★ *Symposium on Arrhythmias*

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Hemodynamics of Cardiac Arrhythmias

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Experimental and clinical investigations have been made in hemodynamics, by means of intracardiac catheterization, especially considering intracardiac and vascular pressures. The atrial systolic pressure of extrasystoles increases in accordance with ventricular systole regardless of the nature of the extrasystoles, and it influences the atrial pressure of the following normal contraction.

A close relationship can be found between the ventricular and vascular pressures and the coupling of extrasystoles. During ventricular extrasystoles there is no blood flow into the aorta but a small amount of blood is ejected into the pulmonary arteries.

There is also a close relationship between the right ventricular and pulmonary arterial pressures and the coupling during atrial fibrillation. Its pressure-coupling curve resembles that of Starling. Changes in the pressure-coupling curve of the pulmonary arteries following digitalization are divided into two types according to the nature of cardiac insufficiency.

It was observed that in the right bundle branch block there is a delay in the onset of the mechanical contraction of the right ventricle compared to that of the left ventricle.

IT IS IMPORTANT to investigate various cardiac arrhythmias encountered clinically from the viewpoint of hemodynamics. Experimental studies of arrhythmias and their hemodynamics¹⁾ have long been carried out but relatively few studies have been made clinically since the main armamentarium of the study, cardiac catheterization, has only recently been introduced into practice²⁻¹¹⁾.

In our department hemodynamics of the experimentally produced and clinically observed arrhythmias have been investigated by means of cardiac catheterization as one of the links in pathophysiological research of the blood circulation. The results of these studies have been published by our colleagues on various occasions¹²⁻¹⁹⁾. In this symposium the outline of those results and findings obtained thereafter will be presented.

I. EXTRASYSTOLES¹²⁻¹⁵⁾

Subjects and method of study

Intracardiac and intravascular pressures were measured during arrhythmias using right and left cardiac catheterization in the dog under barbiturate anesthesia and right cardiac catheterization in man. To produce extrasystoles in the dog the walls of the right or left ventricle or the right atrium were stimulated by one of two catheters inserted in the heart. We were able to produce with this procedure 1,113 ventricular extrasystoles in 20 dogs, 52 ventricular fusion beats in 11 dogs and 120 atrial extrasystoles in 14 dogs. Furthermore, cases of atrioventricular block produced by digitalization and those of ventricular flutter produced by the ligation of one of the coronary arteries were added to the above series. Among 277 clinical cases of cardiac catheteri-

zation cases in which stimulation of the right ventricular wall was considered to be the cause of extrasystoles were selected for discussion.

Results

A. Atrial wave

In extrasystoles the atrial systolic wave, i.e., a wave, increases in height in accordance with the ventricular systolic phase. This increase in height of the a-wave can be seen in the following normal contraction to a lesser extent. Unless there is pathology of the sinoatrial system the cycle of the atrial wave remains normal even when there is abnormal excitement in the lower impulse conducting system.

1) In order to observe the influence of the ventricular systole on the a-wave of extrasystoles the relationship between the height of the a-wave and the Q-P (peak) time was sought. The a-wave of ventricular extrasystoles is higher than that of normal contractions, and when the heights of the a-wave are plotted the curve has the vertex at about 0.1 sec. of the Q-P (peak). On the other hand,

since ventricular fusion beats do not coincide with the ventricular systoles, the a-wave generally showed normal pressure (Fig. 1, A). The a-wave of atrial extrasystoles was absent in the first half of the ventricular systole (Fig. 1, A). However, its pressure is higher than normal when it coincides with the mechanical ventricular contraction (Fig. 1, B).

Furthermore this relationship was analyzed in dogs in which a complete atrioventricular block had been produced. It is apparent from Fig. 2 that the a-waves form a curve with its vertex at 0.1 sec. from the onset of the ventricular systole. From the above fact it might be stated that the increase in the height of the a-wave of extrasystoles has no relation to the nature of the extrasystoles but to the time course of the ventricular contraction.

