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THE POLYGRAPH AS AN AID IN DIAGNOSIS OF CARDIAC CONDITIONS IN CHILDREN *

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That there has been no startling advance in our methods of physical diagnosis since the days of Skoda and his pupils will probably not be denied. These men left us a rich heritage, and we are only now, through the use of scientific instruments, blazing new paths and adding valuable record findings to those of the unaided senses.

The use of the polygraph with adults has proved of great value in correlating physiologic and clinical data. It has removed that element which we speak of as the "personal equation," and instead gives records which are true for all time, and only require correct interpretation. These records have stimulated closer study of the heart and the circulation, so that the anatomist, physiologist, pathologist and clinician have all profited thereby and developed newer conceptions of the intricate cardiac mechanism.

The studies of Gaskell, who showed that the heart muscle itself possesses characteristic tone, that it can originate its own stimulus and conduct it to various parts of the heart, explained many of the phenomena recorded in polygraphic tracings. For example, the physiologist now knows that the auricle contracts an appreciable, measurable interval before the ventricle, and that the stimulus which produces cardiac contraction arises at the mouths of the great veins, spreading down successively over the right auricle, thence through the bundle of His and its branches to the ventricles.

Further, it has been shown that a dissociation between auricle and ventricle can be produced experimentally by destroying the tissue at the auriculo-ventricular junction, which contains special muscle and nerve fibers, and which seems to be a "connecting pathway" for the contraction stimulus.

With the polygraph we can show definitely whether the cardiac rhythm is normal; if normal, whether the arrhythmia is due to respira-

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atory or other influences; whether ventricular contraction follows auricular contraction as it should; whether the excitability of the heart is normal. With this instrument it is possible to study the functions of the cardiac muscle, namely, tonicity, rhythmicity, contractibility and conductivity. Thus far, the function of conductivity is best understood, and we find it disturbed in the usual forms of pulse irregularity. A study of the polygraphic tracings tells whether the irregularity is due to heart block, fibrillation of the auricle, or extra-systole, and, if the latter, which one of the three varieties of extra-systole is present. All these facts are of the greatest importance, for we have at hand by this means, in certain cases, just as precise knowledge (of the cardiac function) as one obtains by finding the malarial parasite in the blood-cells.

Fig. 1.—Modified Sphygmograph. With this instrument long tracings may be taken of brachial artery, apex, respiration, jugular vein and time (in $1/10$ second).

With these facts in mind, we undertook the application of these methods in cardiac conditions in children, to determine (1) if satisfactory tracings could be made from children; (2) if information additional to that obtained in the physical examination was possible; (3) if this information could be utilized in prognosis and treatment.

The instrument used in our work was our modification of the Erlanger sphygmograph with a Hirschfelder attachment (Fig. 1). This apparatus allows a simultaneous tracing to be made (1) of the pulse — known as the sphygmogram; (2) of the heart — cardiogram; (3) of the venous pulse — phlebogram. These three tracings, when studied in

relation to each other, become much more valuable than when taken alone, even with the finest instrument.

The sphygmogram gives information relating to the movements of the left heart, the rate and rhythm of the heart, and the variations in pressure within the artery.

The cardiogram gives the tracings made over the precordium, or apex, and gives exact data concerning the heart movements, and aids in defining the cardiac systole. It should not be forgotten that the cardiogram does not record the pressure within the ventricle, but does give information as to the displacement of the heart in relation to the chest wall. It further indicates certain physiologic events which are

Fig. 2.—The Normal Phlebogram (Hay). Diagram from actual tracings showing the variations in the records of the auricular type of venous pulse. The upper phlebogram is normal, the lowest shows the marked effect of free tricuspid regurgitation in increasing the engorgement of the right auricle. Note the gradual increase of the wave *v* at the expense of the auricular depression *x*. The portion *v'* of the ventricular wave *v* occurs in the phlebogram before the perpendicular line 5.

