THE LENGTH OF THE SYSTOLE OF THE HEART, AS ESTIMATED FROM SPHYGMOGRAPHIC TRACINGS. BY EDGAR THURSTON, *of King's College, London.*

VARIOUS observers[1] have in different ways attempted to measure the duration of the Ventricular Systole, both absolutely, and relatively to the whole cardiac period. Perhaps the most important observations are those of Donders[2], who measured the interval between the first and second sounds. The conclusions at which he arrived are briefly as follows:

In different individuals in a condition of repose with different pulse-rates the interval between the first and second sounds is remarkably constant, varying from ·301 to ·327 seconds for ordinary pulses. Relatively therefore to the whole cardiac period it is greater in the quick than in the slow pulses. In the same individual, when the pulse was quickened, as by change of position, &c., the duration of the interval was absolutely lessened, as from ·327 to ·298 for a rise of from 63·4 to 83·6 per minute, while the proportion of the interval to the whole cardiac period reckoned as 100, rose from 34·8 to 41·5.

The following is an attempt to determine the absolute and relative duration of the ventricular systole by the interpretation of sphygmographic tracings of the radial artery. It is of course necessary first of all to prove the precise nature of the several points observed in such tracings.

In all tracings of healthy pulses, the following main features can be readily distinguished:—a primary uprise nearly vertical, followed by a gradual line of descent, this being interrupted by a well marked secondary uprise, termed the dicrotic wave, from the summit of which the descent is continued onwards to the commencement of the next period. This dicrotic wave is a constant factor, in a greater or less degree of development, of tracings from the radial artery, though it is stated by Marey to be present only in some cases at the wrist. Frequently a swelling is seen on the line of descent before the dicrotic wave, with which it must not be confounded. This is called the tidal or predicrotic wave, and concerning it, I will borrow the words of

[1] Ludwig, Valentin, Volkmann, Marey, Chauveau and Landois.
[2] *Nederlandsch. Arch. v. Genees en Naturkunde*, II. 139 (1865), translated in full in *Dublin Quarterly Journal of Medical Science*, Feb. 1868.

Dr Galabin in his article on 'Secondary Pulse-waves'[1], in which he states that "though waves occur in the tracing which have no separate existence in the pulse, the instrument is more clinically useful than if it followed the artery more closely, for slight differences in form of pulse wave are thus transformed into a form much more manifest to the eye." With this statement I entirely agree, for I have found by experience that the determination of the exact spot at which the dicrotic wave commences is, in cases where that event is not well marked, rendered an easy matter, since it is indicated by the termination of the predicrotic wave, which serves to bring it out with greater distinctness than would otherwise have been possible.

It was first noticed by Marey, and has since been observed by Dr Galabin, that the predicrotic wave may be broken up into two, and this has been stated to be entirely due to the secondary spring which presses on the base of the lever in the old knife-edge instruments. The instrument with which I have always worked possesses no such spring, but I have in several instances noticed the wave split up in the manner described by these two authorities.

With these passing remarks on the predicrotic wave, which do not bear directly on the subject of the present communication, I proceed to the consideration of two important factors of sphygmographic tracings:—(1) The primary uprise of the tracing is caused by the systole of the ventricle. (2) The dicrotic notch is the result of closure of the aortic valves. This latter statement requires further consideration, it being opposed to the views entertained by some physiologists at the present day; but in support of it the following proofs can be brought forward:—

a. From the calculation of cardio-sphygmograph tracings, *i.e.*, tracings taken simultaneously from one of the systemic arteries and the apex of the heart, it has been shewn[2] that the dicrotic wave occurs precisely the same time after the closure of the aortic valves that the primary uprise occurs after the commencement of the systole of the ventricle.

b. It cannot be a secondary result of the primary shock, as there are many reasons for the assumption that the blood-vessels not being exposed tubes do not develope minor undulations, such as are found in experiments with elastic tubes. It is evident that though the arteries are possessed of definite walls, these are from a hydrodynamical point of view formed by all the tissues between their inner coats and the surface of the body, the thus formed compound walls damping from within outwards any undulations transmitted to their tissues by their contained blood. This continual damping reduces the shock, and thus reduces the tendency to the formation of secondary waves.

A careful analysis of the results arrived at by Donders, and a comparison of them with measurements of sphygmographic tracings, tend to throw great light on the true nature of the dicrotic wave.

[1] *Journ. Anat. and Phys.*, Nov. 1873.
[2] *Proc. Roy. Soc.* 1871, p. 318.