Fig. 1. Influence of ventricular systole upon a-wave of r. atrial pressure in VES or AES.

Fig. 2. Influence of ventricular systole upon a-wave of r. atrial pressure curve in complete A-V block.

In a case (Fig. 3) that showed a Wenckebach's period the Q-P (peak) times of the a-wave of the pulmonary arterial wedge and that of the right atrium always exceeded 0.25 second. Therefore, only the descending limb of the curve was obtained and the a-wave returned to normal during the diastolic phase.

2) It was observed that the a-wave of the normal contraction immediately following an extrasystole is somewhat higher than that of ordinary contractions ensuing thereafter. This phenomenon is more apparent after ventricular extrasystoles than after atrial extrasystoles (Fig. 4).

3) The rhythmicity of the a-waves of the atrium was observed when abnormal excite-

Fig. 3. Influence of ventricular systole upon a-wave of r. atrial or "wedge" pressure curve in Wenckebach's period.

ment occurred in the lower conducting system. In idiopathic ventricular tachycardia the rhythm of ventricular contractions is totally irregular on the electrocardiogram. Nevertheless, the rhythm of the a-waves of the right atrial pressure curve was quite regular (Fig. 5). Also in ventricular flutter produced by the ligation of the coronary artery the a-waves of the wedge pressure curve showed a regular rhythm and markedly increased in height.

Fig. 5. Right atrial pressure curve in attack of ventricular tachycardia.

Fig. 4. Influence of VES (A) and AES (B) upon a-wave in r. atrial pressure curve of following normal beat.

B. Ventricular, pulmonary arterial and aortic waves

During extrasystoles there exists a close relationship between the intracardiac and intravascular pressures and the coupling. This relationship can be observed to a lesser extent in the normal contractions immediately following extrasystoles.

1) Ventricular wave

The ventricular systolic pressure of sporadic extrasystoles, whether atrial or ventricular, is directly related to the couplings. In the right ventricle the pressure-coupling curve of the normal contraction immediately following extrasystoles showed a linearity, but no definite trend was noted for the left ventricle (Fig. 6).

The electrical mechanical latent period (EMLP) of extrasystoles showed an inverse relationship to the coupling, i. e., the shorter the coupling the longer the EMLP. However, a difference between various arrhythmias was not apparent. In the immediately ensuing normal contraction the EMLP tended to be shorter than normal (Fig. 7).

In the clinical cases of ventricular extrasystoles the right ventricular pressure and

Fig. 6. Extrasystoles: Relationship between coupling and systolic pressure in right (A) and left (B) ventricles.

Fig. 7. Extrasystoles: Relationship between coupling and EMLP in right (A) and left (B) ventricles.

Fig. 8. Extrasystoles: Relationship between coupling and pulse pressure in pulmonary artery (A) and aorta (B).

the EMLP presented a similar relationship to the couplings as shown in the animals.

2) Pulmonary arterial wave and aortic wave

Regarding the relationship between the pulse pressure and the coupling, there is a difference in the efficacy of ejection between various types of arrhythmias (Fig. 8). In atrial extrasystoles some blood was ejected

Fig. 9. Extrasystoles: Relationship between coupling and systolic pressure in pulmonary artery (A) and aorta (B).

Fig. 10. Extrasystoles: Relationship between coupling and ejection period in pulmonary (A) and aorta (B).

into both the pulmonary arteries and the aorta. On the other hand, in ventricular extrasystoles there was some ejection into the pulmonary arteries while no blood was ejected into the aorta. In ventricular fusion beats, however, some blood was ejected also into the aorta.

Concerning the relationship between the systolic pressure and the coupling (Fig. 9), and between the ejection period and the coupling (Fig. 10), there was a definite direct correlation except in ventricular extrasystoles where there is no blood ejection. Further, in the normal contraction immediately following an extrasystole the systolic pressure of the pulmonary arteries showed a linear increase and that of the aorta a gradual decrease.

