

# The Hemodynamic Feature for Syndrome Diagnosis of Heart Failure

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## ABSTRACT

The hemodynamically unified algorithm for the diagnosis of left and right ventricular heart failure (HF) based on the basic circulatory syndromes of perfusion (arterial) insufficiency and venous stasis was considered. The systematic principle of research taking into account the defining biological quality of a human being as an erect being and a complex assessment of the hemodynamic characteristics of the state of the cardiovascular system (CVS) according to the main perfusion mechanisms "blood volume - vascular capacity - pumping function of the heart - pressure - blood flow" and according to the main blocks of blood circulation in standing or lying positions of patients expands the diagnostic space and provides high diagnostic informativeness of research, including at the stage of preclinical manifestations of HF.

**Keywords:** Anthropophysiological Approach; Standing or Lying Patient'S Position; Hemodynamics; Circulatory Syndromes; Systemic and Syndromic Analysis; Perfusion; Left Ventricular Failure; Right Ventricular Heart Failure

## Introduction

It was generally known that the essence of heart failure (HF) and the primary hemodynamic basis of its clinical manifestations were circulatory syndromes of arterial and (or) venous blood insufficiency in the small or pulmonary blood circulation (PC) and (or) large or systemic blood circulation (SC), the determining hemodynamic mechanism of which is another form of insufficiency of the pumping function of the heart [1,2]. And to be more precise, the functional inadequacy of the entire perfusion complex, which includes the volume of circulating blood, systemic pressure, the condition of the vascular capacity and the pumping function of the heart, to the hemodynamic demand for adequate final circulatory and metabolic maintenance of systems and organs in the PC and SC, including the heart [3]. However, the primary clinical diagnosis of HF was usually focused on the physical clinical manifestations of pathognomonic circulatory syndromes, which are most obvious and specific in congestive forms of HF [4]. With this practice, the perfusion forms of HF remain clinically unidentifiable, which were characterized by insufficient arterial perfusion, respectively, in the pulmonary circulation and in the SC in the right

ventricular (RHF) and left ventricular (LHF) forms of HF [5-7].

Even more diagnostically closed for clinical practice were conditions in which there was still no clinically or instrumentally identifiable circulatory insufficiency, but there was already a real perfusion mismatch (according to peripheral - organ or regional hemodynamic request) between the pumping function of the heart and the condition of the vascular capacity. This was manifested in the hyperresistiveness of arterial vessels, which reflects a compensatory decrease in vascular capacity and was accompanied by a relative (to cardiac output) decrease in peripheral blood flow. In general, pathogenetic perfusion disorders were not only the earliest manifestation of HF, but, as a rule, precede the development of stagnant forms of HF. Emphasizing the importance of congestive forms of HF in the clinic, the absence of a diagnostic algorithm and non-invasive methods of hemodynamic detection of the circulatory syndrome of venous stasis at the preclinical stage of the development of HF was noted [8-11].

The certain hopes were associated with the assessment of the actual pumping function of the heart and the determination of car-

diac stroke volume (CSV) and minute blood volume (MBV). However, clinical practice shows that HF can occur both with reduced and unchanged and even increased cardiac output in terms of CSV and MBV. For example, the well-known hyperkinetic syndrome in hyperthyroidism, beriberi, anaemia, Paget's disease or centralization of blood circulation by SC. CH can be both with a reduced and with a preserved fraction of the emission according to CSV [12]. In general, evaluating the search for early diagnosis of HF, it should be noted that all efforts, as a rule, were focused on assessing the pumping function of the heart, the structural condition and contractility of the myocardium [13]. It is clear the importance of violation of the contractile function of the myocardium for the heart in its implementation of the pumping function, but not for maintaining a high, but sufficient, or rather, necessary cardiac output in various hemodynamic situations to ensure adequate peripheral circulation and blood supply to organs and tissues in accordance with their metabolic activity, especially in pregnancy [14-16].

It was obvious that in all clinical forms of HF there was a stage in its development when there were already pathognomonic circulatory manifestations, but there was still no physical reflection of them in the usual clinical manifestations. When these manifestations become clinically obvious and are determined by standard (protocol) diagnostic procedures, then, as a rule, this refers to stagnant forms of HF, pathogenetically the most late, and therefore the most fatal [17]. And with congestive forms of HF, there were stages when the corresponding hemodynamic disorders were already real before the known clinical symptoms of LHF and RHF. So, with LHF, these were syndromes of venous stasis and insufficiency in the lungs, which were the circulatory basis, first of all, swelling of the alveolar walls (crepitation), and then the appearance of exudate in the alveolar cavity (wet wheezing, haemoptysis). And with congestive heart failure, the clinical signs of its manifestation will always be preceded by the stage of corresponding hemodynamic changes in the SC [18,19].

