ORIGINAL ARTICLE

Cardiology

Synchronization of Wave Flows of Arterial and Venous Blood with Phases of the Cardiac Cycle in Norm (Part 1)

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Abstract

Hemodynamic indices studied in practically healthy people were obtained by catheterization in various vascular areas: the chambers of the heart (left ventricle, right ventricle, left atrium, right atrium, coronary sinus), pulmonary trunk, aorta, inferior vena cava, superior vena cava, right hepatic vein, and sigmoid sinus. In the investigated areas, using the mean values of the hemodynamic parameters, we constructed graphics of the "curves" of the central, arterial, and venous pressure, synchronized with each other and ECG. Separation of a sequential scheme of the cardiac cycle (CC) into the phases indicated in the text allowed us to determine (on the superimposed curves) the points of intersection (equal pressure values—zeroing of the pressure gradients) of the hemodynamic and wave processes simultaneously occurring in various parts of the vascular bed (including those remote from the heart). As a result of the analysis, we propose a scheme (which is key to periodization of the CC phases) of the sequences of zones of temporal equalization of pressure (a rapidly acting matrix of pressure equalization points) initiated by the systole of the three-chamber ventricular block, part of which is the trigger mechanism for the next phase of CC. **(International Journal of Biomedicine. 2018;8(2):123-128.)**

Key Words: cardiac cycle • hemodynamic parameters • ECG • chambers of the heart

Abbreviations

Ao, aorta; **AV**, aortic valve; **CC**, cardiac cycle; **CS**, coronary sinus; **CFB,** central fibrous body; **DP**, diastolic pressure; **EDP**, end-diastolic pressure**; IVC**, inferior vena cava; **IJV**, internal jugular vein; **LA**, left atrium; **LV**, left ventricle; **MP**, mean pressure; **MV**, mitral valve; **PV**, pulmonary valve; **PT**, pulmonary trunk; **PP**, pulse pressure; **RV,** right ventricle; **RA**, right atrium; **RHV,** right hepatic vein; **SP**, systolic pressure; **SS**, sigmoid sinus; **SVC**, superior vena cava; **TV**, tricuspid valve; **ZTEP**, zone of temporal equalization of pressure.

Methods and Discussion

The aim of this study was to construct mutually synchronized graphs: ECG, hemodynamic processes of the chambers of the heart, brain, lung, and wave parameters of hemodynamics of the central, venous, and arterial blood flow in humans in norm.

The method of catheterization and the detailed characteristics of the studied groups based on analysis of the hemodynamic parameters of the arterial, venous, and central blood flow have been repeatedly published.[1-4] The studied indicators were obtained by catheterization in healthy people in the supine position, at rest, and free to breathe atmospheric air [4-6] (Table 1).

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Table 1.

Hemodynamic data in the norm by average values in mmHg

Variable		SP		DP		PP		MP	
CS		8.6		2.5		6.2		5.6	
PT		22.2		10.2		12.1		14	
Ao		107.6		71		40.3		86.5	
SS		10.5		8.3		2.4		9.4	
Variable	SP		EDP		MDP		PP		MP
RV	25.1		4.47		2.61		22.7		14.47
LV	109.6		11.4		2.64		105.7		106.2

Variable	A	X - collapse	V	Y - collapse	PP	MP
RA	5.7	2.4	4.6	3.4	3.5	4.47
LA	10.5	2.44	12.3	7.9	8.2	7.15

Based on the mean values of hemodynamic parameters obtained by catheterization—in the heart (RV, LV, RA, LA, CS), Ao, PT, SS, IJV, IVC, and SVC—we constructed graphs of the sequential dynamic pressure change in the each studied point, which were synchronized with each other and with ECG. Synchronized wave flows, which constitute a significant part of the thesaurus of the human body's "biosphere" and correlate with phases of CC, are shown in Figure 1. Numbers and colors indicate the vessels and organs in which the catheterization was performed.