II. ATRIAL FIBRILLATION

Subjects and method of study

The relationship between the intracardiac, pulmonary arterial and pulmonary arterial wedge pressures and the couplings was sought

from data obtained from 36 cases of atrial fibrillation by means of right cardiac catheterization. In this series were included 9 cases of mitral stenosis, 11 of mitral stenosis-insufficiency, 1 of mitral insufficiency, 9 of hypertension, 5 of hyperthyroidism and 1 of ventricular septal defect. In 15 of these cases the effects of rapid digitalization on the hemodynamics were observed.

Results

A. Pressure-coupling curve¹⁶⁾

The correlation between intracardiac and intravascular pressures and the couplings in atrial fibrillation had a similar tendency as that in extrasystoles.

1) The right ventricular pressure curve and the coupling

The systolic, pulse and enddiastolic pressures had a direct relationship (Fig. 11, B) and the EMLP an inverse relationship with the couplings (Fig. 12, B). There was also

Fig. 11. Atrial fibrillation: Relationship between coupling and pressure of pulmonary artery or right ventricle or ejection period.

Fig. 12. Atrial fibrillation: Relationship between coupling and effective filling pressure or EMLP in right ventricle.

a direct relationship between the effective pressures and the couplings (Fig. 12, A).

2) The pulmonary arterial pressure curve and the coupling

The systolic and pulse pressures and the ejection period showed a direct relationship with the couplings (Fig. 11, A).

3) Pressure coupling curves

By analyzing data on the systolic pressures of the right ventricle and the pulmonary arteries and the coupling it became clear that the pressure-coupling relationship formed a

Fig. 13. Comparison of pressure-coupling curve to true Starling's curve.

Fig. 14. Comparison between atrial fibrillation and ventricular premature beat.

TABLE I RELATIONSHIP BETWEEN PRESSURE-COUPLING CURVE AND HEMODYNAMIC DATA

		Total No. of Cases	A		B		C	
			Cases	%	Cases	%	Cases	%
<i>w. p.</i>	11—20 mmHg	8	7	88	7	88	0	0
	21—30	7	7	100	7	100	5	71
	31—40	5	5	100	4	80	2	40
<i>p. a. p.</i>	11—20	2	2	100	2	100	0	0
	21—30	10	9	90	9	90	2	20
	31—40	6	6	100	6	100	4	67
	41<	4	4	100	3	75	2	50
<i>r. v. p.</i>	21—30	4	3	75	4	100	0	0
	31—40	8	8	100	8	100	3	38
	41—50	4	4	100	3	75	1	25
	51<	6	6	100	5	83	4	67
<i>r. a. p.</i>	<5	3	3	100	3	100	0	0
	6—10	13	12	92	13	100	7	54
	11<	6	6	100	4	67	1	17
<i>c. o.</i>	<3.00	9	9	100	9	100	4	44
	3.01—4.00	5	4	80	5	100	1	20
	4.01—5.00	3	3	100	3	100	2	67
	5.01<	5	5	100	3	100	1	20

w. p.: Wedge pressure
p. a. p.: Pulmonary arterial pressure (mean)
r. v. p.: r. Ventricular pressure (max)
r. a. p.: r. Auricular pressure
c. o.: Cardiac output (Cardiac index)

curve. It is shown in Fig. 13. The curve presents an ascending limb for short couplings, then a plateau, and a descending limb for longer couplings. The above three portions of the curve are named A, B and C, respectively. At first glance the curve resembles that of Starling but the B and C portions are longer than the corresponding portions of a genuine Starling's curve. Fig. 11 shows a case with the portions A and B, and Fig. 14 A, a case with the portions A, B and C. The latter is a case of combined atrial fibrillation and ventricular extrasystoles. When ventricular extrasystoles are plotted they lie also on the curve of atrial fibrillation. The EMLP of ventricular extrasystoles also lies on the curve of atrial fibrillation.

The relationship was sought between the pressure-coupling curve and the degree of cardiac failure (Table I). In many cases where the C limb (descending limb) appeared there were signs of cardiac failure, i. e., elevation of the pulmonary arterial wedge, pulmonary arterial, right ventricular and right atrial pressures.