According to Donders, the length of interval between the first and second sounds in a state of rest occupies from 0·309 to 0·327 of a second. In one instance with a pulse of average rapidity, *i.e.* 67 per minute, the interval between the primary and dicrotic rises, which I shall in future call the first part of the beat, was found by measurement to be contained 2·8 times in each period, and occupied therefore ·310 of a second, while in a pulse of 73 per minute it occurred 2·6 times in each period, occupying ·316 of a second. The following short Table is copied from the paper by Donders, to which reference has been already made :—

TABLE I.

Pulse rate.	Position.	Length of Systole.	
		In per cent. of the whole period.	In seconds.
63·4	Sitting.	34·8 (40·6 *auct.*)	0·327
83·6	Standing.	41·5	0·298

Subjoined are the results arrived at by myself from the estimation of sphygmographic tracings with similar rapidities of pulse :—

TABLE II.

Pulse rate.	Position.	First part of the period.	
		In per cent. of the whole period.	In seconds.
64	Sitting.	34·5	0·323
84	Sitting.	41·3	0·295

These numbers, derived from two entirely different methods of investigation, agree so closely that they must be considered not as mere coincidences, but as a positive indication that the dicrotic wave corresponds to the moment of closure of the aortic valves.

Professor A. H. Garrod[1] has stated his conclusions derived from the comparison of a large number of sphygmographic tracings in the form of a proposition, viz:—"The length of interval between the commencement of the primary and dicrotic rises is constant for any given pulse rate, and varies as the cube root of the pulse rate, being found from the equation, $xy = 47\sqrt[3]{x}$, where 47 is a constant number, x = the pulse rate, and y = the ratio borne by the above-named part to the whole beat."

[1] *Proc. Roy. Soc.* 1870, p. 351 ; 1875, p. 142.

This proposition is stated to be true not only of the radial, but also of the carotid and posterior tibial arteries, and the length of the interval is therefore constant throughout the larger arteries.

It appears, therefore, that there are two important theories as to the length of the systole of the ventricle, one authority basing his views on the investigation of the cardiac sounds, and the other on the examination of sphygmographic tracings. By both theories it is allowed that the shorter the period is, *i.e.* the more rapid the pulse, the greater is the proportion occupied by the systole to the whole beat. But with regard to the actual time occupied by the systole, whereas Donders believes that it occupies from 0·309 to 0·327 of a second, continuing tolerably equal with different rapidities of pulse, Professor A. H. Garrod maintains on the contrary that it varies as the cube root of the pulse rate.

With a view of proving or disproving the correctness of the statement that the length of systole varies as the cube root of the pulse rate, I have been engaged during the past six months in a series of investigations of sphygmographic tracings.

The form of instrument used in all cases was the rack-work modification, as made by Brequet of Paris. The tracings were taken on highly glazed card, coated with a thin film of soot, by passing it through the flame of a composite candle, and afterwards varnished with ordinary spirit varnish. The frame supporting the card ran its full distance in 7 seconds; consequently by multiplying the number of periods that occurred in a single tracing by 8·57143, the rapidity of the pulse per minute was arrived at. The measurements of the tracings were made with an ordinary springbow, the distance between the points of which can be varied by means of a screw.

If, as is usually the case, the commencement of the primary and dicrotic rises are at a different level on the tracing, the length of the first part of the beat cannot be measured by simply superimposing the springbow on the tracing, but lines must be drawn upwards from the commencement of each period. It is found in practice exceedingly inconvenient to describe lines on the tracing with the lever of the instrument, for, in addition to the fact that it is not an easy matter to arrest the motion of the clockwork at the precise moment when the tip of the lever is opposite the commencement of a period, this process necessitates an extra strain on the machinery. If simply vertical lines are projected upwards, the systole is represented as being shorter than it really is, owing to the fact that the lever moving about an axis describes the arc of a large circle. To obviate this difficulty, a simple piece of apparatus was devised by Professor Garrod, which I have found of great value. This consists of a strip of wood attached to a wooden base, against which the tracing rests. Into the base is fixed a screw in such a position that it is exactly the same height above the trace-supporting piece of wood, that the axis of the lever is above the summit of that portion of the sphygmograph which contains the clockwork. A strong needle is threaded with a piece of cotton of the same length as the lever, which is attached by its opposite end to the screw, the point of the needle passing through a knot in a piece of string of similar length, which is likewise attached around the screw; with this simple contrivance lines can be drawn on the tracing, corresponding accurately to those which would be described by the lever.

In all cases the proportion was taken in each period of the tracing of the relation of the first part to the whole beat, and an average found for the whole tracing, as slight differences in this respect may be found to exist in individual periods, due to trifling imperfection in the clockwork, which should be wound up to its full extent before taking an observation, and also to the effects of the respiratory movements on the circulation. I have frequently noticed that persons not accustomed to the application of the sphygmograph to their arteries involuntarily hold their breath while the tracing is being taken. This should however be, if possible, avoided, inasmuch as the cardiac movements are thereby affected.