Based on our data, which does not contradict other authors, we believe that at the onset of ventricular systole, when the LV isometric contraction phase begins (after closing of MV), TV is still open and the blood from RA enters RV, due to the RA appendage systole ("asynchronous period of ventricular systole–1") (Fig.1). During this period, two wave hemodynamic impulses are formed: 1) the contracting myocardium of LV creates a wave hemodynamic impulse CS; 2) the closing TV, due to blood reflux from RV into RA, generates a retrograde spreading impulse in SVC in the SS direction. After TV closes, the "synchronization period of isometric ventricular contraction–1" (all valves are closed) occurs. In this period (Fig.1), which lasts until the opening of PV, against the background of the minimum pressure in Ao and PT, intersections of the curves are noted, i.e. the pressure is equalized (ZTEP) between: 1) RV (EDP), LA (med), SS (min.2); 2) LA (med), SS (min.1). During this period, the systole of RV is linked up to the formation of the hemodynamic impulse of CS. We believe that the CS impulse has a complex formation mechanism associated with different phases of the isometric contraction of the ventricles, being directly dependent on their functional phases and properties.

We consider it necessary to note the significant role of CFB, a complex multifunctional membrane, in this phase.[7] In the phase of isometric contraction of LV, it is transformed under the influence of synchronous (multidirectional) effects, changing the shape and configuration of the fibrous rings at the entrance and exit (the fibrous ring of AV) of LV. We believe that the centripetal impulses arriving in this phase can initiate the vibrations of the CFB membrane, which are further spread along fibrous fibers (tensor sensors) and muscle bundles to the intracardiac structures, the walls of Ao and pulmonary veins. During ventricular systole (isometric phase), CFB is a continuous, tightly stretched membrane (all valves are closed) performing the function of a repeater of centrifugal signals over all adjacent hemodynamic formations, whose pressure is lower than in RV and LV. During the diastole (a phase of isometric relaxation), CFB is a relaxed, partially perforated membrane, which is a conductor and regulator (through fixed valve rings, having a difference in the periodicity of opening-closing of flaps of valves) of centripetal wave signals to the ventricles of the heart. The membrane of the oval window influences the hemodynamics of both atriums, bending in the direction of a less pressor effect. The role and functions of the CFB will be considered in detail in the next publication.

We believe that the short-term equilibrium state is denoted by the intersection dot of the hemodynamic curves— ZTEP [RV(EDP), LA(v-ascending part), SS(min.), CS (ascending part)], which is a trigger mechanism for the opening of PV. Presenting ZTEPs, which have extremely small values of duration, we, in general, describe the fast processes where in the norm, with a total duration of the cardiac cycle of 0.8 seconds, for example, the phase of isovolumetric contraction of atria is 0.03 sec.[8]

Following the period of synchronization of the ventricles, the "asynchronous period of ventricular systole–1" occurs: the LV isometric contraction period, when, with closed mitral and aortic valves, PV opens and the phase of rapid ejection of blood from RV begins. During this period, which lasts until the opening of AV, against the background of the maximum pressure in the CS, RV, and PT and minimum pressure in SS, there are three ZTEPs: 1) LV(ascending part), RV (maximum), PT (maximum); 2) SS(max-1), CS(maximum); 3) RA(x-collapse), LA(x-collapse), the minimum pressure in RA and LA is equalized. In this phase, RV, already in the state of systole, has a sucking action on a united hemodynamic chamber (SVC-RA-IVC) due to sagging of TV into the RV cavity. We believe that during this period, with the "disconnected" ventricles and phase-association of RV with a PT camera (RV and PT maximum), against the background of the creation of the maximum pressure in SS, IJV, SVC, CS and the minimum pressure in the "atrial block" (RA(x-collapse), LA(x-collapse), ZTEPs indicate the level of temporal hemodynamic stability during the single systole of the "three-chamber ventricular block" before the opening of AV (i.e. this ZTEP is the trigger mechanism for opening the aortic valve).

The next period, from the opening of AV to the closing of PV (tricuspid and mitral valves are closed, valves of Ao and PT are open) is the period of "synchronization of the actual ventricular systole–2." During this period, which lasts until the PT valve closes, against the background of the maximum pressure in Ao and SS, there is one ZTEP: CS (average), RA (v-ascending wave), LA (v-ascending wave). We believe that this ZTEP is a starting point for the regulation of two oppositely directed processes during a united systole of the ventricles: 1) reaching the maximum pressure in LV; 2) reducing the pressure in PT. After opening AV, the spheroid of the pulse wave formed by the LV systole, spreading along the blood flow in the intrapericardial section of Ao, creating the effect of hydrodynamic kick, presses the valve flaps against the aorta walls.