B. Digitalization and pressure-coupling curve¹⁷⁾

In all 15 cases of atrial fibrillation with cardiac failure digitalization caused a decrease in the pulse rate, and right atrial and pulmonary arterial wedge pressures. The influence of digitalization on the pressure-coupling curve will be discussed briefly. A typical case is presented in Fig. 15. The solid line represents the pulmonary pressure-coupling curve before digitalization and the broken line that after digitalization. These cases can be divided into two groups, A and B, according to the mode of changes in the pulmonary pressure-coupling curve (Fig. 16). In group A both the systolic and diastolic pressures of the pulmonary arteries as well as the pulse pressure decreased by digitalization. These indicate an improvement in left ventricular failure and a decrease in right ventricular load. The basic diseases of a good number of cases belonging to this group were hypertension and mild mitral valvular disease. In group B the pulmonary systolic and pulse pressures increased. The fact that there was no decrease

Fig. 15. Digitalis effect to pulmonary arterial pressure-coupling curve in a case of atrial fibrillation.

in the right ventricular pressure indicates either remaining left ventricular failure or the presence of pulmonary hypertension. On the other hand, a marked increase in the pulmonary arterial pressure may indicate an elevated right ventricular systolic force. Belonging to this group were cases with severe mitral stenosis and severe hyperthyroidism.

III. RIGHT BUNDLE BRANCH BLOCK¹⁸⁾¹⁹⁾

Subjects and method of study

Six cases were selected in which the catheter passed into the left ventricle through the atrial defect. The EMLP of both ventricles were compared and the characteristics of the hemodynamics in the right bundle branch block were observed.

Results

Due to the delay in the impulse conduction via one of the bundle branches the mechanical contraction of the corresponding ventricle falls behind the contralateral ventricle.

1) The difference in the onset of mechanical contraction was assessed by comparing Q-RVs with Q-LVs. In 3 cases of complete right bundle branch block the lag of the right

Fig. 16. Types of digitalis effect to pulmonary pressure-coupling curve of atrial fibrillation.

ventricle behind the left was fairly marked; that is, QRVs-QLVs times were 0.023–0.056 second. On the other hand, the contractions of both ventricles were well synchronised, i.e., in a case with incomplete right bundle branch block, QRVs-QLVs was 0.001 second, and in two cases with right ventricular hypertrophy, 0.003 and 0.002 second.

2) The EMLP of right bundle branch block and that of normal contractions were compared in a case where right bundle branch block appeared transiently.

During the attack of the bundle branch block the apparent interval of Q-RVs was markedly prolonged, 0.13–0.14 second, but this was shortened to 0.06 sec. upon return to a normal electrocardiogram. In the simultaneously recorded phonocardiogram the 1st heart sound started at the same time, regardless of the presence or absence of right bundle branch block; that is, the Q-I times were constantly 0.04 second. The above facts indicate that the onset of the left ventricular contraction is normal even if there is delay in the onset of the right ventricular contraction due to right bundle branch block. Therefore, even if one is unable to insert the catheter into the left ventricle Q-LVs value can be obtained from the Q-I time.

Conclusion

The hemodynamics of cardiac arrhythmias were studied by means of direct cardiac catheterization and the following results were obtained:

1) Changes in the intracardiac and intravascular pressures during sporadic extrasystoles and atrial fibrillation have a close correlation with the couplings. In sporadic ventricular extrasystoles some blood is ejected into the pulmonary arteries while no blood is ejected into the aorta.

2) The atrial systolic waves during extrasystoles, regardless of their nature, form a curve with its convex upward in accordance with the ventricular systolic phase.

3) The pressure-coupling curve of atrial fibrillation resembles that of Starling. The mode of changes in this curve by digitalization is classified into two categories.

4) From the ventricular pressures it was made clear that the onset of the mechanical contraction of the right ventricle in right bundle branch block is delayed compared to that of the left ventricle.

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