helpful in determining pathologic states of the heart. In other words, the cardiogram gives information regarding the duration of the systole and diastole, the beginning of ventricular systole, and indicates the period of the action of the aortic valves and the opening of both cuspid valves. Sometimes the normal type of cardiogram becomes inverted — where there is such marked hypertrophy and dilatation of the right ventricle as to force the left ventricle out of position on the chest wall. How valuable such information may be to the clinician need not be

Fig. 3.—Normal tracings from jugular vein, apex, carotid and radial arteries recorded simultaneously (Mackenzie). The line above the jugular tracing is the time in $1/5$ second. Note the waves, *a*, *c* and *r*. The beginning of the wave *c* occurs just $1/10$ second before the rise (due to ventricular systole) in the radial as shown in line 3 in radial and jugular tracings. The *a* wave, due to auricular systole, begins about $1/5$ second before *c* as shown by line 1, in the jugular tracing. This is during the diastole of the ventricle as shown by the falling line in the radial tracing at this time. The beginning of the wave *r*, occurs usually at the beginning of the rise in the radial. Its fall, however, marks the opening of the auriculo-ventricular valves and is coincident with the diastolic notch of the radial tracing. The jugular pulse varies considerably, but the waves *a*, *c* and *r* can be measured off as has been explained.

Fig. 4.—Digitalis heart-block, in a boy 15 years old. After stopping digitalis the heart-rate became normal. At *A'* in the jugular tracing is evidence of auricular contraction, while there is no contraction of the ventricle. A, right jugular, B, brachial, C, apex curves.

emphasized here, since he may be able to note on subsequent records in convalescence the gradual return of the left ventricle to its place, as shown by a positive cardiogram.

The phlebogram is of these three records the most important, as by representing the variations in venous pressure (when taken in the neck),

Fig. 5.—M. M., aged 10 years; respiratory arrhythmia; mitral insufficiency. Large jugular tracing, third heart sound. "II" wave in jugular. A, right jugular, B, brachial, C, apex curves.

Fig. 6.—E. M., aged 15 years; normal heart; respiratory arrhythmia. Note the large jugular waves in upper tracing.

it indicates the activities of the right side of the heart. While in some instances the interpretation of these tracings has led to controversial theories, in the main observers agree, and at all events the records stand ready for any advance in this field of medicine.

In reply to the first problem which we undertook to answer: Can tracings be obtained satisfactorily from children? In our series of cases,

Fig. 7.—B. W., aged 4½ years. Congenital pulmonary stenosis. Note the large jugular waves. A, time, 0.1 second; B, right jugular, C, brachial curves.

Fig. 8.—M. K., aged 5. Mitral insufficiency—uncompensated. Note large jugular waves and pretodiastolic wave in cardiogram (associated with "third heart sound"). A, time 0.1 second; B, right jugular, C, brachial, D, apex curves.

the ages of the children varied from $4\frac{1}{2}$ to 15 years, and all were suffering from cardiac lesions, either congenital or acquired. In each case we obtained satisfactory tracings from the brachial artery, precordium and the jugular bulb. With only slight modification of the appliances to suit the smaller anatomical areas we were able to make records without difficulty. For examples of well-marked jugular tracings in children see Figures 5 to 14 inclusive.

Before taking up the second question, or the value of tracings taken in children, it may be well to review briefly the anatomic and physiologic essentials on which interpretations are made.

Fig. 9.—M. P., aged 5. Mitral insufficiency and stenosis; cardiac enlargement. Note respiration effect on cardiac rhythm; increased frequency with inspiration, decreased with expiration. Cardiac cycle W. 0.5 sec., cycle X—.6 sec. Note protodiastolic wave "p" in cardiogram (associated with third heart sound) and corresponding wave "h" in jugular.

The right jugular bulb, which is found to be about one inch outside of the sterno-clavicular articulation, is the point over which the cup is placed to obtain the venous tracing. The right internal jugular, innominate vein, and superior vena cava, extend almost in a straight line from the heart. The pulsations are best obtained by lowering the child's head and placing it in such a position that there is a relaxation of the sterno-cleido-mastoid muscle. The best point to obtain the tracing from the jugular vein is about three-quarters to one inch external to the right sterno-clavicular articulation.

