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RELATIONSHIP BETWEEN MORPHOFUNCTIONAL PARAMETERS OF THE CARDIOVASCULAR SYSTEM AND SPORTS PERFORMANCE OF SOCCER PLAYERS OF VARIOUS ROLES

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Key words: soccer players, sports performance, game-based sports, game roles, adaptation, cardiovascular system, myocardium, dilatation, hypertrophy.

Annotation. The article presents the physiological features of soccer players' cardiovascular system (studies using tetrapolar rheography and echocardiography), depending on the role and the sports performance level. The dominant type of blood circulation is hyperkinetic. In high-performance soccer players, more significant degrees of cardiovascular system activity's efficiency, a decrease in afterload and an increase in the heart contractile function were revealed. High-performance forwards have the lowest values of systolic and diastolic pressure, end-systolic volume and end-systolic size, heart rate, double product and have the highest heart contractility indicators among all soccer players (end-diastolic and shock volume, thickness of the posterior wall of the left ventricle).

Introduction. High level of adaptation to the specificity of physical loads (anaerobic loads based on speed and strength) in game sports (including soccer) is due to a complicated set of morphofunctional alterations: changes in an activity of divisions in the vegetative nervous system, energy support of muscle activity and activity of the cardiovascular system (CVS) [1-3].

Stronger parasympathetic influence on the heart rate and the myocardium adrenoreactivity at rest supports the efficiency of its activity and maximum performance in case of excessive physical loads [4]. Burr J.F. et al (2015) note that the sports performance level among hockey players is defined by an adequate cardiac output, increased venous return and vasodilatation of vessels [5]. Such biochemical blood indicators as initial and final levels of lactate, urea, non-organic phosphorus and creatine phosphokinase (CPK) are also connected to a level of sports performance [6]. A correlation between aminotransferases' activity and myocardium hypertrophy was revealed: researchers found a strong relation between the CPK level and the end-diastolic volume (EDV) (r=0,97), between the CPK and the end-systolic volume (ESV) (r=0,96) [4].

Factors that define high adaptation of the CVS of soccer players to loads include: HR decrease in the range of 46-59 beats/min, increase in stroke volume

(SV) to 154 ml (120 ml is standard), increase of stroke index (SI), end-diastolic volume (EDV) and index of end-diastolic volume (EDI) [7]. A substantial degree of the development of dilatation of the heart ventricles contributing to a resourceful support of muscle activity (characterized by the EDI indicator) combined with a moderate bradycardia at rest are pre-conditions for successful competitive activity [7]. Ashmarin D.V. presents same data: during the process of adaptation to training loads, increase of SV and ejection fraction (EF) related to an increase of myocardial contractile function in case of a decreased mechanical work (CVS) support a slight decrease of cardiac output (CO) as a manifestation of the CVS activity's efficiency in soccer players [8]. The eukinetic blood type is considered as the most favorable [1, 9].

Mimina E.N. et al (2020) revealed that an increase of physical performance and adaptation potential among athletes (soccer, boxing) is supported by efficiency of the cardiorespiratory system's functions by 30% in average (based on indicators of a specific physiological value of performed physical loads) that led to an increase of myocardium effectiveness coefficient by more than 60%, i.e. is associated with indicators of a specific physiological value of performed physical loads – sphygmic value (beats/W), minute volume value of blood circulation (ml/min/W), respiratory (cycle/W) and oxygen value (ml/W). The best ability to classify a level of myocardium's functional reserves according to phasographic speed indicators of the heart electric activity was performed by the βT indicator, which reflects repolarization processes and allows evaluating a degree of the myocardium's stress: it is a stable and sensitive indicator showing integrative reaction of adaptation reserves of cardiohemodynamics [10].

Long-term physical loads in athletes of game-based sports lead to the myocardium hypertrophy and dilatation [11-12]. Francavilla C.V. et al (2018) also note that among soccer players there is hypertrophy of the left ventricular (LV) myocardium area and the interventricular septum (IVS) with dilatation of cavities of the heart's left compartments [13]. Following parameters are attributed to specific changes in case of forming the myocardium's physiological hypertrophy among athletes: the IVS thickness is in range of 9,9±0,16 mm, thickness of the VL wall – 9,3±1,0 mm, the end-diastolic dimension (EDD) – 51,6±1,1 mm, the LV mass index (LVMI) – 105±32 g/m², diameter of the left atrium – 34,2±4,5 mm [14].