The final period of ventricular systole is the "asynchronous period of systole and diastole of ventricles – 2." It includes also the asynchronous period of ventricular diastole, consisting of two parts: 1) from the closing of PV to the opening of TV, when against the background of the continuing systole of LV, in RV (with closed tricuspid and pulmonary valves) an isometric relaxation phase begins; furthermore, against the background of the maximum pressure in LV and Ao, there is a pressure equalization in SS(max), RV (med), and PT(v-ascending wave); 2) from the opening of TV to the closing of AV, when against the background of the continuing systole of LA the phase of the actual diastole of RV arrives, with the equalization of the decreasing pressure in CS and RV on the background of the beginning of pressure decrease in the LV-Ao unit, setting the maximum systolic gradient in the "three-chamber ventricular block."
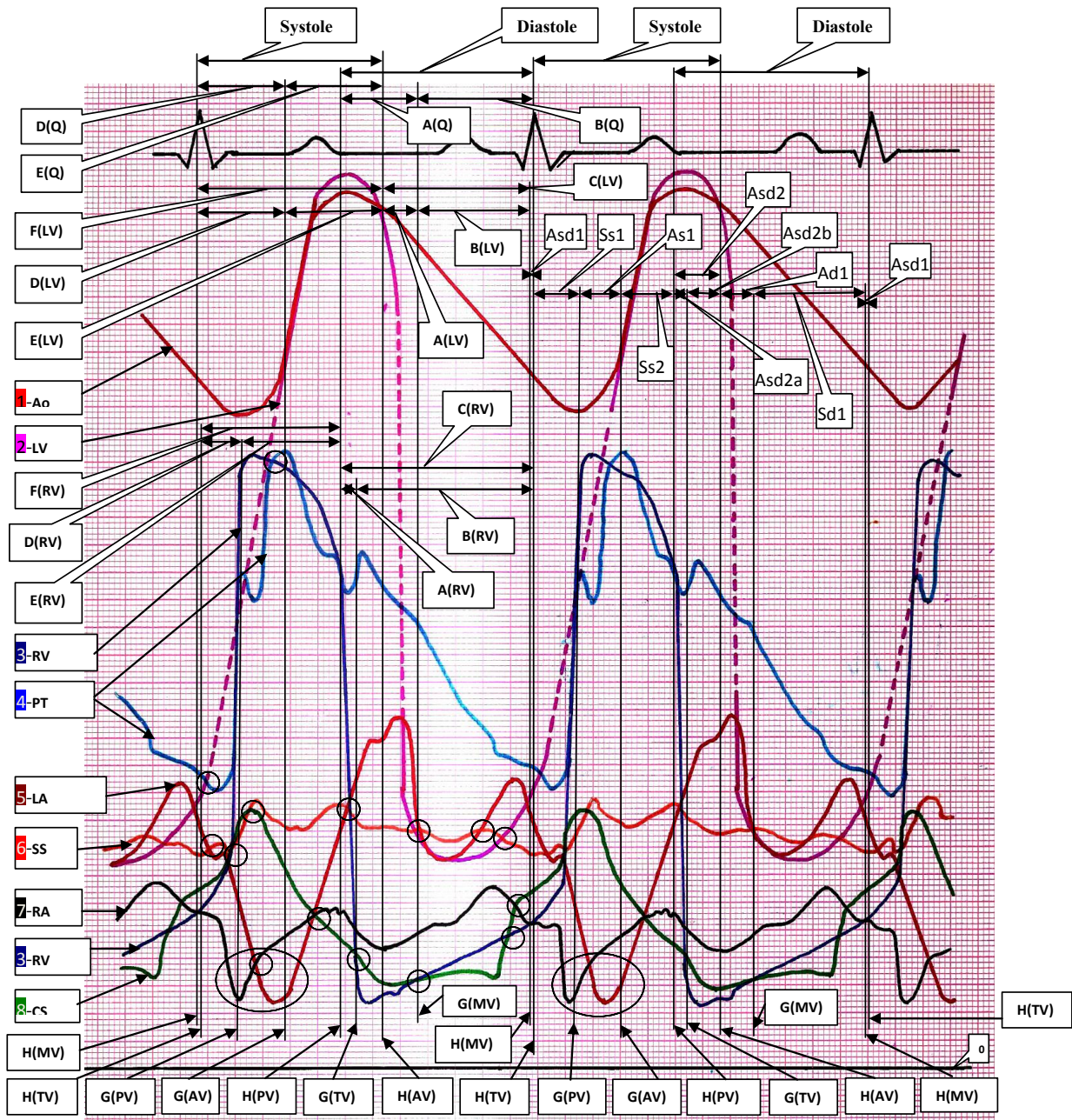
Fig. 1. Cardiac cycle in norm	
A(Q) – isometric ventricular relaxation	**H(PV)** – closing of PV
B(Q) – actual ventricular diastole	**G(TV)** – opening of TV
C(LV) – LV diastole	**H(AV)** – closing of AV
A(LV) – isometric relaxation of LV	**G(MV)** – opening of MV
B(LV) – actual LV diastole	**H(TV)** – closing of TV
C(RV) – RV diastole	**H(MV)** – closing of MV
A(RV) – isometric relaxation of RV	**G(PV)** – opening of PV
B(RV) – actual RV diastole	
D(Q) – isometric ventricular contraction	**Asd1** – asynchronous period of ventricular systole-diastole -1
E(Q) – actual ventricular systole	**Ss1** – synchronization period of isometric ventricular contraction-1
F(LV) – LV systole	**As1** – asynchronous period of ventricular systole -1
D(LV) – LV isometric contraction period	**Ss2** – of synchronization of the actual ventricular systole -2
E(LV) – actual LV systole	**Asd2** – asynchronous period of ventricular systole-diastole -2
F(RV) – RV systole	**Asd2a** – from the closing of PV to the opening of TV
D(RV) – RV isometric contraction period	**Asd2b** – from the opening of TV to the closing of AV
E(RV) – actual RV systole	**Ad1** – asynchronous period of ventricular diastole -1
G(AV) – opening of AV	**Sd1** – period of synchronization of ventricular diastole-1

