds without doubt to marked over-filling of the pulmonary artery which is caused by an abnormally large input. A certain relation exists between this exaggeration of the pulmonary arterial pulsation and the increased inflow in the lesser circulation. But, as we have stated (Donzelot et al., 1955), the electrokymographic method is not favourable for a measured or exact estimation of amplitude. Further in the case of atrial septal defects, the pulmonary artery pressures are variable, and to such a point that no constant relationship has been established between the height of the pressure and the estimated flow.

But one impression is gained from our observations; it seems that there is a relation between the level of the pressure and the amplitude of pulsation. With equal flow a large kinetic tracing would go hand in hand with low, i.e. normal pressures (Fig. 7), while with high pressures the corresponding pulsations are of smaller amplitude (Fig. 8). A more detailed study on a larger number of cases
would appear to us necessary to confirm these facts; but they seem to us logical, for the amplitude of beats corresponds to marked volumetric changes during the passage of each systolic wave and this implies good arterial elasticity and considerable variations between systolic and diastolic pressures. A high pressure raises as a rule both systolic and diastolic pressures, the latter proportionately more; the arterial system that is subjected to a continued abnormally high pressure tends, in general, to undergo modifications of its walls which become thickened and by a double anatomical and functional process more rigid.

![Fig. 7. Atrial septal defect without pulmonary hypertension. The electrokymogram of the left pulmonary artery (below) and the pressure curve (above) have identical form. The pulmonary arterial pressure is not raised, the beats are of large amplitude. (In the course of the catheterization the patient developed a transient complete right branch block.)](image)

![Fig. 8. Atrial septal defect with pulmonary hypertension. The shape of the curves is identical but the raised pressure (above) is accompanied by a smaller amplitude of pulsation in the left main branch of the pulmonary artery (below).](image)

(c) Eisenmenger's Complex. This congenital defect is not common and we have only examined two cases. Such limited observations do not allow us to draw hard and fast conclusions. The electrokymogram seems sufficiently characteristic; a horizontal plateau taking up the second half of systole (Fig. 9).

The pressure curves are more typically arterial but the end of systole is a little prolonged. The diastolic notch comes early and the diastolic downstroke is at first steep and then more gradual. Further, systolic and diastolic pressures are somewhat approximated and set at a high level.

**Summary and Conclusions**

A comparative study is reported of the radiological kinetics and pulmonary arterial pressures in 40 patients suffering from various forms of congenital heart disease.

In congenital heart disease with decreased pulmonary flow (21 patients; 13 simple pulmonary stenosis and 8 tetralogy of Fallot) comparison of the tracings shows the existence of two different alterations in the electrokymogram, either reduced amplitude en dôme, or a series of small undulations without any relation to the electrical events in the cardiac cycle. The comparison of the two types of tracing warrants the conclusion that in the first case there is pulmonary valvular stenosis and in the second case, a double stenosis, valvular and infundibular or infundibular.
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In congenital heart disease with increased pulmonary flow (17 patients; 2 patent ductus and 15 atrial septal defects), the tracings are superimposable. There seems to be an inverse relation between the level of the pressure and the size of the pulsations. For a given flow a large kinetic pulsation corresponds to low pressures, and a reduced kinetic pulsation to raised pressures.

In the Eisenmenger complex, the two curves are again apparently analogous and are characterized by the existence of a plateau extending from systole into diastole.

The comparative study of the electrokymogram and pressure curves registered at the level of the pulmonary arterial tree appears to be of interest. Such a study allows a precision of diagnosis of the site of pulmonary stenosis and also, without any doubt, allows an estimation of the flow, both in cases of persistent ductus arteriosus and atrial septal defect.

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