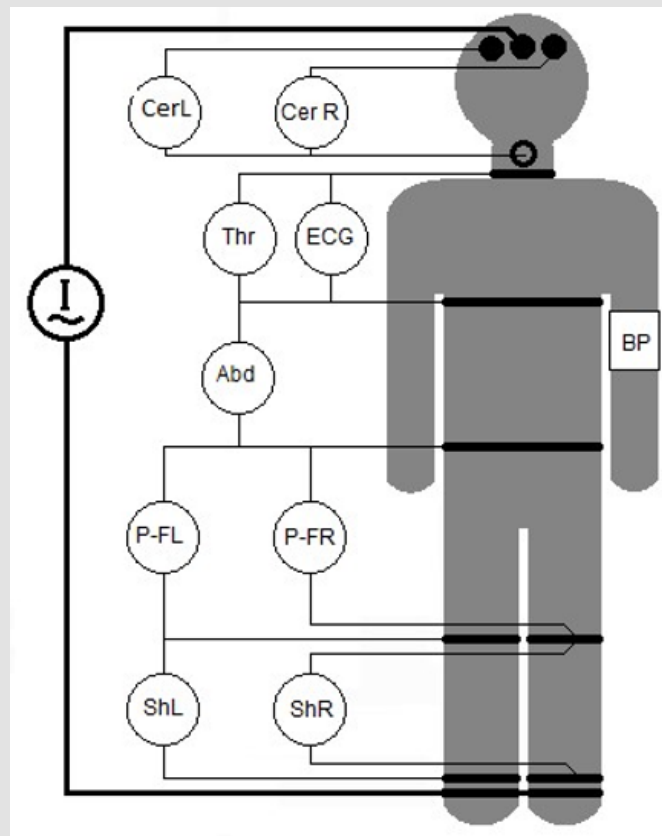
For an adequate diagnosis of such a circulatory condition as HF, for example, it is necessary to obtain systemic information, if not on all, then on the majority of blocks of regional circulation (head, lungs, abdomen, pelvis, lower extremities). Only in the case of the manifestation of pathognomonic hemodynamic syndromes in most of these blocks, it is possible to diagnostically verify the state of HF [20,21]. Existing methods of diagnosis, especially at the stage of preclinical manifestation of the corresponding circulatory disorders, were neither conceptually nor methodologically oriented to such a task [22-24]. Taking into account the ever-increasing number of polyclinic patients with HF, the need for dynamic monitoring of the condition of all patients with HF, as well as the understanding of the need to identify HF at the preclinical stage of hemodynamic preconditions and pathognomonic circulatory disorders, not only a non-invasive instrumental technique is desirable, but also a fundamentally new approach that allows obtaining the required system diagnostic information about the condition of the cardiovascular system.

## Materials and Methods

### Trial Design

Between 2012 and 2020, a prospective, open, randomized hospital-based study was conducted at Maternal Hospital №1 and Vinnitsya Regional Perinatal Center. The study involved Caucasian women from the Podilia region and was conducted in accordance with university research paper No. 0122U002435. Anthropo-physiological examination of the cardiovascular system, considering the importance of blood circulation characteristics in the standing and lying positions of the body for a vertically oriented individual, was performed using the ANTROPOS-CAVASCREEN hardware and software complex developed by the researchers [11,16]. This included non-invasive and simple instrumental techniques such as sphygmomanometric blood pressure measurement, electrometric local blood flow measurement, and electrocardiography with simultaneous thoracic and regional tetrapolar rheography (Figure 1). These techniques provided systemic information on all main blocks of blood circulation, including the volume of circulating blood, blood pressure, heart pumping function, arterial and venous blood circulation in the pulmonary circulation, systemic circulation as a whole, and individually in specific regions such as the head, abdomen, pelvis-thigh, and lower extremities [8].