Then, the "asynchronous period of ventricular diastole–1" begins. This period lasts from the closing of AV to the opening of MV, when the phase of isometric relaxation of LV occurs against the background of the continuing diastole of RV (mitral and aortic valves are closed). ZTEPs in the investigated period were not revealed.

With the opening of MV, the period of "synchronization of ventricular diastole–1" occurs, which continues until the closing of MV. In this period, against the background of the average pressure in Ao and PT and the minimum pressure in LV and RV, there is a pressure equalization at six points: 1) LA(v-descending wave), LV(mDP), SS(med); 2) LA(a-ascending wave), SS(med); 3) SS(med), LV(min); 4) CS (min), RV(mDP); 5) CS(min), RV(EDP); 6) CS(med), RA (a-descending wave), i.e., six ZTEPs.

It should be recalled that the impulse of pulse wave reaches all metabolic zones of the body in the interval from the opening to closing of AV.[9] Intentionally simplifying the structure and genesis of information connections of hemodynamic flows, we believe that the centrifugal communicatory control wave impulse (pulse wave), having passed the exchange zones of body organs, i.e., the mosaic peripheral resistance (depending on the activity of exchange, the intensity of local blood flow), is transformed into a network of centripetal informational feedback flows (hydrodynamics of the venous network) (Fig.1) with a summary information thesaurus from all exchange zones and concentration in RA for the preparation of the next CC.

RA, defined as the "physiological zero of hydrostatic pressure," [10] i.e. the initial and final phase of hydrodynamics of the vascular bed, is considered by us as a focal zone of interference of central and peripheral hemodynamic and wave processes, which has, possibly, the greatest information thesaurus of the body's biosphere [5,6] and has the possibility of pressor impact on the sinoatrial node (whose bed is the RA wall), protected from direct wave and hemodynamic effects of RA only by a layer of endocardium, devoid of elastic and other properties that protect against the pressor impact. A similar direct pressor impact is also possible on the atrioventricular node and conducting pathways.

A more detailed description of ZTEPs—the interaction of their central and remote sites, the sequence during the phases of CC in humans in norm—we intend to present in the next paper. In this paper, we note that the crossing points of the pressure curves represent short periods of zeroing of the pressure gradients in the investigated zones, synchronized short-term equilibrium states of both sequential and distributed sections of the hemodynamic vascular systems that affect the CC course. Their average indices, which do not exceed the limits of confidence intervals for the coefficients of hemodynamic parameters obtained during the catheterization and defined as ZTEPs, have a fixed sequence during CC. We believe that in the vascular systems of each of the main systems of the body's biosphere (heart, brain, liver, kidney, etc.), during very short time intervals, there are ZTEP formations of a certain sequence, forming a variable matrix of control hemodynamic points, providing a sequence (phasing) and synchronism of the course of metabolic processes within the limits of the norm. Changes in the sequence, movement, and emergence of new ZTEPs can lead to desynchronization of the matrix, the transition to a different level of regulation with a disturbances in metabolic processes.

