Synchronization of Wave Flows of Arterial and Venous Blood and Phases of the Cardiac Cycle: Part 4

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Abstract

Hemodynamic indices of healthy people obtained by catheterization in such vascular areas as the chambers of the heart (both ventricles, both atria, coronary sinus), IVC, SVC, RHV, right renal vein, sigmoid sinus, and aorta were analyzed. Using the mean values of hemodynamic parameters, we constructed graphs of the curves of the central, arterial, and venous pressure, synchronized with each other, with an ECG, and with the peripheral pulse wave.

In the present work, to generalize the results obtained, we constructed integral curves of the dynamics of the blood substrate ("bolus," BB) vector from the entrance (the fusion of venous flows: SVC, IVC, RHV, and coronary sinus) to the exit from the heart-lung-heart system in the form of LVEF. It was revealed that the complete CC consists of two BBs, simultaneously passing the hemodynamic pathway: heart-lung-heart. One BB completes the transformation, leaving PC after contact with the external gaseous medium in the lung and the formation of the pulse wave spheroid in LV, going into SC in the form of LVEF; another BB, after the formation of the pulse wave spheroid in RV, goes into PC, followed by hemodynamic, metabolic and gas transformation. CMIP is a universal indicator of the quality and stability of the relationship of all hemodynamic structures (flows in vessels and heart chambers) included in integral hemodynamic flows (IC-1, IC-2) throughout the complete CC. Changes in the configuration or level of CMIP is an indicator of imbalance and restructuring of the integral indicators of blood flow (therefore, components of hemodynamic flows), indicating a deviation in the parameters of stability of homeostasis as a whole. (**International Journal of Biomedicine. 2019;9(2):106-110.**)

Key Words: cardiac cycle • hemodynamic parameters • synchronization • wave flows

Abbreviations

Ao, aorta; **AV**, aortic valve; **BB**, "bolus" of the blood; **CC**, cardiac cycle; **CS**, coronary sinus; **CMIP**, cardiac mean integral pressure; **IC**, integral curve; **IVC**, inferior vena cava; **LVEF**, left ventricular ejection fraction; **LV**, left ventricle; **MV**, mitral valve; **PC**, pulmonary circulation; **PV**, pulmonary valve; **PPW**, peripheral pulse wave; **PT**, pulmonary trunk; **RVEF**, right ventricular ejection fraction; **RV**, right ventricle; **RA**, right atrium; **RHV**, right hepatic vein; **SC**, systemic circulation; **SN**, the sinus node; **SS**, sigmoid sinus; **SVC**, superior vena cava; **TV**, tricuspid valve; **ZTEP**, zone of temporal equalization of pressure.

Basic Part

The purpose of this part of the work was to determine the dynamics of the vector of the BB passage from merging venous blood flows in RA (entry into the heart-lung-heart system) to the exit from the system in the structure of LVEF.

Completing the analysis and discussion of data from previous publications,⁽¹⁻³⁾ we present Table 1, which includes integral indicators of hemodynamics of "complete CC."

Based on the previously cited digital and graphic data on the hemodynamic and metabolic indices of the heart activity as a whole, we put forward the task of plotting the dynamics of the BB passage vector from the merging of venous blood flows (IVC, SVC, CS, VH), which are feedback channels (wave and metabolic) between the body and the heart.

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Table 1. Norm

<p> ■ – characteristic points of PPW (V.V. Boronov) A(Q) – isometric ventricular relaxation B(Q) – actual ventricular diastole C(LV) – LV diastole A(LV) – isometric LV relaxation B(LV) – actual LV diastole C(RV) – RV diastole A(RV) – isometric RV relaxation B(RV) – actual RV diastole D(Q) – isometric ventricular contraction E(Q) – actual ventricular systole F(LV) – LV systole D(LV) – isometric LV contraction E(LV) – actual LV systole F(RV) – RV systole D(RV) – isometric RV contraction E(RV) – actual RV systole G(AV) – opening of AV H(PV) – closing of PV G(TV) – opening of TV H(AV) – closing of AV G(MV) – opening of MV H(TV) – closing of TV </p>	<p> H(MV) – closing of MV G(PV) – opening of PV H(PV) – closing of PV Asd1 – asynchronous period of ventricular systole-diastole -1 Ss1 – synchronization period of isometric ventricular contraction-1 As1 – asynchronous period of ventricular systole -1 Ss2 – synchronization of the actual ventricular systole -2 Asd2 – asynchronous period of ventricular systole-diastole -2 Asd2a – from closing of PV to opening of TV Asd2b – from opening of TV to closing of AV Sd – period of synchronization of ventricular relaxation Sda – isometric relaxation of LV Sdb – actual LV diastole Ad1 – asynchronous period of ventricular diastole -1 Sd1 – period of synchronization of ventricular diastole-1 → – PW phases; ○ – ZTEP: SS-VH-SVC-RV-LA — – dynamic curve ZTEP — – coincidence between ZTEP and IPPW — – integral curves (IC-1 and IC2) ○ – intersection of the integral curve with ZTEP of TV ○ – point of "stabilization" of ICs of the right and left parts of the heart — – CMIP ○ – intersection of CMIP with ZTEP (SS-RV и PT-SS) </p>
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We emphasize the presence in the metabolic component of the blood of parameters having, along with chemical properties, physical characteristics (volume, density, total pressure of gases, etc.), whose effects on hemodynamic parameters have been repeatedly cited.⁽⁴⁻⁶⁾