With such a system characteristic of hemodynamic parameters, it was possible to most fully assess the condition of the cardiovascular system based on the ratio of the main hemodynamic mechanisms "blood volume - vascular capacity - pumping function of the heart - pressure - blood flow" and in the anthropo-physiologically full diagnostic criteria of the functioning of the cardiovascular system, in particular, in a person - in conditions standing and lying down (Figure 1). The study utilized a wide range of 382 hemodynamic parameters from the normative base of the ANTROPOS-CAVASCREEN diagnostic system for the comprehensive assessment of the cardiovascular system's state and syndromic diagnosis of circulatory syndromes, including pathognomonic heart failure [11]. General hemodynamic parameters, such as the total volume of circulating blood, average arterial pressure, contractile function index of the heart, cardiac stroke volume, heart rate index, cardiac output, and systolic heart index, were determined for individual use and for calculating regional blood circulation indicators. Regional hemodynamic parameters [15] were estimated based on blood circulation in 7 regions of the SC (head left and right, abdomen, pelvis-femur left and right, lower leg left and right), arterial blood flow were estimated based on the arterial inflow index (A-region was determined by the amplitude of the first derivative of the differential rheogram) of the corresponding vascular region, according to the indicators of arterial impedance (the region were determined by the ratio of pressure (AIP), cardiac output (AIO) and perfusion (AIP) values to the values of regional arterial blood flow - ABF region) the state of vascular capacity is estimated, according to regional indicators of blood filling or blood volume (BV-region is determined by the basic impedance of the rheogram - Z0) and venous outflow (VO region is determined by the ratio of ABF and Z0 region), the state of venous hemodynamic was assessed.



Note: Designations according to the connected system of potential electrodes: Cer - head, Thr - chest, Abd - abdomen, P-F - pelvis-femur, Sh - shin; R - right, L - left. BP - cuff blood pressure measurement, ECG - electrocardiogram.

**Figure 1:** The scheme of tetrapolar overlay of current (I) and potential electrodes for rheographic registration of hemodynamic parameters.

The diagnostic informativeness of the proposed method was evaluated in a sample of 1905 individuals of varying sexes and ages, including healthy individuals, those with chronic diseases without clinical manifestations, and those with ongoing diseases. Hemodynamic parameters were recorded in both standing and lying positions, and the analysis was performed on a pooled sample [11]. According to the mandatory condition of anthropo-physiological research, the registration of hemodynamic parameters was carried out in the STANDING and LYING positions of the body, and the analysis was based on a connected sample. The prevalence of hemodynamic syndromes and pathognomonic HF was estimated across different age groups for males and females separately: up to 8 years (n=16), 9-14 years (n=68), 15-21 years (n=226), 22-35 years old (n=326), 36-55 years old for women and 36-60 years old for men (n=658), up to 70 years old (n=413) and over 70 years old (n=198). The age samples were formed in accordance with the original classification of the stages of ontogenetic adaptation to Earth's gravity in the process of formation and vital activity in conditions characteristic of human pronograde position [11].

The statistical assessment of differences in related samples (standing lying) and the trend of age dynamics was carried out using the non-parametric sign criterion (Psc) and the assessment of the specificity of the largest subgroups in the direction of the differences [15]. The trial was approved by the biological and medical ethics committee of the National Pirogov Memorial Medical University and was carried out strictly in accordance with the code of ethics of the World Medical Association (declaration of Helsinki) for experiments involving humans. All participants in the trial provided written informed consent.

## Results

It was important to note that according to the analyzed total sample, the share of persons with a clinical diagnosis of HF (of course, congestive heart failure) and only in women over 40 years of age was 2.0%, and together with men of the same age, it was only 0,5%. The identification of the circulatory syndrome of arterial insufficiency in the pulmonary circulation is carried out when the ABF PC indicator exceeds the lower normative limit of the diagnostic scale,

which corresponds to a critical (significant) decrease in pulmonary arterial blood flow, and according to the corresponding criterion, LHF was diagnosed by perfusion. An even earlier form of HF according to perfusion was identified when there are still no direct manifestations of arterial insufficiency (according to the ABF PC indicator), but the circulatory syndrome of increased vascular resistance or hyper resistivity (according to the cardiac type) is already detected, which is determined by an increase in arterial impedance indicators (AIO according to pump function ) according to pulmonary circulation, which go beyond the upper normative limit of the diagnostic scale. Such hemodynamic ratios reflect the state of perfusion mismatch of the percussive cardiac output and blood volume in the PC of blood flow in the pulmonary artery system.

