DYNAMICS OF CARDIAC CONTRACTION IN PULSUS ALTERNANS

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The phenomenon of pulsus alternans was first described by Traube [14] in 1872. Many theories have been put forward to explain the mechanism of the alternation, and according to the most popular of these it is due to partial asystole of the myocardium [1, 2, 7, 11]. Synchronized investigations of the hemodynamic, mechanical, acoustic, and electrical manifestations of the cardiac activity have enabled closer studies to be made of the dynamics of the ventricular contractions in this form of cardiac pathology. In experiments on animals with pulsus alternans, changes have been described in the phonocardiogram [9], the intraventricular pressure and the duration of the periods of contraction and ejection [2, 4, 10, 13]. One or two clinical papers have also been published [6, 12] on the subject of the changes in the phonocardiogram and in the phases of the cardiac cycle in pulsus alternans.

The present communication describes the results of the study of the dynamics of the cardiac contraction in experimental pulsus alternans of different degrees of severity.

METHOD

The investigation was conducted on 22 adult dogs weighing 9-18 kg, anesthetized with morphine and urethane. In the experiments synchronized recordings were made of the electrocardiogram, the phonocardiogram, and the

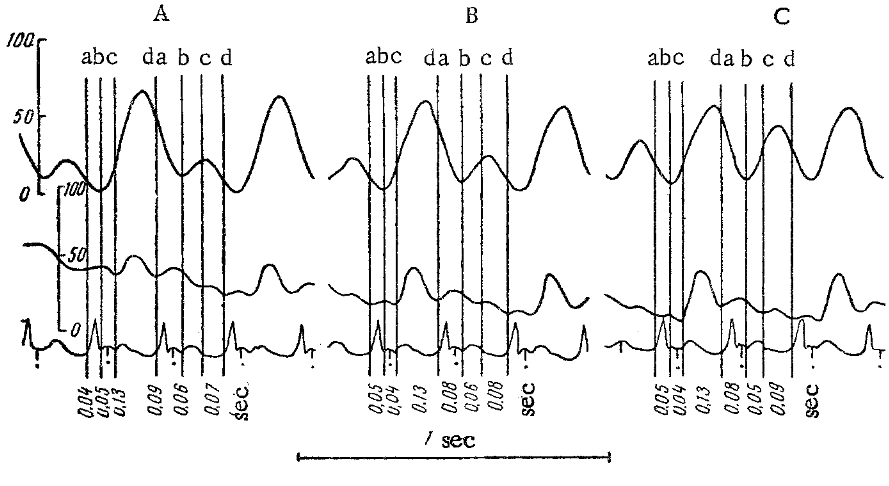

Fig. 1. Changes in duration of phases of systole in different degrees of pulsus alternans. Ratio of ventricular contractions 1:3 (A), 1:2 (B), 2:3 (C). ab) Phase of asynchronous contraction; bc) isometric; cd) ejection. Significance of curves (from top to bottom): pressure in left ventricle, in aorta; ECG standard lead II. The dots denote the times of stimulation of the sino-auricular node.

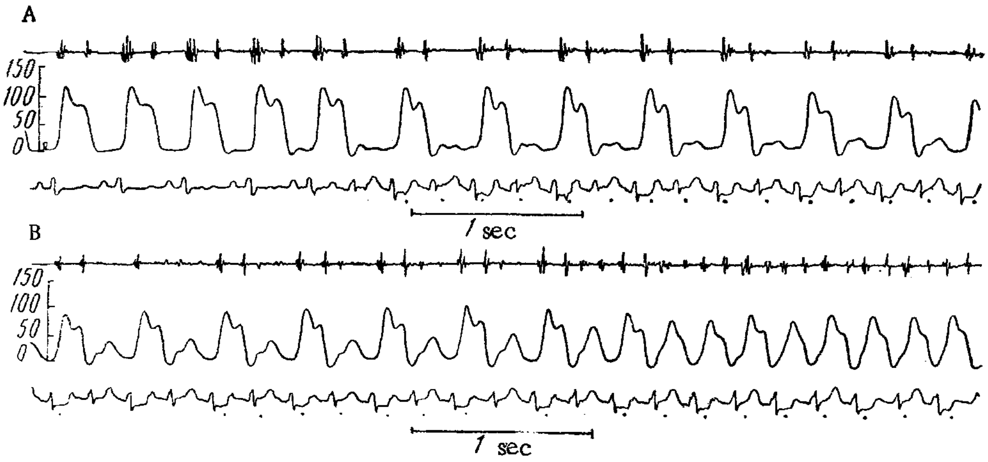

Fig. 2. Changes in the phonocardiogram during different degrees of pulsus alternans. A) Alternation of the first sound; B) alternation of the 1st and 2nd sounds. Significance of the curves (from top to bottom): pressure in left ventricle; ECG in standard lead II. The dots denote the times of electrical stimulation of the sino-auricular node. Tracing B is the direct continuation of tracing A.

intraventricular pressure. A type EMZ-01 electromanograph with a jet recording system was used for this purpose.