In a pulse of 72 per minute the measurements of the first part of the beat were as follows in each period of the tracing: 2·6; 2·6; 2·7; 2·66; 2·75; 2·66; 2·75; 2·66; 2·83; 2·75; 2·66; 2·75; with an average of 2·69.

In determinations of the pulse rate, the most accurate method is to take the mean of the rate as deduced from the actual tracing, and as calculated in the ordinary manner at the wrist immediately before or after the experiment.

If x = the pulse rate, and y = the number of times that the first part is contained in a whole beat, the part of a minute which is occupied by the first part is evidently represented by the expression $\frac{1}{xy}$, and it has been already stated, that, according to the view entertained by Professor Garrod, $xy = 47\sqrt[3]{x}$. It should be possible, therefore, if this equation is correct, to determine the time occupied by the first part of the beat by multiplying the cube root of the pulse rate by the constant number 47.

The following Table contains some of my results obtained from measurements of tracings of the radial artery, to which alone my attention has been confined, the rapidity of pulse being indicated, as also the actual length of time occupied by the first part of the beat estimated by (1) measurement with a springbow, (2) calculation from the equation $xy = 47\frac{3}{x}$.

TABLE III.

Pulse rate.	Length of first part of beat.	
	Determined by actual measurement.	Calculated from equation $xy = 47\sqrt[3]{x}$ (approximately).
47	·3468 of a second	·3378 of a second
60	·317 ,,	·321 ,,
70	·310 ,,	·3102 ,,
72	·3108 ,,	·3072 ,,
84	·300 ,,	·294 ,,
85·5	·2898 ,,	·292 ,,
90	·286 ,,	·283 ,,
128	·2556 ,,	·2592 ,,

In the consideration of the results contained in the above Table, it must of course be borne in mind that the actual measurements are subject to a certain amount of experimental error, but they cling so closely to the calculated results as to prove conclusively that the length of the first part of the beat does really vary, and that it varies, not as rapidly as the pulse-rate, but as its cube root.

It must not be supposed, however, that the variation in the length of systole with different pulse rates is capable only of demonstration by mathematical calculation, for it requires no very minute power of perception to recognize with the unaided eye, by comparison of a series of tracings of various rapidities of pulse, that the first part of the beat occupies a considerably greater length of time in slow than in rapid pulses.

With regard to the relative, in contradistinction to the absolute, length of the first part to the whole period, I have arranged the results of my investigations in connection with this point in a tabular form, the rapidity of pulse being indicated, as also the actual relation determined by measurement of tracings, and the relation which should exist if the equation $xy = 47\sqrt[3]{x}$ is true; and the truth of this equation is, in my opinion, proved beyond all doubt. The results were not obtained from a single individual, but from a number of different persons between the ages of 18 and 35, by which it is shewn that the law is in a state of health a universal one, and not merely an exceptional coincidence of occasional occurrence.

TABLE IV.

Pulse rate.	Ratio of first part to whole period.	
	Found by measurement.	Calculated from equation $xy = 47\sqrt{x}$ (approximately).
43	3·81	3·8
ditto	3·87	ditto
47	3·68	3·63
60	3·15	3·12
66	2·9	2·9
70	2·76	2·76
ditto	2·72	ditto
72	2·713	2·7
72·5	2·693	2·692
ditto	2·707	ditto
78	2·51	2·56
84	2·42	2·4
85·5	2·4	2·38
90	2·335	2·25
ditto	2·24	ditto
93·5	2·29	2·2
137	1·8	1·8

I must now dwell briefly on a point, on which great stress is laid by some of the opponents of the views which I have just held out. They would ask, Is it possible to measure the tracing with such a degree of accuracy as to obtain such figures as 2·693 or 2·76? Further, Can one distinguish between 3·2 and 3·33 or between 2·7 and 2·75? To such questions I reply, that, in every case in which the commencements of the primary uprise and dicrotic notch are sharply defined, it is quite possible to calculate the number of times that the first part is contained in a whole period to one, if not two, places of decimals, for by continued practice and delicacy of manipulation exceedingly small variations can be detected.

It will be observed, however, that in some instances the calculations have been extended to a third place of decimals, this being derived from the calculation of the average of the different periods, and not from actual measurement. An example will serve best to illustrate this latter statement. In one instance, with a pulse of 137 per minute, the measurements of the individual beats ran as follows: 1·75, 1·8, 1·75; with an average of 1·766.

Finally, the conclusion at which I have been led to arrive is:—

That the law enunciated by Professor Garrod—to the effect that the length of the systole of the heart, as indicated in the radial artery, is constant for any given pulse rate, and varies as the cube root of the rapidity—is the correct expression of the length of the systole as transmitted to the human wrist.