A similar study by catheterization was conducted in the group of patients with acquired heart defects. A total of 240 people aged between 18 and 68 (72 men and 168 women) were examined. Below are given the hemodynamic data of patient S., a 47-year-old man, with a mixed aortic valve disease with prevalence of aortic valve stenosis, and stage 2 pulmonary hypertension (Table 2, Fig.2).

Table 2.

Hemodynamic data of patient S. in mmHg

Variable		SP		DP		PP		MP	
CS		22		10.5		11.5		16.25	
PT		80		35		45		57.5	
Ao		105		72		33		85	
SS		15		12.5		2.5		13.75	
Variable		SP	EDP		MDP		PP		MP
RV		75	13.5		12.5		62.5		44
LV		210	35		25		185		112.5
Variable	A	X - collapse		V	Y - collapse		PP		MP
RA	17	7		10	9		10		11
LA	40	38		60	25		35		42

The defeat of the valvular apparatus of the heart with acquired defects leads to a loss of the sealing of the chambers of the heart in the phase of isometric contraction of the ventricles due to a disturbance in the closing ability of the valves, in combination with excessive pressure in the heart chambers (stenosis, insufficiency). The consequence is a disturbance in the controlling waveforms generated by the myocardium, as well as distortion of the temporal relationships of the phases and periods of CC (including changes in the topology and composition of the "pressure equalization zones"), leading to an imbalance and desynchronization of the regulation of hemodynamic and wave processes, both in the chambers of the heart and in the metabolic zones of the body. We think it is inexpedient to give in this paper a detailed analysis of Figure 2, in connection with the obvious incompatibility of all pressure equalization zones in the investigated hemodynamic zones during the cardiac cycle.