The hemodynamic identification of the circulatory syndrome of peripheral arterial insufficiency according to SC was carried out accordingly when it exceeds the lower normative limit of the diagnostic scale of regional indicators of arterial inflow (A-region), which corresponds to a circulatory critical (significant) decrease in arterial blood flow in the corresponding region. When identifying such a borderline syndrome in the majority of peripheral regions and according to the corresponding criterion, HF was diagnosed by perfusion type. The earliest form of HF according to perfusion type was identified when there were still no direct manifestations of arterial insufficiency (according to the A-region indicator) or they are manifested only in separate vascular regions, but the circulatory syndrome of increased vascular resistance or hyper resistivity (according to the cardiac type) is already manifested systemically (according to SC). This hemodynamic syndrome was determined by a critical increase (exceeding the upper normative limit of the diagnostic scale) of arterial impedance indicators in the pumping mode (AIO was determined by the ratio of CSV parameters to ABF region) in most vascular regions of the SC. Such hemodynamic ratios reflect the state of perfusion mismatch of cardiac output and blood volume according to regional arterial blood flow.

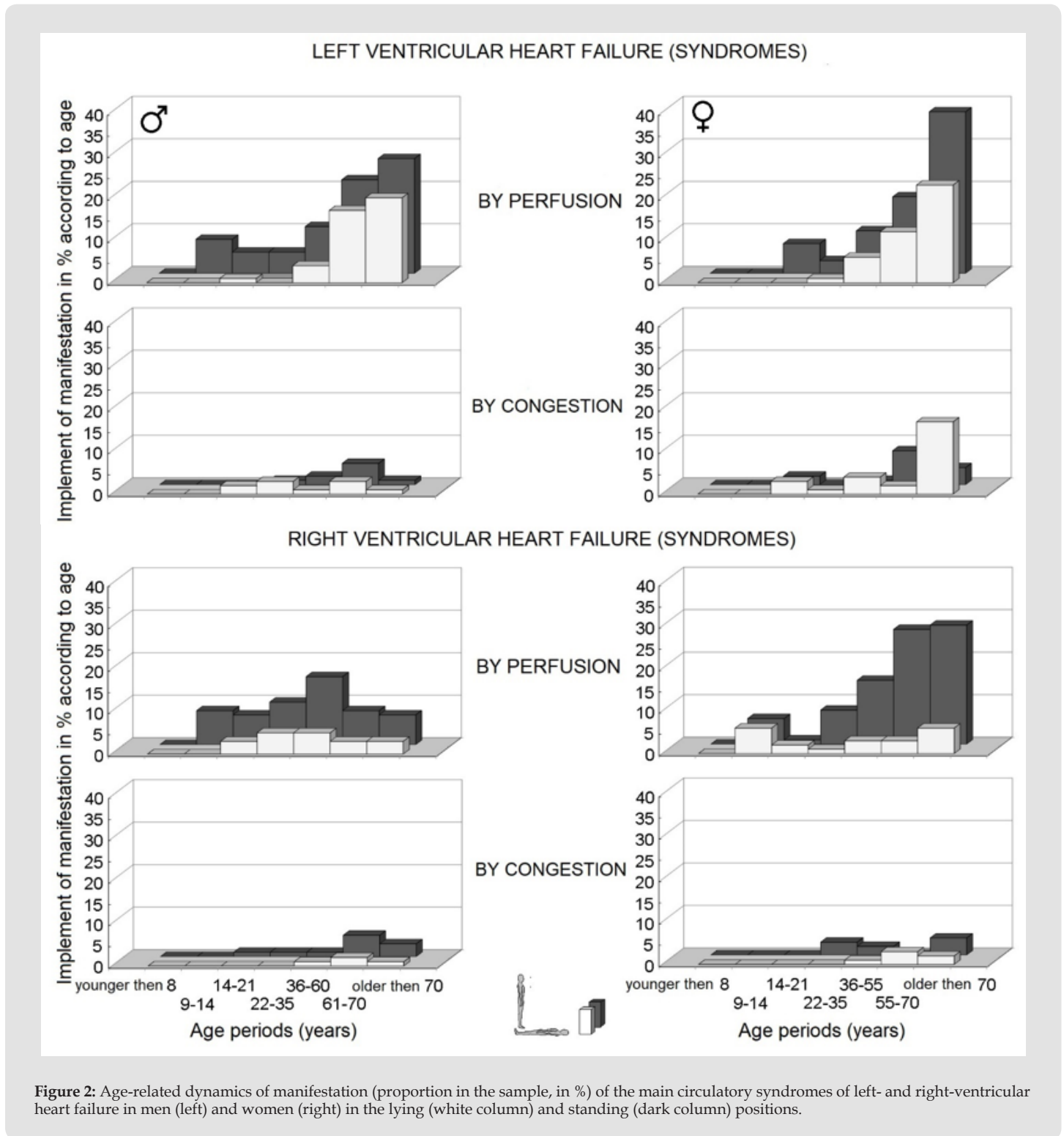
The circulatory syndrome of venous insufficiency according to the PC is identified when it exceeds the lower normative limit of the diagnostic scale of the indicator of venous outflow according to the PC (marginal decrease in VO) and at the same time exceeds the upper normative limit of the diagnostic scale of the indicator of the volume of circulating blood in the small circle of blood circulation (CBV), which corresponds to the limit ( stagnant) increase in pulmonary blood volume. An isolated increase in the pulmonary volume of circulating blood (PCV) without marginal changes in the venous outflow index (VOI) was identified as a borderline hemodynamic syndrome of venous stasis. When identifying any of these circulatory syndromes, according to the corresponding hemodynamic criteria, a congestive pulmonary congestive heart failure as LHF was diagnosed. The circulatory syndrome of venous insufficiency in the peripheral regional blood circulation was identified when it goes beyond the lower normative limit of the diagnostic scale of the venous outflow indicator in the corresponding region (limiting decrease in the VO region) with si-