Adaptation changes in echocardiographic parameters among soccer players were shown in the following: the EDV was 52,9±0,36 ml, the IVS thickness – 7,24±0,31 mm, the thickness of the left ventricle's posterior wall (LVPW) – 8,88±0,19 mm, the myocardium mass – 200,0±1,99 g [15]. According to data, signs of physiological myocardium hypertrophy among soccer players are increase in LVPW thickness (9,8±1,5 mm), IVS (10,1±1,0 mm), EDD (53,3±3,7 mm), end-systolic dimension (ESD) (33,0±3,1 mm), mass of the LV myocardium (187,1±40,6 g), EF (67,2±9,5%) and the right ventricle diameter (23,1±3,5 mm) [16].

Decrease in HR indicators and increase of SV, EF, SI and EDV allow considering a better blood filling of ventricles during the diastole process [17]. Researchers also note a relation of cardiac hemodynamics (CHD) indicators with a level of physical fitness and athletic performance of game-based sports athletes: decrease of dBP by 12,4%, sBP – by 5,2%, mBP – by 9,2% was registered. CHD parameters that are markers of growth of functional fitness as a response to speed and strength loads in athletes were also demonstrated: HR decrease by 13,3%, SV increase by 19,8%, MBV – by 13,2% and SI – by 15,5% [17].

There is some evidence that among athletes with a predominant demonstration of speed qualities and endurance, morphofunctional shifts in the CVS activity (presence of the myocardium hypertrophy, dilatation of the heart's cavities, increase in mass of the left ventricle's myocardium (LVMM), IVS, LVPW, SV, EDV and ESV) depend on specificity of motor activity, which implies differences of adaptation alterations in athletes with different game roles [4, 18, 19].

Thus, features of morphofunctional characteristics of the CVS in athletes of game-based sports depending on their role and the level of athletic performance remain insufficiently studied.

The purpose of this study is to reveal functional and morphological parameters of the CVS connected to sports performance among soccer players with various game roles.

Methods and organization. Evaluation of the CVS functional state in elite athletes took place during the period of 2020-2021 in the Scientific Research Institute of Olympic Sports of the Ural State University of Physical Culture (Chelyabinsk). 46 male athletes aged 17-22 years who engaged in soccer participated in the study. Average body length of participants was 183,7±1,83 cm, average body mass – 73,0±3,18 kg. Sports qualification of athletes – I sports degree, Candidate Master of Sports (CMS) and Master of Sports (MS).

Four groups were formed associated with sports performance and identified by coaches during the competitive period: high-performance (HP) and low-performance (LP) backs and halfbacks (1 and 2 group), HP and LP forwards (3 and 4 group). We assessed the sports result according to following parameters: success of long pass, performance of the goal attempt, assists, dribbling, tackling and interception.

Registration of the following CHD parameters was carried out with tetrapolar rheography in a position of lying on the back using the "MARG 10-01" certified computer system made by Microlux (Chelyabinsk): systolic blood pressure (sBP, mm of Hg), diastolic blood pressure (dBP, mm of Hg), mean blood pressure (mBP), heart rate (HR, beats/min), double product ((sBP*HR):100, c.u.), stroke volume (SV, mm), cardiac output (CO, mm), cardiac index (CI, ml/m^2), ejection fraction (EF, %), end-diastolic volume (EDV, ml), left ventricle stroke work index (LVSWI, g*min/m^2), preejection period (PEP, ms), left ventricle ejection time (LVET, ms), left ventricle work index (LVWI, kg*min/m^2), unit index (UI, ml/m^2), oxygen delivery index (ODI, ml/min/m2), end-diastolic index (EDI, ml/m^2), total peripheral resistance (TPR, dyn*s*cm) and total peripheral resistance stroke index (TPRSI, dyn*s*cm*cm^{-5}).

Evaluation of linear dimensions and volume indicators of the myocardium was carried our using the Echo-CG method on the “Unison-2-03” device with a transthoracic access [20]. Measuring wall thickness and sizes of regions of the heart was made in the M-mode. We assessed following parameters of the myocardium: ejection fraction (EF, %), stroke volume (SV, ml), end-diastolic dimension (EDD, mm), end-systolic dimension (ESD, mm), thickness of the left ventricle back wall (LVBW, mm), end-diastolic volume (EDV, ml), end-systolic volume (ESV, mm), thickness of the interventricular septum (IVS, mm).