To produce alternation of the ventricular contractions the method of electrical stimulation of the sino-auricular node was used [2]. The electrical stimuli were applied by means of a bipolar intracardial electrode and a type SIF-4 stimulator designed at the Institute of Normal and Pathological Physiology. The impulse was rectangular in shape, its voltage 1.5-3 V, and its duration 2 msec. The impulses followed one another at the rate of 300 per min.

To prevent the onset of respiratory atriventricular block during electrical stimulation of the sino-auricular node [2], bilateral vagotomy was performed on the animals.

For the analysis of the phases of cardiac contraction [3-5, 8] on the tracing of the pressure in the left ventricle and aorta (Fig. 1), determinations were made of the duration of: 1) the phase of asynchronous contraction (of the electromechanical period, or the period of spreading of the wave of contraction), given by the interval ab from the beginning of the Q wave of the electrocardiogram (ECG) to the beginning of the rise of intraventricular pressure; 2) the phase of isometric contraction, given by the interval bc from the beginning of the rise of intraventricular pressure to the beginning of the rise of pressure in the aorta; 3) the phase of contraction, consisting of the phase of asynchronous contraction and the phase of isometric contraction; 4) the phase of ejection of blood, given by the interval cd from the beginning of the rise of intra-aortic pressure to the incisura on the curve of intra-aortic pressure; 5) mechanical systole, consisting of the phase of isometric contraction and the phase of ejection; and 6) electromechanical systole, consisting of the mechanical systole and the phase of asynchronous contraction.

Determinations of the mean rate of increase of intraventricular pressure, the intrasystolic index (the ratio between the duration of the phase of ejection and the duration of the mechanical systole, in %), and the index of contraction of the myocardium (the ratio between the duration of the phase of contraction and the duration of the electromechanical systole, in %) were also made.

These calculations were made before the beginning of electrical stimulation when the original rhythm was present, during stimulation when pulsus alternans had developed, and when the cardiac contractions reproduced fully the rhythm of stimulation.

RESULTS

The investigations showed that alternation of the cardiac contractions is accompanied by alternation of the tones of the phonocardiogram. Alternation of both sounds I and II was observed. If the alternation was of a very marked degree, sound II was often absent (Fig. 2A).

Duration of phases of cardiac cycle with different degrees of alternation (M± m in thousandths of a second)								Index of cardiac dynamics (M± m in %)	
contraction of ventricles	deg. of alternation (ratio between contr.)	phase				mechanical systole	electromechanical systole	index of contr. of myocardium	intrasystolic index
		asynchronous contr.	isometric contr.	contraction	ejection				
Strong	1:3	40± 2	43± 3	83± 5	133± 12	186± 11	216± 9	38.1± 2.3	75± 1.8
Weak		72± 7	58± 2	130± 9	79± 10	137± 9	209± 7	62.3± 2.5	57.1± 2.9
Strong	1:2	43± 3	40± 0	83± 4	129± 7	169± 11	214± 5	37.7± 1.9	75.9± 1.7
Weak		66± 9	54± 3	120± 11	92± 8	146± 8	212± 6	56± 2.7	62.6± 2.1
Strong	2:3	43± 3	39± 1	82± 9	130± 11	169± 11	212± 4	37.2± 1.8	76.5± 1.5
Weak		60± 8	48± 8	108± 12	104± 8	152± 12	212± 5	50.5± 1.7	67.8± 2.2
Reproduction of rhythm (270-280/min)		49± 8	47± 3	97± 9	113± 14	158± 14	207± 8	42.7± 2.2	65.6± 1.9

The duration of the interval between the Ist and IInd sounds on the phonocardiogram was independent of the degree of alternation of the cardiac contractions. The more marked the alternation, the shorter the interval between the Ist and IInd sounds during the weaker ventricular systole. The length of the interval between the Ist and IInd sounds during weak ventricular systole, as soon as a IInd sound appeared (Fig. 2B), was 0.12 sec. The interval between the Ist and IInd sounds during the strong ventricular contraction was 0.15 sec. With a decrease in the alternation, the interval between the Ist and IInd sounds during the weak systole was 0.14 sec, and during the strong systole 0.16 sec.

The intensity and duration of the Ist and IInd sounds during the weaker ventricular systole were less than during the stronger systole. The more marked the alternation of the cardiac contractions, the shorter the duration of mechanical systole during the weak ventricular contraction. The phases of this systole also showed changes. The phase of asynchronous contraction and the phase of isometric contraction were much longer during the weaker ventricular systole than during the stronger. During the weaker systole the duration of the phase of contraction was correspondingly increased. Conversely, the duration of the phase of ejection was shorter during the weaker ventricular systole than during the stronger. These changes in the phases of the cardiac cycle were more marked the greater the degree of alternation (Fig. 1, table).