multaneous going beyond the upper normative limit of the diagnostic scale of the regional indicator of blood volume in the corresponding block of the peripheral circulation and is a circulatory reflection of stagnation in violation of venous outflow. An isolated marginal increase in the blood volume index in the peripheral circulatory region without marginal changes in the venous outflow index was identified as the hemodynamic syndrome of venous stasis. When any of these syndromes were detected in the majority of peripheral regions, according to the corresponding hemodynamic criterion, RHF was diagnosed according to the peripheral congestive type.

According to the proposed method of diagnosing heart failure, all four basic circulatory syndromes pathognomonic for this condition were clearly identified - arterial insufficiency or limitation (hyperresistiveness of the cardiac type) and venous insufficiency or stagnation according to the PC and SC. This allows you to clearly differentiate different hemodynamic forms of heart failure:

1. LHF by arterial or (s) congestive pulmonary type, respectively, incomplete (... or ...) and complete (... and...) forms.
2. RHF by perfusion or (and) peripheral congestive type, respectively, incomplete (... or ...) and complete (... and...) forms.
3. Mixed forms of HF.
4. By perfusion type - with a combination of perfusion-type LHF and arterial-type LHF.
5. According to the congestive type - for LHF by pulmonary congestive type and RHF by peripheral congestive type.
6. Cross perfusion-congestive forms - with a combination of LHF by pulmonary congestive type and RHF by perfusion type also, conversely, with LHF by arterial type and RHF by peripheral congestive type.

According to our proposed method of diagnosis, three syndromic forms of mixed HF (subtotal form), as well as the full (total) form of HF, represented by all four pathognomonic circulatory syndromes, were real. It should be especially noted that for each of the basic circulatory syndromes, the proposed diagnostic method allows identifying two hemodynamic forms of pathognomonic circulatory syndromes of HF. According to arterial circulation according to PC and SC, in the order of increasing severity of hemodynamic disorders, these were syndromes of hyper resistive arterial vessels of the cardiac type (the earliest form of perfusion disorders) and arterial insufficiency (the final form of perfusion disorders). According to venous circulation, there were syndromes of venous stasis (the earliest form of impaired venous outflow) and venous insufficiency (full circulatory syndrome of impaired venous circulation). The selection of 8 hemodynamic forms of the basic circulatory syndromes of LHF and RHF strengthens the possibilities for differentiated and early clinical manifestations of early predictive diagnosis of HF (Figure 2).



**Figure 2:** Age-related dynamics of manifestation (proportion in the sample, in %) of the main circulatory syndromes of left- and right-ventricular heart failure in men (left) and women (right) in the lying (white column) and standing (dark column) positions.