Conclusion

Our data made it possible to identify the presence and sequence of synchronous short-term equilibrium states between both consecutive and distributed parts of the vascular bed (ZTEPs), having extremely small time values, in synchronized hemodynamic and wave processes of the central, arterial and venous bed during CC. We believe that some ZTEPs are trigger mechanisms for the subsequent phases of CC.
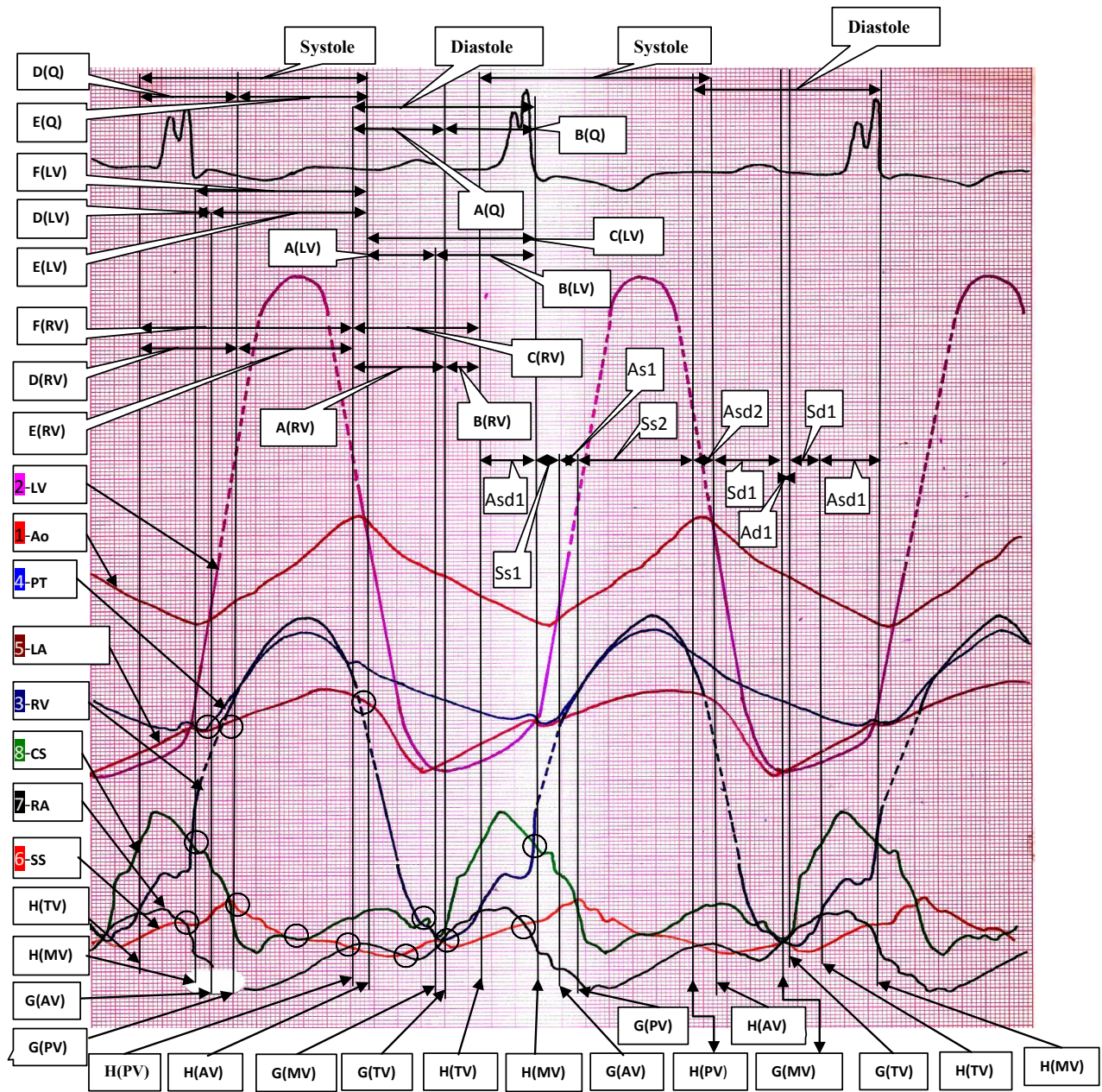
Fig. 2. Cardiac cycle in Patient S. with a mixed aortic valve disease with prevalence of aortic valve stenosis.

A(Q) – isometric ventricular relaxation	**G(AV)** – opening of AV
B(Q) – actual ventricular diastole	**H(PV)** – closing of PV
C(LV) – LV diastole	**G(TV)** – opening of TV
A(LV) – isometric relaxation of LV	**H(AV)** – closing of AV
B(LV) – actual LV diastole	**G(MV)** – opening of MV
C(RV) – RV diastole	**H(TV)** – closing of TV
A(RV) – isometric relaxation of RV	**H(MV)** – closing of MV
B(RV) – actual RV diastole	**G(PV)** – opening of PV
D(Q) – isometric ventricular contraction	
E(Q) – actual ventricular systole	**Asd1** – asynchronous period of ventricular systole-diastole -1
F(LV) – LV systole	**Ss1** – synchronization period of isometric ventricular contraction -1
D(LV) – LV isometric contraction period	**As1** – asynchronous period of ventricular systole -1
E(LV) – actual LV systole	**Ss2** – of synchronization of the actual ventricular systole -2
F(RV) – RV systole	**Asd2** – asynchronous period of ventricular systole-diastole -2
D(RV) – RV isometric contraction period	**Ad1** – asynchronous period of ventricular diastole -1
E(RV) – actual RV systole	**Sd1** – period of synchronization of ventricular diastole -1

We consider it advisable to propose (Fig.1) a sequence of ZTEPs, initiated by the systole of the three-chamber ventricular block of the heart, as a synchronized sequence that is key in the periodization of the CC phases, as well as in hemodynamic and wave processes in the human vascular system. We believe that the pressure profile in RA can serve as a test hemodynamic curve, on the basis of which a fast-acting matrix of successive points of the temporary equalization of pressure (creation of short-term equilibrium states) is formed in the vascular systems of the body and heart, providing the synchronization and sequence of the hemodynamic processes in the body as a whole.

We believe that the detailed determination of the correlation of phases and ZTEPs during CC will allow creating qualitatively new non-invasive methods for determining hemodynamic parameters of the heart and affecting them.

Competing interests

The authors declare that they have no competing interests.

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