In pulsus alternans the mean rate of increase of the intraventricular pressure during the weaker systole was only $^1/_3$ - $^1/_4$ the mean rate of increase in the intraventricular pressure during the stronger systole. For example, when the smaller oscillation of intraventricular pressure was $^1/_3$ the size of the larger wave, the mean rate of increase of intraventricular pressure during the stronger systole was 1286 mm Hg/sec, compared with 400 mm Hg/sec during the stronger systole. The more marked the degree of alternation of the cardiac contractions, the larger the index of contraction of the myocardium and the smaller the intrasystolic index during the weak ventricular systole by comparison with the stronger systole (see table). The changes in the duration of the phases of the cardiac cycle and in the phonocardiogram during pulsus alternans are due, on the one hand, to differences in the strength of contraction of the ventricles, and on the other hand, to differences in the level of the final diastolic pressure in the aorta. An increase in the length of the phase of asynchronous contraction during the weaker ventricular systole is evidence of slowing of the spread of the contraction wave through the myocardium of the ventricles. A shorter systole is due to a weaker strength of contraction, as demonstrated by the decrease in the rate of contraction; the latter may be judged by the decrease in the rate of elevation of the intraventricular pressure.

The final diastolic pressure in the aorta at the beginning of weak systole during pulsus alternans was always higher than at the beginning of the stronger systole. For this reason, the ejection of blood from the ventricle into the aorta during weak systole could begin only at a higher intraventricular pressure than was present during the stronger systole, when ejection began at a lower level of the intraventricular pressure. The mean rate of increase of the intraventricular pressure during the weak systole was lower than during the stronger systole. All these phenomena led to a lengthening of the phase of isometric contraction during the weaker ventricular systole. The shortening of the phase of election and of the duration of mechanical systole during the weak ventricular contraction resulted from the fact that each weak systole was accompanied by a smaller ejection of blood into the aorta than each strong systole. This accounts for the shortening of the interval between the Ist and IInd sounds of the phonocardiogram during the strong ventricular systole.

The increase in the index of contraction of the myocardium was due to an increase in the length of the phase of contraction and to shortening of the phase of ejection. The decrease in the intrasystolic index resulted from a shortening of the phase of ejection and lengthening of the phase of isometric contraction. Changes in the phases of the cardiac cycle in pulsus alternans were observed when the duration of the cycles and of the electromechanical systoles was equal, for the myocardial contractions took place as a result of the rhythmic electrical stimulation of the sino-auricular node. In severe alternation, the IInd sound of the phonocardiogram was frequently absent. This is because the weak ventricular systole could not be accompanied by the ejection of blood into the aorta, so that only the Ist sound appeared on the phonocardiogram. The IInd sound appeared when, in the course of the weak systole, the intraventricular pressure began to exceed the diastolic pressure in the aorta, and ejection of blood into the great vessels took place.

The pulsus alternans found in clinical practice is present only in those cases when the weak systole is accompanied by ejection of blood from the ventricle into the aorta. With a more marked degree of alternation a pulse deficit may arise: the pulse waves occur at a slower rhythm (by half) than the frequency of the electrocardiographic complexes and of the Ist sound of the phonocardiogram.

LITERATURE CITED

1. E. B. Babskii, V. S. Sal'manovich, and L. S. Ul'yaninskii, et al., In book: The Physiology and Pathology of the Heart [in Russian], Moscow (1963), p. 218.
2. E. B. Babskii and L. S. Ul'yaninskii, Electrical Stimulation of the Heart [in Russian], Moscow (1961).
3. V. L. Karpman, In book: The Physiology and Pathology of the Heart [in Russian], Moscow (1963), p. 240.
4. K. Wiggers, Dynamics of the Circulation [Russian translation], Moscow (1957).
5. K. Blumberger, Arch. Kreisl.—Forsch., 6, 203 (1940).
6. Idem, Ibid, 20, 25 (1953).
7. W. H. Gaskell, Phil. Trans. Roy. Soc. (London), 173 (1882), p. 993.
8. K. Holldack, Dtsch. Arch. klin. Med., 198, 71 (1951).
9. R. H. Kahn, Pflüg. Arch. ges. Physiol., 140, (1911), p. 471.
10. R. H. Kahn and E. Starkenstein, Ibid, 133, 579 (1910).
11. B. Kisch, Der Herzalternans. Leipzig (1932).
12. A. H. Lemmerz and R. Z. Schmidt, Kreisl.—Forsch., 51, 131 (1962)
13. H. Straub, Dtsch. Arch. klin. Med., 123, 403 (1917).
14. L. Traube, Berl. klin. Wschr., 9, 185, 221 (1872).