The normal venous tracing shows three distinct waves, called the (a), (c) and (v) waves (Figs. 2 and 3). The (a) wave occurs early in diastole of the ventricle, as can be seen by placing the hand over the apex and watching the time of this rise in the jugular pulse. The wave, however, is the result of the auricular contraction.

Following the (a) wave, a negative phase is recorded, termed (x), caused in greater part by the diastole of the ventricles, but this is interrupted by the (c) wave which is synchronous with the carotid pulsation.

The "a-c interval" is almost constant in point of duration, i. e., one-fifth of a second in the normal heart — and indicates the time of passage

Fig. 10.—T. S., aged 7 years. Mitral insufficiency—uncompensated. Note the large jugular waves (B). A, time 0.1 second. B, right jugular. C, brachial curves.

of the contraction stimulus through the "conducting pathway" (Bundle of His).

The third wave (v) occurs synchronously with the systole of the ventricle. It is increased in size by any factors which tend to more rapidly fill the right auricle, and hence the veins.

A second negative diastolic phase (y) follows the (v) wave and records the emptying of the cervical veins. The importance of noting this wave is seen in cases of engorged right heart with over-distended veins in the neck. In these instances it is found practically absent.

To analyze a tracing from the jugular vein, one must compare it with a tracing taken at the same time from the brachial or radial artery (see Fig. 2). With a pair of compasses, place the left point on the first vertical or base line in the radial tracing; place the other point at the beginning of any rise; then move back the right leg of the compass one-tenth of a second, as indicated on the timer above; then place the left leg on the base line of the jugular, and the right point will fall on the beginning of the rise of the (c) wave. This should be the time for (c) in the jugular tracing, for it occurs one-tenth of a second earlier in the jugular than in the radial. Then measure one-fifth of a second to the left of this (a) wave, which should fall on "a." The wave following (c) is (v).

Fig. 11.—L. B., aged 12 years. Neurotic heart. Note character of jugular and cardiac tracings. A well-defined "p" is present in the cardiogram, with an occasional "h" wave in the jugular tracing. A, time 0.1 second; B, right jugular; C, brachial; D, apex.

In interpreting any polygraphic tracing, it is advisable to consider the functions of cardiac muscle, particularly that of conductivity. Cases of Stokes-Adams disease have recently been reported in adolescents, and undoubtedly cases of partial heart-block occur with severe cardiac lesions.

Normally, the a-c interval is of short duration. If the function of conductivity is interfered with, then the passage of the stimulus through the auriculo-ventricular bundle (or bundle of His) is delayed, causing the a-c interval to be lengthened. This form of cardiac arrhythmia is found in acute ulcerative endocarditis, and not infrequently in cases of heart-block which have come to necropsy actual destruction of the bundle of His has been found.

If the lesion in this auriculo-ventricular bundle is so extensive as to cause complete "blocking" of the stimulus, then ventricular contraction does not follow that of the auricle, as it normally should, resulting in what is known as "heart-block." The dissociation between auricle and ventricle may be absolutely complete (the auricle beating independently of the ventricle and vice versa) or the ventricle may beat to every second, third or fourth auricular contraction.

Digitalis is often indiscriminately prescribed to children because they "have a valvular lesion." The polygraph teaches that it should never be prescribed for any individual whose a-c interval is prolonged, since it then only depresses the function of conductivity and accentuates any arrhythmia which is present. Such an instance from our series is presented in Figure 4. The patient was a boy of 15 admitted to the hospital with marked decompression. He had been taking digitalis in large doses—15 minims of the tincture four times a day. On the seventh day the pulse, which had been regular, showed marked arrhythmia. The tracing, Figure 4, was taken on the eighth day, and shows typical heart block. The digitalis was then stopped, and seven days later his pulse was regular. The cause of such irregularities can best be recognized by the polygraph. Here we have a condition which, if not recognized, may become serious. Ordinary methods of physical examination do not reveal the real condition.