IC-1 and IC-2, given in Table 1, show the dynamics of the average pressure between the hemodynamic parameters of two extreme (consecutive) points (RA, RV, PT, etc. on the Norm Graphs⁽¹⁻³⁾) relevant for each period of CC (Asd 1, Ss1, Ss2, etc.). CMIP is a graph of the calculated pressure between IC-1 and IC-2 passing synchronously each period and phase of CC in the right and left regions of the heart during the complete CC.

The formation of the vector of BB passing the complete CC (from entering RV to LVEF) is determined by the contraction of the myocardium and the creation of pressure gradients in the system of intracardiac valves (closing-opening) between the heart chambers.

We would like to note that the initial period of the BB formation inside RA occurs as a result of the inflow of hemodynamic flows to the heart from the whole body, which have metabolic characteristics that are expressed, among other indicators, in the variable physical characteristics (density and viscosity) of blood. We consider the possible direct pressure of BB located inside RV on baroreceptors of the SN, which is separated from the blood flow by only one endocardial layer (without muscular inclusions and elastic structures). The mechanism of autogeneration of the heart contractions, in our opinion, is realized by the TV closure wave (outrunning zeroing of the pressure gradient between RA and RV), including impulses of CS and the RA appendage, that (when TV is closing) forms a retrograde wave impulse propagating in the direction of SVC, topographically falling into the SN area.

Graphically (the Norm Graphs⁽¹⁻³⁾), this is an ascending part of wave “a” of RA, corresponding to the P wave on the ECG (i.e. the onset of the RA systole passing into the contraction of the spongy part of RA [the RA appendage]), which in the final phase of the systole is isolated from the sinus part by border bundles,⁽⁷⁾ and which corresponds to the PQ interval on the ECG. We believe that this mechanism (including the physical properties of the RA BB) can be a physical initiator of the electrical impulse in SN, which launches the work of the cardiac conduction system (autorun).

Thus, taking into account the autonomy of the myogenic nature of heart contractions⁽⁸⁾ (the ability for long-term uninterrupted work of a denervated heart^(9,10)), a pressor action of BB (inside RA) on SN can be considered as a factor affecting the autogeneration of electrical impulses in SN. In other words, BB inside RA—which is the informational result of the body’s activity as a whole, whose thesaurus includes wave, hemodynamic, metabolic, and gas-dynamic information resources—can be the initiator of an impulse trigger (SN), which launches a synchronized sequence of heart activity phases.

In Table 2, the corresponding designations identify the sequence of two parallel complete CCs of BB from the entrance (RA) to the exit (LVEF) from the heart system. Column 1 (extreme calculation points) describes the synchronized

sequence of the valve apparatus of the heart (opening-closing). Columns 2 and 3 describe the periods, phases, and vectors of the complete CC of the IC-1 curve (red) and the IC-2 curve (burgundy) with a step-by-step interval for BB movement, determined by the average pressure values of successive hemodynamic areas of the heart system and the vascular system (bypassing the exchange zones: lung, brain, etc.).

Thus, RV-PT-LA (during the actual RV systole, with closed TV and MV) determines the BB vector on the hemodynamic, metabolic and gas exchange pathways: RV-LA (represented by the average pressure curve at each point of RV and LA); Ao-SS-RV (during the period of actual RV diastole, with opened TV and closed MV) determines the BB vector after ejection from Ao at the nearest pressure recording point (SS) after passing through the pial chamber of the brain in the direction of RA-RV (transmission pressure).