Statistical processing of results was conducted using the Microsoft Excel-2010 analysis package. Differences in indicators in each selection were registered using the Student’s test (differences were considered as significant if $p<0,05$).

Results and discussion. According to results of tetrapolar rheography, following CHD parameters of soccer players with different roles and the level of sports performance were revealed (table 1). The functional state of the CVS of all soccer players is characterized by moderate bradycardia and low indicators of the double product (DP), which indicates efficiency of its activity. Meanwhile, lower HR values were registered in the 1 and 3 groups (high-performance backs/halfbacks and forwards). Among forwards (3 group), the HR is significantly lower than in the 4 group ($p<0,05$). Moreover, sBP and dBP indicators in groups 1 and 3 were lower than in groups 2 and 4. Consequentially, DP values of HR athletes of the 1 and 3 groups was lower by 10-20% ($p<0,05$) in comparison with LR soccer players. In our opinion, it reflects not only a more pronounced efficiency of the CVS activity, but also a higher level of its functional capabilities.

Indicators of the myocardium contractile function, i.e. stroke volume, ejection fraction and preejection period, did not have any significant differences in case of lower LVET values in 2 and 4 groups compared to 1 and 3 groups ($p<0,05$).

Table 1

Hemodynamics indicators of HP and LP soccer players (M±m)

Indicators	Role			
	backs/halfbacks (n=24)		forwards (n=22)	
	1 group (HP) (n=11)	2 group (LP) (n=13)	3 group (HP) (n=10)	4 group (LP) (n=12)
HR (beats/min)	52,17±1,39	56,17±1,94	50,31±1,97	57,37±1,46*
sBP (mm of Hg)	111,83±1,07	116,09±1,00*	104,77±1,33	117,44±1,29*
dBP (mm of Hg)	60,51±0,53	65,39±1,08*	65,31±0,99	66,87±1,38*
mBP (mm of Hg)	77,41±1,45	83,91±1,38*	78,00±1,11	85,00±1,53*
DP (c. u.)	58,24±0,01	64,96±0,02*	52,50±0,03	66,69±1,88*
RR (cycle/min)	15,33±0,45	15,82±0,37*	15,15±1,02	15,69±0,78*
SV (ml)	137,42±5,49	144,78±4,08	138,00±14,00	138,55±8,64
SI (ml/m²)	82,25±2,15	84,34±1,18	78,50±5,50	81,55±3,04
CO (l)	7,37±0,48	8,42±0,37	8,56±0,51	8,52±0,42
CI (ml/m²)	4,43±0,23	4,87±31,75	3,95±0,35	4,77±0,20
EDI (ml/m²)	130,08±1,42	132,26±1,66	129,44±1,26	124,31±1,69*
EF (%)	63,16±0,27	62,96±0,33	63,50±0,50	62,88±0,45
PEP (ms)	100,92±1,58	99,69±1,55	103,50±0,50	100,66±2,71
LVET (ms)	318,33±3,52	307,91±2,91*	323,00±6,00	305,00±6,17*
LVWI (kg*min/m²)	4,56±0,27	5,40±0,21*	4,05±0,35	5,30 ±0,32*
TPR (dyn*s*cm)	1397,33±77,80	1345,39±48,60	1410,50±132,50	1350,00±60,36
ODI (ml/min/m²)	833,66±54,12	868,68±31,75	828,50±26,50	845,22±42,27
LVSWI (g*min/m²)	85,08±2,59	92,70±2,44*	80,50±5,5	89,77±4,44
TPRSI (dyn*s*cm*cm^{-5})	73,42±2,92	76,65±1,38	75,50±5,50	79,11±4,67

Note: * – differences between the 1st and 2nd, between the 3rd and 4th groups are considered significant if $p<0,05$

The blood circulation type regardless of sports performance and role of examined athletes of all groups was identified as hyperkinetic (more than 3,5 ml/m^2). It is due to higher values of the stroke volume (more than 130 ml in all groups) that, alongside with high values of the EDI (standard is 60-100 ml/m^2) and moderate bradycardia, are attributed to factors defining high CVS adaptation of soccer players to loads [7].