In Figure 2 shows data on the age-related dynamics of manifestation (proportion by sample, in %) of all four main circulatory syndromes of heart failure. With LHF, these were circulatory syndromes by perfusion (hemodynamically identified as syndromes of arterial insufficiency or hyper resistance of arterial vessels according to SC) and by stasis (hemodynamically identified as syndromes of venous insufficiency and stagnation by PC). With RHF, these were circulatory syndromes due to perfusion (hemodynamically identified as syndromes of arterial insufficiency or hyper resistance of arterial vessels according to PC) and stasis (hemodynamically identified as syndromes of venous insufficiency and stagnation according to SC). First of all, it should be noted that in all cases, and according to our sample it was 2% of women with a clinically diagnosed heart failure, the condition was also confirmed according to the data of the considered diagnostic algorithm. Since in clinical practice the concept of congestive heart failure was usually identified with congestive forms of the left and right ventricles of the heart, the correspondence of the data obtained by the proposed method of diagnosis with known data on the prevalence of congestive heart failure [2,15] indicates the diagnostic reliability of the proposed method. According to the summary data obtained for Europe, the prevalence of HF was 1,7%, in the USA - 2,4-3,0%, in the UK - 1,5-1,6% [25].

According to the data obtained by the method proposed by us, congestive forms of LHF and RHF in men and women in different age groups are detected from 1,0% to 3,0% when diagnosed in the lying position and up to 5,0% in the standing position. And only in women over the age of 70, the prevalence of congestive LHF increased to 17,0%. A similar feature was noted according to the data of the Working Group on Heart Failure of the European Society of Cardiology - precisely in the oldest age group, the prevalence of congestive heart failure in women was higher than in men [2]. The data obtained by us on the age-related dynamics of the manifestation of congestive heart failure (see Figure 2) were well comparable with these data, both quantitatively and in terms of trend. However, the percentage of identified patients with congestive heart failure by the proposed method was significantly higher in the respective age groups, including a sample of women over 70 years old. This testifies to the high diagnostic sensitivity of the proposed diagnostic method and demon-

strates advanced diagnostic capabilities of the circulatory condition pathognomonic for congestive heart failure (Figure 3).

The advantage of the proposed non-invasive method of diagnosing HF is demonstrated by the data on the manifestation of LHF and RHF according to the arterial (perfusion) type (Figure 2). These data fully demonstrate the possibilities of diagnostic evaluation of the pumping function of the heart for its direct purpose - circulatory supply of the PC and SC. With the general characteristic trend of an increase in the manifestation of HF with age, its level in the arterial (perfusion) form was significantly higher than in congestive forms, in all age groups and in the left and right heart ( $P < 0.01$ ). The proposed diagnostic method represents an actual opportunity to identify perfusion forms of HF, as the earliest manifested and diagnostically closed for currently used clinical and instrumental methods, and thereby expands the information space in the HF clinic. No less important information was demonstrated by data on the comparative manifestation of HF during diagnosis in accordance with the methodical algorithm of the proposed method in the standing and lying positions. For all forms of HF (see Figures 2 & 3), there is a clear and pronounced prevalence of the level of manifestation of all circulatory syndromes of HF in the standing position ( $P < 0.05$ ).

This is especially evident in RHF and LHF of the perfusion (arterial) type ( $P < 0.01$ ). It is in the standing position, in comparison with lying down, that the trend of age dynamics characteristic of CF was emphasized. To a certain extent, this can be taken as evidence of the special significance of CVS tension in the mode of anti-gravitational blood circulation during the entire postnatal ontogenesis in the conditions of upright walking typical for humans as a biological species for the formation of a characteristic species-specific profile of the main chronic CVS diseases (arterial hypertension, ischemic heart disease, etc.), including for the development of at first amortization manifestations of the pumping function of the heart, and then in a certain part of the population with the subsequent evolution into chronic heart failure. Prevalence (in % by sample) of HF in the standing position compared to the lying position demonstrates and justifies the relevance of the anthropo-physiological approach, which constitutes the methodological and methodical basis of the proposed method of diagnosis.