In Table 2, all given calculated points and parameters of phase indicators are synchronized with each other, with the ECG and a graph of PPW. The initial data, which became the basis of logical and constructive calculations, were cited earlier by us in the Norm tables.^(1-3,5,6)

IC-1 and IC-2, which were presented in Table 1, as well as a description of the synchronized sequences and vectors of these curves in Table 2, demonstrate the content of the complete CC, consisting of the dynamics of two BBs simultaneously passing through the hemodynamic heart-lung-heart systems. One BB completes the transformation, leaving the vascular bed in the structure of LVEF; the second BB is transferred to the system (lung) of further hemodynamic, gas and metabolic transformations, with subsequent metamorphoses in the left heart up to the ejection into Ao.

In other words, the complete CC of each BB of RA, which has the maximum information thesaurus of the body, including the hemodynamic feedback (information) from a previous cardiac output, consists of two completed CCs in the traditional sense (where each myocardial contraction equals one CC). We gave baseline data earlier in the form of tables and graphs.⁽¹⁻³⁾

We believe that the stabilization point (Table 1) of the integral curves in ZTEP (TV and MV) determines: 1) the pressure dynamics of parallel processes in the right and left parts of the heart—a sequential launch of isometric contraction phases (the right side of the ventricular block after the left side); 2) the PT opening pressure level, synchronizing the work of the valve apparatus of the heart (opening-closing), the ventricular block as a whole and the formation of chambers (arterial and venous) of variable capacity. At the stabilization point (ZTEP of the heart valves) of both integral curves, the regulatory mechanism (synchronization) of the ventricular block function is initiated during the formation of spheroids of RVEF (current cycle) and LVEF (the end of the previous cycle). At the same time, the emerging LVEF participates in the formation of RVEF.

CMIP, which affects the formation of the RV spheroid, determines the pressure level at the trigger point (Table 1); after ZTEP (SS-VH-SVC-CS-RV-LA) is formed, PV opens and the spheroid is released (BB of RV) in the lung system. When pCMIPmax is reached, AV opens and the second spheroid (BB of LV) is released into the bloodstream, rushing towards the exchange

zones. We believe that CMIP is an integral hemodynamic indicator of the stability of homeostasis as a whole.

CMIP is a calculated parameter for the mean pressure values of the extreme values of IC-1 and IC-2, which generalizes the dynamics of two parallel current processes during the complete CC. CMIP is an indicator of the mutual hemodynamic influence of the arterial and venous BBs by changing the character of influence at the point of stabilization (Table 1). CMIP contains a total amount of information from all the hemodynamic flows that we studied and is a universal indicator of the quality and stability of the relationships of all the components of the hemodynamics of the vascular bed throughout the complete CC.

Changes in the configuration or level of CMIP is an indicator of imbalance and restructuring of the integral indicators of blood flow (therefore, components of hemodynamic flows), indicating a deviation in the parameters of stability of homeostasis as a whole. We consider the cardiovascular system as a single integrated system of inflow and outflow from the heart (quantum generator), which operates according to the trigger principle, where the regulation of the wave and metabolic processes occurs at the input (IVC, SVC, CS, RA) and output (LV, Ao) from the system. The regulation of processes (wave and metabolic) in SC begins at the exit from the ventricular block (Ao), with a phase change during CC in the arterial chamber of variable capacity (Ao, Ao-LV), and then by wave feedbacks through the zones of exchange of the venous part of the ventricular block, with phase changes of variable capacity (IVC, SVC-RA; IVC, SVC, CS, RA-RV) connected through a lung exchange zone with entrance into the arterial block of the heart (LA), forming a closed system of the information control and regulation of the heart and body as a whole.

In other words, the wave impulses generated by the heart are formed while taking into account the integral hemodynamic pressure at the inlet, intracardiac route, and exit from the working parts of the heart. We believe that the trigger point^(2,3) and ZTEP⁽¹⁻³⁾ of the valvular apparatus of the heart play a leading role in the synchronization of these processes. We believe that the role of fibrous structures and ligamentous apparatus of the heart is very significant. For example, the ligamentum arteriosum, connecting the left pulmonary artery (54.2%) or the bifurcation of PT (41.1%) with the beginning of the downward section Ao (75.7%) outside the epicardium, has also the role of a two-way feedback channel between Ao and PT with periodic vector changes. The impact of the ligamentum arteriosum on BB hemodynamics, in our opinion, is realized by means of a transmission pressor-depressor (a change in the tension vector) interaction between Ao and PT with pressure changes: 1) in the trigger point at the opening of PV (venous BB); 2) in case of LV Ejection into Ao (arterial BB). In other words, it is one of the mechanisms of mutual regulation (two-way feedback) at both “exits” from the heart to both circulatory systems: SC and PC. For exchange zones, in addition to the main ZTEP (heart valves), there is a specific ZTEP for each organ, which allows for dual regulation (random filter): a systemic regulation at the input-output level of a trigger zone and more subtle regulation at the level of each exchange zone.