According to the LVWI, degree of stress of the myocardium's work is higher in LP soccer players (5,40±0,21 kg*min/m² against 4,56±0,27 in the 1 group and 5,30±0,32 kg*min/m² in the 4 group against 4,05±0,35 in the 3 group, $p<0,05$), similar differences are revealed in the LVSWI indicator. This conclusion is confirmed in a certain degree by TPSI indicators, as well as mBP and ESV that are higher in the 2 and 4 groups in comparison with the 1 and 3 groups, They reflect a higher level of afterload among low-performance athletes. At the same time, the TPR indicator in all groups is at the lower limit of normal, which is, combined with indicators of systolic and diastolic blood pressure, allows considering the vascular tone in elite soccer players of all comparison groups that is close to the normal state (i.e. long-term CVS adaptation is characterized by an increase of afterload).

When evaluating Echo-CG indicators, we revealed following features related to a role in game and sports performance (table 2).

Adaptation to loads of examined soccer players is characterized according to the Echo-CG by such morphofunctional alterations as the moderate myocardium hypertrophy and the cavity dilatation. High-performance athletes had higher values of both volume-based characteristics (EDV, SV) and morphological parameters (IVS, LVMM, LVPW). It should be noted that the hypertrophy was at limits of physiological norm of the “athletic heart” (less than 13 mm). Therefore, since the EDV indicators are higher (both in backs/halfbacks and forwards) compared with low-performance athletes, and the ESV is lower, values of the stroke volume in the 1 and 3 groups are higher than in the 2 and 4 groups respectively.

Table 2

Echocardiographic indicators in HP and LP soccer players (M±m)

Indicators	Role in game			
	backs/halfbacks (n=24)		forwards (n=22)	
	HP (n=11)	LP (n=13)	HP (n=10)	LP (n=12)
EDV (ml)	109,63±1,28	101,99±0,75*	113,02±1,33	94,32±0,97*
ESV (ml)	47,77±0,05	51,05±1,27*	42,31±0,95	44,92±1,55
EF (%)	66,47±1,45	63,89+±1,75	61,25±1,64	59,75±0,25
SV (ml)	58,65±0,44	54,13±0,07*	69,65±1,73	52,03±0,13*
LVPW (mm)	9,91±0,44	8,65±0,44*	11,36±1,25	8,44±0,37*
IVS (mm)	12,23±0,72	9,03±0,36*	11,22±0,21	9,50±0,48*
LVMM (g)	148,01±0,54	135,37±0,93*	136,75±1,36	128,07±1,40*
Contracted LVM (mm)	32,47±0,86	33,44±0,75	34,40±1,70	31,25±1,02
EDD (mm)	45,07±0,26	44,73±0,73	41,95±1,98	37,23±1,19*
ESD (mm)	30,18±0,72	29,63±0,61	25,53±0,62	27,62±0,85
LV diameter (mm)	46,59±0,85	42,52±1,02*	44,24±1,32	43,70±1,82

Note: * – differences between the 1st and 2nd, between the 3rd and 4th groups are considered significant if $p<0,05$

High-performance forwards had the highest values of the EDV and SV and the least values of the ESS. Meanwhile, increase of volume-based parameters lines up with more pronounced manifestations of the myocardium hypertrophy (LVPW thickness). We assume that it reflects the specificity of the heart adaptation among players of this role, since this adaptation alterations support to a possibility to implement speed and strength short-term loads of anaerobic character (running to goal with a ball with a high speed).

Conclusion. Thus, adaptation of soccer players to the specificity of speed and strength loads of anaerobic character consists of a complex of morphofunctional alterations in the CVS: development of the activity's efficiency at rest (moderate bradycardia, reduced afterloads that is reflected by the sBP, dBP and mBP indicators), the myocardium hypertrophy (within limits of the physiological norms of the "athletic heart") and the dilatation of the left ventricle cavity. When combined, it supports a high cardiac contractility and allows increasing significantly the CO in case of loads. The dominating blood circulation type is the hyperkinetic one.

Among high-performance soccer players in comparison with low-performance ones, we registered a higher degree of the CVS activity's efficiency (lower indicators of the HR, sBP, dBP mBP and DP), reduced afterloads (mBP, ESV) and increase in the cardiac contractility. It is shown by parameters of the EDV, SV, as well as the EDD combined with the hypertrophy (higher indicators of the LVPW and IVS thickness, LVMM).

Specific functional and morphological changes in the CVS activity were registered in athletes depending on their role in game. They were defined among high-performance forwards in a form of the lowest values of sBP and dBP, ESV and ESD (reduced afterloads), HR and DP (activity's efficiency) at rest combined with the highest indicators among all examined groups reflecting high cardiac contractility (values of the EDV, SV, LVPW thickness).

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