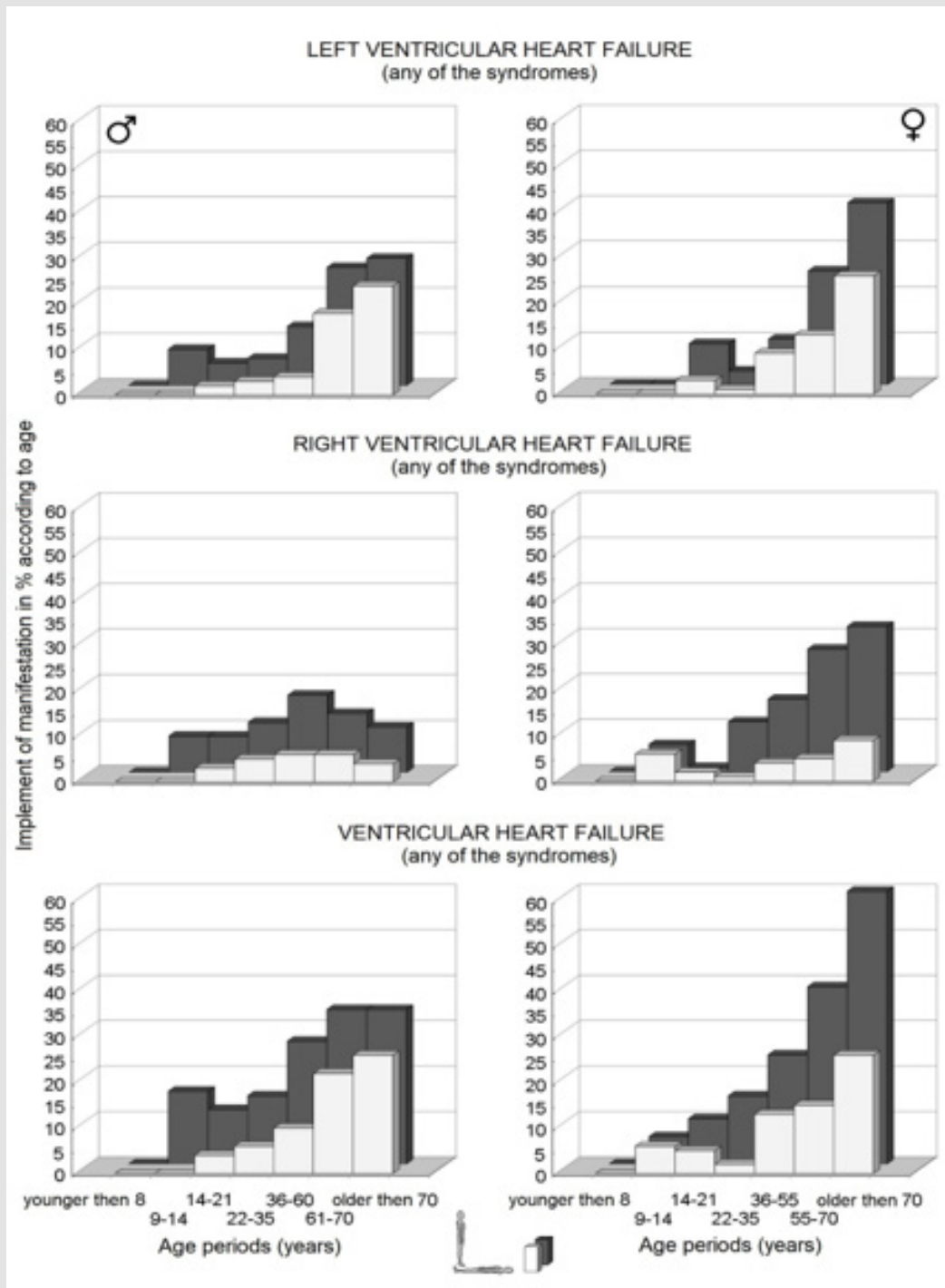


Figure 3: Age dynamics of the level of integral (according to any of the syndromes) manifestations (proportion by sample, in %) of heart failure in men (left) and women (right) according to the main late life conditions - standing (dark bar) and lying down (white bar).

## Conclusion

In the hemodynamically unified algorithm of the proposed method of diagnosis, including HF, a systematic research principle is laid down, firstly, taking into account the defining biological quality of a person as a straight being, and, secondly, a comprehensive assessment of the hemodynamic characteristics of the state of the cardiovascular system according to the main perfusion mechanisms "blood volume - vascular capacity - pumping function" of the heart - pressure - blood flow and on the main blocks and components of blood circulation in the conditions required for late studies STANDING and LYING. Conducting such a study not only expands the diagnostic perspectives in predictive search of the HF, but also increases its diagnostic informativeness.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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