Thus, we believe that the cardiovascular system autonomously generates and controls the values of CMIP, a universal parameter, which regulates and reflects the synchronization of all wave impulses and hemodynamic flows, adequate to the metabolic needs of the body as a whole.

Table 2. Norm

Step-by-step calculation of the average on the gradient between the extreme points for each period (Asd1, Ss1, As1, Ss2, etc.) of CC

	Extreme points of CC	IC-1 (—)	IC-2 (—)
Cycle 1	H(MV) (closing of MV) – H(TV) (closing of TV)	Asd1(actual RV diastole) – Δ AO-RV	Asd1 (isometric LV contraction) – LV
	H(TV) (closing of TV) – G(PV) (opening of PV)	Ss1 (isometric RV contraction) – RV	Ss1 (isometric LV contraction) – LV
	G(PV) (opening of PV) – G(AV) (opening of AV)	Ac1 (actual RV systole) – Δ RV-LA	Ss1 (isometric LV contraction) – LV
	G(AV) (opening of AV) – H(PV) (closing of PV)	Ss2 (actual RV systole) – Δ RV-LA	Ss2 (actual LV systole) – Δ LV-RA
	H(PV) (closing of PV) – G(TV) (opening of TV)	Asd2a (isometric RV relaxation) – Δ P-T-LA	Asd2a (actual LV systole) – Δ LV-RA
	G(TV) (opening of TV) – H(AV) (closing of AV)	Asd2b (actual RV diastole) – Δ P-T-LA	Asd2b (actual LV systole) – Δ LV-RV
	H(AV) (closing of AV) – G(MV) (opening of MV)	Sda (isometric LV relaxation) – Δ P-T-LA	Sda (isometric LV relaxation) – Δ Ao- RV
	G(MV) (opening of MV) – H(MV) (closing of MV)	Sdb (actual LV diastole) – Δ P-T-LV	Sdb (actual LV diastole) – Δ Ao- RV
Cycle 2	H(MV) (closing of MV) – H(TV) (closing of TV)	Asd1 (isometric LV contraction) – LV	Asd1 (actual RV diastole) – Δ AO-RV
	H(TV) (closing of TV) – G(PV) (opening of PV)	Ss1 (isometric LV contraction) – LV	Ss1 (isometric RV contraction) – RV
	G(PV) (opening of PV) – G(AV) (opening of AV)	Ss1 (isometric LV contraction) – LV	As1 (actual RV diastole) – Δ RV-LA
	G(AV) (opening of AV) – H(PV) (closing of PV)	Ss2 (actual LV systole) – Δ LV-RA	Ss2 (actual RV diastole) – Δ RV-LA
	H(PV) (closing of PV) – G(TV) (opening of TV)	Asd2a (actual LV systole) – Δ LV-RA	Asd2a (isometric RV relaxation) – Δ P-T-LA
	G(TV) (opening of TV) – H(AV) (closing of AV)	Asd2b (actual LV systole) – Δ LV-RV	Asd2b (actual RV diastole) – Δ P-T-LA
	H(AV) (closing of AV) – G(MV) (opening of MV)	Sda (isometric LV relaxation) – Δ Ao-RV	Sda (isometric RV relaxation) – Δ P-T-LA
	G(MV) (opening of MV) – H(MV) (closing of MV)	Sdb (actual LV diastole) – Δ Ao- RV	Sdb (actual LV diastole) – Δ P-T-LV

We believe that a high degree of similarity of graphic profiles and the coincidence of key points (max-min) PPW and CMIP throughout the complete cardiac cycle are significant for promising diagnostic technologies.

Conclusion

Complete cardiac cycle, during which BB from the venous substrate of RA is transformed into arterial LVEF, consists of two completed heart contraction cycles. Two BBs pass the hemodynamic route (heart - lung - heart) at the same time. One BB completes the transformation, leaving SC in the form of arterial LVEF; the second BB goes into PC in the form of a venous RVEF for further hemodynamic, metabolic and gas transformations until the new arterial ejection fraction of the next cycle is formed.

CMIP contains a total amount of information from all the hemodynamic flows that we studied and is a universal indicator of the quality and stability of the relationships of integral hemodynamic flows (IC-1; IC-2) throughout the complete cardiac cycle. Changes in the configuration or level of CMIP indicates a deviation in the parameters of stability of homeostasis as a whole.

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