Of the other functions of cardiac muscle, that of stimulus production was found particularly interesting in our series of tracings. In *every case* we found a quickening of the pulse with inspiration and a slowing with expiration. This is known as respiratory arrhythmia (Figs. 9, 5 and 6). That it is caused by irregularly produced stimuli is shown by the fact that ventricular contraction follows auricular contraction normally; in other words, that there is no disturbance of conductivity, an important fact to recognize. The cardiac muscle in neurotic children is particularly predisposed to this disturbance.

No evidences of the function of excitability were noted in our records. This was contrary to our expectations, since the child is apparently susceptible to abnormal or irregular stimuli in other portions of its organism. We concluded, therefore, that the myocardium in the young does not exhibit any extra systoles, even in rapidly beating hearts.

Another point of interest in our study was the occurrence of the "third heart sound." This is accompanied by characteristic waves in the cardiogram and phlebogram (Figs. 5, 8, 9, 10). The significance of this is as follows:

In some cases the existence of this extra heart sound was not noted on the preliminary physical examination, and it was only recognized after its appearance on the tracing had specifically called our attention to its presence. Thayer states that it can be heard at the apex in about

Fig. 12.—G. S., aged 12 years. Mitral stenosis. Note large jugular waves (upper tracing).

Fig. 13.—E. B., aged 13 years. Mitral insufficiency; overacting heart with slight hypertrophy. Note the excellent jugular tracing with normal *a c v* waves. Auricular type.

Fig. 14.—T. S., aged 6½ years. Mitral insufficiency and aortic insufficiency. Diagram represents passage of stimuli through auriculo-ventricular bundle. Normal

30 per cent. of normal individuals, when they are lying on the left side. In the first decade it occurs in 58.9 per cent. of cases.

This protodiastolic wave in the cardiogram is associated with an extra wave (h) appearing soon after the (v) wave in the jugular tracing (Figs. 5, 8, 9, 10) and therefore occurs in the early filling of the heart; in other words, at the very beginning of diastole. At this time the mitral and tricuspid valves are closed by the elastic recoil of the heart walls. Hirschfelder believes that it is due to the sudden snapping together of these valves. This wave may be pronounced whenever there is a ventricular distention — as in dilatation following hypertrophy, in stenosis of the mitral valve, and in aortic insufficiency, in which there is found to be an increase of intraventricular pressure. It is always accompanied by a wave designated as “p” on the cardiogram.

CONCLUSION

When making a physical examination of a patient with heart disease, perhaps the least important for the patient is the determination of the precise valve involved. The examiner should endeavor to determine the exact power of the heart to respond, to study the functioning ability of the myocardium and obtain data of the cardiac activity. These facts, in conjunction with the physical findings as to size, possible dilatation, or organic lesion, enable the physician to form a much more precise opinion as to the prognosis, while his treatment, at least, is based on scientific facts and can be controlled by further observations.

The results of our study may be summarized as follows:

1. Tracings satisfactory for diagnosis can be obtained in children.
2. The polygraph offers a means of accurate diagnosis which is not afforded by ordinary methods of examination, and should be used in addition to these — it will not replace them.
3. The information obtained from polygraphic tracings is of value for prognosis and treatment. Digitalis heart-block should be suspected where the pulse becomes irregular under the use of this drug.
4. Respiratory arrhythmia was found in our series with surprising frequency. This is said to be physiological, but we are led to suspect that it may frequently be misleading, and that the physician may suspect serious cardiac weakness. This was illustrated in cases of scarlet fever, diphtheria and measles studied by us at the Contagious Hospital. The “irregular hearts” were shown to have marked respiratory arrhythmia. We have yet to find extra systoles or auricular fibrillation in children.

The use of the polygraph will not stultify physical findings; on the contrary, more careful examinations will be made, for its use enhances their value and interprets observations which have thus far been unexplained.

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